ASME BPVC.XI-2015

SECTION XI

2015 ASME Boiler and Pressure Vessel Code

An International Code

Rules for Inservice Inspection of Nuclear Power Plant Components

ASME

SETTING THE STANDARD

AN INTERNATIONAL CODE

2015 ASME Boiler & Pressure Vessel Code

2015 Edition July 1, 2015

XI

RULES FOR INSERVICE INSPECTION OF NUCLEAR POWER PLANT COMPONENTS

ASME Boiler and Pressure Vessel Committee
on Nuclear Inservice Inspection

The American Society of Mechanical Engineers®

Two Park Avenue • New York, NY • 10016 USA

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[*] The 2015 Edition of Section III is the last edition in which Section III, Division 1, Subsection NH, *Class 1 Components in Elevated Temperature Service*, will be published. The requirements located within Subsection NH have been moved to Section III, Division 5, Subsection HB, Subpart B for the elevated temperature construction of Class A components.

INTERPRETATIONS

Interpretations of the Code have historically been posted in January and July at http://cstools.asme.org/interpretations.cfm. Interpretations issued during the previous two calendar years are included with the publication of the applicable Section of the Code in the 2015 Edition. Interpretations of Section III, Divisions 1 and 2 and Section III Appendices are included with Subsection NCA.

Following the 2015 Edition, interpretations will not be included in editions; they will be issued in real time in ASME's Interpretations Database at http://go.asme.org/Interpretations. Historical BPVC interpretations may also be found in the Database.

CODE CASES

The Boiler and Pressure Vessel Code committees meet regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases that have been adopted will appear in the appropriate 2015 Code Cases book: "Boilers and Pressure Vessels" or "Nuclear Components." Supplements will be sent or made available automatically to the purchasers of the Code Cases books up to the publication of the 2017 Code.

(15)

FOREWORD*

In 1911, The American Society of Mechanical Engineers established the Boiler and Pressure Vessel Committee to formulate standard rules for the construction of steam boilers and other pressure vessels. In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

(a) Committee on Power Boilers (I)

(b) Committee on Materials (II)

(c) Committee on Construction of Nuclear Facility Components (III)

(d) Committee on Heating Boilers (IV)

(e) Committee on Nondestructive Examination (V)

(f) Committee on Pressure Vessels (VIII)

(g) Committee on Welding, Brazing, and Fusing (IX)

(h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)

(i) Committee on Nuclear Inservice Inspection (XI)

(j) Committee on Transport Tanks (XII)

(k) Technical Oversight Management Committee (TOMC)

Where reference is made to "the Committee" in this Foreword, each of these committees is included individually and collectively.

The Committee's function is to establish rules of safety relating only to pressure integrity, which govern the construction** of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. The Committee also interprets these rules when questions arise regarding their intent. The technical consistency of the Sections of the Code and coordination of standards development activities of the Committees is supported and guided by the Technical Oversight Management Committee. This Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks, or nuclear components, or the inservice inspection of nuclear components or transport tanks. Users of the Code should refer to the pertinent codes, standards, laws, regulations, or other relevant documents for safety issues other than those relating to pressure integrity. Except for Sections XI and XII, and with a few other exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property, and to provide a margin for deterioration in service to give a reasonably long, safe period of usefulness. Advancements in design and materials and evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects that are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgement* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the

* The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. Therefore, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Code.

** *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design, or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees). Proposed revisions to the Code resulting from inquiries will be presented to the Committee for appropriate action. The action of the Committee becomes effective only after confirmation by ballot of the Committee and approval by ASME. Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute (ANSI) and published at http://go.asme.org/BPVCPublicReview to invite comments from all interested persons. After public review and final approval by ASME, revisions are published at regular intervals in Editions of the Code.

The Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the Committee. ASME is to be notified should questions arise concerning improper use of an ASME Certification Mark.

When required by context in this Section, the singular shall be interpreted as the plural, and vice versa, and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

STATEMENT OF POLICY ON THE USE OF THE CERTIFICATION MARK AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use the Certification Mark for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the Certification Mark who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the Certification Mark, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding the Certification Mark and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code." An ASME corporate logo shall not be used by any organization other than ASME.

The Certification Mark shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of the Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the Certification Mark. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Certification Mark described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL STANDARDS COMMITTEES (15)

1 INTRODUCTION

(a) The following information provides guidance to Code users for submitting technical inquiries to the committees. See Guideline on the Approval of New Materials Under the ASME Boiler and Pressure Vessel Code in Section II, Parts C and D for additional requirements for requests involving adding new materials to the Code. Technical inquiries include requests for revisions or additions to the Code rules, requests for Code Cases, and requests for Code Interpretations, as described below.

(1) Code Revisions. Code revisions are considered to accommodate technological developments, address administrative requirements, incorporate Code Cases, or to clarify Code intent.

(2) Code Cases. Code Cases represent alternatives or additions to existing Code rules. Code Cases are written as a question and reply, and are usually intended to be incorporated into the Code at a later date. When used, Code Cases prescribe mandatory requirements in the same sense as the text of the Code. However, users are cautioned that not all jurisdictions or owners automatically accept Code Cases. The most common applications for Code Cases are:

(-a) to permit early implementation of an approved Code revision based on an urgent need

(-b) to permit the use of a new material for Code construction

(-c) to gain experience with new materials or alternative rules prior to incorporation directly into the Code

(3) Code Interpretations. Code Interpretations provide clarification of the meaning of existing rules in the Code, and are also presented in question and reply format. Interpretations do not introduce new requirements. In cases where existing Code text does not fully convey the meaning that was intended, and revision of the rules is required to support an interpretation, an Intent Interpretation will be issued and the Code will be revised.

(b) The Code rules, Code Cases, and Code Interpretations established by the committees are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Code rules.

(c) Inquiries that do not comply with these provisions or that do not provide sufficient information for a committee's full understanding may result in the request being returned to the inquirer with no action.

2 INQUIRY FORMAT

Submittals to a committee shall include:

(a) Purpose. Specify one of the following:

(1) revision of present Code rules

(2) new or additional Code rules

(3) Code Case

(4) Code Interpretation

(b) Background. Provide the information needed for the committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, Division, edition, addenda (if applicable), paragraphs, figures, and tables. Preferably, provide a copy of the specific referenced portions of the Code.

(c) Presentations. The inquirer may desire or be asked to attend a meeting of the committee to make a formal presentation or to answer questions from the committee members with regard to the inquiry. Attendance at a committee meeting shall be at the expense of the inquirer. The inquirer's attendance or lack of attendance at a meeting shall not be a basis for acceptance or rejection of the inquiry by the committee.

3 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions shall provide the following:

(a) Proposed Revisions or Additions. For revisions, identify the rules of the Code that require revision and submit a copy of the appropriate rules as they appear in the Code, marked up with the proposed revision. For additions, provide the recommended wording referenced to the existing Code rules.

(b) Statement of Need. Provide a brief explanation of the need for the revision or addition.

(c) Background Information. Provide background information to support the revision or addition, including any data or changes in technology that form the basis for the request that will allow the committee to adequately evaluate the proposed revision or addition. Sketches, tables, figures, and graphs should be submitted as appropriate. When applicable, identify any pertinent paragraph in the Code that would be affected by the revision or addition and identify paragraphs in the Code that reference the paragraphs that are to be revised or added.

4 CODE CASES

Requests for Code Cases shall provide a Statement of Need and Background Information similar to that defined in 3(b) and 3(c), respectively, for Code revisions or additions. The urgency of the Code Case (e.g., project underway or imminent, new procedure, etc.) must be defined and it must be confirmed that the request is in connection with equipment that will bear the Certification Mark, with the exception of Section XI applications. The proposed Code Case should identify the Code Section and Division, and be written as a *Question* and a *Reply* in the same format as existing Code Cases. Requests for Code Cases should also indicate the applicable Code editions and addenda (if applicable) to which the proposed Code Case applies.

5 CODE INTERPRETATIONS

(a) Requests for Code Interpretations shall provide the following:

(1) Inquiry. Provide a condensed and precise question, omitting superfluous background information and, when possible, composed in such a way that a "yes" or a "no" *Reply,* with brief provisos if needed, is acceptable. The question should be technically and editorially correct.

(2) Reply. Provide a proposed *Reply* that will clearly and concisely answer the *Inquiry* question. Preferably, the *Reply* should be "yes" or "no," with brief provisos if needed.

(3) Background Information. Provide any background information that will assist the committee in understanding the proposed *Inquiry* and *Reply.*

(b) Requests for Code Interpretations must be limited to an interpretation of a particular requirement in the Code or a Code Case. The committee cannot consider consulting type requests such as the following:

(1) a review of calculations, design drawings, welding qualifications, or descriptions of equipment or parts to determine compliance with Code requirements;

(2) a request for assistance in performing any Code-prescribed functions relating to, but not limited to, material selection, designs, calculations, fabrication, inspection, pressure testing, or installation;

(3) a request seeking the rationale for Code requirements.

6 SUBMITTALS

Submittals to and responses from the committees shall meet the following:

(a) Submittal. Inquiries from Code users shall be in English and preferably be submitted in typewritten form; however, legible handwritten inquiries will also be considered. They shall include the name, address, telephone number, fax number, and e-mail address, if available, of the inquirer and be mailed to the following address:

Secretary
ASME Boiler and Pressure Vessel Committee
Two Park Avenue
New York, NY 10016-5990

As an alternative, inquiries may be submitted via e-mail to: SecretaryBPV@asme.org or via our online tool at http://go.asme.org/InterpretationRequest.

(b) Response. The Secretary of the appropriate committee shall acknowledge receipt of each properly prepared inquiry and shall provide a written response to the inquirer upon completion of the requested action by the committee.

(**15**)

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January 1, 2015

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PREFACE TO SECTION XI

INTRODUCTION

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, of the ASME Boiler and Pressure Vessel Code provides requirements for examination, testing, and inspection of components and systems, and repair/replacement activities in a nuclear power plant. Application of this Section of the Code begins when the requirements of the Construction Code have been satisfied.

GENERAL

The rules of this Section constitute requirements to maintain the nuclear power plant and to return the plant to service, following plant outages, in a safe and expeditious manner. The rules require a mandatory program of examinations, testing, and inspections to evidence adequate safety and to manage deterioration and aging effects. The rules also stipulate duties of the Authorized Nuclear Inservice Inspector to verify that the mandatory program has been completed, permitting the plant to return to service in an expeditious manner.

INSERVICE TESTING OF PUMP AND VALVES

With the 1998 Edition with the 2000 Addenda, all requirements for testing pumps and valves have been removed from Section XI, Division 1. These requirements are now located in the ASME Code for Operation and Maintenance of Nuclear Power Plants.

OWNER RESPONSIBILITIES

The Owner of the nuclear power plant is assigned the responsibilities to develop a program which will demonstrate conformance to the requirements of this Section of the Code.

These responsibilities include:

(a) provision of access in the design and arrangement of the plant to conduct the examination and tests;

(b) development of plans and schedules, including detailed examination and testing procedures for filing with the enforcement and regulatory authorities having jurisdiction at the plant site;

(c) conduct of the program of examination and tests, system leakage and hydrostatic pressure tests; and

(d) recording of the results of the examinations and tests, including corrective actions required and the actions taken.

DUTIES OF THE AUTHORIZED NUCLEAR INSERVICE INSPECTOR

Section XI differs from Section VI, Recommended Rules for the Care and Operation of Heating Boilers, and Section VII, Recommended Guidelines for the Care of Power Boilers, in that the requirements for Inservice Inspection of Nuclear Power Plants are mandatory, while the other two Sections are recommended practices. Duties of the Authorized Nuclear Inservice Inspector are assigned by Section XI to verify that the responsibilities of the Owner and the mandatory requirements of this Section are met. Duties of the Authorized Nuclear Inservice Inspector include the following:

(a) verifying system pressure tests;

(b) reviewing nondestructive examination procedures and Repair/Replacement Programs and Plans; and

(c) verifying that the visual examinations and tests have been completed and the results recorded.

Listed as one of the duties is the prerogative of the Inspector to require requalification of any operator or procedure when he has reason to believe the requirements are not being met.

ORGANIZATION OF SECTION XI

(15)

1 DIVISIONS

Section XI consists of three Divisions, as follows:

Division 1 = Rules for Inspection and Testing of Components of Light-Water-Cooled Plants
Division 2 = Rules for Inspection and Testing of Components of Gas-Cooled Plants
Division 3 = Rules for Inspection and Testing of Components of Liquid-Metal-Cooled Plants

2 SUBSECTIONS

The Divisions are broken down into Subsections which are designated by capital letters, preceded by the letters IW in Division 1, by the letters IG in Division 2, and by the letters IM in Division 3.

Division 1 consists of Subsections covering the following aspects of the rules:

Subsection	Title
IWA	General Requirements
IWB	Class 1 Components
IWC	Class 2 Components
IWD	Class 3 Components
IWE	Class MC and CC Components
IWF	Class 1, 2, 3, and MC Component Supports
IWG	Core Internal Structures (In course of preparation)
IWL	Class CC Concrete Components

Division 2 consists of Subsections covering the following aspects of the rules:

Subsection	Title
IGA	General Requirements
IGB	Class 1 Components
IGC	Class 2 Components
IGD	Class 3 Components
IGG	Reactor Internals
IGH	Elevated Temperature Material
IGI	Graphite and Thermal Insulation Materials
IGK	Concrete Reactor Vessels
IGP	Pumps
IGQ	Compressors
IGV	Valves

Division 3 consists of Subsections covering the following aspects of the rules:

Subsection	Title
IMA	General Requirements
IMB	Class 1 Components
IMC	Class 2 Components
IMD	Class 3 Components
IMF	Class 1, 2, and 3 Component Supports
IMV	Valves

Subsections are divided into Articles, Subarticles, paragraphs, and, where necessary, into subparagraphs.

3 ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections, followed by Arabic numbers, such as IWA-1000 or IWB-2000. Where possible, Articles dealing with the same general topics are given the same number in each Subsection, in accordance with the following scheme:

Article Number	Title
1000	Scope and Responsibility
2000	Examination and Inspection
3000	Acceptance Standards
4000	Repair/Replacement Activities
5000	System Pressure Tests
6000	Records and Reports

The numbering of Articles and material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the requirements have been prepared with some gaps in the numbering.

4 SUBARTICLES

Subarticles are numbered in units of 100, such as IWA-1100 or IWA-1200.

5 SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as IWA-2130, and may have no text. When a number such as IWA-1110 is followed by text, it is considered a paragraph.

6 PARAGRAPHS

Paragraphs are numbered in units of 1, such as IWA-2131 or IWA-2132.

7 SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as IWA-1111.1 or IWA-1111.2. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as IWA-1111(a) or IWA-1111(b).

8 REFERENCES

References used within this Section generally fall into one of six categories, as explained below.

(a) References to Other Portions of This Section. When a reference is made to another Article, Subarticle, or paragraph number, all numbers subsidiary to that reference shall be included. For example, reference to IWA-2000 includes all materials in Article IWA-2000; reference to IWA-2200 includes all material in Subarticle IWA-2200; reference to IWA-2220 includes all paragraphs in IWA-2220, IWA-2221, and IWA-2222.

(b) References to Other Sections. Other Sections referred to in Section XI are as follows:

(1) Section II, Material Specifications. When a requirement for a material or for the examination or testing of a material is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S." Materials conforming to ASTM specifications may be used in accordance with the provisions of the last paragraph of the Foreword to the Boiler Code.

(2) Section III, Nuclear Power Plant Components. Section III references begin with the letter "N" and relate to nuclear power plant design or construction requirements.

(3) Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

(4) Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

(c) References to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials. For example, reference to ASTM E71-64 refers to the specification so designated and published by American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428.

(2) Recommended practices for qualifying and certifying nondestructive examination personnel are published by the American Society for Nondestructive Testing (ASNT). These documents are designated SNT-TC-1A and CP-189. A reference to SNT-TC-1A or CP-189 shall be understood to mean the practice and its supplements, so designated and published by the American Society for Nondestructive Testing (ASNT), 1711 Arlingate Lane, P. O. Box 28518, Columbus, OH 43228-0518.

(3) Specifications and standards for materials, processes, examination and test procedures, qualifications of personnel, and other requirements of the Code approved by the American National Standards Institute are designated by the letters ANSI followed by the serialization for the particular specification or standard. Standards published by ASME are available from ASME (https://www.asme.org/).

(4) Specifications and standards for materials, processes, examination and test procedures, and other requirements of the Code relating to concrete are listed in Table IWA-1600-1, designated by the letters ACI, and are approved and published by the American Concrete Institute. Standards published by the American Concrete Institute can be obtained by writing ACI, Box 19150, 22400 West Seven Mile Road, Detroit, MI 48219.

(5) Specifications and standards for determining water chemistry as identified in Table IWA-1600-1 by the letter designation APHA are approved and published by the American Public Health Association. Standards published by the American Public Health Association can be obtained by writing APHA, 1015 15th Street, NW, Washington, D.C. 20005.

(6) Specifications and standards for welding are listed in Table IWA-1600-1 and are approved and published by the American Welding Society. Standards published by the American Welding Society can be obtained by writing AWS, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, FL 33135.

(d) References to Government Regulations. U.S. Federal regulations issued by executive departments and agencies, as published in the Federal Register, are codified in the Code of Federal Regulations. The Code of Federal Regulations is published by the Office of the Federal Register, National Archives and Records Service, General Service Administration, and may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Title 10 of the Code of Federal Regulations contains the regulations for atomic energy. The abbreviated reference "10 CFR 50" is used to mean "Title 10, Code of Federal Regulations, Part 50."

(e) References to Appendices. Two types of Appendices are used in Section XI and are designated Mandatory and Nonmandatory.

(1) Mandatory Appendices contain requirements which must be followed in Section XI activities; such references are designated by a Roman numeral followed by Arabic numerals. A reference to III-1100, for example, refers to a Mandatory Appendix.

(2) Nonmandatory Appendices provide information or guidance for the use of Section XI; such references are designated by a capital letter followed by Arabic numerals. A reference to A-3300, for example, refers to a Nonmandatory Appendix.

(f) References to Technical Reports. The following reports prepared at the request of the American Society of Mechanical Engineers and published by Electric Power Research Institute are relevant to Code-related articles of Section XI. Requests for copies should be directed to EPRI Research Reports Center, Box 50490, Palo Alto, CA 94303.

(1) NP-1406-SR — Nondestructive Examination Acceptance Standards Technical Basis and Development for Boiler and Pressure Vessel Code, ASME Section XI, Division 1, Special Report, May 1980.

(2) NP-719-SR — Flaw Evaluation Procedures — Background and Application of ASME Section XI Appendix A — Special Report, August 1978.

SUMMARY OF CHANGES

After publication of the 2015 Edition, Errata to the BPV Code may be posted on the ASME Web site to provide corrections to incorrectly published items, or to correct typographical or grammatical errors in the BPV Code. Such Errata shall be used on the date posted.

Information regarding Special Notices and Errata is published by ASME at http://go.asme.org/BPVCerrata.

Changes given below are identified on the pages by a margin note, **(15)**, placed next to the affected area.

The Record Numbers listed below are explained in more detail in "List of Changes in Record Number Order" following this Summary of Changes.

Page	*Location*	*Change (Record Number)*
xiv	Foreword	*(1)* Revised *(2)* New footnote added by errata *(13-860)*
xvii	Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees	In last line of 6(a), URL revised
xix	Personnel	Updated
xxxvii	Organization of Section XI	Last line of 8(c)(3) editorially revised
2	IWA-1400	*(1)* Endnote in subpara. (a) revised *(12-1455)* *(2)* Subparagraphs (l) and (m) revised *(12-552)*
3	Table IWA-1600-1	*(1)* Third row added *(14-921)* *(2)* Year updated in fourth, 20th, and 24th rows *(14-260, 14-921)* *(3)* Thirteenth row revised *(14-260)*
6	IWA-2210	Revised *(13-1241)*
7	Table IWA-2211-1	Second row added *(13-1241)*
6	IWA-2212	Subparagraph (c) added *(13-1241)*
8	IWA-2234	First paragraph corrected by errata *(13-2077)*
8	IWA-2310	Subparagraph (a) revised *(14-921, 14-922)*
11	IWA-2350	Revised *(14-921)*
11	IWA-2360	Subparagraph (c) added *(14-921)*
14	IWA-3200	Subparagraph (a) revised *(12-552)*
14	IWA-3300	Subparagraph (b) corrected by errata *(13-1249)*
28	IWA-4150	Subparagraph (c) revised *(09-1679)*
39	IWA-4621	Subparagraph (c) revised *(12-1239)*
48	IWA-4651	*(1)* Subparagraph (g) revised *(12-1239)* *(2)* Subparagraph (i) added *(12-1239)*
48	IWA-4652.4	Former subpara. (b)(12) deleted, and remaining subparagraphs redesignated *(12-1239)*
51	Figure IWA-4652.4-2	Revised editorially

Page	*Location*	*Change (Record Number)*
53	Figure IWA-4655-2	Revised editorially
51	IWA-4661	Subparagraphs (d) and (e) revised *(13-1691)*
51	IWA-4662.1	First paragraph revised *(13-1691)*
55	IWA-4664	Subparagraph (a) added, and remaining subparagraphs redesignated *(13-1691)*
67	IWA-5213	Subparagraph (a)(4) added *(13-1599)*
69	IWA-5246	Added *(13-781)*
71	IWA-6200	Revised in its entirety *(09-1679)*
73	Article IWA-9000	*(1)* Definition of "*analytical evaluation*" added *(12-552)* *(2)* Definitions of "*text information*" and "*unit of data storage*" deleted by errata *(14-776)*
83	Table IWB-2500-1 (B-A)	Third and fourth entries in final column revised *(12-1353)*
88	Table IWB-2500-1 (B-G-1)	General Note added *(14-771)*
91	Table IWB-2500-1 (B-G-2)	General Note added *(14-771)*
98	Table IWB-2500-1 (B-O)	*(1)* First and second entries in sixth column revised *(12-45)* *(2)* Note (1) added, and remaining Note redesignated *(12-45)*
111	Figure IWB-2500-8	*(1)* Illustration (f) added *(12-1979)* *(2)* General Notes (a) through (c) added, and original General Note revised and designated as (d) *(12-1979)*
117	Figure IWB-2500-12(a)	Revised in its entirety *(14-699)*
118	Figure IWB-2500-12(b)	Added *(14-699)*
119	Figure IWB-2500-12(c)	Added *(14-699)*
125	IWB-3112	Subparagraph (a) revised *(09-1679)*
126	IWB-3132.1	Revised *(09-1679)*
126	IWB-3132.3	Revised *(12-1411)*
127	IWB-3142.4	Subparagraph (a) and designator (b) added *(13-1257)*
130	IWB-3514	Subparagraph (b) added, and remaining subparagraph redesignated *(12-1411)*
130	IWB-3514.1	In subpara. (a), last cross-reference revised *(12-1411)*
133	IWB-3514.8	Revised *(12-552)*
139	IWB-3610	Subparagraphs (a), (b), (b)(1), (b)(2), and (e) revised *(12-552)*
140	Figure IWB-3610-1	Revised editorially
141	IWB-3613	First sentence revised *(12-552)*
142	IWB-3640	Revised in its entirety *(12-552)*
143	IWB-3662	Subparagraph (f) revised *(12-552)*
143	IWB-3700	Title revised *(12-552)*
143	IWB-3720	Subparagraph (a) revised *(12-552)*
146	IWC-1221	Subparagraph (d) revised *(14-1159)*
146	IWC-1222	Subparagraph (d) revised *(14-1159)*

Page	*Location*	*Change (Record Number)*
154	Table IWC-2500-1 (C-D)	General Note added *(14-771)*
162	Figure IWC-2500-4	*(1)* Revised in its entirety *(13-790)* *(2)* Note (3) added, and remaining Note redesignated *(13-790)*
166	Figure IWC-2500-5	Revised editorially
167	Figure IWC-2500-6(a)	Revised in its entirety *(14-845)*
168	Figure IWC-2500-6(b)	Added *(14-845)*
169	Figure IWC-2500-6(c)	Added *(14-845)*
177	IWC-3112	Subparagraph (a) revised *(09-1679)*
177	IWC-3122.1	Revised *(09-1679)*
183	IWC-3514	Subparagraph (b) added, and remaining subparagraph redesignated *(12-1411)*
183	IWC-3514.1	In subpara. (a), last cross-reference revised *(12-1411)*
185	IWC-3514.6	Revised *(12-552)*
185	IWC-3600	Revised in its entirety *(12-552)*
187	IWC-5222	*(1)* Subparagraphs (a) and (b) revised *(13-1592)* *(2)* Subparagraph (c) added *(13-1592)*
197	Table IWD-3410-1	First entry in final column corrected by errata *(14-776, 14-1395)*
197	IWD-3600	Revised in its entirety *(12-552)*
199	IWD-5222	Revised in its entirety *(13-1592)*
214	IWF-1230	Revised *(13-2071)*
214	IWF-1300	Subparagraph (e) revised *(13-114)*
215	Figure IWF-1300-1	Illustration (e) corrected by errata *(14-2304)*
222	IWF-3122.1	Revised *(09-1679)*
235	IWL-3221.1	Subparagraph (b) revised in its entirety *(10-142)*
243	I-3200	Subparagraph (c) revised *(14-1375)*
248	Mandatory Appendix I, Supplement 11	Subparagraph (a) corrected by errata *(13-2077)*
250	Mandatory Appendix II	Revised in its entirety *(09-1679)*
256	III-1100	Subparagraph (b) revised *(13-301)*
266	Mandatory Appendix III Supplements	*(1)* Supplement 1 revised in its entirety *(13-301)* *(2)* Supplement 2 added *(13-301)*
276	Mandatory Appendix IV, Supplement 2, 1.0	Subparagraph (d)(2) revised *(12-2015)*
296	VIII-2100	Subparagraph (d)(3)(-b) revised *(14-1378)*
297	VIII-3110	Subparagraph (b) added, and remaining subparagraphs redesignated *(14-1380)*
297	VIII-3120	Subparagraph (b) added, and remaining subparagraphs redesignated *(14-1380)*

Page	*Location*	*Change (Record Number)*
315	Mandatory Appendix VIII, Supplement 10	*(1)* 2.2 revised *(14-1375)* *(2)* 3.0(b) added *(14-1375)* *(3)* 3.2(b) and (c) revised *(14-1375)* *(4)* 3.3(a) and (b) revised *(14-1375)*
319	Mandatory Appendix VIII, Supplement 12	In 3.0(a)(3), cross-reference corrected by errata *(14-776, 14-1418)*
320	Mandatory Appendix VIII, Supplement 14	3.3(b) revised *(14-1381)*
324	A-1100	First paragraph and subpara. (h) revised *(12-552)*
326	Article A-3000	Revised in its entirety *(10-783)*
369	A-4200	*(1)* Third equation corrected by errata *(14-1395)* *(2)* Subparagraph (c) added *(14-940)*
378	A-5200	Subparagraph (b)(1)(-d) revised *(12-552)*
382	Article A-9000	Definition of *flaw evaluation* deleted *(12-552)*
384	Nonmandatory Appendix C	Title revised *(12-552)*
384	C-1100	Revised in its entirety *(12-552)*
385	C-1200	Subparagraph (h) revised *(12-552)*
385	C-1300	Definition of "*N*" revised *(12-552)*
388	Article C-2000	Title revised *(12-552)*
389	C-2400	Second sentence revised *(12-552)*
389	C-2500	Fourth sentence revised *(12-552)*
392	C-2610	Revised *(12-552)*
394	C-2620	Revised *(12-552)*
395	C-3200	Last sentence revised *(12-552)*
397	C-4222	Revised *(12-552)*
397	C-4230	Revised *(12-552)*
403	Article C-5000	Title revised *(12-552)*
403	C-5200	Revised in its entirety *(12-552)*
403	C-5310	Second sentence revised *(12-552)*
403	C-5311	Second sentence revised *(12-552)*
405	Table C-5310-1	Note (2) revised *(12-552)*
406	Table C-5310-2	Note (2) revised *(12-552)*
407	Table C-5310-3	Note (2) revised *(12-552)*
408	Table C-5310-4	Note (2) revised *(12-552)*
403	C-5312	Second sentence revised *(12-552)*
409	Table C-5310-5	Note (2) revised *(12-552)*
408	C-5410	Second sentence revised *(12-552)*
410	Table C-5410-1	Notes (2) and (3) revised *(12-552)*

Page	*Location*	*Change (Record Number)*
411	Article C-6000	Title revised *(12-552)*
411	C-6200	Revised in its entirety *(12-552)*
411	C-6310	Second sentence revised *(12-552)*
411	C-6311	Second sentence and Step 2 revised *(12-552)*
411	C-6312	Step 2 revised *(12-552)*
416	C-6410	Second sentence revised *(12-552)*
422	Article C-7000	Title revised *(12-552)*
422	C-7200	Title and subpara. (b) revised *(12-552)*
426	C-8200	Subparagraph (a) revised *(12-552)*
426	C-8300	First sentence revised *(12-552)*
426	C-8310	Subparagraphs (a) and (b) revised *(12-552)*
428	C-8330	Last sentence revised *(12-552)*
440	Table C-8520-1	Note (3) revised *(12-552)*
441	Table C-8520-1M	Note (3) revised *(12-552)*
443	Nonmandatory Appendix D	Revised in its entirety *(04-1097)*
444	E-1100	First sentence revised *(12-552)*
444	E-1300	Definition of K_{IC} corrected by errata *(14-1989)*
445	Table E-2	*(1)* Ninth entry under second column corrected by errata *(14-1989)* *(2)* Note (2) revised *(12-552)*
447	G-2110	Second equation corrected by errata *(14-320)*
458	G-2223	Equation (3) corrected by errata *(13-1249)*
459	G-2400	Subparagraph (b) revised *(12-552)*
464	Nonmandatory Appendix H	Title revised *(12-552)*
464	H-1100	First and last paragraphs revised *(12-552)*
467	Article H-2000	Title revised *(12-552)*
468	Article H-3000	Last word revised *(12-552)*
469	H-4100	First sentence revised *(12-552)*
469	H-4200	First sentence revised *(12-552)*
489	K-4322	Penultimate sentence corrected by errata *(14-320)*
491	K-4331	Metric version of eq. (5) and last paragraph before subpara. (c) corrected by errata *(14-320)*
499	L-2210	Subparagraph (a) revised *(12-552)*
505	L-4300	Subparagraph (a) revised *(09-1679)*
506	M-1100	Last two sentences added *(12-1471)*
507	M-2200	First paragraph revised *(12-1471)*
507	M-2500	Revised *(12-1471)*

Page	*Location*	*Change (Record Number)*
513	O-1200	Subparagraph (e) revised *(12-552)*
516	O-3100	Revised *(12-552)*
517	O-3300	Title revised *(12-552)*
526	R-1220	Revised in its entirety *(10-1820)*
526	R-1300	*(1)* Title of R-1310 revised *(13-2138)* *(2)* New R-1320 added, and remaining paragraph redesignated *(13-2138)* *(3)* Table R-1320-1 added *(13-2138)* *(4)* R-1330 revised *(13-2138)*
530	Table R-2500-1	Sixth and seventh entries for third through fifth and eighth columns and Note (7) revised *(10-1820)*
547	Table R-S2-1	SCC section revised *(10-1820)*
552	Nonmandatory Appendix R, Supplement 2, 4.1	Subparagraphs (a) through (c) revised *(10-1820)*
578	Figure U-S2-2.2-1	Upper left corner of illustration corrected by errata *(14-776)*
579	Figure U-S2-2.2-2	Upper left corner of illustration corrected by errata *(14-776)*

NOTE: Volume 63 of the Interpretations to Section XI of the ASME Boiler and Pressure Vessel Code follows the last page of Section XI.

LIST OF CHANGES IN RECORD NUMBER ORDER

Record Number	Change
04-1097	Revised Nonmandatory Appendix D completely. This provides the owner guidance when making a new weld to reduce the weld crown flush with the base material. Research has found that having the weld crown above the base material can distort the UT signal/response.
09-1679	Incorporated Code Case N-532-5 by revising Article IWA-5000, replacing Mandatory Appendix II Form NIS-1 with N-532-5 Form OAR-1, and revising Mandatory Appendix II Form NIS-2 to incorporate the content of Form NIS-2A from Code Case N-532-5 to avoid administrative revision of 24 affected Code Cases.
10-142	For Class CC containments with unbonded post-tensioning systems, revised tendon prestress force terminology used for tendon "acceptance by examination" to preclude acceptance of an individual tendon force that is below minimum design without verifying that the average force of the subject tendon and its adjacent tendons are above minimum design. Under IWL-3221 Acceptance by Examination (specifically, IWL-3221.1 Tendon Force and Elongation), revised terminology from "predicted force" to "lower limit force" in several places under IWL-3221.1(b), defining the term "lower limit force" in its first usage in the subsubparagraph.
10-783	Improved the flaw evaluation procedures in A-3000 by updating the surface flaw equations to a fourth order polynomial for stress, providing fracture mechanics coefficients derived specifically for a cylindrical geometry and included closed form equations for computing G coefficients in addition to the tables. For subsurface, a similar nonlinear expression for stress has been added with G coefficients provided in tabular format. The changes are a complete rewrite of the article to permit the future expansion of the methods to other flaw geometries.
10-1820	Revised Tables R-2500-1 and R-S2-1 and para. 4.1 of Supplement 2 to define examination for PWSCC or IGSCC susceptible locations in accordance with the existing PWSCC or IGSCC inspection program, respectively, when the only degradation mechanism present at the location is PWSCC or IGSCC.
12-45	Added note to Table IWB-2500-1, Examination Category B-O, Item No. B14.10 that provides alternative extent of examination requirements.
12-552	The following "Proposed Definition" was added to the Article IWA-9000 glossary. Revised all uses of this term to reflect the definition throughout Article IWA-3000, IWB/C/D-3400-3700 (except IWB-3522, IWC-3516, and IWD-3511), Figures IWB/C/D-2500-X (secondary to SGWCS), and Nonmandatory Appendices A, C, and H. Two instances of "flaw evaluation" were corrected in IWA-1400. Note that IWB-3630, IWB-3700, IWB-3660, and Nonmandatory Appendices E, G, K, L, and O were not revised in their entirety because they deal with postulated flaws. As a result, they do not meet the new definition of "analytical evaluation" where acceptance standards are exceeded. For these cases, the term "evaluation" was maintained. Some other revisions were made to some of these sections to eliminate misuse of all uses of "evaluation" terms.
12-1239	Revised IWA-4621 and IWA-4651 to clarify peening requirements. Eliminated peening as a qualification variable in IWA-4652.
12-1353	Added an "or" between Notes (3) and (5) for Item no. B1.30 and Notes (4) and (5) for Item no. B1.40.
12-1411	Provided additional guidance to use analytical evaluation when the acceptance standards of IWB-3514 and IWC-3514 are not applicable due to the material being susceptible to stress corrosion cracking.
12-1455	Revised endnote 1 in IWA-1400(a). Paragraph 1400(a) is currently supplemented by Endnote 1, which indicates, "Classification criteria are specified in 10CFR50." Endnote 1 was revised to the following: "Classification criteria are as specified in the facility's current licensing basis."
12-1471	Added the following sentences to the end of M-1100: "This Nonmandatory Appendix provides guidance. However, if used, all provisions of the appendix are mandatory." Revised the sentence in M-2200 that originally read, "The verification process for the model shall include test results from the following testing methods," to read, "The verification process for the model shall include test results from at least one of the following testing methods." This change is proposed

Record Number	Change
	because it is not always possible to implement each of the four test methods. For example, it is not always possible to perform experiments or hand calculations for model verification. Revised the last sentence in M-2500 to read, "The mathematical model shall be considered acceptable when the test problems included in the verification process agree with known solutions within the greater of ±1 in. (25 mm) or 10% of the metal path." This change is consistent with the qualification acceptance criteria included in para. 3.6a of Mandatory Appendix VIII, Supplement 5 (Qualification Requirements for Nozzle Examination from the Outside Surface) for examination procedures, equipment, and personnel.
12-1979	Added Figure IWB-2500-8(f) for a double-groove alternative configuration for NPS 4 (DN 100) or larger.
12-2015	Revised Mandatory Appendix IV, Supplement 2, para. 1.0 (d)(2) to add the option for qualification of an eddy current procedure with flaws $^1/_{16}$ in. or less in length.
13-114	Revised IWF-1300(e) to clarify insulation removal requirements for support examinations.
13-301	Added Mandatory Appendix III, Supplement 2 specific to cast austenitic welds, which will include the requirements in N-824. Revised Mandatory Appendix III, Supplement 1 to exclude cast materials.
13-781	Added IWA-5246 to define pressure test requirements for ISI-classed portions of the reactor vessel head flange leak detection piping.
13-790	Revised Figures IWC-2500-4(a) through (d) to clarify requirements for Class 2 nozzle-to-vessel volumetric examinations.
13-860	In the Foreword, the subtitle has been deleted and replaced with an ANSI disclaimer as a footnote.
13-1241	Revised IWA-2210 and Table IWA-2211-1 to clarify the illumination, distance, and resolution demonstration requirements for VT-2 visual examinations and to clarify that the angle-of-view requirements for direct visual in Section V only apply to VT-1 examination.
13-1249	Errata correction. See Summary of Changes for details.
13-1257	Revised IWB-3142.4.
13-1592	Clarified the guidance for visual examination of Class 2 open-ended piping into IWC-5222(b) and new IWC-5222(c), and clarified the guidance for visual examination of Class 3 open-ended piping into IWD-5222(b) and (c).
13-1599	Applied Class 1 holding time requirements to Class 2 or Class 3 segments pressurized and examined in conjunction with the Class 1 system leakage test.
13-1691	Reduced testing requirements for bare filler metal used for dry underwater welding, added requirement for qualification in accordance with Construction Code as well as Section IX, and added LBW to Code requirements.
13-2071	Revised IWF-1230 to clarify support exemptions.
13-2077	Errata correction. See Summary of Changes for details.
13-2138	Revised R-1310 to be only applicable to Supplement 1. Renumbered existing R-1320 to R-1330. Added new R-1320 containing PRA guidance for the method contained in Supplement 2.
14-260	Updated reference information in Table IWA-1600-1.
14-320	Errata correction. See Summary of Changes for details.
14-699	Added illustrations for bolts with integral heads to Figure IWB-2500-12. Edited dimensions D_b and D_s to read "Depth = D_b" and "Depth = D_s," respectively, in Figure IWB-2500-12(a). Moved point "M" to a location at the base of the threads. Rotated dimension line D_s at the top of the stud to show the minor diameter. Extended threads at the top of the stud through the nut. Added words "as measured from the thread root" every place where the dimension $^1/_4$ in. or 1 in. is used to help define the examination volume for Figures 2500-12 (a) through (c).
14-771	Added Notes (4) and (8) to Table IWB-2500-1 and Note (7) to Table IWC-2500-1.
14-776	Errata correction. See Summary of Changes for details.
14-845	Added illustrations for bolts with integral heads to Figure IWC-2500-6. Added threads to Figure IWC-2500-6(a). Added words "as measured from the thread root" every place where the dimension $^1/_4$ in. is used to help define an examination volume.
14-921	Updated ANSI/ASNT CP-189 from the 1995 Edition to the 2006 Edition.
14-922	Revised IWA-2300 to remove reference to SNT-TC-1A and ANSI N45.2.6

Record Number	Change
14-940	Revised the section in A-4200 that describes the methods for using RT_{T0} to index the K_{Ia} curve to add a separate equation (RTK_{Ia}) to index the K_{Ia} curve as a function of temperature.
14-1159	Revised IWC-1221(d) and IWC-1222(d).
14-1375	Revised I-3200(c) to remove demonstration requirements from the examination coverage section. Revised Supplement 10, para. 2.2 to define the flaw location for these configurations, and added 3.0(b) to describe single-side qualifications if no austenitic base material exists.
14-1378	Revised VIII-2100(d)(3)(b) to add "+1 ft (300 mm) to allow for manufacturing tolerances."
14-1380	Provided directions on how the qualification test specimens may be segments of full-scale mockups or separate specimens cut from full-scale segments, provided that security sample is maintained.
14-1381	Added requirement that flaws in ferritic material for depth sizing qualification must be circumferentially oriented.
14-1395	Errata correction. See Summary of Changes for details.
14-1418	Errata correction. See Summary of Changes for details.
14-1989	Errata correction. See Summary of Changes for details.
14-2304	Errata correction. See Summary of Changes for details.

CROSS-REFERENCING AND STYLISTIC CHANGES IN THE BOILER AND PRESSURE VESSEL CODE

There have been structural and stylistic changes to BPVC, starting with the 2011 Addenda, that should be noted to aid navigating the contents. The following is an overview of the changes:

Subparagraph Breakdowns/Nested Lists Hierarchy

- First-level breakdowns are designated as (a), (b), (c), etc., as in the past.
- Second-level breakdowns are designated as (1), (2), (3), etc., as in the past.
- Third-level breakdowns are now designated as (-a), (-b), (-c), etc.
- Fourth-level breakdowns are now designated as (-1), (-2), (-3), etc.
- Fifth-level breakdowns are now designated as (+a), (+b), (+c), etc.
- Sixth-level breakdowns are now designated as (+1), (+2), etc.

Footnotes

With the exception of those included in the front matter (roman-numbered pages), all footnotes are treated as endnotes. The endnotes are referenced in numeric order and appear at the end of each BPVC section/subsection.

Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees

Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees has been moved to the front matter. This information now appears in all Boiler Code Sections (except for Code Case books).

Cross-References

It is our intention to establish cross-reference link functionality in the current edition and moving forward. To facilitate this, cross-reference style has changed. Cross-references within a subsection or subarticle will not include the designator/identifier of that subsection/subarticle. Examples follow:

- *(Sub-)Paragraph Cross-References.* The cross-references to subparagraph breakdowns will follow the hierarchy of the designators under which the breakdown appears.
  - If subparagraph (-a) appears in X.1(c)(1) and is referenced in X.1(c)(1), it will be referenced as (-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(c)(2), it will be referenced as (1)(-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).
- *Equation Cross-References.* The cross-references to equations will follow the same logic. For example, if eq. (1) appears in X.1(a)(1) but is referenced in X.1(b), it will be referenced as eq. (a)(1)(1). If eq. (1) appears in X.1(a)(1) but is referenced in a different subsection/subarticle/paragraph, it will be referenced as eq. X.1(a)(1)(1).

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DIVISION 1
RULES FOR INSPECTION AND TESTING OF COMPONENTS OF LIGHT-WATER-COOLED PLANTS

SUBSECTION IWA
GENERAL REQUIREMENTS

ARTICLE IWA-1000
SCOPE AND RESPONSIBILITY

IWA-1100 SCOPE

This Division provides requirements for inservice inspection and testing of light-water-cooled nuclear power plants. The requirements identify the areas subject to inspection, responsibilities, provisions for accessibility and inspectability, examination methods and procedures, personnel qualifications, frequency of inspection, record keeping and report requirements, procedures for evaluation of inspection results and subsequent disposition of results of evaluations, and repair/replacement activity requirements, including procurement, design, welding, brazing, defect removal, fabrication, installation, examination, and pressure testing.

IWA-1200 JURISDICTION

The jurisdiction of this Division covers individual components and complete plants that have met all the requirements of the Construction Code, commencing when the Construction Code requirements have been met, irrespective of physical location. When portions of systems or plants are completed at different times, jurisdiction of this Division shall cover only those portions for which all of the construction requirements have been met. Prior to installation, an item that has met all requirements of the Construction Code may be corrected using the rules of either the Construction Code or this Division, as determined by the Owner.

IWA-1300 APPLICATION

IWA-1310 COMPONENTS SUBJECT TO INSPECTION AND TESTING

Components identified in this Division for inspection and testing shall be included in the inservice inspection plan. These components include nuclear power plant items such as vessels, containments, piping systems, pumps, valves, core support structures, and storage tanks, including their respective supports. The selection of components for the inservice inspection plan is subject to review by the regulatory and enforcement authorities having jurisdiction at the plant site.

IWA-1320 CLASSIFICATIONS

(a) Application of the rules of this Division shall be governed by the group classification criteria of the regulatory authority having jurisdiction at the plant site as follows.

(1) The rules of Subsection IWB shall be applied to those systems whose components are classified ASME Class 1.

(2) The rules of Subsection IWC shall be applied to those systems whose components are classified ASME Class 2.

(3) The rules of Subsection IWD shall be applied to those systems whose components are classified ASME Class 3.

(4) The requirements of Subsection IWE shall be applied to components classified ASME Class MC and to metallic shell and penetration liners classified ASME Class CC.

(5) The requirements of Subsection IWF shall be applied to supports classified ASME Class 1, 2, 3, or MC.

(6) The requirements of Subsection IWL shall be applied to reinforced concrete and post-tensioning systems classified ASME Class CC.

(b) Optional construction of a component within a system boundary to a classification higher than the minimum class established in the component Design Specification (either upgrading from Class 2 to Class 1 or from Class 3 to Class 2) shall not affect the overall system classification by which the applicable rules of this Division are determined.

(c) Where all components within the system boundary or isolable portions of the system boundary are classified to a higher class than required by the group classification criteria, the rules of (a) may be applied to the higher classification, provided the rules of the applicable Subsection are applied in their entirety.

(d) The portion of piping that penetrates a containment vessel, which may differ from the classification of the balance of the piping system, need not affect the overall system classification that determines the applicable rules of this Division.

(e) If systems safety criteria permit a system to be nonnuclear safety Class and an Owner optionally classifies and constructs that system, or a portion thereof, to Class 2 or Class 3 requirements, the application of the rules of (a) is at the option of the Owner and is not a requirement of this Division.

(15) IWA-1400 OWNER'S RESPONSIBILITY

The responsibilities of the Owner shall include the following:

(a) determination of the appropriate Code class(es) for each component[1] of the plant, and identification of the system boundaries for each class of components subject to inspection and the components exempt from examination requirements.

(b) design and arrangement of system components to include allowances for adequate access and clearances for conduct of the examination and tests.

(c) preparation of plans, schedules, and inservice inspection summary reports.

(d) submittal of plans, schedules, and preservice and inservice inspection summary reports to the enforcement and regulatory authorities having jurisdiction at the plant site, if required by these authorities.

(e) preparation of written examination instructions and procedures, including diagrams or system drawings identifying the extent of areas of components subject to examination.

(f) verification of qualification to the required level of responsibility of personnel who perform the examinations.

(g) possession of an arrangement with an Authorized Inspection Agency to provide inspection services.

(h) performance of required examinations and tests.

(i) recording of examination and test results that provide a basis for evaluation and facilitate comparison with the results of subsequent examinations.

(j) evaluation of examination and test results.

(k) performance of repair/replacement activities in accordance with written programs and plans.

(l) maintenance of adequate inspection, examination, test, analytical evaluation, and repair/replacement activity records such as radiographs, diagrams, drawings, calculations, examination and test data, description of procedures used, and evidence of personnel qualifications.

(m) retention of all inspection, examination, test, and repair/replacement activity records and analytical evaluation calculations for the service lifetime of the component or system.

(n) the retention and maintenance of all basic calibration blocks used for ultrasonic examination of the components.

(o) documentation of a Quality Assurance Program in accordance with one of the following:

(1) Title 10, Code of Federal Regulations, Part 50

(2) ASME NQA-1, Part I

(p) recording of regions in ferritic steel components where acceptance standards have been modified as required in IWB-3410.2.

(q) recording of regions in components where flaws or relevant conditions exceeding the acceptance standards have been evaluated by analysis to allow continued operation as permitted by IWB-3132.3, IWB-3142.4, IWC-3122.3, IWC-3132.3, IWD-3132.3, IWE-3122.3, IWF-3112.3, IWF-3122.3, and IWL-3212. Any continued operation time or cycle limits inherent in the analysis shall also be recorded.

(r) methods other than written signature may be used for indicating certification, authorization, and approval of records; controls and safeguards shall be provided and described in the Quality Assurance Program to ensure the integrity of the certification, authorization, and approval.

IWA-1500 ACCESSIBILITY

Provisions for accessibility shall include the following considerations:[2]

(a) access for the Inspector, examination personnel, and equipment necessary to conduct the examinations

(b) sufficient space for removal and storage of structural members, shielding, and insulation

(c) installation and support of handling machinery (e.g., hoists) where required to facilitate removal, disassembly, and storage of equipment, components, and other materials

(d) performance of examinations alternative to those specified in the event structural defects or indications are revealed that may require such alternative examinations

(e) performance of necessary operations associated with repair/replacement activities

IWA-1600 REFERENCED STANDARDS AND SPECIFICATIONS

When standards and specifications are referenced in this Division, their revision date or indicator shall be as shown in Table IWA-1600-1.

(15)

Table IWA-1600-1
Referenced Standards and Specifications

Standard, Method, or Specification	Revision Date or Indicator
ACI 201.1R	2008
ACI 349.3R	2002 (Reapproved 2010)
ANSI/ASNT CP-105	2006
ANSI/ASNT CP-189	2006
ANSI/AWS D3.6M	Current Edition
APHA 427	1981
APHA 4500-S^{2-}	1989
4110 [Note (1)]	2000
4500-NO_3^- [Note (1)]	2000
4500-S^{2-} [Note (1)]	2000
ASME NQA-1	1994 or 2008 Edition with the 2009 Addenda
ASME QAI-1	Current Edition and Addenda
ASME/ANS RA-S	2008 with RA-Sa–2009 Addenda and RA-Sb–013 Addenda
ASTM D95	1970 through 2005 (Reapproved 2010)
ASTM D512	1981 through 2010
ASTM D974	1987 through 2007
ASTM D992	1978
ASTM D3867	1979 through 2009
ASTM D4327	1988 through 2011
ASTM E29	2013
ASTM E185	2010
ASTM E1065	2003
ASTM E1324	2005
ASTM E1921	2013
ASTM E2215	2010

NOTE:
(1) This method is published in "Standard Methods for the Examination of Water and Wastewater," published jointly by the American Public Health Association (APHA), the American Water Works Association (AWWA), and the Water Environment Federation (WEF).

IWA-1700 STANDARD UNITS

(a) Either U.S. Customary, SI, or any local customary units may be used to demonstrate compliance with all requirements of this edition.

(b) In general, it is expected that a single system of units shall be used for all aspects of design except where unfeasible or impractical. When components are manufactured at different locations where local customary units are different than those used for the general design, the local units may be used for the design and documentation of that component. Similarly, for proprietary components or those uniquely associated with a system of units different than that used for the general design, the alternate units may be used for the design and documentation of that component.

(c) For any single equation, all variables shall be expressed in a single system of units. When separate equations are provided for U.S. Customary and SI units, those equations must be executed using variables in the units associated with the specific equation. Data expressed in other units shall be converted to U.S. Customary or SI units for use in these equations. The result obtained from execution of these equations may be converted to other units.

(d) Production, measurement and test equipment, drawings, welding procedure specifications, welding procedure and performance qualifications, and other fabrication documents may be in U.S. Customary, SI, or local customary units in accordance with the fabricator's practice. When values shown in calculations and analysis, fabrication documents, or measurement and test equipment are in different units, any conversions necessary for verification of Code compliance, and to ensure that dimensional consistency is maintained, shall be in accordance with the following:

(1) Conversion factors shall be accurate to at least four significant figures.

(2) The results of conversions of units shall be expressed to a minimum of three significant figures.

(e) Material that has been manufactured and certified to either the U.S. Customary or SI material specification (e.g., SA-516 or SA-516M) may be used regardless of the unit system used in design. Standard fittings (e.g., flanges, elbows, etc.) that have been certified to either U.S. Customary units or SI units may be used regardless of the units system used in design.

(f) Conversion of units, using the precision specified in (d), shall be performed to assure that dimensional consistency is maintained. Conversion factors between U.S. Customary and SI units may be found in Nonmandatory Appendix P, Guidance for the Use of U.S. Customary and SI Units in the ASME Boiler and Pressure Vessel Code. Whenever local customary units are used, the Owner shall provide the source of the conversion factors, which shall be subject to verification and acceptance by the Authorized Nuclear Inservice Inspector.

(g) Nonmandatory Appendix P provides guidance for use of the U.S. Customary and SI units in this Division.

IWA-1800 TOLERANCES

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered normal, and allowable tolerances or local variances may be considered acceptable, when based on engineering judgment and standard practices, as determined by the engineer.

ARTICLE IWA-2000
EXAMINATION AND INSPECTION

IWA-2100 GENERAL

IWA-2110 DUTIES OF THE INSPECTOR

(a) The Inspector shall review the inspection plan and, as necessary, the implementation schedule (IWA-2420) prior to the start of preservice inspection and each inspection interval. The review shall cover any features that are affected by the requirements of this Division, as applicable, and shall include the following:

(1) examination categories and items

(2) test and examination requirements

(3) examination methods

(4) percentage of parts selected for examination

(5) disposition of test results

(6) test frequency

(7) system pressure tests

(8) sequence of successive examinations

Shop and field preservice examinations are exempt from prior review.

(b) The Inspector shall review any revisions to the inspection plan and, as necessary, the implementation schedule during the preservice inspection or the inspection interval.

(c) The Inspector shall submit a report to the Owner documenting review of the items identified in (a) and (b).

(d) The Inspector shall verify that the required examinations and system pressure tests have been performed and the results recorded.

(e) The Inspector shall verify that the required visual examinations have been performed and the results recorded.

(f) The Inspector shall perform any additional investigations necessary to verify that all applicable requirements of IWA-2110 have been met.

(g) The Inspector shall verify that the nondestructive examination methods used follow the techniques specified in this Division and that the examinations are performed in accordance with written qualified procedures and by personnel employed by the Owner or the Owner's agent and qualified in accordance with IWA-2300.

(h) The Inspector may require, at any time, requalification of any procedure or operator if the Inspector has reason to believe that the requirements are not being met.

(i) The Inspector shall certify the examination records after verifying that the requirements have been met and that the records are correct.

(j) The Inspector shall verify that repair/replacement activities are performed in accordance with the requirements of the Owner's Repair/Replacement Program.

(k) The Inspector shall review the Repair/Replacement Program and its implementation.

IWA-2120 QUALIFICATION OF AUTHORIZED INSPECTION AGENCIES, INSPECTORS, AND SUPERVISORS

(a) The inspection required by this Division shall be performed

(1) where the plant is in the United States, by an Inspector employed by a State or Municipality of the United States or an Inspector regularly employed by an insurance company authorized to write boiler and pressure vessel insurance in the United States

(2) where the plant is in Canada, by an Inspector employed by a Canadian Province or, if authorized by the Province in which the plant is located, by an Inspector regularly employed by an insurance company licensed to write boiler and pressure vessel insurance in that Province

(3) by an Inspector employed by other enforcement authorities in the United States or Canada having jurisdiction over the designated plant

(b) The Authorized Inspection Agency, including its staff of Authorized Nuclear Inservice Inspector Supervisors and the Inspectors, shall meet the requirements of ASME QAI-1.

(c) The Authorized Inspection Agency shall be accredited by ASME in accordance with the provisions set forth in ASME QAI-1.

IWA-2130 ACCESS FOR INSPECTOR

The Owner shall arrange for an Inspector to have access to all parts of the plant as necessary to make the required inspections. The Owner shall keep the Inspector informed of the progress of the preparatory work necessary to permit inspections and shall notify the Inspector at a time reasonably in advance of when the components will be ready for inspection.

IWA-2200 EXAMINATION METHODS

(a) The three types of examinations used during inservice inspection are defined as visual, surface, and volumetric. The examination method to be used is specified

in Tables IWB-2500-1 (B-A) through IWB-2500-1 (B-Q), IWC-2500-1 (C-A) through IWC-2500-1 (C-H), IWD-2500-1 (D-A) through IWD-2500-1 (D-B), IWE-2500-1 (E-A) through IWE-2500-1 (E-G), IWF-2500-1 (F-A), and IWL-2500-1 (L-A) through IWL-2500-1 (L-B). If a component must be examined in a high radiation area, remotely controlled equipment may be advisable.

(b) When preparation of a surface for nondestructive examination is required, the preparation shall be by a mechanical method. Such surfaces shall be blended into the surrounding area as may be required to perform the examination. The wall thickness shall not be reduced below the minimum thickness required by design. Nonmandatory Appendix D may be used for such surface preparation.

(c) All nondestructive examinations of the required examination surface or volume shall be conducted to the maximum extent practical. When performing VT-1, surface, radiographic, or ultrasonic examination on a component with defined surface or volume, essentially 100% of the required surface or volume shall be examined. Essentially 100% coverage is achieved when the applicable examination coverage is greater than 90%; however, in no case shall the examination be terminated when greater than 90% coverage is achieved, if additional coverage of the required examination surface or volume is practical. Nonmandatory Appendix S provides guidance that may be used for evaluating examination coverage.

(15) IWA-2210 VISUAL EXAMINATION

Visual examination shall be conducted in accordance with the requirements of Section V, Article 9, except that the angle of view requirements for direct visual only apply to VT-1, and the requirements for illumination, distance, and resolution demonstration shall be in accordance with Table IWA-2211-1.

IWA-2211 VT-1 Examination

(a) VT-1 examination is conducted to detect discontinuities and imperfections on the surface of components, including such conditions as cracks, wear, corrosion, or erosion.

(b) The VT-1 examination procedure shall be demonstrated capable of resolving characters in accordance with Table IWA-2211-1.

(c) Direct visual examination distance requirements shall be as specified in Table IWA-2211-1.

(d) Illumination for examinations shall meet the requirements specified in Table IWA-2211-1.

(e) It is not necessary to measure illumination levels on each examination surface when the same portable nonbattery-powered light source (e.g., drop light) or similar installed lighting equipment is demonstrated to provide the illumination specified at the maximum examination distance.

(f) When battery powered lights are used, the adequacy of illumination levels shall be checked before and after each examination or series of examinations, not to exceed 4 hr between checks.

(g) Remote visual examination may be substituted for direct examination. The remote examination procedure shall be demonstrated capable of resolving characters as specified in Table IWA-2211-1. Additionally, the remote examination system shall have the capability of distinguishing and differentiating between the colors applicable to the component examination being conducted.

IWA-2212 VT-2 Examination (15)

(a) VT-2 examination is conducted to detect evidence of leakage from pressure-retaining components, as required during the conduct of system pressure test.

(b) VT-2 examination shall be conducted in accordance with Article IWA-5000.

(c) As indicated in Table IWA-2211-1, there are no illumination, distance, and resolution demonstration requirements for VT-2.

IWA-2213 VT-3 Examination

(a) VT-3 examination is conducted to determine the general mechanical and structural condition of components and their supports by verifying parameters such as clearances, settings, and physical displacements; and to detect discontinuities and imperfections, such as loss of integrity at bolted or welded connections, loose or missing parts, debris, corrosion, wear, or erosion. VT-3 includes examination for conditions that could affect operability or functional adequacy of constant load and spring-type supports.

(b) The VT-3 examination procedure shall be demonstrated capable of resolving characters as specified in Table IWA-2211-1.

(c) There are no direct visual examination distance requirements provided the examiner can resolve the characters specified in Table IWA-2211-1.

(d) Illumination for examinations shall meet the requirements specified in Table IWA-2211-1.

(e) It is not necessary to measure illumination levels on each examination surface when the same portable nonbattery-powered light source (e.g., drop light) or similar installed lighting equipment is demonstrated to provide the illumination specified at the maximum examination distance.

(f) When battery-powered lights are used, the adequacy of illumination levels shall be checked before and after each examination or series of examinations, not to exceed 4 hr between checks.

(g) Remote visual examination may be substituted for direct examination. The remote examination procedure shall be demonstrated capable of resolving characters in accordance with Table IWA-2211-1. Additionally, the

Table IWA-2211-1
Visual Examinations (15)

Visual Examination	Minimum Illumination, fc (lx) [Note (1)]	Maximum Direct Examination Distance, ft (mm)	Maximum Height for Procedure Demonstration Characters, in. (mm) [Note (2)]
VT-1	50 (550)	2 (600)	0.044 (1.1)
VT-2	N/A	N/A	N/A
VT-3	50 (550)	N/A	0.105 (2.7)

NOTES:
(1) Resolution of the specified characters can be used in lieu of illumination measurement to verify illumination adequacy.
(2) For procedure demonstration, a test chart or card containing text with some lowercase characters, without an ascender or descender (e.g., a, c, e, o), that meet the specified height requirements is required. Measurements on the test chart or card shall be made once before its initial use with an optical comparator (10X or greater) or other suitable instrument. At least one character of each specified character size shall be measured, to ensure that the card meets the applicable requirements. Alternatively, a production lot of cards may be verified by measurements on the first and last cards produced and at least one card in the approximate middle of the production run. A production lot shall not exceed 50 cards.

remote examination system shall have the capability of distinguishing and differentiating between the colors applicable to the component examination being conducted.

IWA-2215 Replication

Surface replication methods may be used for VT-1 and VT-3 examinations when the surface resolution is at least equivalent to that of direct visual observation.

IWA-2220 SURFACE EXAMINATION

(a) A surface examination indicates the presence of surface discontinuities. It may be conducted using a magnetic particle, liquid penetrant, eddy current, or ultrasonic method.

(b) Any linear indication detected by magnetic particle, liquid penetrant, or eddy current examination that exceeds the allowable linear surface flaw standards shall be recorded.

(c) Any flaw recorded by ultrasonic examination shall be compared to the volumetric examination acceptance standards of Table IWB-3514-1 or Table IWB-3514-2 for surface planar flaw.

IWA-2221 Magnetic Particle Examination

(a) Magnetic particle examination shall be conducted in accordance with Section V, Article 7.

(b) Magnetic particle examination of coated materials shall be conducted in accordance with Section V, Article 7, Mandatory Appendix I.

(c) For nonfluorescent particles the visible light intensity required is 50 fc. Alternatively, light shall be sufficient if the examination can resolve standard test chart characters as described for VT-1 in IWA-2210.

IWA-2222 Liquid Penetrant Examination

(a) Liquid penetrant examination shall be conducted in accordance with Section V, Article 6.

(b) For visible dye penetrant, the visible light intensity required is 50 fc. Alternatively, lighting shall be sufficient if the examiner can resolve standard test chart characters as described for VT-1 in IWA-2210.

IWA-2223 Eddy Current Examination

Eddy current examination for detection of surface flaws shall be conducted in accordance with Mandatory Appendix IV.

IWA-2224 Ultrasonic Examination

An ultrasonic examination performed from the inside surface of piping may be used as a surface examination method for Categories B-J and B-F piping welds NPS 4 and larger. The ultrasonic examination technique shall be demonstrated capable of detecting an acceptable flaw having the greatest a/t ratio or a 0.50 aspect ratio at the surface being examined.

IWA-2230 VOLUMETRIC EXAMINATION

A volumetric examination indicates the presence of discontinuities throughout the volume of material and may be conducted from either the inside or outside surface of a component.

IWA-2231 Radiographic Examination

For radiographic examinations employing either X-ray equipment or radioactive isotopes, the procedure shall be as specified in Section V, Article 2.

IWA-2232 Ultrasonic Examination

Ultrasonic examination shall be conducted in accordance with Mandatory Appendix I.

IWA-2233 Eddy Current Examination

Eddy current examination shall be conducted in accordance with Section V, Article 8, Mandatory Appendix II.

(15) IWA-2234 Acoustic Emission Examination

Acoustic emission may be used in lieu of the successive inspections of IWB-2420(b) or IWC-2420(b) to monitor growth of flaws detected by other NDE methods. The flaws shall be sized by ultrasonic examination in accordance with Mandatory Appendix I prior to initiating use of acoustic emission. Acoustic emission monitoring shall be initiated prior to resuming operation of the system. Acoustic emission shall be conducted in accordance with Section V, Article 13, with the following additional requirements.

(a) The following flaw growth calculation and acceptance criteria shall be used.

(1) Every two months during the current inspection period, calculate the flaw growth in accordance with Section V, Article 13, Mandatory Appendix I. Using this growth rate, predict the flaw size at the end of the current inspection period.

(2) If the calculated flaw size at the end of the current inspection period meets the acceptance criteria of IWB-3600 or IWC-3600, as applicable, continue the two-month monitoring process described in (1) above.

(3) If the calculated flaw size at the end of the current inspection period does not meet the acceptance criteria of IWB-3600 or IWC-3600, as applicable, the following actions shall be performed.

(-a) Calculate the flaw size at the end of the next two-month time span. If this calculated flaw size meets the acceptance criteria of IWB-3600 or IWC-3600, as applicable, continue the two-month monitoring process described in (1).

(-b) If the calculated flaw size at the end of the next two-month time span does not meet the acceptance criteria of IWB-3600 or IWC-3600, as applicable, the component shall be corrected by repair/replacement activity in accordance with IWB-3130 or IWC-3120, as applicable.

(b) If no flaw growth is observed for one operating cycle, the component examination schedule may revert to the original schedule of successive inspections of IWB-2410 or IWC-2410, as applicable.

IWA-2240 ALTERNATIVE EXAMINATIONS

Alternative examination methods, a combination of methods, or newly developed techniques may be substituted for the methods specified in this Division, provided the Inspector is satisfied that the results are demonstrated to be equivalent or superior to those of the specified method.

IWA-2300 QUALIFICATIONS OF NONDESTRUCTIVE EXAMINATION PERSONNEL

IWA-2310 GENERAL (15)

(a) Personnel performing nondestructive examinations (NDE) shall be qualified and certified using a written practice prepared in accordance with ANSI/ASNT CP-189, Standard for Qualification and Certification of Nondestructive Testing Personnel, and ANSI/ASNT CP-105, Standard for Topical Outlines for Qualification of Nondestructive Testing Personnel, as amended by the requirements of this Division. Certifications based on earlier editions of ANSI/ASNT CP-189 are valid until recertification is required. Recertification shall be in accordance with the edition of ANSI/ASNT CP-189 referenced in IWA-1600 as amended by the requirements of this Division. Outside agencies, as defined in Mandatory Appendix VII, may be used to qualify NDE personnel; however, the Employer shall be solely responsible for the certification of Levels I, II, and III personnel. Nondestructive and visual examination personnel qualified and certified in accordance with the requirements of this Division are qualified and certified to perform examinations in accordance with the requirements of previous Editions and Addenda.

(b) As an alternative to a personnel qualification program based on CP-189, the ASNT Central Certification Program (ACCP) may be used. The supplemental requirements of this Division shall apply to qualification of personnel in accordance with the ACCP.

IWA-2311 Written Practice

(a) The Employer shall prepare a written practice in accordance with ANSI/ASNT CP-189.

(b) The written practice shall specify the duties and responsibilities of the Principal Level III.

IWA-2312 NDE Methods Listed in ANSI/ASNT CP-189

(a) Qualifications shall be based on the methods, techniques, procedures, and equipment used for the NDE required by this Division.

(b) Training, qualification, and certification of ultrasonic examination personnel shall also comply with the requirements of Mandatory Appendix VII.

(c) Training, qualification, and certification of visual examination personnel shall comply with the requirements of Mandatory Appendix VI.

(d) The visual examination training and experience hours specified in ANSI/ASNT CP-189 shall be applied to the combined certification of an individual for VT-1,

VT-2, and VT-3 visual examination. Certification in only one of the VT techniques is a limited certification, and the requirements of IWA-2350 apply.

(e) Personnel certified in an NDE method, and whose training and experience in that method met the requirements of an edition of ASNT SNT-TC-1A or ANSI/ASNT CP-189 referenced by a previous edition or addenda of this Division, do not require additional training or experience hours when being certified or recertified to the same level by an employer, except as specified in (b).

IWA-2313 NDE Methods Not Listed in ANSI/ASNT CP-189

Personnel using NDE methods not addressed in ANSI/ASNT CP-189 shall be qualified as defined in ANSI/ASNT CP-189 or the ACCP and the Employer's written practice.

IWA-2314 Certification and Recertification

(a) Personnel shall be qualified by examination and shall be certified in accordance with ANSI/ASNT CP-189, except that the ASNT Level III certificate is not required. Levels I, II, and III personnel shall be recertified by qualification examinations every 5 yr.

(b) Personnel qualified in accordance with the ACCP shall be recertified by examination every 5 yr.

(c) An ACCP certificate with current endorsements obtained by examination satisfies the General and Practical Examination requirements for Levels I and II NDE personnel.

(d) Levels I, II, and III NDE personnel may be certified or recertified without additional training or experience hours when

(1) certification or recertification is to the same level, and

(2) the candidate's training and experience in the NDE method met the requirements of an edition of ASNT SNT-TC-1A or ANSI/ASNT CP-189 referenced by a previous edition or addenda of this Division.

IWA-2315 Personnel Requirements for Eddy Current Examination of Steam Generator Tubing

Personnel performing analysis or evaluation of data shall be qualified by examination to perform analysis of multifrequency data and to use multiparameter signal combination techniques. The qualification shall include a practical examination that includes techniques used and the types of flaws that may be found during examination of steam generator tubing.

IWA-2316 Alternative Qualifications of VT-2 Visual Examination Personnel

(a) For system leakage tests and hydrostatic tests performed in accordance with IWA-5211(a) and IWA-5211(b), in lieu of the requirements of IWA-2310 through IWA-2314, VT-2 visual examination personnel may be qualified by satisfying the following requirements:

(1) at least 40 hr plant walkdown experience, such as that gained by licensed and nonlicensed operators, local leak rate personnel, system engineers, quality control personnel, and nondestructive examination personnel

(2) at least 4 hr of training in the Section XI requirements and plant-specific procedures for VT-2 visual examination

(3) the vision test requirements of IWA-2321

(b) Personnel qualified in accordance with these alternative requirements shall not perform VT-2 functions other than examinations (e.g., verifying adequacy of procedures, training VT-2 personnel).

(c) These alternative qualification requirements shall be described in the Employer's written practice.

IWA-2317 Alternative Qualifications of VT-3 Visual Examination Personnel

(a) In lieu of the requirements of IWA-2310 through IWA-2314, VT-3 visual examination personnel may be qualified by satisfying the following requirements:

(1) at least 40 hr plant experience, such as that gained by plant personnel involved in installation, maintenance, or examination of pumps, valves, and supports, quality control personnel, and nondestructive examination personnel

(2) at least 8 hr of training in the Section XI requirements and plant-specific procedures for VT-3 visual examination

(3) the vision test requirements of IWA-2321

(4) for initial qualification, and at least every 3 yr thereafter, pass a written examination of at least 30 questions covering VT-3 examination attributes, VT-3 examination requirements, and plant-specific VT-3 procedures.

(b) The alternative qualification requirements shall be described in the Employer's written practice.

IWA-2320 QUALIFICATION EXAMINATIONS

IWA-2321 Vision Tests

The following tests shall be administered annually to NDE personnel:

(a) Personnel shall demonstrate natural or corrected near-distance acuity of 20/25 or greater Snellen fraction, with at least one eye, by reading words or identifying characters on a near-distance test chart, such as a Jaeger chart, that meets the requirements of IWA-2322. Equivalent measures of near-distance acuity may be used. In addition, personnel performing VT-2 or VT-3 visual examinations shall demonstrate natural or corrected far-distance acuity of 20/30 or greater Snellen fraction or equivalent with at least one eye.

(b) As an alternative to the visual acuity demonstration requirements of (a), any vision test administered by an optometrist, opthamalogist, or other healthcare professional who administers vision tests and documents compliance with the acuity requirements of (a) is acceptable.

(c) Personnel shall demonstrate the capability to distinguish the colors applicable to the NDE methods for which certified and to differentiate contrast between these colors.

IWA-2322 Near-Distance Test Chart Qualification

A measurement of one of the near-distance test chart characters shall be made once before initial use, with an optical comparator (10X or greater) or other suitable instrument, to verify that the height of a representative lower case character, without an ascender or descender (e.g., a, c, e, o), for the selected type size, meets the requirements of Table IWA-2322-1. This measurement shall be documented and traceable to the test chart.

IWA-2323 Level III Personnel

The qualifications of Level III NDE personnel shall be evaluated using written examinations and a Demonstration Examination. The written examinations shall cover the Basic, Method, Specific, and Practical areas of knowledge as defined in (a), (b), (c), and (d). The Demonstration Examination shall be in accordance with ANSI/ASNT CP-189, Level II Practical Examination rules. The administration of multiple-choice written examinations may be delegated by the Level III, with valid Level III certifications in the applicable test methods, to a noncertified proctor, if so documented.

(a) The Basic Examination shall consist of at least 65 questions (required only once if certification is sought in more than one method).

(1) at least 20 questions related to understanding of ANSI/ASNT CP-189

(2) at least 30 questions related to applicable materials, fabrication, and product technology

(3) at least 15 questions that are similar to published Level II questions for other NDT methods

(b) The Method Examination shall consist of at least 65 questions.

(1) at least 30 questions related to fundamentals and principles that are similar to published ASNT Level III questions for each method

(2) at least 15 questions related to application and establishment of procedures and techniques that are similar to published ASNT Level III questions for each method

(3) at least 20 questions related to capability for interpreting codes, standards, and specifications related to the method

(c) The Specific Examination shall contain at least 30 questions covering equipment, techniques, procedures, and administration of the Employer's written practice. The Specific Examination shall also cover the NDE requirements of this Division, including acceptance standards and referenced codes and standards.

(d) The Practical Examination shall be in accordance with ANSI/ASNT CP-189 requirements.

(e) An ASNT Level III certificate with current endorsements obtained by examination for the applicable method satisfies the Basic and Method Examination requirements.

(f) When an outside agency administers the examination and only a pass or fail grade is issued, the Employer shall assign a grade of 80% for a pass grade.

(g) Level III personnel shall be recertified using the written Method, Specific, and Practical Examinations and the Demonstration Examination. Alternatively, Level III personnel may be recertified using only the written Method and Specific Examinations, provided the following conditions are met.

(1) The Level III candidate was previously certified or recertified using all the written examinations and the Demonstration Examination.

(2) The Level III candidate is not being recertified due to interrupted service as defined in the Employer's written practice.

(3) The Level III candidate is not being certified by a new Employer.

(h) For initial certification, the grades for the Basic, Method, Specific, Practical, and Demonstration Examinations shall be averaged to determine the overall grade. For recertification, the grades of applicable examinations administered in accordance with (g) shall be averaged to determine the overall grade.

(i) An ACCP certificate with current endorsements obtained by examination satisfies the Basic, Method, Practical, and Demonstration examination requirements for Level III NDE personnel.

Table IWA-2322-1
Near-Distance Acuity Test Distances and Character Heights

Test Distance, in. (mm)	Maximum Lower Case Character Height, in. (mm)
12 (300)	0.022 (0.56)
13 (330)	0.024 (0.61)
14 (350)	0.025 (0.64)
15 (380)	0.027 (0.69)
16 (400)	0.029 (0.74)

GENERAL NOTE: The test distances (eye to chart) and corresponding character heights provide a visual angle of 6.25 minutes, which is equivalent to a Snellen fraction of 20/25.

IWA-2330 LEVEL I RESPONSIBILITIES

Level I personnel shall use written procedures when performing specific setups, calibrations, and examinations and when recording data. These activities shall be conducted under the guidance of Level II or Level III personnel. Level I personnel shall not evaluate or accept the results of a nondestructive examination.

IWA-2340 LEVEL III EDUCATION

Level III candidates shall have high school or equivalent education.

(15) IWA-2350 LIMITED CERTIFICATION

Limited certification provisions of ANSI/ASNT CP-189 do not apply. Limited certification in a method is permitted for personnel who are restricted to performing examinations of limited scope, i.e., limited operations or limited techniques within the method. Topics that are not relevant to the limited certification may be deleted from the applicable training outline and may be accompanied by a corresponding reduction in training hours, examination content, and number of examination questions. Only questions related to the limited training are required. In addition, the required experience may be reduced by a corresponding amount. The specific methods and techniques covered by limited certification and the training, examination, and experience requirements for limited certification shall be defined in the written practice and documented in the individual's certification records.

(15) IWA-2360 LEVEL I AND LEVEL II TRAINING AND EXPERIENCE

(a) A candidate may be qualified directly to Level II with no time as a Level I provided the required training and experience consists of the sum of the hours required for Level I and Level II certification.

(b) NDE training course outlines and materials shall be approved by a Level III. Previous training and experience may be accepted if verified by a Level III. The method of verification shall be documented in the candidate's certification records.

(c) Experience is work time in an NDE method. Classroom and laboratory training time shall not be credited as experience.

IWA-2370 LEVEL III EXPERIENCE

Candidates for Level III certification shall meet one of the following criteria:

(a) Graduate of a 4-yr accredited engineering or science college or university with a degree in engineering or science, plus 1 yr experience in NDE in an assignment comparable to that of a Level II in the examination method.

(b) Completion with a passing grade of at least the equivalent of 2 full years of engineering or science study at a university, college, or technical school, plus 2 yr experience in an assignment comparable to that of a Level II in the examination method.

(c) Four years experience in an assignment comparable to that of a Level II in the examination method.

IWA-2380 NDE INSTRUCTOR

In lieu of the requirements of CP-189, a candidate being considered for qualification as an NDE Instructor shall satisfy the Level III Basic and Method Examination requirements of IWA-2323 and shall meet one of the following requirements:

(a) maintain a current teacher or vocational instruction certificate issued by a state, municipal, provincial, or federal authority; or

(b) complete a minimum of 40 hr instruction in training and teaching techniques.

IWA-2400 INSPECTION PROGRAM

IWA-2410 APPLICATION OF CODE EDITION AND ADDENDA

The Code Edition and Addenda for preservice inspection and for initial and successive inservice inspection intervals shall be as required by the regulatory authority having jurisdiction at the plant site.

IWA-2420 INSPECTION PLANS AND SCHEDULES

Inspection plans and schedules shall be prepared for the preservice inspection, the first inservice inspection interval, and subsequent inservice inspection intervals.

(a) Each inspection plan shall include the following:

(1) inspection period and interval dates

(2) the Edition and Addenda of this Division that apply to the required examinations and tests

(3) the classification and identification of the components subject to examination and test

(4) Code Cases proposed for use and the extent of their application

(b) An implementation schedule for performance of examinations and tests shall be prepared for each inspection plan. The schedule shall include the following:

(1) identification of the components selected for examination and test, including successive exams from prior periods

(2) the Code requirements by examination category and item number for each component and the examination or test to be performed and the extent of the examination or test

(3) identification of drawings showing items that require examination

(4) list of examination procedures

(5) description of alternative examinations and identification of components to be examined using alternative methods

(6) identification of calibration blocks used for ultrasonic examination of components

IWA-2425 Inspection Plan and Schedule Supporting Documents

Supporting documents necessary for inspection plan and schedule implementation such as diagrams or system drawings showing boundaries and system classifications, procedures, specifications, and other documents required for implementation of the inservice examinations and tests shall be available at the plant site.

IWA-2430 INSPECTION INTERVALS

(a) The inservice examinations and system pressure tests required by Subsection IWB, Subsection IWC, Subsection IWD, Subsection IWE, and inservice examinations and tests of Subsection IWF shall be completed during each of the inspection intervals for the service lifetime of the plant. The inspections shall be performed in accordance with the schedule of the Inspection Program of IWA-2431.

(b) The inspection interval shall be determined by calendar years following placement of the plant into commercial service.

(c) For components inspected under the Inspection Program, the following shall apply:

(1) Each inspection interval may be extended by as much as 1 yr and may be reduced without restriction, provided the examinations required for the interval have been completed. Successive intervals shall not extend more than 1 yr beyond the original pattern of 10-yr intervals and shall not exceed 11 yr in length. If an inspection interval is extended, neither the start and end dates nor the inservice inspection program for the successive interval need be revised.

(2) Examinations may be performed to satisfy the requirements of the extended period or interval in conjunction with examinations performed to satisfy the requirements of the successive period or interval. However, an examination performed to satisfy requirements of either the extended period or interval or the successive period or interval shall not be credited to both periods or intervals.

(3) That portion of an inspection interval described as an inspection period may be extended by as much as 1 yr and may be reduced without restriction, provided the examinations required for that period have been completed. This adjustment shall not alter the requirements for scheduling inspection intervals.

(4) The inspection interval for which an examination was performed shall be identified on examination records.

(d) In addition to (c), for plants that are out of service continuously for 6 months or more, the inspection interval during which the outage occurred may be extended for a period equivalent to the outage and the original pattern of intervals extended accordingly for successive intervals.

(e) The inspection intervals for items installed by repair/replacement activities shall coincide with remaining intervals, as determined by the calendar years of plant service at the time of the repair/replacement activities.

(f) The inspection intervals for inservice examination of heat exchanger tubing shall be in accordance with the requirements of IWB-2413.

(g) The inspection intervals for inservice examination of Class CC components shall be in accordance with the requirements of IWA-2431.

IWA-2431 Inspection Program

The inspection intervals shall comply with the following, except as modified by IWA-2430(c) and IWA-2430(d):

(a) 1st Inspection Interval — 10 yr following initial start of plant commercial service

(b) Successive Inspection Intervals — 10 yr following the previous inspection interval

IWA-2440 APPLICATION OF CODE CASES

IWA-2441 Section XI Code Cases

(a) Code Cases to be used during a preservice or inservice inspection shall be identified in the Inspection Plan.

(b) Code Cases shall be applicable, as indicated in the Applicability Index for Section XI Cases found in the *Code Cases: Nuclear Components* book, to the Edition and Addenda specified in the Inspection Plan.

(c) Code Cases shall be in effect at the time the Inspection Plan is filed with the regulatory and enforcement authorities having jurisdiction at the plant site except as provided in (d), (e), or IWA-2442.

(d) Cases superseded at the time the Inspection Plan is filed, but acceptable to the regulatory and enforcement authorities having jurisdiction at the plant site, may be used.

(e) Code Cases issued subsequent to filing the Inspection Plan may be proposed for use in amendments to the Inspection Plan.

(f) Superseded Code Cases approved for use in accordance with (a) through (e) may continue to be used.

(g) The use of any Code Case and revisions to previously approved Code Cases are subject to acceptance by the regulatory and enforcement authorities having jurisdiction at the plant site.

IWA-2442 Annulled Section XI Code Cases

Code Cases approved for use in accordance with IWA-2441 may be used after annulment for the duration of that Inspection Plan.

IWA-2500 EXTENT OF EXAMINATION

Requirements for examination of welds apply only to welds joining items and not welds correcting flaws in base material (including core closure welds in casting), unless otherwise stated.

IWA-2600 WELD REFERENCE SYSTEM

IWA-2610 GENERAL

A reference system shall be established for all welds and areas subject to surface or volumetric examination. Each such weld and area shall be located and identified by a system of reference points. The system shall permit identification of each weld, location of each weld centerline, and designation of regular intervals along the length of the weld.

IWA-2620 PIPING

Requirements for piping are provided in III-4300. The rules of III-4300 may also be applied to piping not within the scope of III-1100.

IWA-2630 VESSELS

The requirements of Section V, Article 4, Nonmandatory Appendix A are acceptable for vessels examined in accordance with Section V, Article 4.

IWA-2640 OTHER COMPONENTS

A reference system for component welds is given in IWA-2641. A different system may be used provided it meets the requirements of IWA-2610.

IWA-2641 Layout of Component Reference Points

The layout of the weld shall consist of placing reference points on the center line of the weld. The standard spacing of the reference points shall be 12 in. (300 mm). All points shall be identified with their numbers: 0, 1, 2, 3, 4, etc. The numbers of points, distance apart, and starting point shall be recorded on the reporting form. The weld center line shall be the divider for the two examination surfaces.

(a) Circumferential (Girth) Welds. The standard starting point shall be component 0 deg. The reference points shall be numbered clockwise as viewed from the top of the component. The examination surfaces shall be identified as above or below the weld.

(b) Longitudinal (Vertical) Welds. Longitudinal welds shall be laid out from the center line of circumferential welds at the top end of the weld. The examination surface shall be identified as clockwise or counterclockwise as viewed from the top of the component.

(c) Nozzle-to-Vessel Welds. The external reference circle shall have a sufficient whole number of inches radius so that the circle falls on the vessel external surface beyond the weld fillet. The internal reference circle shall have a sufficient whole number of inches radius so that the circle falls within $^1/_2$ in. (13 mm) of the weld centerline. Zero deg point on the weld shall be the top of the nozzle. The 0 deg point for welds of nozzles centered in heads shall be located at the 0 deg axis of the vessel. Angular layout of the weld shall be made clockwise on the external surface, counterclockwise on the internal surface. Zero, 90, 180, and 270 deg lines shall be marked on all nozzle welds examined; 30 deg increment lines shall be marked on nozzle welds greater than 4 in. (100 mm) radius; 15 deg increment lines shall be marked on nozzle welds greater than 12 in. (300 mm) radius; 5 deg increment lines shall be marked on nozzle welds greater than 24 in. (600 mm) radius.

ARTICLE IWA-3000
STANDARDS FOR EXAMINATION EVALUATION

IWA-3100 EVALUATION

(a) Evaluation shall be made of flaws detected during an inservice examination as required by Article IWB-3000 for Class 1 pressure-retaining components, Article IWC-3000 for Class 2 pressure-retaining components, Article IWD-3000 for Class 3 pressure-retaining components, Article IWE-3000 for Class MC pressure-retaining components, or Article IWF-3000 for component supports.

(b) If acceptance standards for a particular component, Examination Category, or examination method are not specified in this Division, flaws that exceed the acceptance standards for materials and welds specified in the Section III Edition applicable to the construction of the component shall be evaluated to determine disposition. Such disposition shall be subject to review by the regulatory and enforcement authorities having jurisdiction at the plant site.

(15) IWA-3200 SIGNIFICANT DIGITS FOR LIMITING VALUES

(a) All observed or calculated values of dimensions of component thickness and of flaws detected by nondestructive examinations to be used for comparison with the acceptance standards of Article IWB-3000, Article IWC-3000, Article IWD-3000, or Article IWE-3000, whether obtained as decimals or converted from fractions, shall be expressed to the nearest 0.1 in. (2 mm) for values 1 in. (25 mm) and greater, and to the nearest 0.05 in. (1.5 mm) for values less than 1 in. (25 mm). Rounding-off of values shall be performed in accordance with the Rounding-off Method of ASTM Recommended Practice E29.

(b) Interpolation of percentage values for acceptance standards, as required for intermediate flaw aspect ratios in the tables of allowable flaw standards, shall be rounded to the nearest 0.1%.

(c) Interpolation of decimal or fractional dimensions specified in the tables of allowable flaw standards shall be rounded to the nearest 0.1 in. (2 mm) or $^1/_{16}$ in. (2 mm), respectively.

IWA-3300 FLAW CHARACTERIZATION (15)

(a) Flaws detected by the preservice and inservice examinations shall be sized by the bounding rectangle or square for the purpose of description and dimensioning. The dimensions of a flaw shall be determined by the size of a rectangle or square that fully contains the area of the flaw.

(1) The length ℓ of the rectangle or one side of the square shall be drawn parallel to the inside pressure-retaining surface of the component.

(2) The depth of the rectangle or one side of the square shall be drawn normal to the inside pressure-retaining surface of the component and shall be denoted as a for a surface flaw and $2a$ for a subsurface flaw.

(3) The aspect ratio of a flaw shall be defined by a/ℓ. The flaw aspect ratio shall not exceed 0.5. (see Figure IWA-3320-1, Flaw #3, as an example.)

(b) Flaws shall be characterized in accordance with IWA-3310 through IWA-3390, as applicable. If multiple flaws exist, each flaw shall be evaluated for its interaction with each adjacent flaw on an individual flaw basis, using the original flaw dimensions. First, the proximity of each flaw to the surface shall be determined. Any individual subsurface flaw that is determined to satisfy the criteria for surface interaction ($S < 0.4d_1$) shall be reclassified as a surface flaw. Next, the proximity of any flaw to adjacent flaws shall be evaluated using the original dimensions of each individual flaw. If two or more flaws are combined by the proximity rules, it is not required to consider further interactions based on the dimensions of the combined flaw with other flaws.

(c) The clad thickness dimension may be taken from the manufacturer's drawings.

(d) Flaws detected by the inservice examinations (IWB-2500) of steam generator tubing (Examination Category B-Q) shall be described as a percentage of wall thickness. The depth is the maximum radial dimension of the flaw. The wall thickness t is the nominal wall thickness, and the tube radius r is the mean radius as given by the specification to which the tubes were purchased. These flaws shall be compared with the standards of IWB-3521.

IWA-3310 SURFACE PLANAR FLAWS

(a) A continuous indication shall be considered as a surface planar flaw if the detected area of the flaw is oriented primarily in any single plane, other than parallel to the surface of the component, and any portion of the flaw penetrates a surface of the component, as shown in Figure IWA-3310-1.

(b) A subsurface indication shall be considered a surface flaw if any portion of the flaw is less than $0.4d$ from the surface of the component nearest the flaw. If the nearest surface of the component is clad, S shall be measured to the clad–base metal interface. S is measured as shown in Figure IWA-3310-1. The thickness of the cladding used to establish the clad–base metal interface may be the nominal clad thickness specified on design drawings of the component.

IWA-3320 SUBSURFACE PLANAR FLAWS

(a) A continuous indication shall be considered a subsurface planar flaw if the detected area of the flaw is oriented primarily in any single plane other than parallel to the surface of the component, and if the distance S from the flaw to the nearest surface of the component is as shown in Figure IWA-3320-1. If the nearest surface of the component is clad, S shall be measured to the clad–base metal interface. The thickness of cladding used to establish the clad–base metal interface may be the nominal clad thickness specified on design drawings of the component.

(b) The modified surface proximity rule for discriminating surface from subsurface indications of Figure IWA-3320-2 may be used to eliminate the need for successive examinations of IWB-2420(b) and IWC-2420(c) for subsurface flaws in vessels.

IWA-3330 MULTIPLE PLANAR FLAWS

(a) Discontinuous indications shall be considered single planar flaws if the distance between adjacent flaws is equal to or less than the dimension S, where S is determined as shown in Figure IWA-3330-1.

(b) The rules of IWA-3310 and IWA-3320 shall be applied to characterize multiple planar flaws as surface or subsurface planar flaws, respectively.

(c) The dimensions a and ℓ of such multiple planar flaws shall be those of the square or rectangle that contains the detected area of all flaws within the proximity limits defined in (a).

(d) Combination of multiple planar flaws is not required for fatigue or stress corrosion cracking assessment.

IWA-3340 NONPLANAR FLAWS

(a) A continuous indication whose detected area is not oriented in a single plane (such as two or more intersecting inclined planes, curvilinear geometry, or combinations of nonplanar geometry) shall be resolved into two planar flaws by projection of the flaw area into planes normal to the maximum principal stresses, as shown in Figure IWA-3340-1.

(b) The rules of IWA-3310 and IWA-3320 shall be applied to characterize the projected areas of the flaws as surface or subsurface flaws, respectively.

(c) The dimensions a and ℓ of such flaws shall be those of a rectangle that contains the projected area of the flaw as shown in Figure IWA-3340-1.

IWA-3350 PARALLEL PLANAR FLAWS

(a) Discontinuous indications whose areas are oriented primarily in parallel planes, and other than parallel to the surface of the component, shall be considered single planar flaws if the adjacent planes are within a distance S, where S is determined as shown in Figure IWA-3350-1.

(b) The dimensions a and ℓ of such flaws shall be those of the square or rectangle that contains the detected area of all flaws within the flaw–plane adjacency limits of (a), as shown in Figure IWA-3350-1.

IWA-3360 LAMINAR FLAWS

(a) Planar indications oriented within 10 deg of a plane parallel to the surface of the component shall be considered laminar flaws, except where noted otherwise in referenced figures of IWB-3500.

(b) The area of a laminar flaw shall be 0.75 times the area of the square or rectangle that contains the detected area of those flaws that either overlap or are within a distance S of 1 in. (25 mm) of one another as shown in Figure IWA-3360-1.

IWA-3370 RADIOGRAPHIC EXAMINATION

(a) An indication detected by radiographic examination shall be considered to be a linear flaw unless the indication can be characterized as surface planar, subsurface planar, or laminar by supplemental examination.

(b) The supplemental examination of (a) may be by additional radiography, ultrasonic examination, or other methods provided they comply with the rules of IWA-2240.

IWA-3380 MULTIPLE NONALIGNED COPLANAR FLAWS

(a) Discontinuous indications that are coplanar and nonaligned in the through-wall direction of the section thickness t, and with at least one indication characterized as a surface flaw, shall be considered single planar surface flaws if the separation distances S_1 and S_2 between the individual flaws are equal to or less than the dimensions specified in Flaw #1 of Figure IWA-3380-1.

(b) The dimensions a and ℓ of the combined single flaw of (a) shall be defined by the size of the bounding square or rectangle that contains the individual nonaligned flaws as delineated in Figure IWA-3380-1.

Figure IWA-3310-1
Surface Planar Flaws Oriented in Plane Normal to Pressure-Retaining Surface
Illustrative Flaw Configurations and Determination of Dimensions a and ℓ ($\frac{1}{2}$ in. = 13 mm)

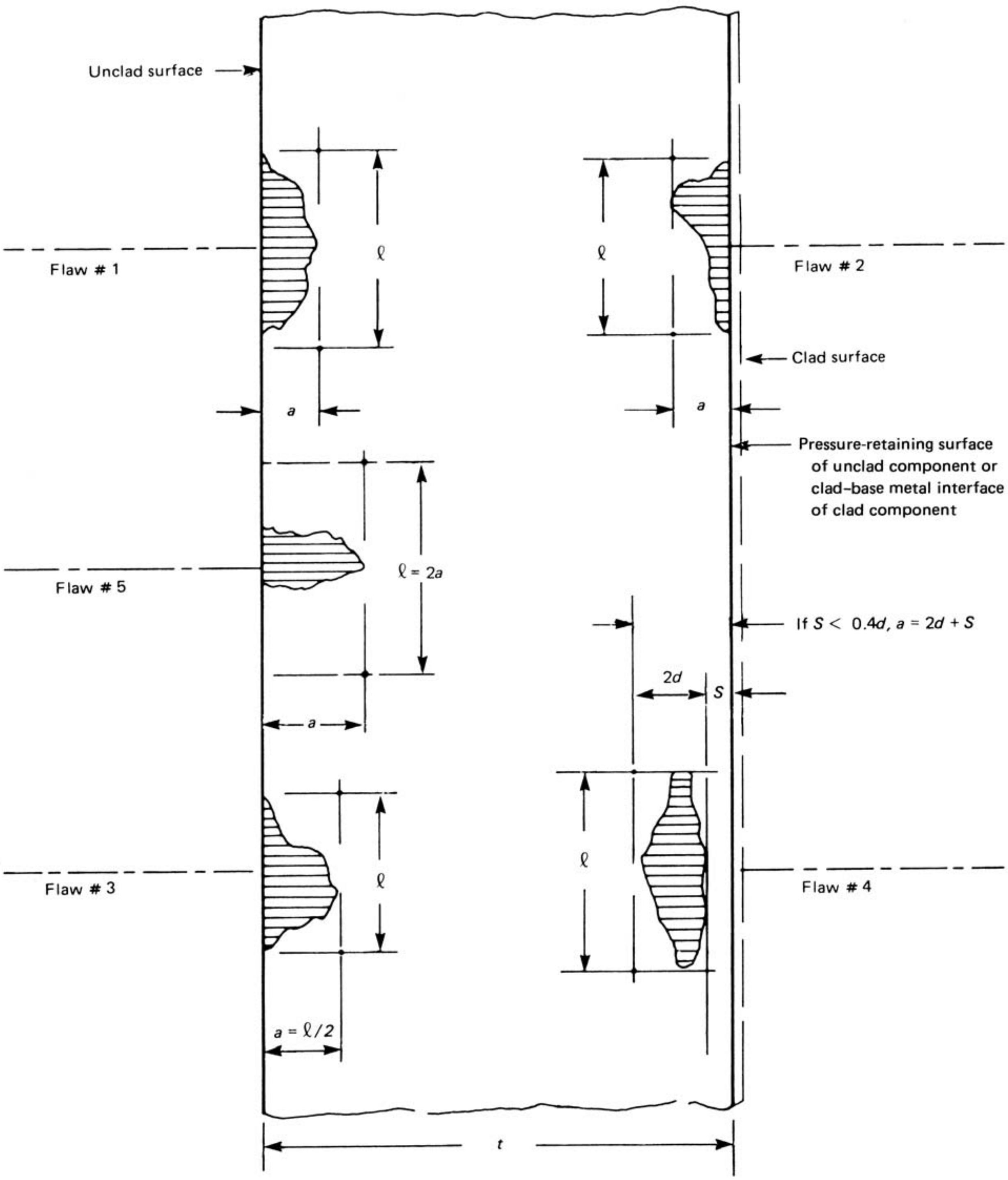


Figure IWA-3320-1
Subsurface Planar Flaws Oriented in Plane Normal to Pressure-Retaining Surface
Illustrative Flaw Configurations and Determination of Dimensions 2a and ℓ Where S Is ≥ 0.4a (1 in. = 25 mm)

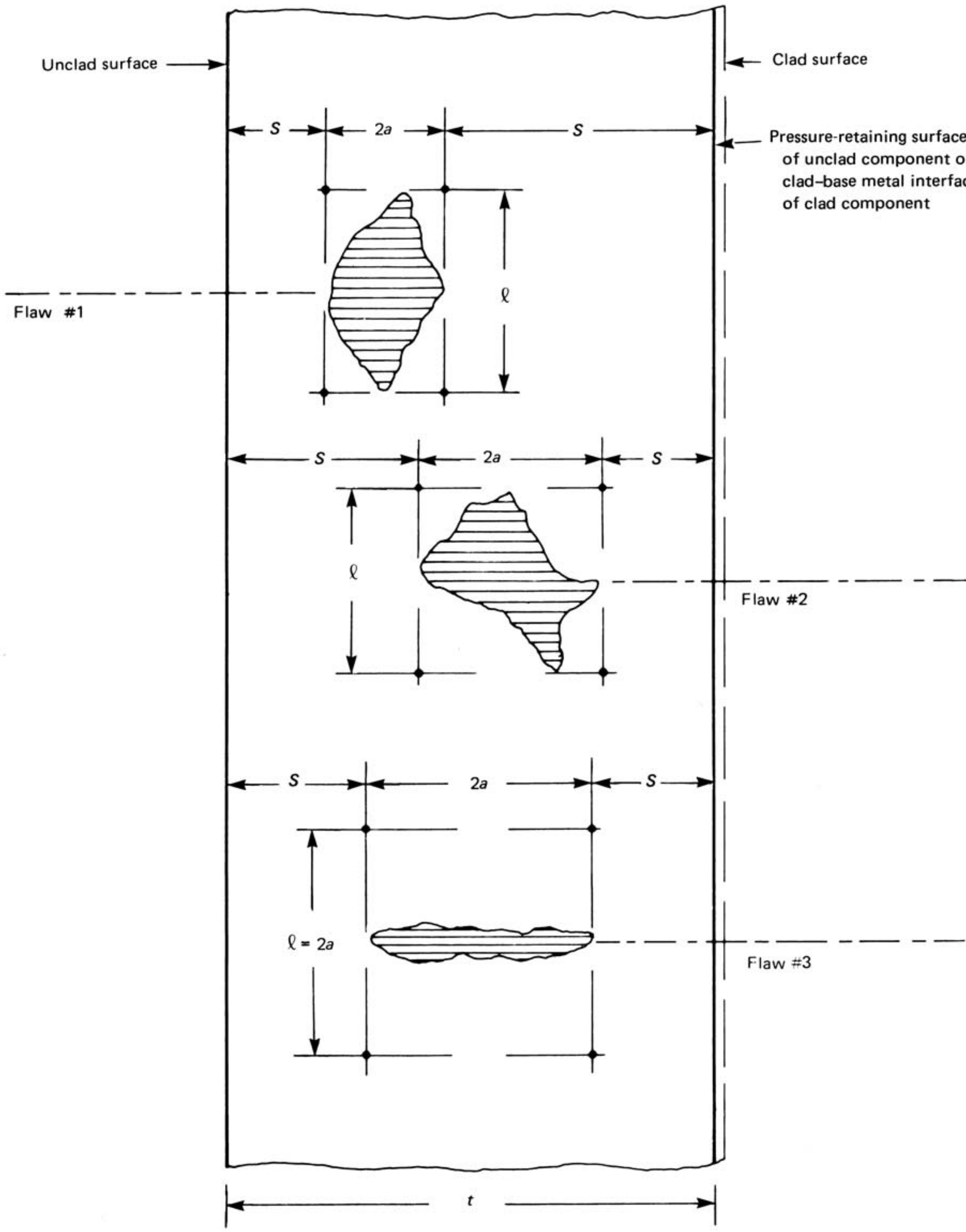
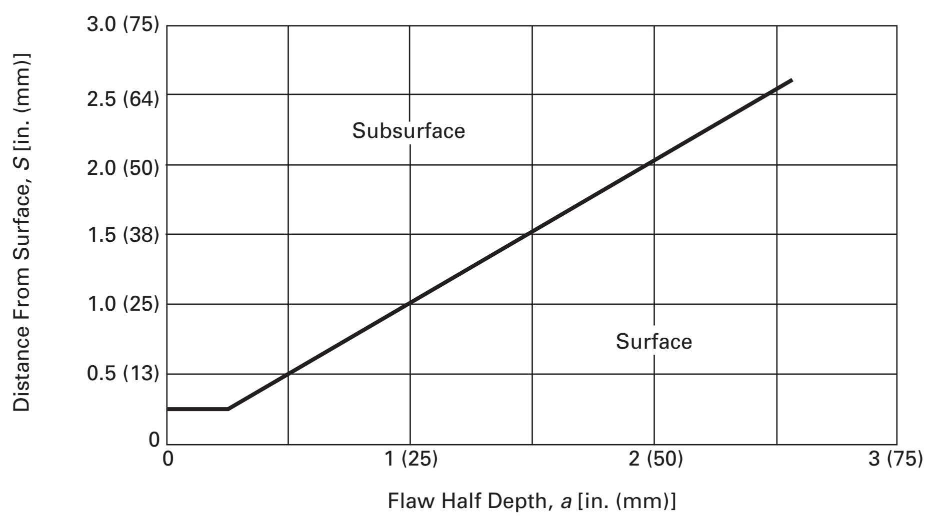


Figure IWA-3320-2
Successive Examination Surface Proximity Rule for Class 1 and Class 2 Vessels



(c) Discontinuous indications that are coplanar and nonaligned in the through-wall direction of the section thickness and characterized as subsurface flaws shall be considered single planar subsurface flaws if the separation distances S_1, S_2, S_3, and S_4 are equal to or less than the dimensions specified in Flaw #2 of Figure IWA-3380-1.

(d) The dimensions a and ℓ of the combined single flaw of (c) shall be defined by the size of the bounding square or rectangle that contains the individual nonaligned flaws as delineated in Figure IWA-3380-1.

(e) Flaw interaction within a group containing a greater number of individual flaws than shown in Figure IWA-3380-1 shall be governed by the same criterion of (a) or (c). However, in all cases, the initial characterization of flaw interactions shall not require a recharacterization even if the bounding square or rectangle reduces the separation distance S to another adjoining flaw to within the flaw interaction distance.

(f) Combination of multiple nonaligned coplanar flaws is not required for fatigue or stress corrosion cracking assessment.

IWA-3390 MULTIPLE ALIGNED SEPARATE FLAWS

(a) Discontinuous flaws, as shown in Figure IWA-3390-1, that are coplanar in the through-wall direction of the section thickness, that are located within two parallel planes ½ in. (13 mm) apart (i.e., normal to the pressure-retaining surface of the component), and that are aligned to reduce the net section thickness may be treated as separate and individual planar flaws if the following requirements are met.

(1) The a dimensions for the flaw aspect ratio, a/ℓ of the individual flaws do not exceed the allowable flaw standards for the respective Examination Category applicable to the component.

(2) The additive flaw depth dimensions within the bounding parallel planes shown in Figure IWA-3390-1 are not in excess of the following limits:[3]

(-a) two surface flaws (one a_1 on the outer and the other a_2 on the inner surface of the component), $(a_1 + a_2) \le (a_s + a'_s)/2$ within planes A–A′ and B–B′;

(-b) two subsurface flaws, $(a_1 + a_2) \le (a_e + a'_e)/2$ within planes C–C′ and D–D′;

(-c) two surface and one subsurface flaws:

(-1) $(a_1 + a_3) \le (a_s + a_e)/2$ within planes E–E′ and F–F′

(-2) $(a_1 + a_2 + a_3) \le (a_s + a_e + a'_s)/3$ within planes F–F′ and G–G′

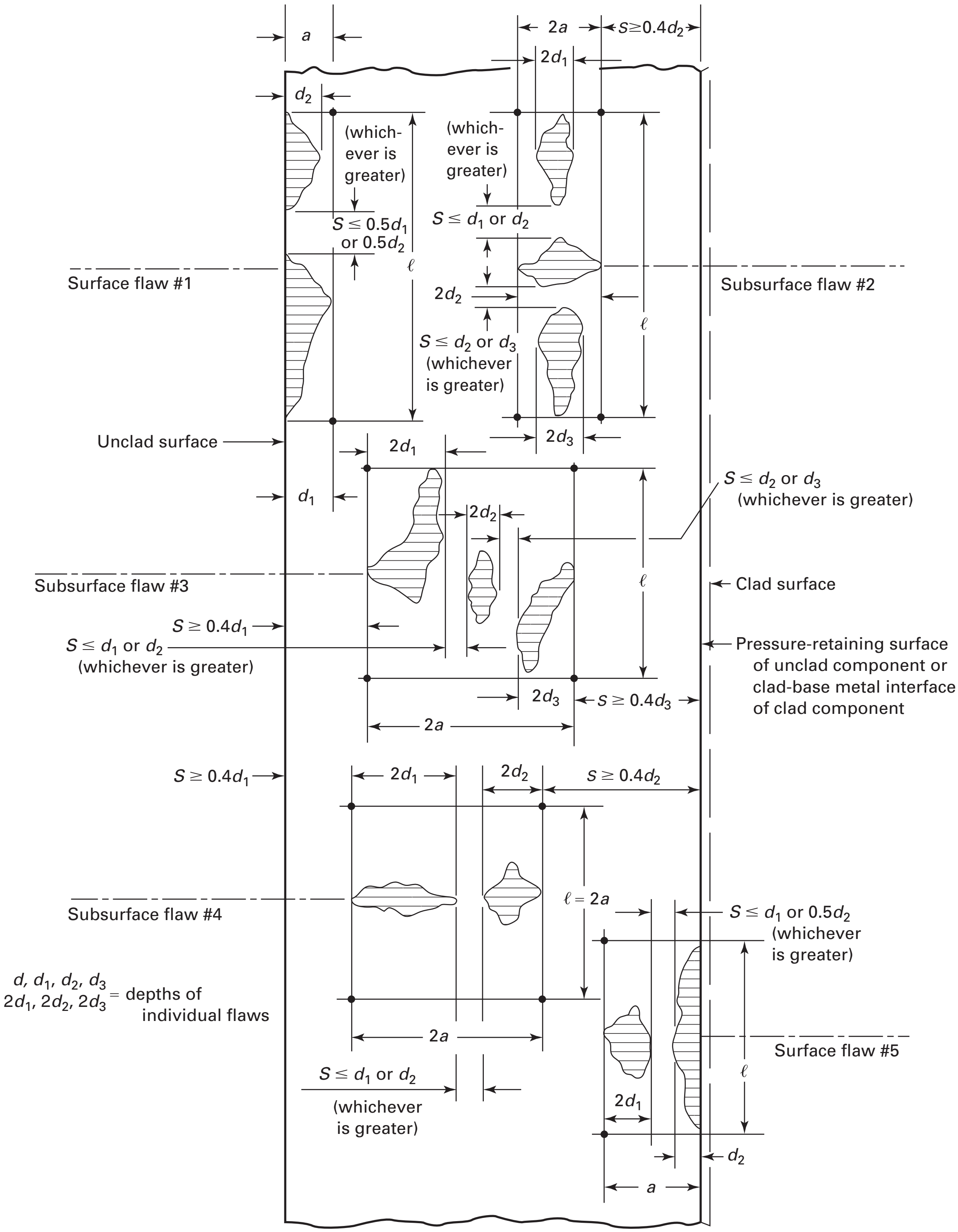
(-3) $(a_2 + a_3) \le (a'_s + a_e)/2$ within planes G–G′ and H–H′

IWA-3400 LINEAR FLAWS DETECTED BY SURFACE OR VOLUMETRIC EXAMINATIONS

(a) Linear flaws detected by surface (PT/MT) or volumetric (RT) examination methods shall be considered single linear surface flaws provided the separation distance between flaws is equal to or less than the dimension S, where S is determined as shown in Figure IWA-3400-1.

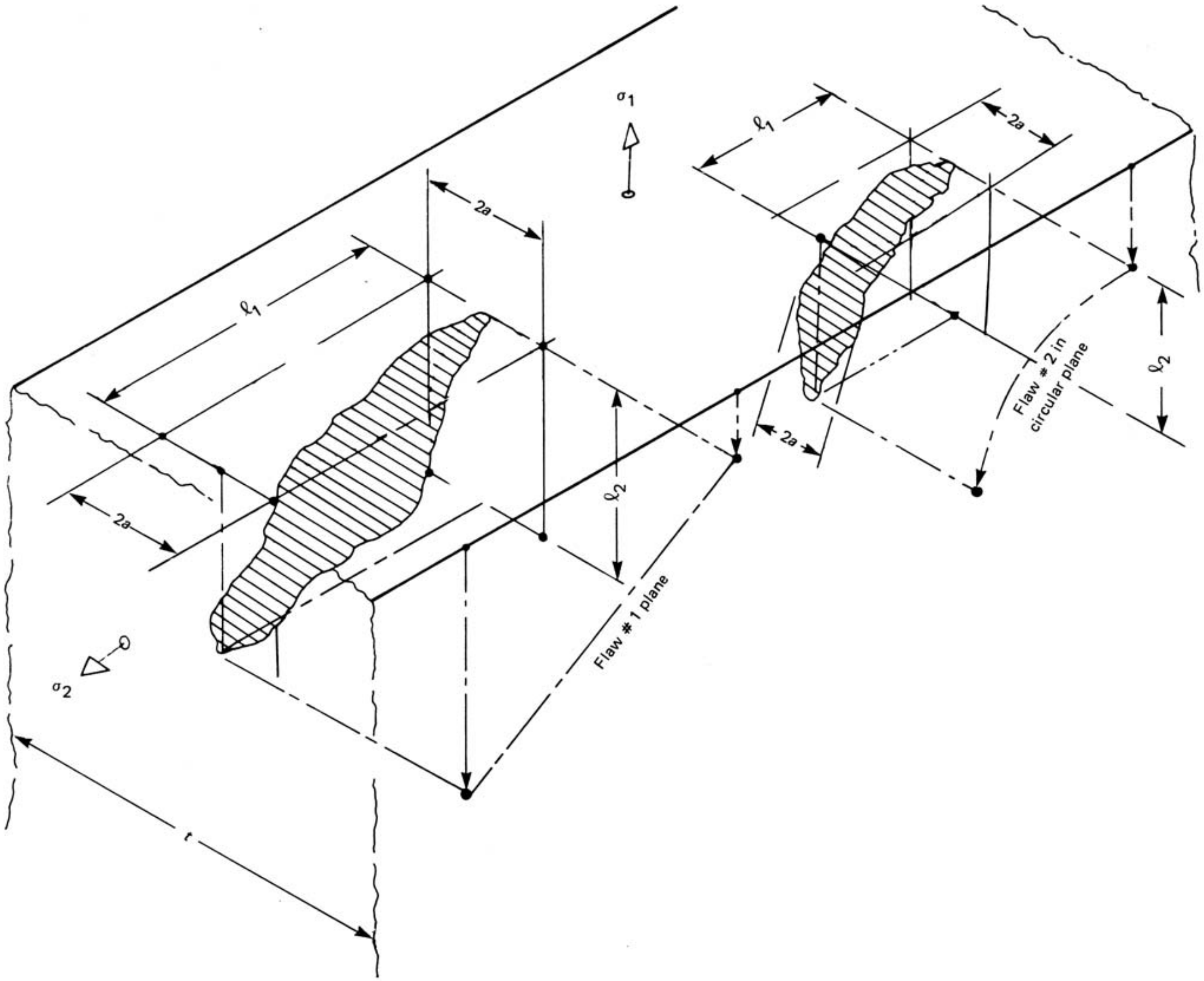
(b) The overall length ℓ of a single and discontinuous linear flaw shall be determined as shown in Figure IWA-3400-1.

Figure IWA-3330-1
Multiple Planar Flaws Oriented in Plane Normal to Pressure-Retaining Surface



GENERAL NOTE: For use in determining allowable flaw size and comparison with acceptance standards of IWB-3500.

Figure IWA-3340-1
Nonplanar Elliptical Subsurface Flaws



GENERAL NOTE: Flaw area shall be projected in planes normal to principal stresses σ_1 and σ_2 to determine critical orientation for comparison with allowable indication standards.

Figure IWA-3350-1
Parallel Planar Flaws

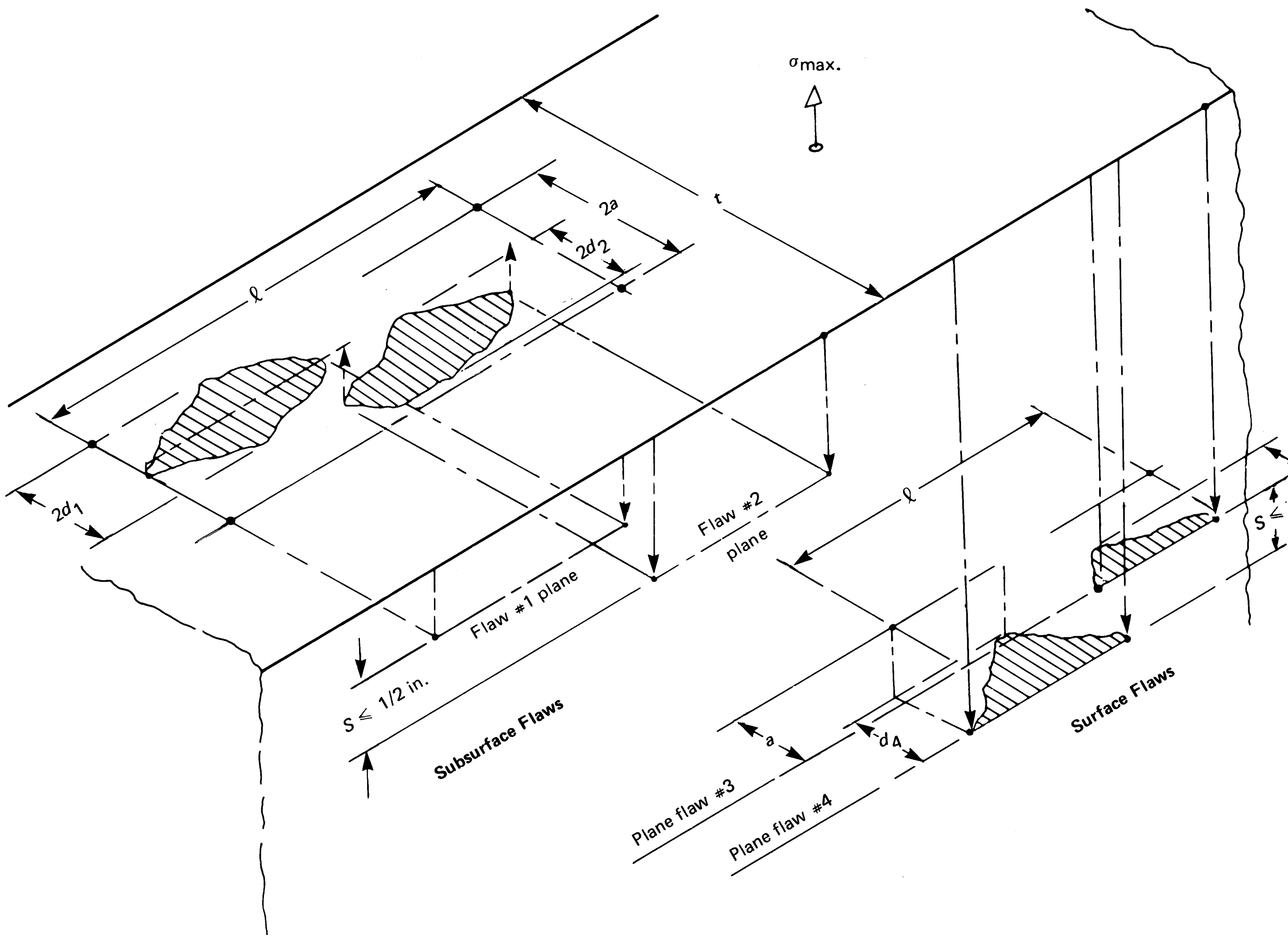


Figure IWA-3360-1
Laminar Flaws

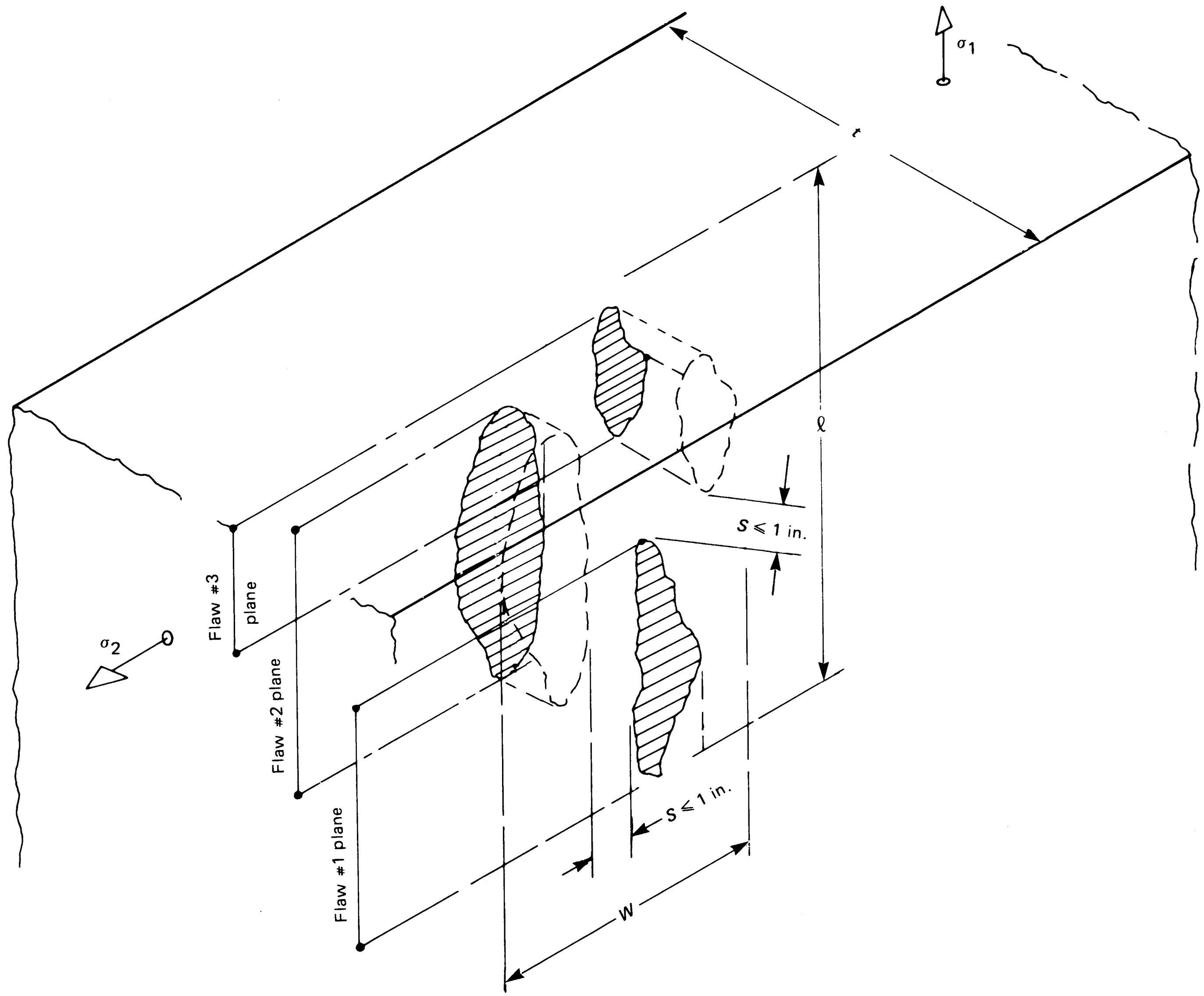
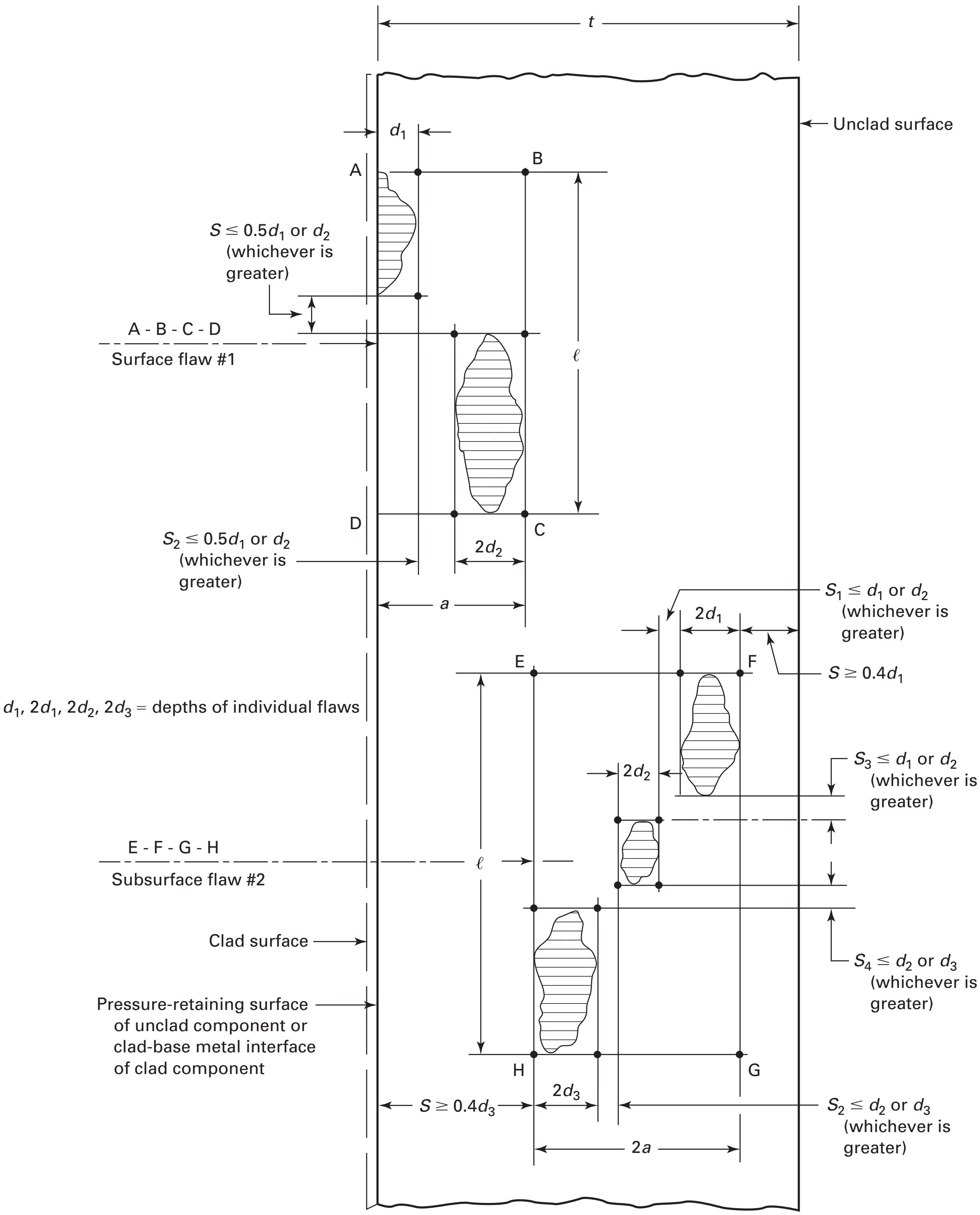


Figure IWA-3380-1
Nonaligned Coplanar Flaws in Plane Normal to Pressure-Retaining Surface
Illustrative Flaw Configurations



GENERAL NOTE: For use in determining allowable flaw size and comparison with acceptance standards of IWB-3500.

Figure IWA-3390-1
Multiple Aligned Planar Flaws (½ in. = 13 mm)

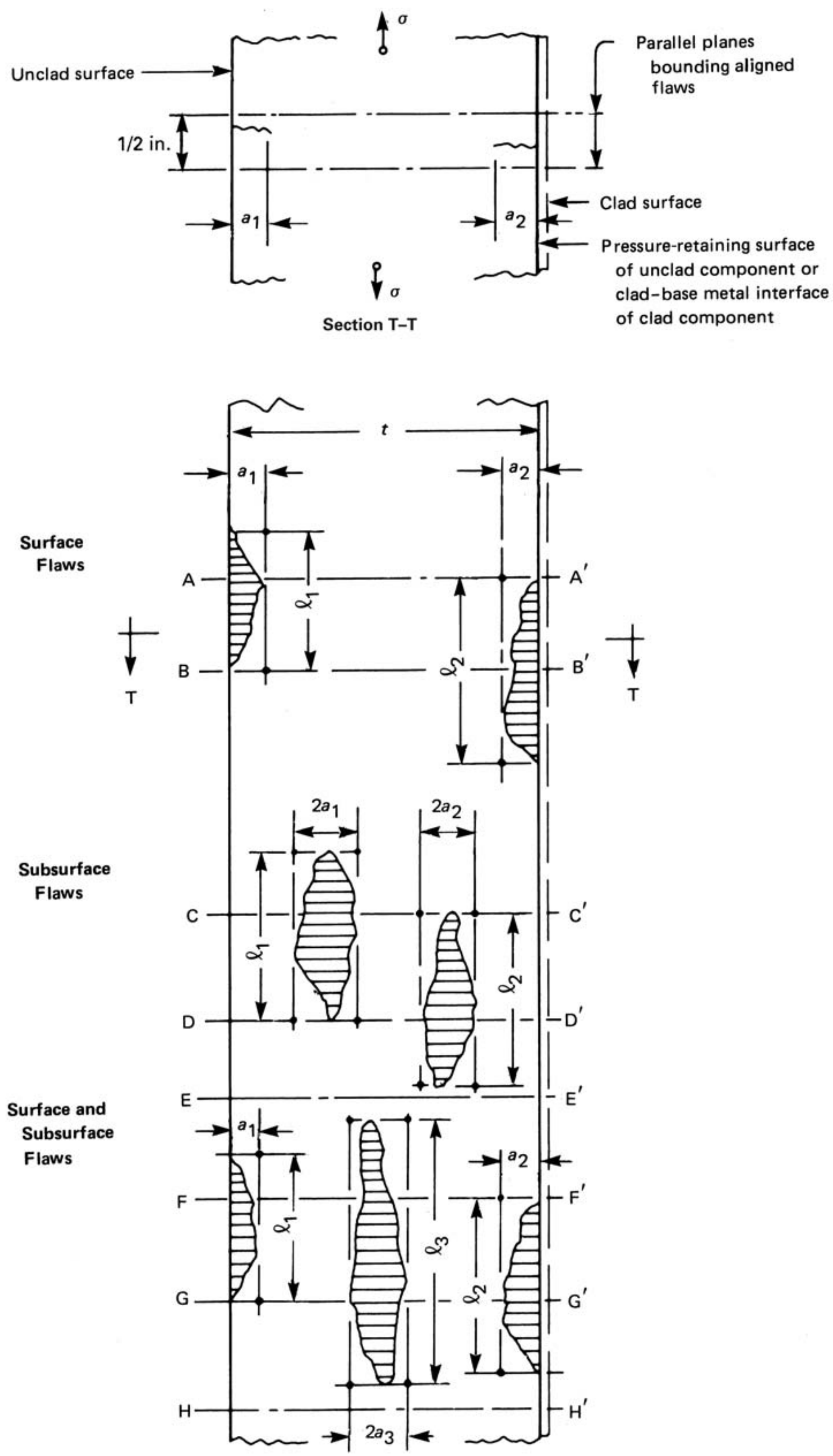
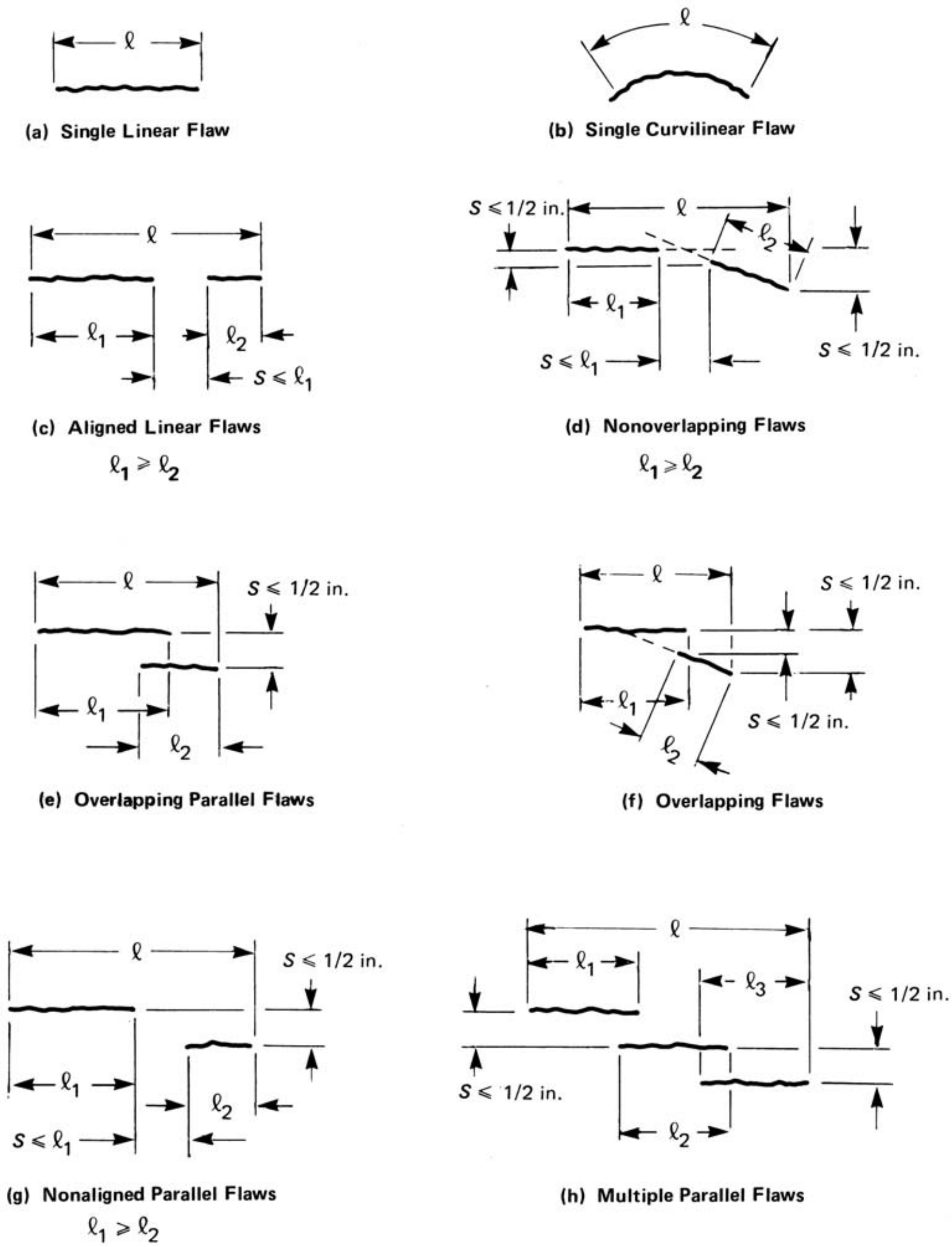


Figure IWA-3400-1
Linear Surface Flaws
Illustrative Flaw Configurations and Determination of Length ℓ ($\frac{1}{2}$ in. = 13 mm)



ARTICLE IWA-4000
REPAIR/REPLACEMENT ACTIVITIES

IWA-4100 GENERAL REQUIREMENTS

IWA-4110 SCOPE

(a) The requirements of this Article apply regardless of the reason for the repair/replacement activity[4] or the method that detected the condition requiring the repair/replacement activity.

(b) This Article provides requirements for repair/replacement activities[4] associated with pressure-retaining components and their supports, including appurtenances, subassemblies, parts of a component, core support structures, metal containments and their integral attachments, and metallic portions of Class CC containments and their integral attachments. Repair/replacement activities include welding, brazing, defect removal, metal removal by thermal means, rerating, and removing, adding, and modifying items or systems. These requirements are applicable to procurement, design, fabrication,[5] installation, examination, and pressure testing of items within the scope of this Division.

(c) This Article provides requirements for repair/replacement activities performed on concrete containments and post-tensioning system items for concrete containments as specified in Article IWL-4000.

IWA-4120 APPLICABILITY

(a) The requirements of this Article apply to items classified by the Owner in accordance with IWA-1400(a) as Code Class 1, 2, 3, MC, or CC, and their associated supports. Class 1 heat exchanger tube plugs and Class 2 and 3 welded or brazed heat exchanger tube plugs shall be considered pressure-retaining material.

(b) The requirements of this Article do not apply to the following, except as provided in (c) through (e):[6]

(1) valve operators, controllers, position indicators, pump impellers, pump drivers, or other accessories and devices unless they have been classified as Code Class 1, 2, or 3 pressure-retaining items in accordance with IWA-1320

(2) instruments or permanently-sealed, fluid-filled tubing systems furnished with instruments, but do apply to instrument, control, and sampling piping when classified as Code Class 1, 2, or 3 in accordance with IWA-1320

(3) rupture disk material (the requirements of this Article do apply to the portion of a rupture disk holder that forms the pressure boundary)

(4) orifice plates connecting piping of the same design pressure that are held in place mechanically

(5) other than component supports or core supports, material that is not associated with the pressure-retaining function of a component, such as shafts, stems, trim, spray nozzles, bearings, bushings, springs, wear plates, seals, packing, gaskets, valve seats, and ceramic insulating material and special alloys used as seal material in electrical penetration assemblies

(6) component support items such as gaskets, seals, bushing, springs, compression spring end plates, bearings, retaining rings, washers, wear shoes, shims, slide plates, and hydraulic fluids. Requirements, if any, for these items shall be stated in the Owner's Requirements.

(7) Classes 2 and 3 heat exchanger tube mechanical plugs

(c) If items identified in (b) require welding or brazing to the pressure-retaining portion of a component or to a component support such installation shall comply with the requirements of this Article.

(d) Applicable Construction Code requirements, such as design requirements for Class 1 valve stems, Owner responsibilities for assuring adequacy of intervening elements in the component support load path, and nondestructive examination of springs for Class 1 component supports, shall be met for items identified in (b).

(e) Nonmandatory Appendix J provides guidance in determining applicability of this Article.

IWA-4130 ALTERNATIVE REQUIREMENTS

IWA-4131 Small Items

IWA-4131.1 Applicability. Repair/replacement activities involving the following items need not meet any other requirement of Article IWA-4000, provided the alternative requirements of IWA-4131.2 are met.[6]

(a) Class 1 piping, tubing (except heat exchanger tubing, and sleeves and plugs used for heat exchanger tubing), valves, fittings, and associated supports, no larger than the smaller of (1) or (2) below:

(1) NPS[7] 1 (DN 25); or

(2) the size and design such that, in the event of postulated failure during normal plant operating conditions, the reactor can be shut down and cooled in an orderly manner, assuming makeup is provided by normal reactor coolant makeup systems operable from on-site emergency power.

(b) Class 2 and 3 piping, tubing [except heat exchanger tubing, and sleeves and welded or brazed plugs used for heat exchanger tubing in heat exchangers not included in (c)], valves, and fittings, NPS 1 (DN 25) and smaller, and associated supports.

(c) Class 2 and Class 3 items, other than those described in (b), in segments of piping or tubing NPS 1 (DN 25) and smaller, and associated supports, that satisfy the following requirements:

(1) The interior free volume of the item shall be 1 ft^3 (0.028 m^3) or less.

(2) The item shall have no more than a total of four process connections. Instrument connections and normally closed vent and drain lines are not required to be counted as process connections.

(3) All connections shall meet the NPS 1 (DN 25) and smaller size criteria for the item to be considered a small item.

(d) Mechanical clamping devices installed on small items under IWA-4131 need not meet the provisions of IWA-4133, provided the requirements of IWA-4131.2 are met.

IWA-4131.2 Requirements. For repair/replacement activities involving items identified in IWA-4131.1, the requirements of Article IWA-4000 need not be met except as provided in (a) through (e) below.

(a) Items shall be procured in accordance with the requirements of IWA-4142 and the technical requirements of IWA-4200. For Section III items, the requirements of NA-3700 or NCA-3800 need not be met, provided the Owner's Quality Assurance Program provides measures to assure that material is furnished in accordance with the material specification and the applicable material requirements of Section III. A Repair/Replacement Plan, possession of a Certificate of Authorization, and an agreement with an Authorized Inspection Agency are not required for the organization constructing or fabricating these items.

(b) Repair/replacement activities shall be performed and documented in accordance with the requirements of IWA-4142 and the technical requirements of IWA-4400 and IWA-4520. A Repair/Replacement Plan, pressure testing, services of an Authorized Inspection Agency, and completion of NIS-2 forms are not required.

(c) If an item to be subjected to a repair/replacement activity does not satisfy the requirements of this Division, the evaluation and corrective provisions of IWA-4160 apply.

(d) The applicable provisions of IWA-4310, IWA-4320, and IWA-4330 shall apply, except for IWA-4331(d).

(e) Use of these alternative requirements, including specifying the size of Class 1 items to which these requirements will be applied, shall be documented by the Owner in the Repair/Replacement program.

IWA-4132 Items Rotated From Stock

Snubbers, pumps, pressure relief valves,[6] control rod drive mechanisms, or pressure-retaining items of pump seal packages, rotated from stock need not meet any other requirement of Article IWA-4000, provided the following requirements are met:

(a) The rotation shall be only for testing or preventive maintenance of the removed items.

(b) Items being removed and installed shall be of the same design and construction.

(c) Items being removed shall have no evidence of failure at the time of removal.

(d) Items being rotated shall be removed and installed only by mechanical means.

(e) Items being installed shall previously have been in service.

(f) The Owner shall track the items, by unique item identification, to ensure traceability of the installed location and inservice inspection and testing records.

(g) Use of an Inspector and an NIS-2 form are not required.

(h) Repair/replacement activities on removed items shall be performed in accordance with the requirements of this Article.

IWA-4133 Mechanical Clamping Devices Used as Piping Pressure Boundary

Mechanical clamping devices used to replace piping pressure boundary need not meet any other requirement of Article IWA-4000, provided the requirements of Nonmandatory Appendix W or IWA-4131.1(d) are met.

IWA-4134 Purchase, Exchange, or Transfer of Material Between Nuclear Plant Sites

Material to be used in an application requiring compliance with NA-3700/NCA-3800 may be purchased, exchanged, or transferred between nuclear plant sites, provided the following requirements are met in lieu of the administrative requirements of IWA-4220.

(a) Materials shall have been furnished to the supplying plant in accordance with NA-3700/NCA-3800.

(b) Since receipt by the supplying plant, the material shall not have been placed in service, welded, brazed, or subjected to any operation that might affect the mechanical properties of the material (e.g., heat treatment or forming).

(c) Documentation required by NA-3700/NCA-3800 shall be provided to the receiving plant with the material.

(d) When the material is fabricated in accordance with specific dimensional requirements in addition to those provided in a national standard (e.g., nonwelded valve bonnet or nonwelded pump casing), the evaluation of suitability required by IWA-4160 shall include an evaluation of the material for its intended application, including any differences that might affect form, fit, or function.

(e) The receiving plant shall obtain certification for the following:

(1) The supplying plant purchased the material in accordance with NA-3700/NCA-3800 and maintained it in accordance with their Quality Assurance Program.

(2) Since receipt by the supplying plant, the material was not placed in service, welded, brazed, or subjected to any operation that might affect the mechanical properties of the material (e.g., heat treatment or forming).

IWA-4140 RESPONSIBILITIES

IWA-4141 Owner's Responsibilities

It is the responsibility of the Owner to provide or cause to be provided the following:

(a) Repair/Replacement Program and Plans required by IWA-4150;

(b) specification requirements for repair/replacement activities.

IWA-4142 Repair/Replacement Organization's Quality Assurance Program

(a) The organization that performs repair/replacement activities shall establish a Quality Assurance Program for control of their activities in accordance with the Repair/Replacement Program and Plans. The Quality Assurance Program shall comply with either of the following:

(1) IWA-1400(o), when the Owner is the Repair/Replacement Organization.

(2) When the Repair/Replacement Organization is other than the Owner, the Repair/Replacement Organization's Quality Assurance Program shall be documented and shall comply with the applicable quality assurance program criteria of 10CFR50 Appendix B supplemented as necessary to be consistent with the Owner's Quality Assurance Program; NQA-1, Part I; or NCA-4000. The Owner shall ensure that the Repair/Replacement Organization's Quality Assurance Program meets the requirements of this Article for the activities to be performed. The program shall be reviewed and accepted by the Owner.

(b) When the performance of repair/replacement activities is split between the Owner and a Repair/Replacement Organization, each organization's Quality Assurance Program shall comply with (a)(1) or (a)(2) for their respective activities. The Owner shall be responsible for establishing interfaces and for assuring that the requirements of this Article are met by the combination of the two Quality Assurance Programs.

IWA-4142.1 Alternative Quality Assurance Program Requirements for Owners.

(a) Applicability. When repair/replacement activities require that the Owner perform activities identified in (1), (2), or (3), the alternative requirements of (b) may be used.

(1) Qualification of Material Organization in accordance with NCA-3800

(2) utilization of unqualified source material in accordance with NCA-3855(a) and (b)

(3) acceptance of small products in accordance with NB/NC/ND/NE/NF-2610(b) and (c)

(b) Requirements. For repair/replacement activities identified in (a), the following requirements may be used in lieu of possession of a Certificate of Authorization or Quality System Certificate (Materials), required by IWA-4221(a) and IWA-4221(b).

(1) These alternative requirements may be used only for the nuclear plants operated by the Owner performing these activities. Materials and small products obtained in accordance with these provisions shall not be transferred to another Owner.

(2) The Owner's Quality Assurance Program required by IWA-1400(o) shall describe how these activities are controlled.

(3) The Owner shall use the requirements of NCA-3800 to qualify the Material Organization.

(4) When accepting small products, the Owner shall perform the activities required of the Certificate Holder by NB/NC/ND/NE/NF-2610(b). The Quality Assurance Program of IWA-1400(o) may be used in lieu of NCA-4000.

(5) When utilizing unqualified source material, the Owner shall perform the activities required of the Certificate Holder by NCA-3855.5(b).

(6) When utilizing unqualified source material or accepting small products, use of these alternative requirements shall be recorded on a Certified Material Test Report or a Certificate of Compliance, as applicable.

IWA-4143 Stamping

(a) Application of the ASME NPT symbol is neither required nor prohibited for the fabrication of parts, appurtenances, piping subassemblies, and supports to be used by the Owner when performed at the Owner's facilities by a Repair/Replacement Organization with a quality assurance program that complies with IWA-4142. These provisions may not be used to manufacture complete pumps, valves, vessels, or tanks.

(b) Application of the ASME NA symbol stamp is neither required nor prohibited for installation.

IWA-4150 REPAIR/REPLACEMENT PROGRAM AND PLAN (**15**)

(a) Repair/replacement activities shall be completed in accordance with the Repair/Replacement Program. The Program is a document or set of documents that defines the managerial and administrative control for completion of repair/replacement activities.

(b) The Edition and Addenda of Section XI used for the Repair/Replacement Program shall correspond with the Edition and Addenda identified in the inservice inspection program applicable to the inspection interval. Alternatively, later Editions and Addenda of Section XI, or specific provisions within an Edition or Addenda later than those

specified in the Owner's Inservice Inspection Program may be used. When provisions of later Editions and Addenda are used, all related requirements shall be met. The later Edition and Addenda shall have been accepted by the enforcement and regulatory authorities having jurisdiction at the plant site.

(c) A Repair/Replacement Plan shall be prepared in accordance with the Repair/Replacement Program whenever a repair/replacement activity is to be performed. Repair/Replacement Plans shall include the essential requirements for completion of the repair/replacement activities. Repair/Replacement Plans are not required for the design phase of a repair/replacement activity, including repair/replacement activities that require design only. However, a Repair/Replacement Plan shall be prepared for rerating activities as defined in IWA-4331(d), whether or not there is accompanying physical work. A Repair/Replacement Plan shall identify the following:

(1) applicable Code Edition, Addenda, and Cases of Section XI

(2) Construction Code Edition, Addenda, Cases, and Owner's Requirements used for the following:

(-a) construction of the item to be affected by the repair/replacement activity

(-b) construction of the item to be installed by the repair/replacement activity

(-c) performance of the repair/replacement activities

(3) The following items, when applicable to the specific repair/replacement activity, shall be documented.

(-a) a description of any defects and nondestructive examination methods used to detect the defects

(-b) the defect removal method, the method of measurement of the cavity created by removing a defect, and, when required by IWA-2600, requirements for reference points

(-c) the applicable welding or brazing procedure, heat treatment, nondestructive examination, tests, and material requirements

(-d) the applicable examination, test, and acceptance criteria to be used to verify acceptability

(4) description of the repair/replacement activities to be performed

(5) expected life of the item after completion of the repair/replacement activity, when less than the remainder of the previous intended life (design life when specified by the Design Specification) of the item;

(6) whether application of the ASME Code Symbol Stamp is required in accordance with IWA-4143;

(7) documentation in accordance with Article IWA-6000.

(d) The Repair/Replacement Program, Plans, and evaluations required by IWA-4160 shall be subject to review by enforcement and regulatory authorities having jurisdiction at the plant site.

IWA-4160 VERIFICATION OF ACCEPTABILITY

(a) If an item does not satisfy the requirements of this Division, the Owner shall determine the cause of unacceptability. Prior to returning the item to service the Owner shall evaluate the suitability of the item subjected to the repair/replacement activity. If the requirements for the original item are determined to be deficient, appropriate corrective provisions shall be included in the Owner's Requirements and Design Specification, as applicable.

(b) Whether or not the repair/replacement activity results from a failure to satisfy the requirements of this Division, the following requirements shall be met. If the expected life of the item after completion of the repair/replacement activity is less than the remainder of the previous intended life [IWA-4150(c)(5)], the Owner shall initiate actions that will result in a plan for additional examinations and evaluations to verify the acceptability of the item for continued service or shall schedule subsequent repair/replacement activities prior to the end of the expected life of the item.

IWA-4170 INSPECTION

The services of an Authorized Inspection Agency shall be used. The Owner shall notify the Authorized Inspection Agency prior to starting a repair/replacement activity and keep the Inspector informed of progress so that necessary inspections may be performed.

IWA-4180 DOCUMENTATION

(a) The reports and records required by Article IWA-6000 shall be completed for all repair/replacement activities.

(b) Documents shall be retained in accordance with IWA-6300.

(c) The following records shall be maintained current with respect to the item's design and configuration:

(1) Design Specifications

(2) Design Report or analysis that demonstrates compliance with the Construction Code or the Owner's Requirements

(3) Overpressure Protection Reports

(d) Revisions or updates to existing reports, records, specifications, and evaluations, as required by (c) or IWA-4311, shall be traceable to and from the original record or report to provide a record of the current status of the item. The review and certification requirements for technical revisions or updates shall be in accordance with the Owner's Requirements and the Construction Code [see IWA-4222(a)(1)].

IWA-4190 APPLICATION OF SECTION XI CODE CASES

(a) Cases shall be applicable, as indicated in the Applicability Index for Section XI Cases found in the *Code Cases: Nuclear Components* book, to the Edition and Addenda specified for the repair/replacement activity.

(b) The use of any Case and revisions to previously approved Cases are subject to acceptance by the regulatory and enforcement authorities having jurisdiction at the plant site.

(c) Cases shall be in effect at the time of the repair/replacement activity except as provided in (d).

(d) Cases that are superseded at the time of the repair/replacement activity, but acceptable to the regulatory and enforcement authorities having jurisdiction at the plant site, may be used.

IWA-4200 ITEMS FOR REPAIR/ REPLACEMENT ACTIVITIES

IWA-4210 GENERAL REQUIREMENTS

In the course of preparation.

IWA-4220 CODE APPLICABILITY

IWA-4221 Construction Code and Owner's Requirements

(a) An item to be used for repair/replacement activities shall meet the Owner's Requirements. Owner's Requirements may be revised, provided they are reconciled in accordance with IWA-4222. Reconciliation documentation shall be prepared.

(b) An item to be used for repair/replacement activities shall meet the Construction Code specified in accordance with (1), (2), or (3) below.

(1) When replacing an existing item, the new item shall meet the Construction Code to which the original item was constructed.

(2) When adding a new component to an existing system, the Owner shall specify a Construction Code that is no earlier than the earliest Construction Code used for construction of the system or of any originally installed component in that system.

(3) When adding a new system, the Owner shall specify a Construction Code that is no earlier than the earliest Construction Code used for other systems that perform a similar function.

(c) As an alternative to (b) above, the item may meet all or portions of the requirements of different Editions and Addenda of the Construction Code, or Section III when the Construction Code was not Section III, provided the requirements of IWA-4222 through IWA-4226, as applicable, are met. Construction Code Cases may also be used. Reconciliations required by this Article shall be documented. All or portions of later different Construction Codes may be used as listed below:

(1) Piping, piping subassemblies, and their supports: B31.1 to B31.7 to Section III.

(2) Pumps, valves, and their supports: from B31.1 to Draft Code for Pumps and Valves for Nuclear Power to Section III.

(3) Vessels and their supports: Section VIII to Section III.

(4) Atmospheric and 0 psig to 15 psig (0 kPa to 100 kPa) storage tanks and their supports: Section VIII, API 620, or API 650 to Section III.

IWA-4222 Reconciliation of Code and Owner's Requirements

(a) Code Requirements and Owner's Requirements may be technical or administrative.

(1) Only technical requirements that could affect materials, design, fabrication, or examination, and affect the pressure boundary, or core support or component support function, need to be reconciled.

(2) Administrative requirements, i.e., those that do not affect the pressure boundary or core support or component support function, need not be reconciled.[8] Examples of such requirements include quality assurance, certification, Code Symbol Stamping, Data Reports, and Authorized Inspection.

(b) The administrative requirements of either the Construction Code of the item being replaced or the Construction Code of the item to be used for replacement shall be met.

IWA-4223 Reconciliation of Components

(a) Reconciliation of later Editions or Addenda of the Construction Codes or alternative Codes as permitted by IWA-4221 is not required. The Owner shall evaluate any changes in weight, configuration, or pressure-temperature rating in accordance with IWA-4311.

(b) An earlier Edition and Addenda of the same Construction Code may be used, provided all technical requirements of the earlier Construction Code are reconciled.

IWA-4224 Reconciliation of Material

IWA-4224.1 Identical Material Procured to a Later Edition or Addenda of the Construction Code, Section III, or Material Specification.

(a) Materials, including welding and brazing materials, may meet the requirements of later dates of issue of the material specification and later Editions and Addenda of the same Construction Code or Section III when the Construction Code was not Section III, provided the materials are the same specification, grade, type, class, or alloy, and heat-treated condition, as applicable.

(b) Differences in the specified material tensile and yield strength shall be compared. If the replacement material has a lower strength, a comparison shall be made of the allowable stresses. If the tensile or yield strength is reduced and allowable stresses are reduced, the effect of the reduction on the design shall be reconciled. For welding materials, any reduction in specified tensile strength shall be evaluated to ensure that the strength of the filler metal meets or exceeds the strength of the base materials.

IWA-4224.2 Identical Material Procured to an Earlier Construction Code Edition or Addenda or Material Specification.

(a) Materials, including welding and brazing materials, may meet the requirements of earlier dates of issue of the material specification and earlier Editions and Addenda of the same Construction Code, provided the materials are the same specification, grade, type, class, or alloy, and heat-treated condition, as applicable.

(b) Differences in the specified material tensile and yield strength shall be compared. If the replacement material has a lower strength, a comparison shall be made of the allowable stresses. If the tensile or yield strength is lower and allowable stresses are lower, the effect of the reduction on the design shall be reconciled. For welding materials, a lower specified tensile strength shall be evaluated to ensure that the strength of the filler metal meets or exceeds the strength of the base materials.

(c) Material examination and testing requirements shall be reconciled to the Construction Code requirements of the item.

IWA-4224.3 Use of a Different Material.

(a) Use of materials of a specification, grade, type, class, or alloy, and heat-treated condition, other than that originally specified, shall be evaluated for suitability for the specified design and operating conditions in accordance with IWA-4311.

(b) Material examination and testing requirements shall be reconciled to the Construction Code requirements of the item.

IWA-4224.4 Substitution of Material Specifications.

(a) When an SA or SB Specification is identified as being identical, or identical except for editorial differences, to the corresponding ASTM A or B Specification, either specification may be used.

(b) When an SFA Specification is identified as being identical, or identical except for editorial differences, to the corresponding AWS specification, either specification may be used.

IWA-4225 Reconciliation of Parts, Appurtenances, and Piping Subassemblies

(a) Parts, appurtenances, and piping subassemblies may be fabricated to later Editions and Addenda of the Construction Code and later different Construction Codes, as permitted by IWA-4221(c), provided materials are reconciled in accordance with IWA-4224. The Owner shall evaluate any changes in weight, configuration, or pressure-temperature rating in accordance with IWA-4311.

(b) An earlier Edition and Addenda of the same Construction Code may be used, provided all technical requirements of the earlier Construction Code are reconciled to the Construction Code requirements of the component or appurtenance into which the replacement item is installed, provided materials are reconciled in accordance with IWA-4224.

IWA-4226 Reconciliation of Design Requirements

IWA-4226.1 Design to All Requirements of a Later Edition or Addenda of the Construction Code. When an item is designed to all requirements of a later Edition or Addenda of the Construction Code, reconciliation beyond the design-related issues defined in IWA-4223, IWA-4224, and IWA-4225 is not required.

IWA-4226.2 Design to Portions of the Requirements of a Later Edition or Addenda of the Construction Code. When an item is designed to portions of the requirements of a later Edition or Addenda of the Construction Code, the following reconciliation, beyond the design-related issues defined in IWA-4223, IWA-4224, and IWA-4225, shall be performed.

(a) Material, fabrication, and examination requirements (e.g., NX-2000, NX-4000, and NX-5000 of Section III) shall be reviewed to reconcile the details applicable to design with the design of the replacement item.

(b) All design requirements related to the later portions shall be met, or any differences between the later design provisions and the previous design shall be reconciled.

IWA-4226.3 Design to All or Portions of a Different Construction Code. When an item is designed to all or portions of a different Construction Code, the following reconciliation, beyond the design-related issues defined in IWA-4223, IWA-4224, and IWA-4225, shall be performed.

(a) Material, fabrication, and examination requirements (e.g., NX-2000, NX-4000, and NX-5000 of Section III) shall be reviewed to reconcile the details applicable to design with the design of the replacement item.

(b) When an item is designed to portions of a different Construction Code, differences between the new design provisions and the previous design shall be reconciled.

IWA-4230 HELICAL-COIL THREADED INSERTS, CLASSES 1, 2, AND 3

Internal threads in pressure-retaining items may be replaced with helical-coil threaded inserts in accordance with the following requirements.

(a) Helical-coil threaded inserts shall satisfy the design requirements of the Construction Code for the specified loading to be applied to the threaded connection. For materials not listed in the Construction Code, primary stresses shall not exceed the lesser of two-thirds of the minimum specified yield strength or one-fourth of the minimum specified tensile strength of the applicable material.

(b) Helical-coil threaded inserts shall be purchased in accordance with the Owner's or Repair/Replacement Organization's Quality Assurance program meeting the requirements of IWA-4142.

(c) Helical-coil threaded inserts shall be supplied with a Certified Material Test Report that provides traceability to the item, material specification, chemical composition, grade or class, and mechanical properties and heat-treated condition prior to final forming.

(d) Helical-coil threaded inserts shall be installed in accordance with the manufacturer's instructions.

IWA-4300 DESIGN

IWA-4310 GENERAL REQUIREMENTS

IWA-4311 Material, Design, or Configuration Changes

When a change is made to the design or configuration of an item or system, including material substitution, the change shall meet the following requirements:

(a) When an analysis of the item or system prior to the change is available, the change shall be evaluated and documented to demonstrate that the existing analysis is bounding for all design conditions. If the existing analysis does not bound all design conditions for the change, a reanalysis shall be performed. The evaluation may show that reanalysis is not required. The evaluation or reanalysis shall document that the proposed change meets the Owner's Requirements, and the Construction Code or alternative provisions of this Division. The evaluation or reanalysis shall be traceable in accordance with IWA-4180(d).

(b) When an analysis of the item or system prior to the change is unavailable (e.g., proprietary design, standard B16.5 flanges or fittings, standard B16.34 valve), an evaluation or a new analysis shall be performed to document that the proposed change meets the Owner's Requirements and the Construction Code or alternative provisions of this Division. The evaluation may show that an analysis is not required. The evaluation or new analysis shall be maintained in the same manner as a Design Report in accordance with (a) and IWA-4180(d).

(c) Later Editions and Addenda of the Construction Code or a later different Construction Code, in accordance with IWA-4221(c), either in its entirety or portions thereof, and Code Cases, may be used, provided the requirements of IWA-4226 are met.

(d) Analyses shall be reviewed and certified in accordance with the requirements of the Construction Code and Owner's Requirements. Evaluations shall be certified as required for analyses.

(e) For any design or configuration change that deviates from the Owner's Requirements, Design Specification, or Design Report, the affected documents shall be revised or updated in accordance with IWA-4180(d).

IWA-4320 PIPING

IWA-4321 Class 1 Mechanical Joints

(a) Flanged joints may be used in Class 1 piping systems.

(b) Expanded joints shall not be used in Class 1 piping systems.

(c) Threaded joints in which the threads provide the only seal shall not be used in Class 1 piping systems. If a seal weld is employed as the sealing medium, the stress analysis of the joint shall include the stresses in the weld resulting from the relative deflections of the mated parts.

(d) Flared, flareless, and compression-type tubing fittings may be used for tubing sizes not exceeding 1 in. O.D. within the limitations of applicable standards and requirements of (2) and (3). In the absence of such standards or specifications, the Owner shall determine that the type of fitting selected is adequate and safe for the Design Conditions in accordance with the following requirements.

(1) The fitting pressure-temperature ratings shall be reconciled with the specified design and operating conditions.

(2) Fittings and their joints shall be suitable for the tubing with which they are to be used, in accordance with the minimum wall thickness of the tubing and method of assembly recommended by the manufacturer.

(3) Fittings shall not be used in services that exceed the manufacturer's maximum pressure-temperature recommendations.

IWA-4330 RERATING

The provisions of this paragraph shall apply for rerating whether or not there is accompanying physical work.

IWA-4331 General Requirements

(a) The applicable design requirements of the Construction Code and Owner's Requirements shall be met. Later Editions and Addenda of the Construction Code or a later, different Construction Code, either in its entirety or portions thereof, and Code Cases may be used, provided the requirements of IWA-4221 are met.

(b) Overpressure protection shall be evaluated in accordance with the Construction Code and Owner's Requirements.

(c) The rerating shall be evaluated or analyzed in accordance with IWA-4311. The Owner's Requirements shall be reviewed and revised or updated when necessary.

(d) Form NIS-2 shall be completed for rerating, except for rerating component supports.

(e) If a nameplate with pressure or temperature rating is attached to the item or piping system, the Owner or his designee shall attach a new nameplate as close as practical to the original nameplate. This nameplate shall contain the revised ratings and a reference to the rerating documentation.

(f) An ASME Certificate of Authorization is not required.

IWA-4332 Flaw Evaluation

Inservice flaws that were previously evaluated and accepted by the evaluation provisions of Article IWB-3000, Article IWC-3000, Article IWD-3000, Article IWE-3000, Article IWF-3000, or Article IWL-3000, or known wall thinning, shall be evaluated or analyzed in accordance with IWA-4311.

IWA-4333 Examination

If rerating results in a design condition for which the Construction Code or Owner's Requirements requires a different examination than was originally performed, that examination shall be performed.

IWA-4334 Pressure Test Requirements

Rerated items shall be subjected to a system leakage test in accordance with Article IWA-5000 for the new service condition if the resulting test pressure would be higher than the pressure of previous pressure tests.

IWA-4340 MITIGATION OF DEFECTS BY MODIFICATION

Modification of items other than Class 1 may be performed to contain or isolate a defective area without removal of the defect, provided the following requirements are met.

(a) These requirements shall apply to physical modifications only.

(b) If the item containing the flaw does not meet the limitations of IWA-4131.1(b), the alternative provisions of IWA-4131 shall not be applied to any portion of the mitigation performed in accordance with IWA-4340.

(c) These requirements shall not be applied when implementing IWA-4133, IWA-4411(h), or Cases that contain provisions for modification of items containing a defect.

(d) The defect shall be characterized using nondestructive examination and evaluated to determine its cause and projected growth.

(e) The modification shall provide for the structural integrity of the item such that it no longer relies on the defective area, including its projected growth, for the expected life of the item. The modification shall meet the Construction Code and Owner's Requirements for the item in accordance with IWA-4220.

(f) Welds and bolting used in the modification shall be added to the inspection plan and examined as required by IWA-4530. Following the modification, examination of the defective area in accordance with IWA-4530 is not required.

(g) In addition to meeting IWA-4160, the Owner shall perform an examination during each of the next two refueling outages to detect propagation of the flaw into the material credited for structural integrity of the item and, for high energy items, shall perform an examination to validate the projected flaw growth of (d) above. For all other items, validation of the projected flaw growth by examination shall be performed, if practicable. Projected or actual flaw growth into material credited for the structural integrity of the item shall be unacceptable. The examination used to validate flaw growth shall be the same method used to characterize the defect, or a volumetric examination in accordance with Mandatory Appendix I shall be performed.

(h) Unless the projected flaw growth is validated during the first or a subsequent examination, or the growth rate has been validated in prior Owner or industry experiences with the same conditions (e.g., system, base material, degradation mechanism, and working fluid), the examination of (g) shall be repeated every refuel outage until the flaw is removed.

(i) If the flaw growth is validated in accordance with (g) or (h), the modification shall be examined in accordance with (g) once per interval, except as required by IWA-4160.

(j) Examinations in accordance with (h) and (i) are not required if the modification bounds the maximum possible extent of flaw growth such that the structural integrity of the item cannot be compromised.

(k) The examinations of (g) through (i) are not required if the original defect is removed and the modification is left in place.

(l) A system pressure test of the modification in accordance with Article IWA-5000 shall be performed. New welds, brazed joints, and mechanical connections, made in the course of the repair/replacement activity, shall be subjected to the required test pressure. The acceptance criteria for leakage at mechanical connections shall be established by the Owner.

(m) Modifications shall not be repeated at locations where the defect has propagated into material credited for the structural integrity of the modified item.

IWA-4400 WELDING, BRAZING, METAL REMOVAL, FABRICATION, AND INSTALLATION

IWA-4410 GENERAL REQUIREMENTS

Welding, brazing, defect removal, metal removal by thermal methods, fabrication, and installation performed by a Repair/Replacement Organization shall be performed in accordance with the requirements of this Subarticle. Mechanical metal removal not associated with defect removal is not within the scope of this Subarticle.

IWA-4411 Welding, Brazing, Fabrication, and Installation

Welding, brazing, fabrication, and installation shall be performed in accordance with the Owner's Requirements and, except as modified below, in accordance with the Construction Code of the item.

(a) Later editions and addenda of the Construction Code, or a later different Construction Code, either in its entirety or portions thereof, and Code Cases may be used provided the substitution is as listed in IWA-4221(c). Filler metal requirements shall be reconciled, as required, in accordance with IWA-4224.

(b) Revised Owner's Requirements may be used, provided they are reconciled in accordance with IWA-4222.

(c) The requirements of IWA-4440 shall be used for qualification of welding and brazing procedures, welders, brazers, and welding and brazing operators.

(d) The requirements of IWA-4500 shall be used for examination and testing of welds and brazes.

(e) The requirements of IWA-4600(b) may be used when welding is to be performed without the postweld heat treatment required by the Construction Code.

(f) The requirements of IWA-4660 may be used for underwater welding.

(g) The requirements of IWA-4700 shall be used for welded tube plugs and sleeves in Class 1 heat exchangers. The requirements of IWA-4700 may be used for welded installation of tube plugs and sleeves in Class 2 and Class 3 heat exchangers.

(h) Classes 1, 2, and 3 austenitic stainless steel pipe weldments may be repaired in accordance with Nonmandatory Appendix Q. If Nonmandatory Appendix Q is used, all requirements of Nonmandatory Appendix Q shall be met, and IWA-4520 and IWA-4530 do not apply.

(i) Welding electrodes and flux, and other welding and brazing filler material shall be stored and handled in accordance with a written procedure. Absorption of moisture by welding fluxes and cored, fabricated, or coated electrodes shall be minimized. When electrode storage and baking conditions are not specified by this Division, the precautions and recommendations of the electrode manufacturer shall be followed. Alternative electrode welding material control procedures may be used if accepted by the Inspector. Procedures for welding and brazing filler material control shall be included in the Repair/Replacement Program.

IWA-4412 Defect Removal

Defect removal shall be accomplished in accordance with the requirements of IWA-4420.

IWA-4413 Metal Removal by Thermal Methods

Metal removal by thermal methods shall be accomplished in accordance with the requirements of IWA-4461.

IWA-4420 DEFECT REMOVAL REQUIREMENTS

IWA-4421 General Requirements

Defects shall be removed or mitigated in accordance with the following requirements:

(a) Defect removal by mechanical processing[9] shall be in accordance with IWA-4462.

(b) Defect removal by thermal methods shall be in accordance with IWA-4461.

(c) Defect removal or mitigation by welding or brazing shall be in accordance with IWA-4411.

(d) Defect removal or mitigation by modification shall be in accordance with IWA-4340.

IWA-4422 Defect Evaluation and Examination

IWA-4422.1 Defect Evaluation.

(a) A defect is considered removed when it has been reduced to an acceptable size. If the resulting section thickness is less than the minimum required thickness, the component shall be corrected by repair/replacement activities in accordance with this Article.

(b) Alternatively, the defect removal area and any remaining portion of the defect may be evaluated and the component accepted in accordance with the appropriate flaw evaluation provisions of Section XI, or the design provisions of the Owner's Requirements and either the Construction Code or Section III.

IWA-4422.2 Nondestructive Examination.

IWA-4422.2.1 Defect Removal Without Welding or Brazing.

(a) After removal of defects detected by visual or surface examination, surface examination of the defect removal area shall be performed.

(b) After removal of defects detected by volumetric examination, volumetric examination of the defect removal area shall be performed. The volumetric examination method that detected the defect shall be used.

(c) The acceptance criteria of either the Construction Code or Section XI shall be met.

(d) Indications detected as a result of excavation that are not associated with the defect being removed shall be evaluated for acceptability in accordance with the Construction Code or Section XI.

IWA-4422.2.2 Defect Removal Followed by Welding or Brazing.

(a) Surface examination of the defect removal area is required prior to welding, except as provided below.

(1) A surface examination is not required when the defect is eliminated by removing the full cross-section of the weld or base material.

(2) When surface examination of the excavation cannot be performed or will not provide meaningful results, surface examination of the excavation is not required. The acceptability of any remaining portion of the defect may be established by evaluation in accordance with

IWA-4422.1(b) in lieu of the surface examination. Alternative NDE methods may be used to characterize any remaining portion of the defect.

(3) If final volumetric examination will be performed on the completed repair, the final volumetric examination method is the same as the method used to detect the defect, and the volume to be examined includes the location of the original defect, surface examination of the defect removal area is not required.

(b) The acceptance criteria of either the Construction Code or Section XI shall be used for the excavation.

(c) Surface examination of defect removal areas is not required for brazed joints.

(d) Indications detected as a result of excavation that are not associated with the defect being removed shall be evaluated for acceptability in accordance with the Construction Code or Section XI.

(e) Examination following welding or brazing shall be in accordance with IWA-4520.

IWA-4440 WELDING AND BRAZING QUALIFICATIONS

(a) All welding and brazing shall be performed in accordance with Welding or Brazing Procedure Specifications that have been qualified by the Owner or Repair/Replacement Organization in accordance with the requirements of the codes specified in the Repair/Replacement Plan.

(b) As an alternative to Section IX, QW-201 or QB-201, a procedure qualification record (PQR) qualified by one Owner may be used by another Owner. The Owner who performed the procedure qualification test shall provide documented certification that the procedure qualification was performed in accordance with Section IX and was conducted in accordance with a Quality Assurance Program that satisfies the requirements of IWA-1400.

(1) The Owner accepting the completed PQR shall be responsible for obtaining any additional supporting information needed for WPS or BPS development.

(2) The Owner accepting the completed PQR shall document, on each resulting WPS or BPS, the parameters applicable to welding or brazing. Each WPS or BPS shall be supported by all necessary PQRs.

(3) The Owner accepting the completed PQR shall accept responsibility for the PQR by documenting the Owner's approval of each WPS or BPS that references the PQR.

(4) The Owner accepting the completed PQR shall demonstrate technical competence in application of the received PQR by completing a performance qualification using the parameters of a resulting WPS or BPS.

(5) The Owner may accept and use a PQR only when it is received directly from the Owner that certified the PQR.

(c) All welders and brazers shall be qualified by the Repair/Replacement Organization in accordance with the requirements of the codes specified in the Repair/Replacement Plan. Alternatively, a welder or brazer qualified by one Owner may be used by another Owner, if the following requirements are met:

(1) The Owner that performed the qualification test shall certify, by signing the record of Performance Qualification (WPQ or BPQ), that testing was performed in accordance with Section IX.

(2) The Owner that performed the qualification test shall certify, in writing, that the qualification was conducted in accordance with a Quality Assurance Program that satisfies the requirements of IWA-1400.

(3) The Owner accepting the WPQ or BPQ shall obtain any necessary supporting information to satisfy Section IX, QW-301.4 (e.g., Welding Procedure Specification, type of tests).

(4) The Owner accepting the WPQ or BPQ shall require each welder or brazer to demonstrate proficiency by completing a renewal qualification test in accordance with Section IX, QW-322.2(a) or QB-322(b).

(-a) If WPQ or BPQ transfer involves prior groove tests, the renewal test shall use a groove configuration.

(-b) When WPQ or BPQ transfer involves prior fillet tests, the renewal tests may use either a groove or a fillet configuration.

(5) The Owner accepting the WPQ or BPQ shall accept responsibility for the Performance Qualification Test and shall document acceptance on the WPQ or BPQ for the renewal test. This WPQ or BPQ shall reference the WPQ or BPQ supplied by the Owner that performed the qualification.

(6) The Owner accepting the WPQ or BPQ shall accept responsibility for compliance with Section IX, QW-322.

(7) The Owner may accept and use a WPQ or BPQ only if it is received directly from the Owner that performed the qualification.

(8) The Owner accepting the WPQ or BPQ shall comply with the Quality Assurance requirements of IWA-4142(a).

(d) Welders and brazers[10] need not be employed directly by the Repair/Replacement Organization, provided the use of such welders is controlled by the Quality Assurance Program of the Repair/Replacement Organization. This Program shall include the following:

(1) requirements for complete and exclusive administration and technical supervision of all welders and brazers by the Repair/Replacement Organization;

(2) requirements for contractual control that provides the necessary authority to assign and remove welders and brazers at the discretion of the Repair/Replacement Organization;

(3) evidence that the Quality Assurance Program is acceptable to the Owner's Authorized Nuclear Inservice Inspector.

IWA-4460 METAL REMOVAL PROCESSES

IWA-4461 Thermal Removal Processes

Thermal removal processes include oxyacetylene cutting, carbon arc gouging, plasma cutting, metal disintegration machining (MDM), and electrodischarge machining (EDM).

IWA-4461.1 P-No. 1. When thermal removal processes are used on P-No. 1 materials, surface oxides shall be removed by mechanical processing prior to welding on cut surfaces.

IWA-4461.2 P-Nos. 3, 4, 5A, 5B, 5C, 6, 7, 9A, 9B, 9C, 10A, 10B, 10C, 10E Through 10K, and 11A Materials.

(a) When preheat is less than that specified in Table IWA-4461.1-1, material shall be removed by a mechanical method from all thermally processed areas, in accordance with the following:

(1) When welding is to be performed, at least $^1/_{32}$ in. (1 mm) of material shall be removed from the cavity to be welded.

(2) When welding is not to be performed, at least $^1/_{16}$ in. (1.5 mm) of material shall be removed and the area shall be faired into the surrounding area.

(3) Resulting irregularities shall be removed to a smooth surface by a mechanical method. This surface shall show no visual evidence of irregularities. The depth of material to be removed as required by (1) or (2) shall be measured from the smooth surface.

(b) When preheat is applied in accordance with Table IWA-4461.1-1, material shall be removed to bright metal by a mechanical method.

IWA-4461.3 P-Nos. 8 and 43 Materials. If thermal removal processes are used on P-No. 8 and P-No. 43 materials, at least $^1/_{16}$ in. (1.5 mm) of material shall be mechanically removed from the thermally processed area.

IWA-4461.4 Alternatives to Mechanical Processing. Mechanical processing of thermally cut surfaces for materials identified in IWA-4461.1 through IWA-4461.3 is not required if the thermal metal removal process is qualified as follows:

(a) The qualification test shall consist of two coupons of the same P-No. material to be cut in production.

(b) The qualification coupons shall be cut using the maximum heat input to be used in production.

(c) The thermally cut surface of each coupon shall be visually examined at 10× and shall be free of cracks. The Owner shall specify surface roughness acceptable for the application and shall verify that the qualification coupon meets that criterion.

(d) Each qualification coupon shall be cross sectioned, and the exposed surfaces shall be polished, etched, and visually examined at 10×. All sectioned surfaces shall be free of cracks.

(e) Corrosion testing of the thermally cut surface and heat-affected zone shall be performed if the cut surface is to be exposed to corrosive media. Alternatively, corrosion resistance of the thermally cut surface may be evaluated. The Owner shall specify the acceptance criteria.

IWA-4462 Mechanical Defect Removal Processes

(a) If a mechanical removal process is used for defect removal where welding is not to be performed, the area shall be faired into surrounding area.

(b) Where welding is to be performed, the cavity shall be ground smooth and clean with beveled sides and edges rounded such that the cavity is suitable for welding.

IWA-4500 EXAMINATION AND TESTING

IWA-4510 GENERAL REQUIREMENTS

IWA-4511 NDE Personnel Qualification

Personnel performing nondestructive examination required by the Construction Code shall be qualified and certified in accordance with the Construction Code identified in the Repair/Replacement Plan or IWA-2300. When using IWA-2300, personnel performing visual examinations shall be qualified for performance of VT-1 visual examinations and shall have received additional training in examination of weldments for fabrication conditions, including dimensional requirements and fabrication flaws.

IWA-4520 EXAMINATION

(a) Welding or brazing areas and welded joints made for fabrication or installation of items by a Repair/Replacement Organization shall be examined in accordance

Table IWA-4461.1-1
Minimum Preheat Temperature, °F (°C)

P-No. 3, and P-No. 11A	P-No. 4 and P-Nos. 9A, 9B, and 9C	P-Nos. 5A, 5B, 5C, and P-No. 6	P-No. 7	P-Nos. 10A, 10B, 10C, and 10E Through 10K
200 (95)	250 (120)	300 (150)	None required	200 (95) [Note (1)]

NOTE:
(1) Applies only to material with a nominal section thickness of $^3/_4$ in. (19 mm) and greater.

with the Construction Code identified in the Repair/Replacement Plan, with the following exceptions:

(1) Base metal repairs on Class 3 items are not required to be volumetrically examined when the Construction Code does not require that full-penetration butt welds in the same location be volumetrically examined.

(2) When welding or brazing is performed in accordance with IWA-4600 or IWA-4700, the examination requirements of IWA-4600 or IWA-4700, respectively, shall be met in lieu of examinations required by the Construction Code or Section III.

(b) Except as required by (a)(2) above, when (a) above requires surface or volumetric examinations to be performed on pressure-retaining installation (but not fabrication) welds or welds made for correction of flaws or defects, the Owner may authorize use of the personnel qualifications, methods, techniques, and acceptance criteria of Section XI, in lieu of those of the Construction Code, provided the following requirements are met:

(1) The surface examination methods shall be limited to those permitted by the Construction Code.

(2) If the Construction Code requires radiographic examination, the Owner may instead authorize use of ultrasonic examination in accordance with IWA-4521.

(3) All other examination requirements of the Construction Code, including surface area requirements and timing of examinations, shall be met.

(4) The weld or braze material deposited as part of the repair/replacement activity shall meet the preservice acceptance standards of Section XI. If Section XI does not provide preservice acceptance standards, the acceptance criteria of the Construction Code or Section III shall be met.

(5) Acceptability of remaining flaws that existed prior to the repair/replacement activity shall be established using the provisions of Article IWA-3000.

(c) These examinations may be performed concurrently with the preservice inspections required by IWA-4530.

IWA-4521 Ultrasonic Examination Requirements

If permitted by IWA-4520(b), ultrasonic examination shall be performed using a procedure qualified in accordance with Mandatory Appendix VIII and the following requirements:

(a) Ultrasonic examination shall not be applied to weld joints that include austenitic castings, austenitic welds with single-side access, or piping with structural austenitic weld inlay.

(b) Ultrasonic examination shall include 100% of the weld volume plus $\frac{1}{2}T$ for Class 1 vessel welds, or $\frac{1}{2}$ in. (13 mm) for all other welds, on each side of the weld volume. A supplemental straight beam examination shall also be used to identify laminations that could limit angle beam examinations.

(c) A written procedure that identifies the ranges of essential variables of VIII-2100(d) shall be followed. The procedure, and any subsequent essential variable changes outside the qualified ranges, shall be demonstrated on a qualification block or specimen that includes both surface and subsurface flaws. The examination volume above shall be included in a supplemental performance demonstration.

(d) The qualification blocks shall be fabricated from material of the same material specification, product form, and material heat treatment condition as one of the materials joined. Alternatively, for piping, the qualification block shall be of a material of similar chemical composition,[11] tensile properties, and metallurgical structure[12] as the material being welded.

(1) The surface condition of the qualification block shall approximate the roughest surface condition for which the examination procedure is applicable.

(2) If two or more base material thicknesses are involved, the qualification block thickness shall be of a size sufficient to contain the entire examination path.

(3) For austenitic materials, the qualification block configuration shall contain a weld representative of the joint to be examined, including the same welding process.

(e) A supplemental performance demonstration using a previously qualified procedure shall be conducted through use of a blind test with appropriate specimens that contain three different construction-type flaws (e.g., slag, lack of fusion, incomplete penetration) distributed throughout the thickness of the specimens, unless such flaws were included in the Mandatory Appendix VIII qualification.

IWA-4530 PRESERVICE INSPECTION

When portions of items requiring preservice or inservice inspection are affected by repair/replacement activities, or for items being fabricated or installed, including welded or brazed joints made for fabrication or installation of items, preservice inspections shall be performed in accordance with IWB-2200, IWC-2200, IWD-2200, IWE-2200, IWF-2200, or IWL-2200 prior to return of the system to service. The preservice inspection may be performed either prior to or following the pressure test required by IWA-4540.

IWA-4540 PRESSURE TESTING OF CLASSES 1, 2, AND 3 ITEMS

(a) Unless exempted by (b), repair/replacement activities performed by welding or brazing on a pressure-retaining boundary shall include a hydrostatic or system leakage test in accordance with Article IWA-5000, prior to, or as part of, returning to service. Only brazed joints and welds made in the course of a repair/replacement activity require pressurization and VT-2 visual examination during the test.

(b) The following are exempt from any pressure test:

(1) cladding

(2) heat exchanger tube plugging and sleeving

(3) welding or brazing that does not penetrate through the pressure boundary

(4) flange seating surface when less than half the flange axial thickness is removed and replaced

(5) components or connections NPS 1 (DN 25) and smaller

(6) tube-to-tubesheet welds when such welds are made on the cladding

(7) seal welds

(8) welded or brazed joints between nonpressure-retaining items and the pressure-retaining portion of the components

(9) valve discs or seats

(c) Replacement components and appurtenances shall be pressure tested in accordance with the Construction Code selected for use in accordance with IWA-4221.

(d) Brazed joints and welds in replacement parts and piping subassemblies, fabricated by the Repair/Replacement Organization, or fabricated in accordance with the Construction Code without a hydrostatic pressure test, shall be tested as required by (a).

IWA-4550 CLASS MC AND METALLIC PORTIONS OF CLASS CC CONTAINMENTS

Items subjected to repair/replacement activities shall be tested in accordance with Article IWE-5000.

IWA-4600 ALTERNATIVE WELDING METHODS

(a) When welding under water, the alternative requirements of IWA-4660 may be used in lieu of the welding requirements of the Construction Code or Section III.

(b) When postweld heat treatment is not to be performed, the following provisions may be used.

(1) The welding methods of IWA-4620, IWA-4630, IWA-4640, or IWA-4670 may be used in lieu of the welding and nondestructive examination requirements of the Construction Code or Section III, provided the requirements of IWA-4610 are met. Existing temper bead Welding Procedure Specifications and Procedure Qualification Records made in accordance with IWA-4610 and IWA-4620, IWA-4630, or IWA-4640 from the 1989 Edition or later editions or addenda may still be used.

(2) For welding of Class MC metal containments and their integral attachments and metallic liners of Class CC containments and their integral attachments, the provisions of IWA-4620 may be used, provided the requirements of IWA-4610 are met. Existing temper bead Welding Procedure Specifications and Procedure Qualification Records made in accordance with IWA-4610 and IWA-4620 from the 1989 Edition or later editions or addenda may still be used. Alternatively, the provisions of IWA-4650 may be used.

IWA-4610 GENERAL REQUIREMENTS FOR TEMPER BEAD WELDING

(a) The area to be welded shall be preheated and maintained as specified in IWA-4620, IWA-4630, IWA-4640, or IWA-4670, as applicable. Except as permitted by IWA-4672(c), thermocouples and recording instruments shall be used to monitor the process temperatures. Their attachment and removal shall be in accordance with Section III.

(b) The welding procedure and the welders or welding operators shall be qualified in accordance with Section IX and the additional requirements of this Subarticle.

(1) *Procedure Qualification*

(-a) The test assembly material for the welding procedure qualification test shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature already applied to the material being welded.

(-b) Consideration shall be given to the effects of welding in a pressurized environment. If they exist, they shall be bounded in the test assembly within the limits of Table IWA-4662.1-1.

(-c) Consideration shall be given to the effects of irradiation on the properties of material, including weld material for applications in the core belt line region of the reactor vessel. Special material requirements in the Design Specification shall also apply to the test assembly materials for these applications.

(-d) If qualifying ambient temperature temper bead procedures of IWA-4670, the maximum interpass temperature for the first three layers of the procedure qualification test assembly shall be 150°F (66°C).

(-e) Temper bead welding procedures used for welding similar materials in IWA-4620, dissimilar materials in IWA-4630, or cladding in IWA-4640 shall be qualified in accordance with Section IX, QW-290, using the following procedure qualification impact testing requirements:

(-1) The test assembly base material for the welding procedure qualification shall meet the impact test requirements of the Construction Code and Owner's Requirements. If such requirements are not in the Construction Code and Owner's Requirements, the impact properties shall be determined by Charpy V-notch impact tests of the procedure qualification base material at or below the lowest service temperature of the item to be repaired. The base metal Charpy V-notch specimens shall be taken from approximately the same depth as the HAZ specimens and should be aligned in the same manner as the HAZ specimens. The location and orientation of the test specimens shall be as specified in (-3) below but shall be in the base metal. Impact testing of austenitic materials (nickel-based P-No. 4X and stainless steel P-No. 8) is not required.

(-2) Charpy V-notch tests of weld metal of the procedure qualification shall meet the requirements as determined in (-1) above.

(-3) Charpy V-notch tests of the heat-affected zone (HAZ) shall be performed at the same temperature as the base metal test of (-1) above. Number, location, and orientation of test specimens shall meet the requirements of (-4) below.

(-4) The specimens shall be removed from a location as near as practical to a depth of one-half the thickness of the deposited weld metal. The coupons for HAZ impact specimens shall be taken transverse to the axis of the weld and etched to define the HAZ. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much HAZ as possible in the resulting fracture. When the material thickness permits, the axis of a HAZ specimen shall be inclined to allow the root of the notch to align parallel to the fusion line.

(-5) If the test material is in the form of a plate or a forging, the axis of the weld shall be oriented parallel to the principal direction of rolling or forging.

(-6) Charpy V-notch tests shall be performed on the weld metal, the heat-affected zone, and unaffected base metal in accordance with SA-370. Specimens shall be in accordance with SA-370, Figure 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion, percentage shear, absorbed energy, test temperature, orientation, and location of all test specimens shall be reported in the Procedure Qualification Record.

(-7) The average lateral expansion value of the three HAZ Charpy V-notch specimens shall be equal to or greater than the average lateral expansion value of the three unaffected base metal specimens. However, if the average lateral expansion value of the HAZ Charpy V-notch specimens is less than the average value for the unaffected base metal specimens and the procedure qualification meets all other requirements, then either of the following shall be performed:

(+a) The welding procedure shall be requalified.

(+b) An Adjustment Temperature for the procedure qualification shall be determined in accordance with the applicable provisions of NB-4335.2 of the 2004 Edition of Section III. The RT_{NDT} or lowest service temperature of the materials for which the welding procedure will be used shall be increased by a temperature equivalent to that of the Adjustment Temperature.

(-f) The parameters for welding the procedure qualification coupons shall be selected such that the resultant qualified essential variable ranges of Section IX bound the procedural requirements (preheat, interpass, grinding bead crowns, surface temper bead, etc.) specified for the procedure in IWA-4620, IWA-4630, IWA-4640, or IWA-4670, as applicable.

(2) Performance Qualification. If the weld is to be performed where physical obstructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair/ replacement activity.

IWA-4611 Defect Removal

IWA-4611.1 General Requirements.

(a) Defects shall be removed in accordance with IWA-4422.1. A defect is considered removed when it has been reduced to an acceptable size.

(b) Examination of defect removal areas shall comply with IWA-4624, IWA-4634, IWA-4644, IWA-4654, as applicable.

(c) Metal removal by thermal methods shall comply with IWA-4413.

IWA-4611.2 Examination Following Defect Removal.

(a) After final processing, the affected surfaces, including surfaces of cavities prepared for welding, shall be examined by the magnetic particle or liquid penetrant method to ensure that the indication has been reduced to an acceptable size in accordance with IWB-3500, IWC-3500, or Article IWD-3000, as applicable. For supports and containment vessels, the provisions of IWA-4422.1(b) may be used. No examination of the defect removal area is required when defect elimination removes the full thickness of the weld and the back side of the weld joint is not accessible for removal of examination materials.

(b) Indications detected as a result of the excavation that are not associated with the defect being removed shall be evaluated for acceptability in accordance with Article IWA-3000.

IWA-4620 TEMPER BEAD WELDING OF SIMILAR MATERIALS

IWA-4621 General Requirements (15)

(a) Repair/replacement activities on P-Nos. 1, 3, 12A, 12B, and 12C[13] base materials and associated welds may be performed without the specified postweld heat treatments, provided the requirements of (b) and (c) and IWA-4623 through IWA-4624 are met.

(b) The maximum area of an individual weld based on the finished surface shall be 500 in.^{2} (325,000 mm^2), and the depth of the weld shall not be greater than one-half of the base metal thickness.

(c) Weld metal and heat-affected zones may be peened to control distortion. Such peening may not be used on the initial (root) layer of weld metal or on the final (face) layer.

(d) Peening intended only to reduce residual surface tensile stresses is permitted on the interior root surface and on the final (face) layer. This peening shall be performed after any surface examinations required by IWA-4624 are completed.

IWA-4623 Welding Procedure

IWA-4623.1 Shielded Metal-Arc Welding. The procedure shall include the requirements of (a) through (f):

(a) The weld metal shall be deposited using low hydrogen electrode meeting the coating moisture content requirements of SFA-5.5. The maximum bead width shall be four times the electrode core diameter.

(b) All covered electrodes from hermetically sealed containers shall immediately be used or placed into holding or drying ovens operating between 225°F (110°C) and 300°F (150°C). Covered electrodes from other than hermetically sealed containers shall be baked and maintained in accordance with the manufacturer's recommendations. After baking and before the electrodes are allowed to cool below 225°F (110°C), they shall be transferred to holding or drying ovens operating between 225°F (110°C) and 350°F (180°C).

(c) Electrodes removed from the holding ovens in (b) for a period in excess of 8 hr for E70XX electrodes or 4 hr for E80XX and E90XX electrodes shall be reprocessed in accordance with (b). Electrodes shall not be rebaked more than once.

(d) The area to be welded plus a band around the area of at least 1.5 times the component thickness or 5 in. (125 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (175°C). The maximum interpass temperature shall be 450°F (230°C).

(e) The cavity shall be buttered using a $^3/_{32}$ in. (2.5 mm) diameter electrode as shown in Figure IWA-4623.1-1, Step 1. The weld bead crown surface shall be removed by grinding or machining before depositing the second layer (see Figure IWA-4623.1-1, Step 2). The second layer shall be deposited with a $^1/_8$ in. (3 mm) diameter electrode. Subsequent layers shall be deposited with a welding electrode no larger than $^5/_{32}$ in. (4 mm) diameter. Bead deposition shall be performed in a manner shown in Figure IWA-4623.1-1, Step 3. The completed weld shall have at least one layer of weld reinforcement deposited and then this reinforcement shall be removed by mechanical means, making the finished surface of the weld substantially flush with the surface surrounding the weld.

(f) The weld area shall receive a postweld hydrogen bakeout by maintaining it at 450°F to 550°F (230°C to 290°C) for a minimum of 2 hr after completion of the weld in P-No. 1 materials. For P-No. 3 materials, the holding time shall be a minimum of 4 hr.

IWA-4623.2 Gas Tungsten-Arc Welding. The procedure shall include the requirements of (a) through (d):

(a) The weld metal shall be deposited by the automatic or machine gas tungsten-arc weld process using cold wire feed.

(b) The area to be welded plus a band around the area of at least 1.5 times the component thickness or 5 in. (125 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 300°F (150°C). The maximum interpass temperature shall be 450°F (230°C).

(c) The cavity shall be buttered with the first three layers of weld metal as shown in Figure IWA-4623.2-1, Steps 1 through 3, with the weld heat input for each layer controlled to within ±10% of that used in the procedure qualification test. Subsequent layers shall be deposited with a heat input equal to or less than that used for layers beyond the third in the procedure qualification (see Figure IWA-4623.2-1, Step 4). The completed weld shall have at least one layer of weld reinforcement deposited and then this reinforcement shall be removed by mechanical means, making the finished surface of the weld substantially flush with the surface surrounding the weld.

(d) The weld area shall receive a postweld hydrogen bakeout by maintaining it at 450°F to 550°F (230°C to 290°C) for a minimum of 2 hr after completion of the weld repair in P-No. 1 materials. For P-No. 3 materials, the holding time shall be a minimum of 4 hr.

IWA-4624 Examination

IWA-4624.1 Examination Criteria.

(a) Prior to welding, surface examination shall be performed on the area to be welded. Surface examination and acceptance criteria shall comply with IWA-4611.2

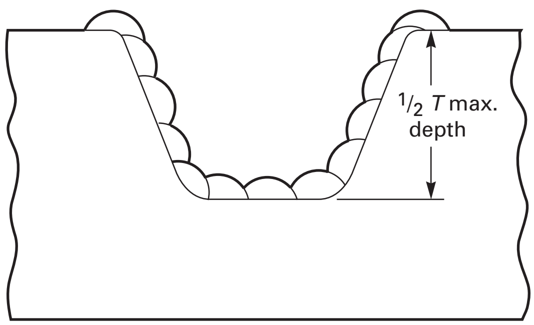
(b) The initial layer shall be examined by the magnetic particle method after grinding or machining. Each subsequent layer shall be examined by the magnetic particle method if a final volumetric examination will not be performed.

(c) For SMAW, the weld shall be nondestructively examined after the completed weld has been at ambient temperature for at least 48 hr. For GTAW, the nondestructive examinations shall be performed after the completed weld has cooled to ambient temperature. The nondestructive examination of the welded region shall include both volumetric [except as permitted in (b)] and surface examination.

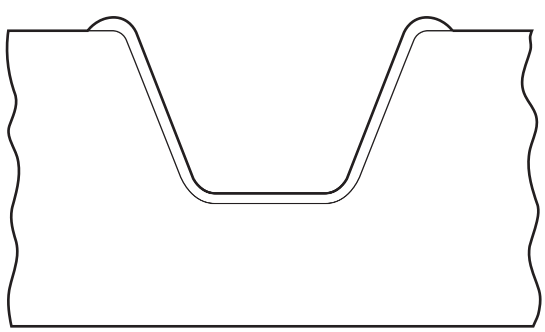
(d) Areas from which weld attached thermocouples have been removed shall be ground and examined by a surface examination method.

IWA-4624.2 Acceptance Criteria. Acceptance criteria for examinations required by IWA-4624.1(b) and IWA-4624.1(c) shall be in accordance with the Construction Code or Section III.

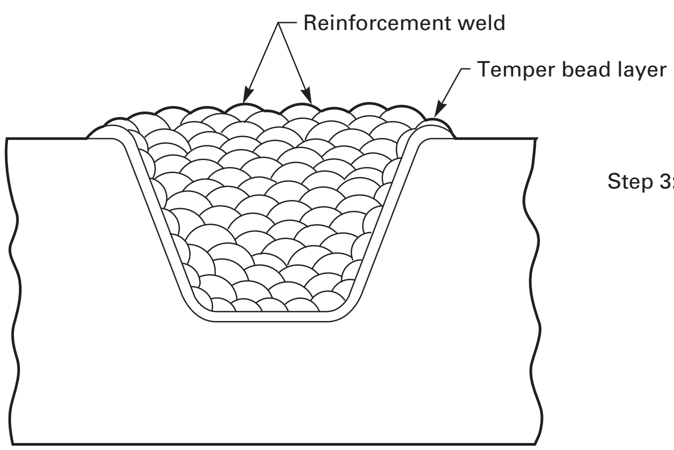
Figure IWA-4623.1-1
Temper Bead Welding and Weld Temper Bead Reinforcement



Step 1: Butter cavity with one layer of weld metal using $^3/_{32}$ in. (2.5 mm) diameter coated electrode.

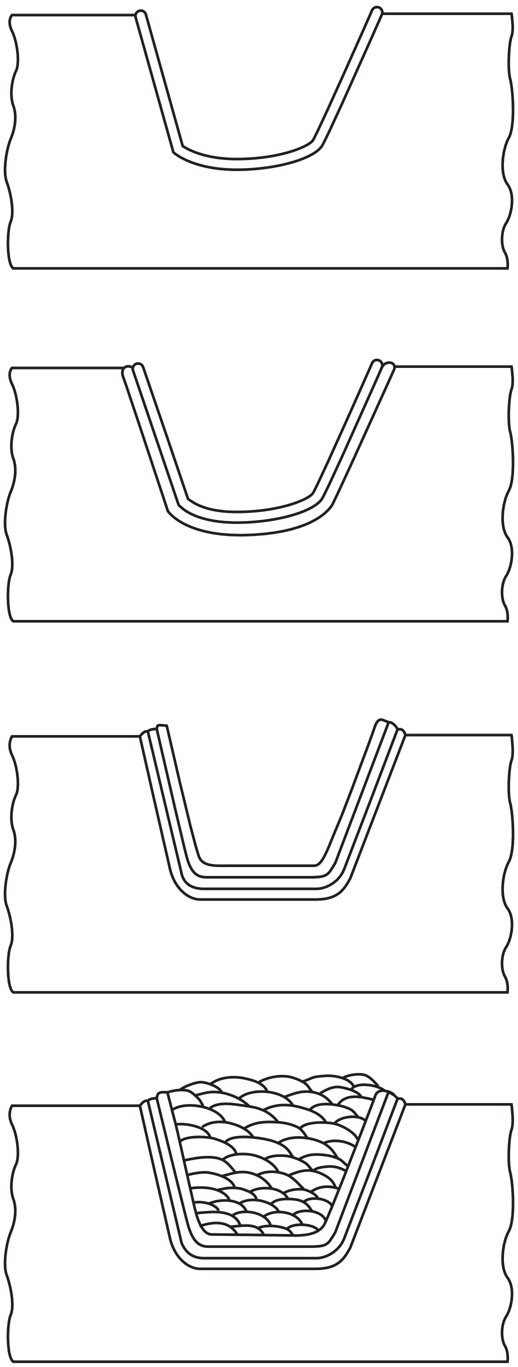


Step 2: Remove the weld bead crown of the first layer by grinding or machining.



Step 3: The second layer shall be deposited with a $^1/_8$ in. (3 mm) diameter electrode. Subsequent layers shall be deposited with welding electrodes no larger than $^5/_{32}$ in. (4 mm) diameter. Bead deposition shall be performed in a manner as shown. Particular care shall be taken in the application of the temper bead reinforcement weld at the tie-in points as well as its removal to ensure that the heat-affected zone of the base metal and the deposited weld metal is tempered and the resulting surface is substantially flush.

Figure IWA-4623.2-1
Automatic or Machine (GTAW) Temper Bead Welding



Step 1: Deposit layer one with first layer weld parameters used in qualifications.

Step 2: Deposit layer two with second layer weld parameters used in qualifications.

Step 3: Deposit layer three with third layer weld parameters used in qualifications.

Step 4: Subsequent layers to be deposited as qualified. Particular care shall be taken in the application of the temper bead reinforcement weld at the tie-in points as well as its removal to ensure that the heat-affected zone of the base metal requiring Construction Code PWHT and the deposited ferritic weld metal (if used) is tempered and the resulting surface is substantially flush.

IWA-4630 TEMPER BEAD WELDING OF DISSIMILAR MATERIALS

IWA-4631 General Requirements

(a) Repair/replacement activities on welds that join P-No. 8 or P-No. 43 material to P-No. 1, 3, 12A, 12B, and 12C material may be made without the specified postweld heat treatment, provided the requirements of (b) and IWA-4633 and IWA-4634 are met.

(b) Repair/replacement activities in accordance with this paragraph are limited to those along the fusion line of a nonferritic weld to ferritic base material where $^1/_8$ in. (3.2 mm) or less of nonferritic weld deposit exists above the original fusion line after defect removal. If the defect penetrates into the ferritic base material, welding of the base material may be performed in accordance with IWA-4633 provided the depth of the weld in the base material does not exceed $^3/_8$ in. (9.5 mm) The repair/replacement activity performed on a completed joint shall not exceed one-half the joint thickness. The surface of the completed weld in the ferritic material shall not exceed 500 in.^{2} (325,000 mm^2).

IWA-4633 Welding Procedure

IWA-4633.1 Shielded Metal-Arc Welding. The procedure shall include the requirements of (a) through (g):

(a) The weld metal shall be deposited using A-No. 8 weld metal (Section IX, Table QW-442) for P-No. 8 to P-No. 1 or P-No. 3 weld joints or F-No. 43 weld metal (Section IX, Table QW-432) for either P-No. 8 or P-No. 43 to P-No. 1 or P-No. 3 weld joints. The maximum bead width shall be four times the electrode core diameter.

(b) All covered electrodes used for qualification test and welding shall be from freshly opened, hermetically sealed packages or heated ovens maintained between 225°F (110°C) and 350°F (180°C). Electrodes withdrawn from hermetically sealed containers or ovens for longer than 8 hr shall be discarded or shall be baked once in accordance with the manufacturer's recommendations and placed immediately back into the holding ovens. If withdrawn again for longer than 8 hr, they shall be discarded.

(c) The electrodes may be maintained in heated ovens in the work area. The oven temperature shall be maintained between 225°F (110°C) and 350°F (180°C). Electrodes exposed to the atmosphere for more than 8 hr shall be discarded or shall be baked once in accordance with the manufacturer's recommendations and placed immediately back into the holding ovens. Electrodes exposed to the atmosphere for more than 8 hr after being baked once shall be discarded.

(d) The area to be welded plus a band around the area of at least 1.5 times the component thickness or 5 in. (125 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (175°C). The maximum interpass temperature shall be 450°F (230°C).

(e) All areas of the ferritic base material, exposed or not, on which weld metal is to be deposited, shall be covered with a single layer of weld deposit using $^3/_{32}$ in. (2.5 mm) diameter electrodes. The weld bead crown surface shall be removed by grinding or machining before depositing the second layer. The second layer shall be deposited with $^1/_8$ in. (3 mm) diameter electrodes. Subsequent layers shall be deposited with welding electrodes no larger than $^5/_{32}$ in. (4 mm) in diameter (see Figure IWA-4633.1-1).

(f) After at least $^3/_{16}$ in. (5 mm) of weld metal has been deposited, the weld area shall receive a postweld hydrogen bakeout by maintaining it at 450°F to 550°F (230°C to 290°C) for 4 hr minimum.

(g) Subsequent to the above postweld hydrogen bakeout, the balance of the welding may be performed using ambient temperature preheat and a maximum interpass temperature of 350°F (180°C).

IWA-4633.2 Gas Tungsten-Arc Welding. The procedure shall include the requirements of (a) through (f):

(a) The weld shall be made using A-No. 8 weld metal (Section IX, Table QW-442) for P-No. 8 to P-No. 1 or P-No. 3 weld joints or F-No. 43 weld metal (Section IX, Table QW-432) for either P-No. 8 or P-No. 43 to P-No. 1 or P-No. 3 weld joints.

(b) The weld metal shall be deposited by the automatic or machine gas tungsten arc weld process using cold wire feed.

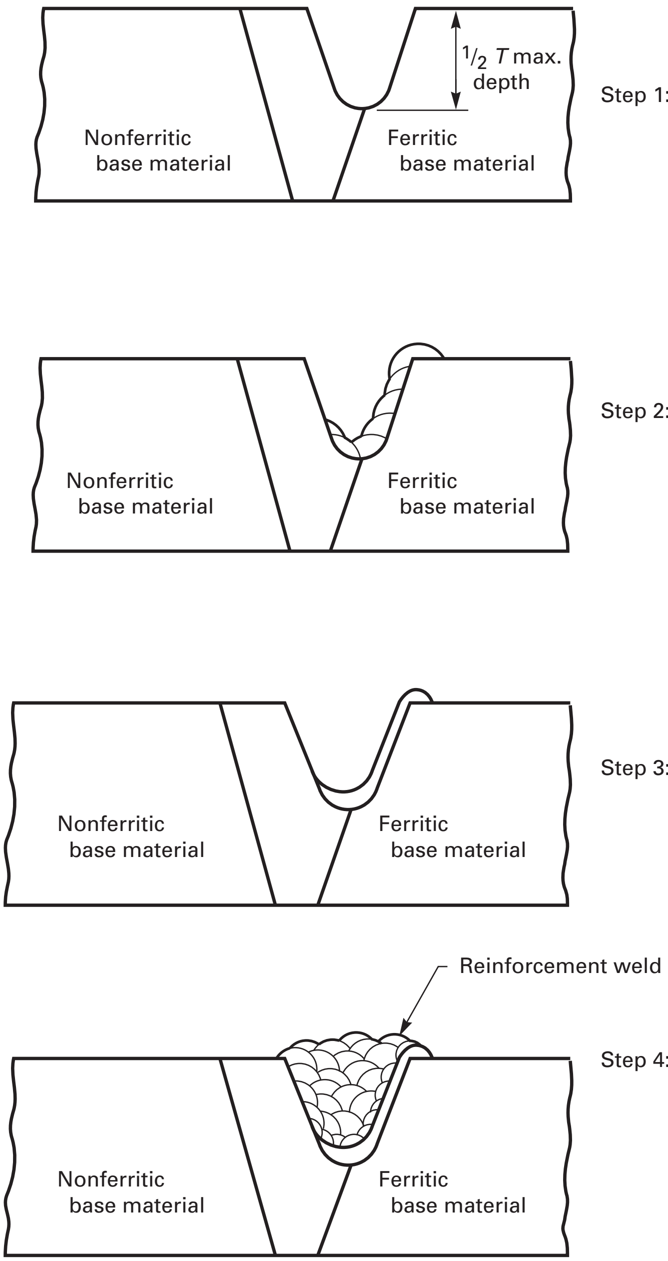
(c) The area to be welded plus a band around the area of at least 1.5 times the component thickness or 5 in. (125 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 300°F (150°C). The maximum interpass temperature shall be 450°F (230°C).

(d) The cavity shall be buttered with the first three layers of weld metal as shown in Figure IWA-4633.2-1, Steps 1 through 3, with the weld heat input for each layer controlled to within ±10% of that used in the procedure qualification test. Subsequent layers shall be deposited with a heat input equal to or less than that used for layers beyond the third in the procedure qualification (see Figure IWA-4643.2-1, Step 4). The completed weld shall have at least one layer of weld reinforcement deposited and then this reinforcement shall be removed by mechanical means, making the finished surface of the weld substantially flush with the surface surrounding the weld.

(e) After at least $^3/_{16}$ in. (5 mm) of weld metal has been deposited, the weld area shall receive a postweld hydrogen bakeout by maintaining it at 450°F to 550°F (230°C to 290°C) for a minimum of 2 hr in P-No. 1 materials. For P-No. 3 materials, the minimum holding time shall be 4 hr.

(f) Subsequent to the above postweld hydrogen bakeout, the balance of the welding may be performed using ambient temperature preheat and a maximum interpass temperature of 350°F (180°C).

Figure IWA-4633.1-1
Temper Bead Welding and Weld Temper Bead Reinforcement of Dissimilar Metal Welds or Buttering



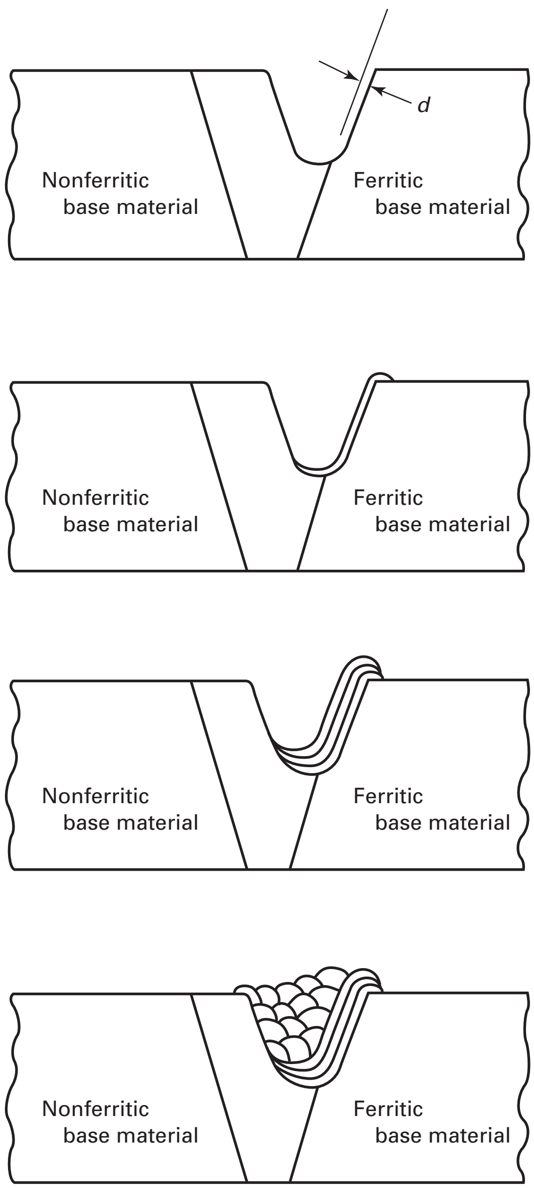
Step 1: Prepare cavity and determine axial depth into ferritic base material.

Step 2: Butter cavity with one layer of weld metal using $^{3}/_{32}$ in. (2.5 mm) diameter coated electrode.

Step 3: Remove the weld bead crown of the first layer by grinding or machining.

Step 4: The second layer shall be deposited with a $^{1}/_{8}$ in. (3 mm) diameter electrode. Subsequent layers shall be deposited with welding electrodes no larger than $^{5}/_{32}$ in. (4 mm) diameter. Bead deposition shall be performed in a manner as shown. Particular care shall be taken in the application of the temper bead reinforcement weld at the tie-in points with the ferritic material as well as its removal to ensure that the heat-affected zone of the base metal and the deposited weld metal is tempered and the resulting surface is substantially flush.

Figure IWA-4633.2-1
Automatic or Machine (GTAW) Temper Bead Welding of Dissimilar Metal Welds or Buttering



Step 1: Prepare and determine distance *d* from original fusion line [See IWA-4631(b)].

Step 2: Deposit layer one with first layer weld parameters used in qualifications. This is the only layer that may contact the ferritic base material.

Step 3: Deposit layers two and three with second and third layer weld parameters used in qualifications.

Step 4: Subsequent layers to be deposited as qualified. NOTE: Particular care shall be taken in the depositing of the fill layers to preserve the tempering of the HAZ of the ferritic base material.

IWA-4634 Examination

IWA-4634.1 Examination Requirements.

(a) Prior to welding, surface examination shall be performed on the area to be welded. Surface examination and acceptance criteria shall comply with IWA-4611.2.

(b) For SMAW, the weld shall be examined after the completed weld has been at ambient temperature for at least 48 hr. For GTAW, the nondestructive examinations shall be performed after the completed weld has cooled to ambient temperature. The examination of the welded region shall include both volumetric and surface examination.

IWA-4634.2 Acceptance Criteria. Acceptance criteria for examinations required by IWA-4634.1(b) shall be in accordance with the Construction Code or Section III.

IWA-4640 TEMPER BEAD WELDING OF CLADDING

IWA-4641 General Requirements

(a) Repair/replacement activities on austenitic stainless steel and nickel base cladding on P-No. 1, 3, 12A, 12B, and 12C base materials when the ferritic material is within $^1/_8$ in. (3 mm) of being exposed may be performed by welding without the specified postweld heat treatments provided the requirements of IWA-4643 and IWA-4644 are met.

(b) The maximum area of an individual cladding repair based on the finished surface shall be 500 in.^{2} (325,000 mm^2), and the depth of the weld into the ferritic material shall not be greater than $^1/_4$ in. (6 mm) or 10% of the base metal thickness, whichever is less.

IWA-4643 Welding Procedure

IWA-4643.1 Shielded Metal-Arc Welding. The procedure shall include the requirements of (a) through (h).

(a) The welds shall be made using A-No. 8 weld metal (Section IX, Table QW-442) for austenitic stainless steel cladding or F-No. 43 weld metal (Section IX, Table QW-432) for either austenitic stainless steel or nickel base cladding.

(b) The maximum bead width shall be four times the electrode core diameter.

(c) All covered electrodes used for the qualification test and welding shall be from freshly opened, hermetically sealed packages or heated ovens maintained between 225°F (110°C) and 350°F (180°C). Electrodes withdrawn from hermetically sealed containers or ovens for longer than 8 hr shall be discarded or shall be baked once in accordance with the manufacturer's recommendations and placed immediately back into the holding ovens. If withdrawn again for longer than 8 hr, they shall be discarded.

(d) The electrodes may be maintained in heated ovens in the work area. The oven temperature shall be maintained between 225°F (110°C) and 350°F (180°C). Electrodes exposed to the atmosphere for more than 8 hr shall be discarded or shall be baked once in accordance with the manufacturer's recommendations and placed immediately back into the holding ovens. Electrodes exposed to the atmosphere for more than 8 hr after being baked once shall be discarded.

(e) The area to be welded plus a band around the area of at least 1.5 times the component thickness or 5 in. (125 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (175°C). The maximum interpass temperature shall be 450°F (230°C).

(f) All areas of the base material on which weld metal is to be deposited shall be covered with a single layer of weld deposit using $^3/_{32}$ in. (2.5 mm) diameter electrodes. The weld bead crown surface of the first layer shall be removed by grinding or machining before depositing the second layer. The second layer shall be deposited with $^1/_8$ in. (3 mm) diameter electrodes. Subsequent layers shall be deposited with electrodes no larger than $^5/_{32}$ in. (4 mm) diameter.

(g) After completion of welding or when at least $^3/_{16}$ in. (5 mm) of weld metal has been deposited, the weld area shall receive a postweld hydrogen bakeout by maintaining it at 450°F to 550°F (230°C to 290°C) for a minimum of 2 hr in P-No. 1 materials. For P-No. 3 materials, the minimum holding time shall be 4 hr.

(h) Subsequent to the above postweld hydrogen bakeout, the balance of the welding, if any, may be performed using ambient temperature preheat and a maximum interpass temperature of 350°F (180°C).

IWA-4643.2 Gas Tungsten-Arc Welding. The procedure shall include the requirements of (a) through (f).

(a) The welds shall be made using A-No. 8 weld metal (Section IX, Table QW-442) for austenitic stainless steel cladding or F-No. 43 weld metal (Section IX, Table QW-432) for either austenitic stainless steel or nickel base cladding.

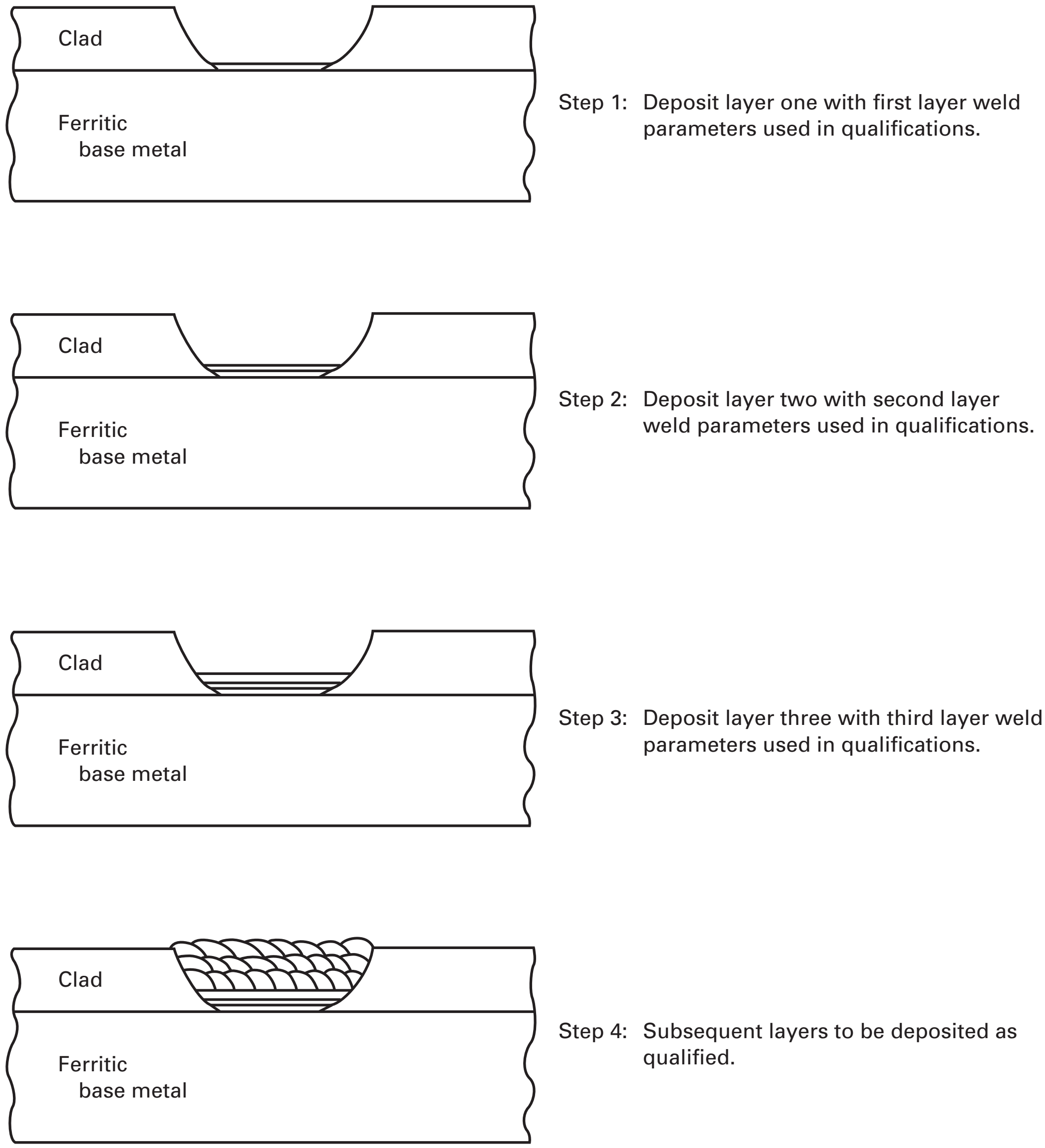
(b) The weld metal shall be deposited by the automatic or machine gas tungsten-arc weld process using cold wire feed.

(c) The area to be welded plus a band around the area of at least 1.5 times the component thickness or 5 in. (125 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 300°F (150°C). The maximum interpass temperature shall be 450°F (230°C).

(d) The cavity shall be buttered with the first three layers of weld metal as shown in Figure IWA-4643.2-1, Steps 1 through 3, with the weld heat input for each layer controlled to within ±10% of that used in the procedure qualification test. Subsequent layers shall be deposited with a heat input equal to or less than that used for layers beyond the third in the procedure qualification (see Figure IWA-4643.2-1, Step 4).

(e) After completion of welding, or when at least $^3/_{16}$ in. (5 mm) of weld metal has been deposited, the weld area shall receive a postweld hydrogen bakeout by

Figure IWA-4643.2-1
Automatic or Machine (GTAW) Temper Bead Welding of Cladding



maintaining it at 450°F to 550°F (230°C to 290°C) for a minimum of 2 hr in P-No. 1 materials. For P-No. 3 materials, the holding time shall be a minimum of 4 hr.

(f) Subsequent to the above postweld hydrogen bakeout, the balance of the welding, if any, may be performed using ambient temperature preheat and a maximum interpass temperature of 350°F (180°C).

IWA-4644 Examination

IWA-4644.1 Examination Requirements.

(a) Prior to welding, surface examination shall be performed on the area to be welded. Examination and acceptance criteria shall comply with IWA-4611.2.

(b) For SMAW, the weld shall be nondestructively examined after the completed weld has been at ambient temperature for at least 48 hr. For GTAW, the nondestructive examinations shall be performed after the completed weld has cooled to ambient temperature. The examination of the welded region shall include both volumetric and surface examination.

IWA-4644.2 Acceptance Criteria. Acceptance criteria for examinations required by IWA-4644.1(b) shall be in accordance with the Construction Code or Section III.

IWA-4650 BUTTER BEAD — TEMPER BEAD WELDING FOR CLASS MC AND FOR CLASS CC METALLIC LINERS

(15) IWA-4651 General Requirements

(a) Repair/replacement activities on P-No. 1, Gr. No. 1 and 2 material may be made without the specified postweld heat treatment, provided the requirements of (b) through (h) and IWA-4652 through IWA-4655 are met.

(b) The shielded metal-arc welding process (SMAW) using low hydrogen electrodes meeting the coating moisture content requirements of SFA-5.5 shall be used.

(c) The following requirements apply to low hydrogen electrodes.

(1) After receipt from the electrode manufacturer and before use, all covered electrodes from hermetically sealed containers shall be immediately used or placed into holding or drying ovens operating between 225°F (110°C) and 350°F (180°C). Covered electrodes from other than hermetically sealed containers shall be baked at the electrode manufacturer's recommended baking temperature. After baking and before cooling below 225°F (110°C), the electrodes shall be transferred to the holding or drying ovens and maintained between 225°F (110°C) and 350°F (180°C).

(2) The electrodes shall be maintained in heated ovens or heated portable containers in the work area until used. The oven temperature shall be maintained between 225°F (110°C) and 350°F (180°C). Electrodes shall be used within 2 hr after removal from the holding or drying ovens or heated portable containers. Electrodes removed from heated ovens for more than 2 hr, but less than 4 hr, shall be returned to a holding oven and held at a temperature between 225°F (110°C) and 350°F (180°C) for at least 8 hr before use. Electrodes removed from heated ovens or heated portable containers for a period in excess of 4 hr shall be rebaked in accordance with (1) before use. Electrodes shall not be rebaked more than once.

(d) Welding materials shall be controlled so that they are identified as acceptable material until consumed.

(e) Welding material contaminated with oil, grease, water, or other foreign material shall not be used.

(f) All welding material shall conform to the material testing requirements of Article NE-2000 for Class MC or CC-2500 for Class CC. For each lot of covered electrodes, weld metal tests shall be made in accordance with test requirements of NE-2431.1 for Class MC or CC-2612.1 for Class CC, and the coupons shall be tested in the as-welded condition. Impact test requirements and acceptance criteria shall be as required by the Construction Code and Owner's Requirements for the component base metal to be welded.

(g) Weld metal and heat-affected zones may be peened to control distortion. Such peening may not be used on the initial (root) layer of weld metal or on the final (face) layer.

(h) Fabrication and welding shall be sequenced to minimize the effects of restraint.

(i) Peening intended only to reduce residual surface tensile stresses is permitted on the interior root surface and on the final (face) layer. This peening shall be performed after any surface examinations required by IWA-4654 are completed.

IWA-4652 Welding Qualification

IWA-4652.1 General Requirements. The welding procedure and welders shall be qualified in accordance with Section IX and the additional requirements of Section III, except as modified or supplemented by IWA-4652.2 through IWA-4652.4.

IWA-4652.2 Procedure Qualification. Welding procedure qualification tests shall be performed in accordance with Section IX for groove welds and the additional requirements of Article NE-4000 for Class MC or Article CC-4000 for Class CC. Impact test requirements and acceptance criteria shall be as required by the Construction Code and Owner's Requirements for the component base material.

IWA-4652.3 Performance Qualification. The welders shall be qualified on a radiographically examined groove weld test in accordance with Section IX and by performance of the production test required by IWA-4652.4. The welder shall use the production Welding Procedure Specification and simulate typical physical obstructions.

IWA-4652.4 Production Test. In addition to the procedure qualification test requirements of IWA-4652.2, one production test is required prior to any welding. A production test simulates welding using the variables listed in (a) and (b). A production test assembly may consist of one or more production tests. (15)

(a) The production test base material that represents the pressure boundary shall be of the same material specification, type, class, group number, or grade as the pressure boundary material to be welded. All other material shall be of the same P-Number as those to be used in the repair/replacement activity. When the original material is no longer manufactured, material similar to the original material specification may be substituted. Electrodes used for the production test shall be the same specification and classification as those used for the weld and shall be treated as required by IWA-4651(c).

(b) The production test shall simulate the repair/replacement weld. The following parameters shall be recorded:

(1) all essential and supplementary essential variables listed for the process in Section IX.

(2) nominal pressure boundary base metal thickness.

(3) maximum nominal attachment base metal thickness.

(4) weld joint geometry (including joint design and fit up tolerances) and the maximum nominal weld thickness. For fillet welds, the nominal thickness is the throat thickness, and for groove welds, the nominal thickness is the depth of the weld groove.

(5) restraint on the weld joint. The restraint shall be maintained on the production test assembly for a minimum of 48 hr after the completed weld has reached ambient temperature.

(6) weld sequencing (both fabrication steps and order of bead sequence).

(7) weld position (see Section IX).

(8) water backing and water temperature within specified tolerances, as applicable.

(9) actual weld electrode size to be used for the butter bead layer and the temper bead layer.

(10) range of electrode sizes to be used to complete the weld joint.

(11) preheat and preheat maintenance within tolerances specified in the Welding Procedure Specification.

(12) guides, templates, and fixtures used for weld placement, as applicable.

(13) maximum temper bead edge clearance (dimension S) as shown in Figures IWA-4652.4-1 and IWA-4652.4-2 and the minimum temper bead edge clearances.

(14) maximum weave width for the butter bead layer.

(c) The production test shall be of sufficient size to permit removal of the test specimens required in (d).

(d) The production test shall be evaluated as follows:

(1) visual examination in accordance with Article IWA-2000 (VT-3) for compliance with the Welding Procedure Specification.

(2) surface examination and acceptance of the welds in the completed test assembly in accordance with Subsection NE for Class MC or Subsection CC for Class CC.

(3) Examination of two cross sections for each production test is required. The cross sections shall be polished, etched, and examined at 10× magnification. Cross sections containing cracks or other deleterious conditions shall be cause for rejection of the production test.

(4) A minimum of two micro-hardness traverses shall be taken from one cross section for each production test. The traverses shall be taken from areas of maximum anticipated hardness including the toe of the butter bead layer as shown in Figure IWA-4652.4-1. The indentation spacing of the heat-affected zone (HAZ) microhardness traverse shall consist of not less than ten indentations. Hardness values for the traverse shall be recorded. The maximum hardness for the pressure boundary HAZ shall not exceed 400 KHN (500 g load).

IWA-4653 Welding Technique

Welding shall be in accordance with the following:

(a) Prior to welding, the area to be welded shall be examined by magnetic particle or liquid penetrant methods in accordance with Subsection NE for Class MC or Subsection CC for Class CC.

(b) All surfaces to be welded and the surrounding areas shall be clean and free of scale, rust, moisture, or other surface contaminants.

(c) The minimum preheat temperature specified in the Welding Procedure Specification and the production test (IWA-4652.4) shall be maintained during tack welding and until completion of the weld.

(d) The maximum interpass temperature shall be 500°F (260°C).

(e) Welding shall consist of the application of a butter bead layer, followed by temper beads or a temper bead layer. Butter bead and alternate temper bead placement is shown in Figure IWA-4652.4-1, detail (a). Similar application of the temper bead technique for the reinforcement of fillet welds is shown in Figure IWA-4652.4-2. The technique described in this paragraph shall be performed in the production test and actual work.

(f) No postweld heat treatment is required.

IWA-4654 Examination

IWA-4654.1 Examination Requirements.

(a) Prior to welding, surface examination shall be performed on the area to be welded. Examination and acceptance criteria shall comply with IWA-4611.2.

(b) The completed weld shall be VT-1 visually examined in accordance with IWA-2200.

(c) The completed weld and a band 1 in. (25 mm) on either side of the weld shall be examined by the magnetic particle method after the completed weld has been at ambient temperature for at least 48 hr.

IWA-4654.2 Acceptance Criteria. Acceptance criteria for examinations required by IWA-4654.1(c) shall be in accordance with the Construction Code or Section III. The acceptance criteria of Subsection NE shall be used for Class MC items and the acceptance criteria of Subsection CC shall be used for Class CC items.

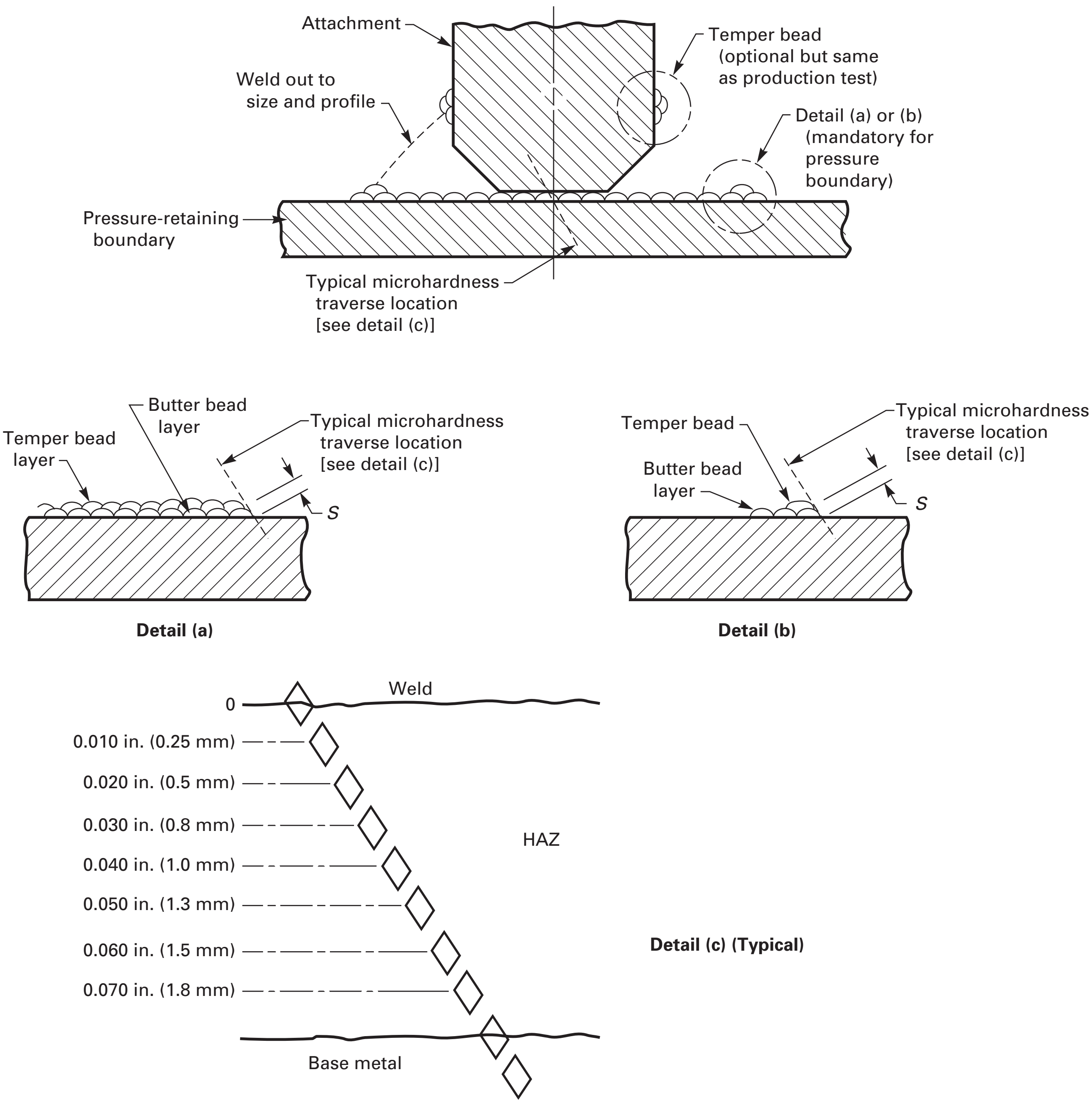
IWA-4655 Welding Techniques

(a) Defects contained wholly in the weld metal shall be corrected in accordance with NE-4400 for Class MC or CC-4540 for Class CC, except as noted in (b).

(b) Improper application of the temper bead or defects in the butter bead or temper bead shall be corrected by application of a new butter bead and temper bead as shown in Figure IWA-4655-1.

(c) The repair technique for undercut greater than $^1/_{32}$ in. (1 mm) is shown in Figure IWA-4655-2.

Figure IWA-4652.4-1 Temper Bead Technique



GENERAL NOTES:

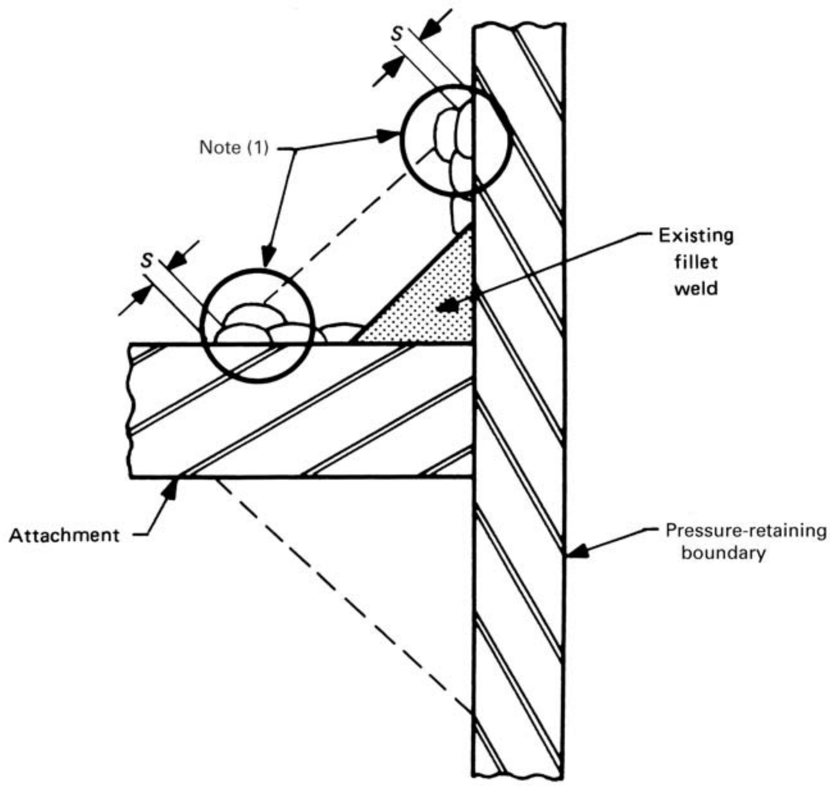
(a) Butter layer may also be deposited as weave bead between butter bead or temper bead.

(b) If weave bead is used, initial and final weave passes must be accompanied by temper bead.

(c) If stringer technique is used, ends of stringer passes must be accompanied by temper bead.

(d) In electrode selection, preference should be given to electrode types with as-welded yield strengths which do not greatly exceed the minimum tensile strength specified for the base metal.

Figure IWA-4652.4-2 (15)
Illustration of the Temper Bead Technique for Reinforcement of Existing Fillet Welds



NOTE:
(1) See Figure IWA-4652.4-1, Detail (a) or (b).

IWA-4660 UNDERWATER WELDING

(15) IWA-4661 Scope and General Requirements

(a) These requirements[14] are for dry or wet underwater welding.

(b) The terms and definitions of ANSI/AWS D3.6M, "Underwater Welding Code," shall be used.

(c) Welding of P-No. 1, P-No. 8, and P-No. 4X materials may be performed under water provided the welding procedures and welders or welding operators are qualified in accordance with Section IX as modified by IWA-4662 or IWA-4663, as applicable.

(d) Dry underwater welding may be performed with GMAW, GTAW, LBW, PAW, SMAW, or a combination of these processes.

(e) Wet underwater welding may be performed with GMAW (FCAW-type only), LBW, SMAW, or a combination of these processes.

(f) IWA-4660 may not be used for welding of irradiated materials other than P-No. 8 materials containing less than 0.1 APPM[15] measured or calculated helium content generated through irradiation.

IWA-4662 Additional Variables for Dry Underwater Welding

IWA-4662.1 Procedure Qualification. Welding procedure specifications for dry underwater welding shall be qualified in accordance with the requirements of Section IX and applicable impact testing requirements of the Construction Code for groove welds. The following variables also apply. (15)

(a) Additional essential variables:

(1) A change in the method for underwater transport and storage of filler material (e.g., from sealed packages to exposed).

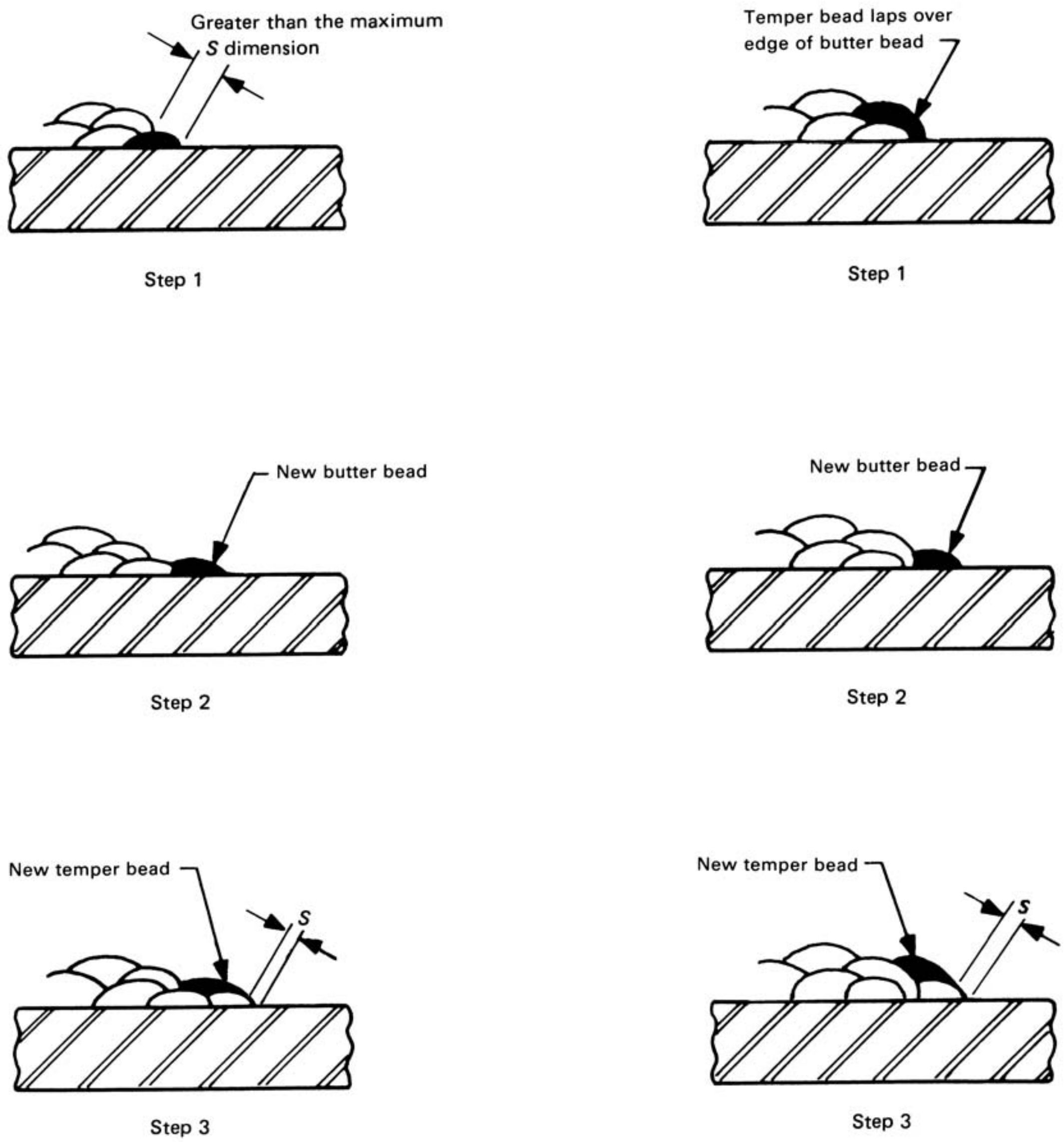
(2) Addition or deletion of waterproof or supplementary coatings for the filler metal or a change in the type of any waterproof or supplementary coatings.

(3) A change in depth beyond that qualified in accordance with Table IWA-4662.1-1.

(4) A change in the nominal background gas composition.[16]

(5) For SMAW and FCAW, use of a larger diameter electrode than that used in qualification.

Figure IWA-4655-1
Welding Techniques for Improper Temper Bead Spacing



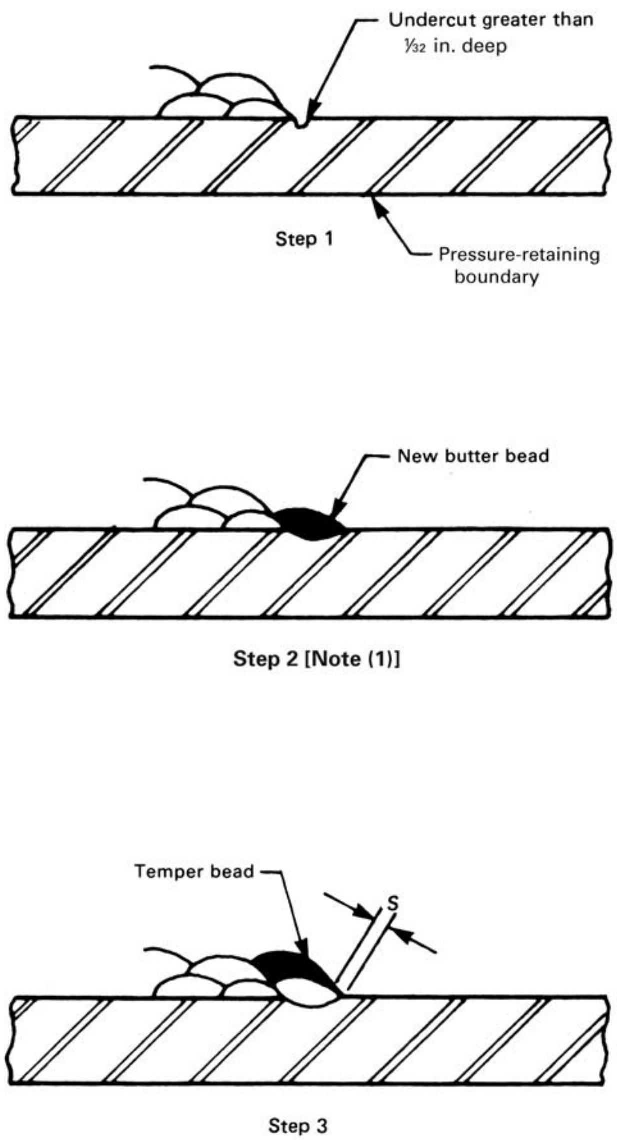
(a) Spacing Too Large

(b) Spacing Too Small

GENERAL NOTE: $^1/_{32}$ in. = 1 mm

(15)

Figure IWA-4655-2 Example of Weld Undercut Welding Technique



GENERAL NOTE: $^{1}/_{32}$ in. = 1 mm

NOTE:
(1) Preparation of the area to be repaired shall be in accordance with IWA-4300.

Table IWA-4662.1-1
Depth Limitations for Underwater Welding Qualification

Type of Welding	Max. Depth Qualified [Note (1)]	Min. Depth Qualified [Note (2)]
Dry Welding	*D* plus 33 ft (10 m)	*D* minus 33 ft (10 m)
Wet Welding with A-No. 8 Filler Metals	*D* plus 10 ft (3 m)	*D* minus 33 ft (10 m)
Wet Welding with F-No. 4X Filler Metals	*D*	*D* minus 33 ft (10 m)
Wet Welding with Other Than A-No. 8 and F-No. 4X Filler Metals	*D* plus 33 ft (10 m)	*D* minus 33 ft (10 m) [Note (3)]

GENERAL NOTE: *D* is qualification test depth.

NOTES:
(1) For the maximum depth qualified, depth shall be measured from the lower extremity of the test weldment with a tolerance of plus or minus 9 in. (230 mm).
(2) For the minimum depth qualified, depth shall be measured from the upper extremity of the test weldment with a tolerance of plus or minus 9 in. (230 mm).
(3) Welds at depths less than 10 ft (3 m) require qualification at the production weld minimum depth.

(6) For P-No. 1 material, a decrease in the minimum distance from the point of welding to the wetted surface in any direction, when the minimum distance is less than 6 in. (150 mm)

(7) For P-No. 1 material, the supplementary essential variables of Section XI apply to nonimpact-tested base metal when the minimum distance from the point of welding to the wetted surface in any direction is less than 6 in. (150 mm)

(b) Additional nonessential variables:

(1) For SMAW and FCAW, an increase in time of electrode exposure to the underwater environment.

(2) A change in the method of protecting, removing moisture from, or otherwise conditioning bare filler metal and bare electrodes in the underwater environment.

IWA-4662.2 Performance Qualification. Welders and welding operators for dry underwater welding shall be qualified in accordance with Section IX and the variables listed below. When a welder or welding operator has not welded with a process in a dry underwater environment for at least six months, the qualifications for that underwater process shall expire.

(a) A change in welding mode (i.e., dry chamber, dry spot, or habitat).

(b) A change in the SFA specification AWS filler metal classification, or if not conforming to an AWS filler metal classification, a change in the manufacturer's trade name for the electrode or filler metal.

(c) Addition or deletion of supplementary coatings for the filler metal or a change in the type of any supplementary coatings.

(d) A change in depth beyond that qualified in accordance with Table IWA-4662.1-1.

(e) For SMAW and GMAW, use of a larger diameter electrode than that used during performance qualification.

IWA-4663 Additional Variables for Wet Underwater Welding

IWA-4663.1 Procedure Qualification. Welding procedure specifications for wet underwater welding shall be qualified to the requirements of Section IX for groove welds, except that for P-No. 1 base metals, the supplementary essential variables of Section IX apply to nonimpact-tested base metal. The following variables also apply.

(a) Additional essential variables:

(1) A change in the method for underwater transport and storage of filler material (e.g., from sealed packages to exposed).

(2) Addition or deletion of waterproof or supplementary coatings for the filler metal or a change in the type of any waterproof or supplementary coatings.

(3) A change in electrode diameter beyond the range used in qualification.

(4) A change in depth beyond that qualified in accordance with Table IWA-4662.1-1.

(5) A change in the SFA specification AWS filler metal classification, or, if not conforming to an AWS filler metal classification, a change in the manufacturer's trade name for the electrode or filler metal.

(6) Addition of welding positions other than those qualified in accordance with Table IWA-4662.1-2.

(7) A change from upward to downward, or vice versa, in the progression specified for any pass of a vertical weld.

(8) A change from the stringer bead technique to the weave bead technique, or vice versa. For P-No. 8 and P-No. 4X base metals, this variable applies only to the vertical position.

(9) A change from ac to dc, or vice versa, and, in dc welding, a change from electrode negative (straight polarity) to electrode positive (reverse polarity), or vice versa.

(10) A change from wet backside to dry backside for backing thickness less than $^1/_4$ in. (6 mm).

(11) For P-No. 1 base metal carbon equivalents as calculated in accordance with Figure IWA-4663.1-1, an increase in the carbon equivalent beyond that of the procedure qualification test coupon.

(12) An increase in the time of electrode exposure to water at qualification depth.

Table IWA-4662.1-2
Procedure and Performance Qualification — Position Limitations

Qualification Test		Position and Type of Weld Qualified [Note (1)]			
		Plate		Pipe	
Weld	Plate or Pipe Positions	Groove	Fillet	Groove	Fillet
Plate-groove	1G	F	F	F	F
	2G	H	H	H	H
	3G	V	V		
	4G	O	O		
Pipe-groove	1G	F	F	F	F
	2G	H	H	H	H
	5G	F, V, O	F, V, O	F, V, O	F, V, O
	6G	All	All	All	All

NOTE:
(1) Positions of welding:
F = Flat
H = Horizontal
V = Vertical
O = Overhead

(13) For P-No. 1 base materials, a change from multipass per side to single pass per side.

(b) Additional nonessential variable: a decrease in included angle, a decrease in root opening, or an increase in root face.

IWA-4663.2 Performance Qualification. Welders and welding operators for wet underwater welding shall be qualified in accordance with Section IX and the variables listed below. For all base metals, bend testing shall be performed in accordance with requirements of Section IX, QW-302.1. Alternatively, testing may be by radiographic examination in accordance with Section IX, QW-302.2. When a welder or welding operator has not welded with a process in a wet underwater environment for at least six months, the qualifications for welding with that process underwater shall expire.

(a) A change in the SFA specification AWS filler metal classification, or, if not conforming to an AWS filler metal classification, a change in the manufacturer's trade name for the electrode or filler metal.

(b) Addition or deletion of waterproof or supplementary coating for the filler metal or a change in the type of any waterproof or supplementary coatings.

(c) A change from salt or borated water to fresh water.

(d) Use of a larger diameter electrode than that used during performance qualification.

(e) A change in depth beyond that qualified in accordance with Table IWA-4662.1-1.

(f) Addition of welding positions other than those qualified in accordance with Table IWA-4662.1-2.

(g) A change in polarity or type of power source (e.g., rectifier, motor-generator, inverter).

(h) A change from stringer bead to weave technique.

(i) A change in the welder's view from beneath to above the water surface.

(j) A decrease in the included angle, a decrease in root opening, or an increase in the root face.

Figure IWA-4663.1-1
Carbon Equivalency Calculation

$$CE = C + \frac{Mn + Si}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

GENERAL NOTE: The chemical analysis for carbon equivalent calculations for the production base material may be obtained from the mill test certificate or chemical analysis. If chemical analysis is not available for Cr, Mo, V, Ni, and Cu, the carbon equivalent may be determined by using 0.1 for the term $\left[\frac{Cr+Mo+V}{5}+\frac{Ni+Cu}{15}\right]$.

IWA-4664 Filler Metal Qualification (15)

(a) Filler metal qualification testing in accordance with (b), (c), and (d) is required for the following:

(1) each heat and lot of filler metal used for wet welding

(2) each heat and lot of flux-coated or flux-cored electrode used for dry welding

(3) each waterproof coating type

(4) each supplementary coating type

(b) An all-weld-metal coupon and a weld pad shall be prepared using the production welding procedure at a depth such that the depth of the production weld will be within the depth limitations of Table IWA-4662.1-1.

(1) For material that conforms to an SFA specification, the coupons shall be prepared in accordance with the applicable SFA specification.

(2) For material that does not conform to an SFA specification, the coupons shall be prepared in accordance with the SFA specification most nearly matching that material (e.g., for ferritic covered electrodes, SFA-5.1).

(c) The coupons shall be tested as follows.

(1) The ferrite number shall be directly measured from the weld pad for austenitic stainless steel, Section IX, Table QW-442, A-No. 8 filler metal.

(2) One all-weld-metal specimen shall be tension tested.

(3) As-deposited chemical composition shall be determined from the weld pad in accordance with the applicable SFA specification or the SFA specification most nearly matching the material.

(4) For ferritic weld metal, Charpy V-notch absorbed energy shall be determined in accordance with IWA-4665 and, if applicable, the Construction Code.

(d) The qualification testing acceptance criteria shall be as follows.

(1) The ferrite number shall meet the requirements of the Construction Code.

(2) The ultimate tensile strength shall meet the minimum tensile strength specified for either of the base metals to be joined.

(3) The chemical composition shall meet the applicable SFA specification requirements for the as-deposited chemical composition. For material that does not conform to an SFA specification, the chemical composition shall meet the requirements specified in the WPS.

(4) Charpy V-notch absorbed energy shall meet the requirements of IWA-4665(b) and, if applicable, the Construction Code.

IWA-4665 Charpy V-Notch Testing Requirements

(a) Charpy V-notch tests of the weld metal shall be performed at 32°F (0°C). Number, location, and orientation of the test specimens shall be as follows.

(1) The specimens shall be removed from a location as near as practical to a depth of one-half the thickness of the deposited weld metal.

(2) The Charpy V-notch test shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Figure 11, type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The absorbed energy and the test temperature, as well as the orientation and location of the tests performed, shall be reported in the Procedure Qualification Record.

(b) The averages of the three weld metal impact tests shall be not less than 25 ft-lb (34 J).

(c) Charpy V-notch tests of the weld metal are not required for austenitic (A-No. 8) or nickel-base (F-No. 4X) filler material.

IWA-4666 Examination

The examination requirements of the Construction Code or Section III shall be met for completed welds. When the nondestructive examinations required by this Division or the Construction Code cannot be performed or will not provide meaningful results because of the underwater environment, the following alternative requirements apply.

IWA-4666.1 Surface Examination. In lieu of any required surface examination, the following apply:

(a) A surface examination shall be conducted with an ultrasonic or eddy current surface examination procedure qualified for the underwater environment.

(b) If ultrasonic and eddy current methods cannot be performed or will not provide meaningful results, the surface shall be VT-1 visually examined with a procedure meeting the requirements of IWA-2200.

(c) Ultrasonic, eddy current and visual surface indications shall be evaluated using the surface examination acceptance criteria of the Construction Code, Section III, or this Division.

(d) Personnel performing visual examinations shall be qualified in accordance with IWA-2300 for performance of VT-1 visual examinations and shall have received additional training in examination of weldments for fabrication conditions, including dimensional requirements and fabrication flaws.

IWA-4666.2 Volumetric Examination. In lieu of any required volumetric examination, the following apply:

(a) A volumetric examination shall be conducted with an ultrasonic examination procedure. The ultrasonic examination shall be conducted in accordance with Section V, Article 4. Indications shall be evaluated using the volumetric acceptance criteria of the Construction Code, Section III, or this Division.

(b) If the ultrasonic method cannot be performed or will not provide meaningful results, a surface examination shall be performed on the root pass and on the finished weld in accordance with IWA-4666.1.

IWA-4670 AMBIENT TEMPERATURE TEMPER BEAD WELDING

Ambient temperature preheat may be used for welding similar materials, dissimilar materials, inlays, onlays, and overlays, with the additional requirements in IWA-4671 through IWA-4673.

IWA-4671 General Requirements

(a) Repair/replacement activities are limited to P-Nos. 1, 3, 12A, 12B, and 12C materials, and their associated welds, and welds joining P-No. 8 or P-No. 43 materials to P-Nos. 1, 3, 12A, 12B, and 12C materials. Welding shall not be used to repair SA-302, Grade B material, unless the

material has been modified to include nickel content of 0.4% to 1.0%, quenching and tempering, and application of a fine grain practice.

(b) The maximum area of an individual weld based on the finished surface over the ferritic material shall be 1,000 in.^{2} (650 000 mm^2) for full circumferential weld overlays and 500 in.^{2} (325 000 mm^2) for all other applications, and, except as permitted in (1), the depth of the weld shall not be greater than one half of the ferritic base metal thickness.

(1) Through-wall circumferential welds are permitted if the following requirements are met:

(-a) For repair/replacement activities associated with existing welds, the existing weld (including any associated buttering) shall be removed in its entirety.

(-b) Temper bead buttering shall be applied across the entire face of the weld preparation area on the base materials requiring tempering and shall extend around the full circumference of the joint.

(c) Repair/replacement activities on a dissimilar-metal weld are limited to those along the fusion line of a nonferritic weld to ferritic base material on which $^1/_8$ in. (3 mm) or less of nonferritic weld deposit exists above the original fusion line.

(d) If a defect penetrates into the ferritic base material, repair of the base material, using a nonferritic weld filler material, may be performed, provided the depth of repair in the base material does not exceed $^3/_8$ in. (10 mm).

(e) Prior to welding, the area to be welded and a band around the area of at least 1$^1/_2$ times the component thickness or 5 in. (130 mm), whichever is less, shall be at least 50°F (10°C).

(f) Except on the initial and final layers, peening may be used.

IWA-4672 Welding Procedure Requirements

The procedure shall include the following requirements:

(a) The weld metal shall be deposited using the automatic or machine GTAW process.

(b) The maximum interpass temperature for field applications shall be 350°F (180°C) for all weld layers, regardless of the interpass temperature used during qualification. The interpass temperature limitations of Section IX, QW-406.3 and QW-406.8 need not be applied.

(c) The interpass temperature shall be determined by direct measurement (e.g., pyrometers, temperature-indicating crayons, thermocouples) during welding. If direct measurement is impractical (e.g., because of geometric limitations or radiological reasons), interpass temperature shall be determined in accordance with the following:

(1) heat flow calculations, including the following variables:

(-a) welding heat input

(-b) initial base material temperature

(-c) configuration, thickness, and mass of the item being welded

(-d) thermal conductivity and diffusivity of the materials being welded

(-e) time per weld pass and delay time between each pass

(-f) time to complete the weld

(2) Measurement of the actual interpass temperature on a test coupon not thicker than the item to be welded. The maximum heat input of the welding procedure shall be used in the welding of the test coupon.

(d) Particular care shall be given to ensure that the weld region is free of potential sources of hydrogen. The surfaces to be welded, filler metal, and shielding gas shall be suitably controlled.

IWA-4673 Examination

(a) Except as permitted in (1), the following examinations shall be performed in accordance with the Construction Code or Section III:

(1) Prior to repair welding, surface examination shall be performed on the area to be welded. If surface examination materials cannot be cleaned from crevices in the area to be welded (e.g., trapped in crevices remaining after removal of the full thickness of a partial penetration or fillet weld), VT-1 visual examination shall be performed, provided the requirements of (b) are met.

(2) If ferritic materials are used, the weld shall be nondestructively examined after the completed weld has been at ambient temperature for at least 48 hr. If austenitic materials are used, the weld shall be nondestructively examined after the three tempering layers (i.e., layers 1, 2, and 3) have been in place for at least 48 hr. Examination of the welded region shall include both volumetric and surface examination methods. Demonstration for ultrasonic examination of the repaired volume is required using representative samples containing construction-type flaws.

(3) Areas from which weld-attached thermocouples have been removed shall be ground and examined using a surface examination method.

(4) Acceptance criteria for surface and volumetric examination shall be in accordance with the Construction Code or Section III.

(b) VT-1 visual examinations performed in accordance with (a)(1) shall meet the following:

(1) VT-1 visual examination shall be performed using a procedure meeting requirements of IWA-2210.

(2) VT-1 visual examination personnel shall be qualified in accordance with IWA-2300 and shall receive additional training in examination of weldments for fabrication conditions, including dimensional requirements and fabrication flaws.

(3) Visual examination acceptance standards shall comply with the following:

(-a) Linear indications are indications in which the length is more than three times the width. Rounded indications are circular or elliptical with length not more than three times the width.

(-b) Only indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant. The following relevant indications are unacceptable:

(-1) any cracks or linear indications

(-2) rounded indications with major dimensions greater than $^3/_{16}$ in. (5 mm)

(-3) four or more rounded indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge

(-4) ten or more rounded indications in any 6 in.^{2} (4 000 mm^2) of surface, with major dimension of this area not to exceed 6 in. (150 mm), with the area taken in the most unfavorable location relative to the indication being evaluated

IWA-4700 HEAT EXCHANGER TUBING

IWA-4710 PLUGGING

IWA-4711 Explosive Welding

If explosive welding is used to weld plugs to Class 1 heat exchanger tubes or heat exchanger tubesheet bore holes, the requirements of IWA-4711.1 through IWA-4711.4 shall be met. These requirements may be used for Class 2 and Class 3 heat exchangers.

IWA-4711.1 General Requirements.

(a) Material used in manufacturing plugs shall be produced in compliance with requirements of a SA or SB material specification or any other material specification that has been approved for Section III.

(b) Each plug shall be traceable to a Certified Material Test Report that indicates the mechanical properties and chemistry.

(c) Records shall be maintained by the Owner, and shall include the following:

(1) plugging procedure

(2) welding procedure qualifications

(3) welding operator performance qualifications

(4) material certifications

(5) location of all plugged tubes or holes

(6) results of heat exchanger examinations required by this Subparagraph

(7) specific tubes or holes plugged by each welding operator

(d) Records of the procedure and welder qualification shall include the results of all tests required by IWA-4711.2, and shall be certified by the Repair/Replacement Organization. The Procedure Qualification Records shall include a description of all essential and nonessential variables [IWA-4711.2.1(a) and IWA-4711.2.1(b)]. The operator performance qualification record shall also list the procedure number and revision that was used for testing; the record of operator experience shall be kept current.

IWA-4711.2 Welding Qualification.

IWA-4711.2.1 Procedure Qualifications. The Welding Procedure Specification for plugging shall be qualified as a new procedure specification and shall be completely requalified if any of the essential variables listed below are changed. Nonessential variables may be changed without requalification, provided the Welding Procedure Specification is amended to show these changes.

(a) Essential Variables

(1) a change in the P-Number classification (Section IX, Table QW/QB-422) of any of the materials being joined. This includes the tube, plug, tubesheet, or tubesheet cladding. If the plug is to be joined to any part of the tubesheet cladding, this cladding must be duplicated in the procedure qualification. Materials not listed under a P-Number require separate qualification.

(2) a decrease in the nominal design tube wall thickness of 10% or more (if the plug is welded to the tube).

(3) a change in the tubesheet hole pattern.

(4) a decrease in the proximity of two simultaneously detonated parts.

(5) any increase in the number of plugs to be simultaneously detonated.

(6) a change in detail controlling explosive densities and charge-to-mass ratios.

(7) a change in the type of explosive.

(8) a change of 10% or more in the explosive charge mass.

(9) a decrease of 15% or more in the tubesheet ligament.

(10) the deletion of cleaning of the tube, plug, or hole contact surfaces, or a change in the cleanliness requirements (including surface oxide removal) for such surfaces prior to explosive welding.

(11) a change of whether or not the tubes had been expanded into contact with the tubesheets in the areas where bonding occurs.

(12) any change in the nominal plug configuration.

(13) a change of 10% or more in the clearance (stand-off) between the tube or hole and the plug in the bonding area.

(b) Nonessential Variables

(1) a change in the P-Number of tubesheet material for tube plugging (when plug is not joined to tubesheet)

(2) a change in the tubesheet cladding (when the plug is not joined to the cladding) when the explosive charge is installed within one tube diameter of the cladding metal

(3) for tube plugging, a change in the tube-to-tubesheet seal welding procedure when the explosive charge is installed within one tube diameter of the tube-to-tubesheet seal weld [see (c)(3)]

(c) Test Assembly

(1) The procedure qualification shall be made on a test assembly that simulates the conditions to be used in production with respect to position, tube hole pattern, and the essential variables listed in this Subparagraph.

(2) The test assembly tubesheet thickness shall be as thick as the production tubesheet, except that it need not be 1 in. greater than the length of the explosive plug.

(3) When the explosive charge in the heat exchanger is to be placed less than one tube diameter from cladding or a tube-to-tubesheet weld, the qualification test assembly shall also contain cladding or tube-to-tubesheet welds, as applicable.

(4) The minimum number of explosive welds required for procedure qualification shall be 10 welds made consecutively.

(d) Examination of Test Assembly

(1) When cladding or welds are required per (c)(3), such cladding and tube-to-tubesheet welds shall be examined by the liquid penetrant method and shall comply with the acceptance standards of Article NB-5000.

(2) Each plug weld and tube-to-tubesheet weld (when applicable) shall be sectioned longitudinally to reveal four cross-sectional faces, 180-deg apart. After polishing and etching the four faces, each explosive weld joint area shall be metallographically examined at 50× or greater magnification for the length of the explosive bond. The bonding shall be considered acceptable if there is a minimum of five times the nominal tube wall thickness of continuous bond between the plug and tube or tubesheet on each cross-sectioned face. Each tube-to-tubesheet weld examination (if applicable) shall be considered acceptable if it is free from explosively produced cracks as determined visually using 10× magnification.

(3) Ligament distortion caused by explosive welding is unacceptable when the adjacent tube I.D. is reduced below the diameter of the tube plug.

(4) The procedure shall be considered qualified if all 10 of the required, consecutively made explosive welds are found to be acceptable.

IWA-4711.2.2 Performance Qualifications. Tube plugging by explosive welding shall be performed by welding operators who have first been qualified in accordance with the following requirements.

(a) Required Tests. The welding operator shall prepare (if applicable), install, and detonate consecutively a minimum of five plugs in conformance with an explosive plug Welding Procedure Specification. Acceptance of these plug welds qualifies the operator for welding with all other explosive plug welding procedures.

(b) Examination of Test Assembly. The five plugs shall be examined in accordance with the requirements of IWA-4711.2.1(d). All five welds must meet these acceptance standards for performance qualification to be accepted.

(c) Renewal of Qualification. Renewal of qualification of an explosive plug welding operator's performance is required when the operator has not used the process for six months or longer, or when there is specific reason to question his ability to make quality welds in accordance with the procedure. Renewal of qualification shall be identical to the initial qualification, except that only one tube plug explosive weld need be made.

IWA-4711.3 Plugging Procedure Specification. The written plugging procedure specification shall delineate all the requirements of the repair/replacement activity, including the following:

(a) safety requirements

(b) plug material, dimensions, and certification requirements

(c) essential and nonessential variables of the explosive welding process

(d) preparation or cleaning of the plug, tube, and tubesheet bore hole, if required

(e) detonation of the charge

(f) nondestructive examination

(g) method of verifying that both ends of the same tube or tubesheet bore hole are to be plugged

IWA-4711.4 Examination. The final examination shall be a VT-1 visual examination in accordance with IWA-2200, looking for proper installation and correct location.

IWA-4712 Fusion Welding

The requirements of IWA-4712.1 through IWA-4712.5 shall be met when manual, machine, or automatic welding is used to join plugs to Class 1 heat exchanger tubes of P-Nos. 8 and 4x material or tubesheet holes of austenitic stainless steel or nickel base material. These requirements may be used for Classes 2 and Class 3 heat exchangers.

IWA-4712.1 Material Requirements.

(a) Material shall be in accordance with the requirements of an SA, SB, SFA, or any other material specification accepted for use by Section III. Material produced to a weld filler metal chemistry shall meet the filler material requirements of Article NB-2000.

(b) Material shall be traceable to a Certified Material Test Report (CMTR).

IWA-4712.2 Welding Qualifications. Welding Procedure Specifications (WPS) and welders or welding operators shall be qualified in accordance with Section IX and the additional requirements and exceptions of this Subparagraph.

(a) Procedure Qualification

(1) Welds shall be made using the shielded metal-arc welding (SMAW), gas tungsten-arc welding (GTAW), or gas metal-arc welding (GMAW) process. Short-circuiting arc GMAW shall not be used.

(2) A separate qualification is required for any change in the P-Number, A-Number, or F-Number of the plug, tube, sleeve, filler metal, or cladding. A separate qualification is also required when the material has no P-Number, A-Number, or F-Number.

(3) If the plug is welded to the cladding, the cladding shall be considered as base material. The qualification test coupon may simulate the cladding by either of the following:

(-a) Cladding with $^3/_{16}$ in. (5 mm) thickness shall be deposited using any qualified WPS that results in the chemical analysis of the deposited cladding nominally matching the chemical analysis of the cladding on the item to be welded.

(-b) Wrought material shall be used. A-No. 8 cladding may be simulated by P-No. 8 material. F-No. 4X cladding may be simulated by similar P-No. 4X material.

(4) The following essential variables, in addition to those specified by Section IX, apply and shall be listed on the WPS:

(-a) a change of more than $^1/_{16}$ in. (1.5 mm) in the extension or recess of either the tube relative to the tubesheet or the plug relative to the material being joined (tube, sleeve, or tubesheet) (see Figure IWA-4712.2-1)

(-b) 10% change in the plug thickness at the weld location

(-c) 10% change in the nominal wall thickness of the tube or sleeve, when the plug is welded to the tube or sleeve

(-d) decrease of 10% or more in the specified width of the ligament between tube holes when the specified width is less than $^3/_8$ in. (10 mm) or three times the specified tube wall thickness, whichever is greater

(5) The tubesheet in the test assembly shall be at least as thick as the production tubesheet, but need not exceed $1^1/_2$ in. (38 mm).

(6) In lieu of the examination and test requirements of Section IX, five consecutive welds of the test assembly shall be examined using a liquid penetrant method in accordance with IWA-2200 and shall meet the acceptance standards of NB-5350. These welds shall then be cross sectioned longitudinally through the center of each plug. The thickness of the assembly may be reduced to facilitate sectioning. One section of each plug shall be polished, etched, and visually examined at 10× magnification. The weld throat and minimum leakage path shall not be less than that required by the Construction Code and Owner's Requirements. The welds shall be free of cracks and lack of fusion. Porosity shall not reduce the weld throat below the required minimum thickness in the leakage path.

(b) Performance Qualification

(1) The test assembly for performance qualification for welders and welding operators shall be the same as for any welding procedure qualification in accordance with the requirements of (a).

(2) For welders and welding operators, five consecutive acceptable welds shall be made and examined in accordance with (a)(6). The performance qualification shall be made in accordance with a WPS that has been qualified in accordance with the requirements of (a).

(3) Welders and welding operators shall be tested under conditions that simulate the weld area access. Such simulated conditions shall include radiation protection gear.

(4) In addition to the preceding requirements, only the following Section IX essential variables for welders apply:

(-a) a change from one welding process to any other welding process

(-b) a change in F-number of filler material

(-c) a change in P-number of either of the base materials

(-d) an addition or deletion of preplaced metal inserts

(-e) addition of welding positions other than those already qualified

(5) Essential variables for welding operators shall be in accordance with Section IX, QW-360.

(6) Renewal of qualification is required when the welder or welding operator has not performed plugging using the process for which he is qualified for 6 months or longer, or when there is a specific reason to question his ability to make quality welds in accordance with the WPS. Renewal of qualification shall be identical to the initial qualification, except that only one weld need be made.

IWA-4712.3 Plugging Procedure. Each plug operation shall be performed in accordance with a procedure delineating the requirements of the complete repair/replacement activity, including the following:

(a) plug material, dimensions, and material certification requirements

(b) the preparation necessary for the joint to be plugged, including examination requirements and a means for removal of surface oxide

(c) requirements for preparation (sizing) of the tube or tubesheet hole I.D. prior to setting plugs, including examination requirements

(d) requirements for inserting the plug into position for welding, including examination requirements

(e) the qualified WPS

(f) requirements for final examination

IWA-4712.4 Examination. Final examination of heat exchanger plugs and welds shall consist of a VT-1 visual examination.

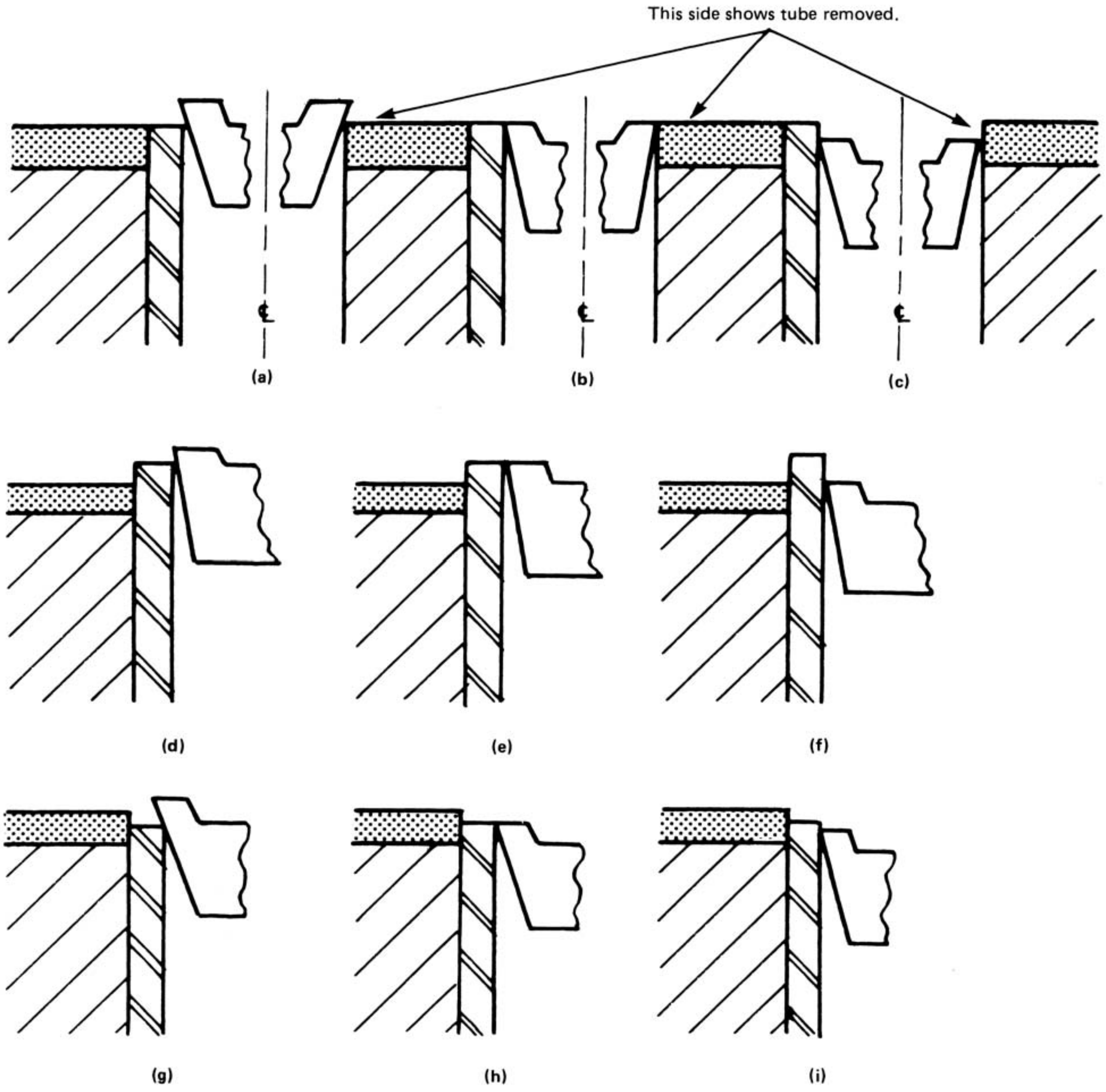
IWA-4712.5 Records. Records shall be maintained by the Owner in accordance with Article IWA-6000, and shall include the following:

(a) Welding Procedure Specification (WPS)

(b) Procedure Qualification Record (PQR)

(c) performance qualification records

Figure IWA-4712.2-1
Examples of Extension and Recess of Tube and Plug



GENERAL NOTE: When tubes have been sleeved, the plugs may be welded to the sleeve, tube, or cladding.

(d) Certified Material Test Reports (CMTR)

(e) location of plugged tubes or tubesheet holes

(f) results of examinations required by IWA-4712

IWA-4713 Heat Exchanger Tube Plugging by Expansion

If the mechanical roll or mechanical expander expansion method is used to expand plugs into Class 1 heat exchanger tubes in tubesheets, such that the plug is permanently deformed and the attachment depends upon friction or interference at the interface, the requirements of IWA-4713.1 through IWA-4713.5 shall be met.

IWA-4713.1 General Requirements.

(a) Plugs shall meet the requirements of IWA-4200.

(b) Prior to installation, plugmaterial shall be traceable to a Certified Material Test Report.

(c) Specimens representing the expanded plug attachment to a tube shall be corrosion tested or analyzed to assess the expected life of the plug.

IWA-4713.2 Plugging Procedure Specification. Each plugging operation shall be performed in accordance with a Plugging Procedure Specification (PPS). This specification shall delineate requirements of the plug installation, including the following:

(a) plug and tube materials and dimensions

(b) preparation of the plug and tube prior to insertion of the plug, including any specified examination requirements and acceptance criteria

(c) the essential variables of IWA-4713.3 and the expansion process used

(d) inserting the plug into position prior to final expanding

(e) plug expansion acceptance criteria

(f) final acceptance criteria

(g) the sequence of operations

(h) pre- and post-installation performance checks of the installation equipment

IWA-4713.3 Plug and Procedure Qualification.

(a) The plug design and PPS shall be tested in accordance with the following requirements:

(1) General Test Requirements

(-a) Testing used to qualify the plug design and PPS shall be conducted using the essential variables specified in (b).

(-b) The test plan shall include:

(-1) test temperatures and pressures

(-2) acceptance criteria

(-3) essential variables

(-4) number of test specimens

(-5) external loading (e.g., incurred by tube stabilizer)

(-6) test configuration

(-7) surface condition (including acceptance criteria)

(-c) For each required test, five specimens shall be tested; each specimen shall meet the acceptance criteria in (2) and (3)

(-d) Following installation of each test specimen, the condition of the adjacent bores shall be evaluated to verify that ligament distortion will not prohibit access for NDE or repair/replacement activities.

(-e) The test assembly shall simulate production conditions with respect to the essential variables in (b). The minimum test assembly tubesheet thickness shall be the lesser of the length of the plug attachment joint plus $^1/_2$ in. (13 mm) or the production tubesheet thickness.

(2) Cyclic Test

(-a) The specimens shall be pressure tested and thermally cycled to simulate the effects of heat exchanger heat-up and cool-down for the expected life of the plug. Test temperatures and pressures shall envelope service conditions. Alternatively, the need to perform an equivalent number of thermal test cycles to simulate the effects of heat exchanger heat-up and cool-down for the expected life of the plug is not necessary if all of the following are met:

(-1) A similar plug has been qualified in accordance with IWA-4713.3 for the expected number of thermal cycles for the life of the plug. In this context, a plug is considered similar if it has all the same essential variables listed in (b) with the exception of the variables in (b)(3) and (b)(4).

(-2) The specimens required by (1)(-c) shall be thermally cycled at least ten times. The thermal cycles shall simulate the effects of heat exchanger heat-up and cool-down.

(-3) An evaluation shall be performed and documented to ensure that the number of thermal cycles performed in (-2) is adequate to ensure the plug satisfies the acceptance criteria in (-b) for the expected life of the plug.

(-b) The test results shall meet leakage and plug movement acceptance criteria specified by the Owner.

(3) Proof Test

(-a) The specimens shall be proof tested at the higher of the following pressures:

(-1) 1.43 times the maximum differential pressure during accident conditions; or

(-2) 3.0 times the maximum differential pressure across the tubesheet during normal operating conditions.

(-b) The test may be conducted at any temperature.

(-c) There shall be no plug ejection.

(4) General Design Considerations

(-a) Testing or an evaluation shall demonstrate that the plug attachment can withstand the specific external loadings (e.g., those incurred by tube stabilizers) and meet the acceptance criteria.

(-b) An evaluation shall be performed to assess the potential for and consequences of increased pressure caused by heating of static fluid in a plugged tube.

(b) The PPS shall be requalified if any of the essential variables listed below are changed.

(1) specified material and heat treatment condition of the plug

(2) a change of plug, tube, or tubesheet material that results in a change of 10% or more in the material thermal expansion coefficient

(3) the pre-expanded plug nominal diameter and nominal wall thickness in the effective attachment joint length

(4) the nominal tube diameter

(5) a change of more than 5% in the nominal tube wall thickness

(6) cleaning method prior to plug insertion

(7) the expansion method (i.e., roll or expander)

(8) the specified effective attachment joint length

(9) whether or not the tube has been expanded into contact with the tubesheet in the area where plug expansion occurs

(10) a design change in the expanded interface between the plug and the tube

(11) for mechanical roll expansion

(-a) joint rolling torque outside the minimum and maximum values used in qualification

(-b) a change in roll expander geometry, material, or design from those used in qualification testing

(-c) a change of roll lubricant

(12) for mechanical expander expansion

(-a) a reduction in minimum pull load or expander travel

(-b) a change in expander or plug inside taper

(-c) a change of expander material or hardness

(-d) a change of expander lubricant

(c) When an essential variable is changed following a completed qualification in accordance with IWA-4713.3, the following alternative requirements may be used in lieu of repeating the testing and evaluations required by (a)(2) and (a)(3).

An evaluation may be performed to show the acceptability of the PPS for the design change being considered, provided the following requirements are met:

(1) Test data that isolate the essential variable and meet the acceptance criteria of (a)(1)(-b)(-2) shall be available.

(2) Cyclic and proof test data shall demonstrate compliance with (a)(2) and (a)(3) respectively, with the revised essential variable.

(3) A changed essential variable shall be evaluated with respect to all other essential variables to ensure that the original acceptance criteria of (a)(1)(-b)(-2) are still met.

IWA-4713.4 Plugging Performance Qualification. Tube plugging by expansion shall be performed by individuals who have demonstrated their ability to expand plugs in accordance with the PPS. At least one test is required for performance qualification.

(a) For manual installation, the installer shall be qualified under conditions simulating the restricted access to the production joint.

(b) Renewal of the performance qualification is required when the expansion plugging equipment operator has not used the process for more than twelve months or when there is reason to question their ability to install plugs in accordance with the PPS. Renewal of qualification shall be identical to the initial qualification.

IWA-4713.5 Records. The following records, in addition to those required by Article IWA-6000, shall be maintained by the Owner:

(a) Plugging Procedure Specifications

(b) record of procedure qualification for the plugging method, including the essential variables and results of all tests required by IWA-4713.3

(c) record of performance qualification for each individual, including the PPS number and revision

(d) Certified Material Test Report for installed plugs

(e) location of all plugged tubes

(f) results of post-installation examinations and evaluations

(g) evaluations performed in accordance with IWA-4713.3(a)(4)

IWA-4720 SLEEVING

IWA-4721 General Requirements

IWA-4721.1 Sleeves. The sleeves shall meet the requirements of IWA-4200. The exemptions of IWA-4130 shall not apply.

The requirements of IWA-4721 through IWA-4724 shall be used for Class 1 heat exchanger tube sleeving. These requirements may be used for Classes 2 and 3 heat exchangers.

IWA-4721.2 Sleeving Procedure Specification. Each sleeving operation shall be performed in accordance with a sleeving procedure specification (SPS) that defines the following:

(a) sleeve and tube materials and dimensions

(b) requirements for preparation of the tube inside surface prior to insertion of the sleeve, including examination requirements and acceptance criteria

(c) requirements for inserting the sleeve into position, including examination requirements and acceptance criteria

(d) the essential and nonessential variables of IWA-4721.3 and the welding or brazing process used

(e) required sleeve attachment dimensions

(f) requirements for final examination and acceptance criteria

(g) the sequence of operations

IWA-4721.3 Qualification.

IWA-4721.3.1 Sleeving Procedure Specification Qualification. The SPS shall be qualified in accordance with this Subsubparagraph, and shall be requalified for any change in an essential variable. Nonessential variables may be changed without requalification provided the SPS is amended to show the changes.

(a) The following essential variables apply to all sleeve installation processes, in addition to those listed for each sleeve attachment process in IWA-4723, IWA-4724, and IWA-4725:

(1) a change in the P-Number classification of any of the materials being joined. This includes the tube, sleeve, tubesheet, or equivalent P-Number for tubesheet cladding. Materials not having a P-Number classification require a separate qualification.

(2) a change of 10% or more in nominal tube or sleeve design wall thickness in the area of the joint.

(3) deletion of tube cleaning prior to sleeve insertion.

(4) a change in sleeve attachment location from within the tubesheet to beyond the tubesheet or vice versa.

(5) a change in sleeve attachment location from within the sludge pile to beyond the sludge pile or vice versa.

(6) the addition or deletion of postweld or postbraze heat treatment.

(7) a change of more than 10% in the nominal tube or sleeve diameter.

(b) The following nonessential variable applies to all sleeve installation processes, in addition to those listed for each sleeve attachment process in IWA-4723, IWA-4724, and IWA-4725: a change in the method of tube cleaning prior to sleeve insertion.

IWA-4721.3.2 Sleeving Performance Qualification.

(a) Sleeve attachment processes shall be performed by welders, brazers, or equipment operators that have been qualified in accordance with this Subsubarticle.

(b) Manual process qualification shall be performed under conditions simulating the restricted access of the production joint.

(c) Renewal of performance qualification is required when the welder, brazer, or equipment operator has not used the process for more than 6 months, or when there is any reason to question his ability to make quality attachments in accordance with SPS. Renewal of qualifications shall be identical to the initial qualification except that only one sleeve attachment shall be made.

IWA-4721.4 Sleeving by a Combination of Processes. If a combination of processes is used for sleeve installation, either at opposite ends of a single sleeve or as a sequence of processes in a single attachment, IWA-4723, IWA-4724, or IWA-4725, as applicable, apply to each process used. The SPS shall require that the processes used during production sleeving be performed in the same sequence as used during qualification.

IWA-4721.5 Records. The following records, in addition to those required by Article IWA-6000, shall be maintained by the Owner:

(a) SPS

(b) procedure qualification for the attachment process

(c) performance qualification for each welder, brazer, and equipment operator

(d) location records of all sleeved tubes and sleeves

(e) results of all required sleeve installation examinations

IWA-4723 Fusion Welding

IWA-4723.1 General Requirements. When fusion welding is used for sleeve attachment, the requirements of IWA-4723.1.1 through IWA-4723.4 shall be met.

IWA-4723.1.1 Procedure Qualification. Welds shall be made using the gas tungsten-arc welding (GTAW), gas-metal arc welding (GMAW), or laser beam welding (LBW) process.

IWA-4723.2 Fusion Welding Qualification.

IWA-4723.2.1 Procedure Qualification.

(a) Essential Variables

(1) for sleeve welds within the tubesheet, when the ligament thickness between the holes is $^3/_8$ in. (10 mm) or less, a reduction in ligament thickness of 10% of the ligament thickness or three times the specified wall thickness, whichever is less

(2) a change in any essential variable listed for the specific welding process in Section IX, QW-250

(b) Test Assembly. The procedure shall be qualified using a test assembly that simulates the conditions that will be encountered in production with respect to the essential variables.

(c) Test Assembly Within Tubesheet. The test assembly tubesheet thickness shall be at least as thick as the production tubesheet except that it need not be more than 1 in. (25 mm) greater than the length of the sleeve attachment.

(d) Examination of Test Assembly

(1) Five consecutive welds shall be examined by a liquid penetrant method in accordance with IWA-2200 and shall meet the acceptance standards of NB-5350. Welds inaccessible for liquid penetrant examination may be sectioned longitudinally through the center of the sleeve prior to performing the liquid penetrant examination.

(2) The five consecutive welds shall also be sectioned longitudinally through the center of each sleeve. The thickness of the assembly may be reduced to facilitate sectioning.

(3) The two faces of a single half-section shall be polished, etched, and visually examined at 10× magnification. The weld throat and minimum leakage path shall not be less than that required by the Construction Code and Owner's Requirements. The weld shall be free of

cracks and lack of fusion. Porosity shall not reduce the weld throat thickness below the required minimum leakage path.

IWA-4723.2.2 Performance Qualification. Welding shall be performed by welders and welding operators that have been qualified in accordance with the following:

(a) The test assembly for the performance qualification for welders and welding operators shall be the same as for any welding procedure qualification in accordance with the requirements of IWA-4723.2.1.

(b) The essential variables for welders and welding operators shall be in accordance with Section IX, QW-350 and QW-360, respectively, for the process to be employed.

(c) For welders, five consecutive acceptable welds shall be made and examined in accordance with IWA-4723.2.1(d). For welding operators, one acceptable weld shall be made and examined in accordance with IWA-4723.2.1(d). The performance qualification shall be made in accordance with a SPS qualified in accordance with IWA-4723.2.1.

(d) Welders shall be tested under simulated access conditions. The qualification test mock-up shall effectively simulate the conditions that will be encountered in production with respect to the essential variables.

(e) Retest shall be performed as required by Section IX, QW-320.

IWA-4723.3 Sleeving Procedure Specification. The SPS shall delineate all the requirements of the fusion welding process, including the variables of Section IX, QW-250.

IWA-4723.4 Examination. The welded sleeve attachment shall be examined to confirm that the attachment is in the correct location and conforms to the Construction Code and Owner's Requirements.

IWA-4724 Brazing

IWA-4724.1 General Requirements. When brazing is used for sleeve attachment, IWA-4724.2 through IWA-4724.4 shall be met.

IWA-4724.2 Brazing Qualification.

IWA-4724.2.1 Procedure Qualification. The brazing procedure shall be qualified as required by Section IX, QB-200 and the following:

(a) An additional essential variable is a change in the designed sleeve installation from free tubes to tubes that are locked to the tube support plate.

(b) Test Assembly. The procedure shall be qualified using a test assembly that simulates the conditions that will be encountered in production with respect to the essential variables.

(c) Test Assembly Within Tubesheet. The test assembly tubesheet thickness shall be at least as thick as the production tubesheet except that it need not be more than 1 in. (25 mm) greater than the length of the sleeve attachment.

(d) Examination of Test Assembly

(1) Each test specimen shall be examined to confirm that the braze bond area conforms to the Construction Code and Owner's Requirements.

(2) The minimum number of braze joints required for procedure qualification shall be five braze joints made consecutively.

IWA-4724.2.2 Performance Qualification. Each brazer and brazing operator shall be qualified as required by Section IX, QB-300, and each test specimen shall be examined to confirm that the braze bond area conforms to the Construction Code and Owner's Requirements.

IWA-4724.3 Sleeving Procedure Specification. The SPS shall delineate all the requirements of the brazing process, including the variables of Section IX, QB-200.

IWA-4724.4 Examination. A final examination of the brazed sleeve attachment shall confirm that the attachment is in the correct location and conforms to the Construction Code and Owner's Requirements.

IWA-4725 Expansion

IWA-4725.1 General Requirements. When a sleeve is expanded against a tube by a mechanical or hydraulic process so that the sleeve is permanently deformed and the attachment depends upon friction or interference at the interface, IWA-4725.2 through IWA-4725.4 shall be met.

IWA-4725.2 Expansion Qualification.

IWA-4725.2.1 Procedure Qualification.

(a) Essential Variables

(1) a change in the basic expansion process

(2) a change of 10% or more in sleeve material yield strength

(3) a change in the expansion length

(4) a change that results in an expansion diameter outside the range of sleeve or tube expansion diameters qualified. The range of sleeve or tube expansion diameters qualified shall be the expansion diameters between the minimum and maximum expansion diameters obtained in qualification tests.

(5) for mechanical expansion:

(-a) a reduction in the minimum rolling torque

(-b) a change in expansion roller geometry

(-c) a reduction in the minimum expansion pressure if expansion is controlled by hydraulic pressure only

(b) Test Assembly. The procedure shall be qualified using a test assembly that simulates the conditions that will be encountered in production with respect to the essential variables.

(c) Test Assembly Within Tubesheet. The test assembly tubesheet thickness shall be at least as thick as the production tubesheet except that it need not be more than 1 in. (25 mm) greater than the length of the sleeve attachment.

(d) Qualification of Test Assembly. Specimens representing the expanded sleeve attachment to a tube shall be cyclic tested in accordance with Section III Appendices, Mandatory Appendix II. This fatigue test shall demonstrate that the sleeve attachment can withstand the specified design loadings without exceeding the specified design leakage limit.

IWA-4725.2.2 Performance Qualification. The expansion operator shall demonstrate the ability to expand sleeve attachments in accordance with the SPS.

IWA-4725.3 Sleeving Procedure Specification. The SPS shall delineate the requirements for mechanical expansion. These requirements shall conform to the Construction Code and Owner's Requirements.

IWA-4725.4 Examination. The expanded sleeve attachment shall be examined to confirm that the attachment is in the correct location and conforms to the requirements of the Construction Code and Owner's Requirements.

ARTICLE IWA-5000
SYSTEM PRESSURE TESTS

IWA-5100 GENERAL

IWA-5110 PERIODIC SYSTEM PRESSURE TESTS

(a) System pressure tests shall be conducted in accordance with the Examination Categories identified in Tables IWB-2500-1 (B-P), IWC-2500-1 (C-H), and IWD-2500-1 (D-B).

(b) The pressure testing requirements for Class MC and CC components are identified in Subsections IWE and IWL, respectively.

(c) Piping that penetrates a containment vessel is exempt from the periodic system pressure test when the piping and isolation valves perform a containment function and the balance of the piping system is outside the scope of this Division.

IWA-5200 SYSTEM TEST REQUIREMENT

IWA-5210 TEST

IWA-5211 Test Description

Pressure-retaining components within each system boundary shall be subject to the following applicable system pressure tests under which conditions a VT-2 visual examination is performed in accordance with IWA-5240 to detect leakage:

(a) a system leakage test conducted while the system is in operation, during a system operability test, or while the system is at test conditions using an external pressurization source;

(b) a system hydrostatic test conducted during a plant shutdown at an elevated test pressure as specified in IWB-5230, IWC-5230, or IWD-5230; and

(c) a system pneumatic test conducted in lieu of either of the above system pressure tests for Class 2 or Class 3 components as permitted by Article IWC-5000 or Article IWD-5000. The requirements for system leakage and hydrostatic tests are applicable to pneumatic tests.

IWA-5212 Pressure and Temperature

(a) System leakage tests and system hydrostatic tests shall be conducted at the pressure and temperature specified in Article IWB-5000, Article IWC-5000, and Article IWD-5000. The system hydrostatic test pressure shall not exceed the maximum allowable test pressure of any component within the system pressure test boundary.

(b) When conducting a system leakage test described in IWA-5211(a), system pressure shall be verified by normal system instrumentation, test instrumentation, or through performance of the system operating or surveillance procedure.

(c) The system test conditions shall be maintained during the course of the visual examination, except as provided in IWA-5245.

(d) When conducting system pressure tests described in IWA-5211(b) and IWA-5211(c), the requirements of IWA-5260 shall be met.

(e) A system hydrostatic test [IWA-5211(b)] and accompanying visual examination are acceptable in lieu of the system leakage test [IWA-5211(a)] and visual examination.

(f) The system test pressure and temperature may be obtained by using any means that comply with the plant Technical Specifications.

IWA-5213 Test Condition Holding Time (15)

The holding time after pressurization to test conditions, before the visual examinations commence, shall be as follows.

(a) For the system leakage tests required by Table IWB-2500-1 (B-P), Table IWC-2500-1 (C-H), or Table IWD-2500-1 (D-B), the following shall be met.

(1) For Class 1 components [Table IWB-2500-1 (B-P)], no holding time is required after attaining test pressure.

(2) For Class 2 [Table IWC-2500-1 (C-H)] and Class 3 [Table IWD-2500-1 (D-B)] components not required to operate during normal plant operation, a 10 min holding time is required after attaining test pressure.

(3) For Class 2 [Table IWC-2500-1 (C-H)] and Class 3 [Table IWD-2500-1 (D-B)] components required to operate during normal plant operation, no holding time is required, provided the system has been in operation for at least 4 hr for insulated components or 10 min for noninsulated components.

(4) For Class 2 [Table IWC-2500-1 (C-H)] and Class 3 [Table IWD-2500-1 (D-B)] components connected directly to the Class 1 system that are pressurized and examined as part of the Class 1 system leakage test, no holding time is required after attaining test pressure.

(b) For system pressure tests required by IWA-4540, a 10 min holding time for noninsulated components, or 4 hr for insulated components, is required after attaining test pressure.

(c) For system pneumatic tests, a 10 min holding time is required after attaining test pressure.

IWA-5214 Preservice Test

A preservice system pressure test is not required by this Article, except following repair/replacement activities as required by IWA-4540.

IWA-5220 TEST PRESSURIZATION BOUNDARIES[17]

IWA-5221 System Leakage Test Boundary

The boundary subject to test pressurization during a system leakage test [IWA-5211(a)] includes the pressure-retaining components to be tested in accordance with IWB-5222, IWC-5222, and IWD-5222.

IWA-5222 System Hydrostatic Test Boundary

(a) The boundary subject to test pressurization during a system hydrostatic test [IWA-5211(b)] shall be defined by the system boundary (or each portion of the boundary) within which the components have the same minimum required classification and are designed to the same pressure rating as governed by the system function and the internal fluid operating conditions, respectively.

(b) Systems which share safety functions for different modes of plant operation, and within which the component classifications differ, shall be subject to separate system hydrostatic tests of each portion of the system boundary having the same minimum required design pressure ratings.

(c) Systems designed to operate at different pressures under several modes of plant operation or post-accident conditions shall be subject to a system hydrostatic test within the test boundary defined by the operating mode with the higher pressure.

(d) Where the respective system design pressure ratings on the suction and discharge sides of system pumps differ, the system hydrostatic test boundary shall be divided into two separate boundaries (such as suction side and discharge side test boundaries). In the case of positive displacement pumps, the boundary interface shall be considered as the pump. In the case of centrifugal pumps, the boundary interface shall be the first shutoff valve on the discharge side of the pump.

IWA-5240 VISUAL EXAMINATION

IWA-5241 Insulated and Noninsulated Components

(a) The VT-2 visual examination shall be conducted by examining the accessible external exposed surfaces of pressure-retaining components for evidence of leakage.

(b) For components whose external surfaces are inaccessible for direct VT-2 visual examination, only the examination of the surrounding area (including floor areas or equipment surfaces located underneath the components) for evidence of leakage shall be required.

(c) Components within rooms, vaults, etc., where access cannot be obtained, may be examined using remote visual equipment or installed leakage detection systems.

(d) Essentially vertical surfaces need only be examined at the lowest elevation where leakage may be detected.

(e) Discoloration or residue on surfaces shall be examined for evidence of boric acid accumulations from borated reactor coolant leakage.

(f) For insulated components in systems borated for the purpose of controlling reactivity, insulation shall be removed from pressure-retaining bolted connections for VT-2 visual examination. Insulation removal and VT-2 visual examination of insulated bolted connections may be deferred until the system is depressurized. When corrosion-resistant bolting material with a chromium content of at least 10%, such as SA-564 Grade 630 H1100, SA-453 Grade 660, SB-637 Type 718, or SB-637 Type 750, is used, it is permissible to perform the VT-2 visual examination without insulation removal.

(g) Essentially horizontal surfaces of insulation shall be examined at each insulation joint if accessible for direct VT-2 examination.

(h) When examining insulated components, the examination of the surrounding area (including floor areas or equipment surfaces located underneath the components) for evidence of leakage, or other areas to which such leakage may be channeled, shall be required.

IWA-5244 Buried Components

(a) For buried components surrounded by an annulus, the VT-2 visual examination shall consist of an examination for evidence of leakage at each end of the annulus and at low point drains.

(b) For buried components without an annulus, the following examination requirements shall be met:

(1) A VT-2 visual examination shall be performed to identify evidence of leakage on ground surfaces in the vicinity of the buried components and in areas where leakage might be channeled or accumulated. The examination shall be performed after the component has been pressurized to system leakage test pressure for at least 24 hr. Portions of buried components where a VT-2 examination is impractical (e.g., component is buried beneath impermeable material or encased in concrete) are exempt from VT-2 examination.

(2) A test that determines the rate of pressure loss, a test that determines the change in flow between the ends of the buried components, or a test that confirms that flow during operation is not impaired shall be performed. Personnel performing these tests need not be qualified for VT-2 visual examination.

(3) The Owner shall specify criteria for the examinations and tests of (1) and (2).

IWA-5245 Elevated Temperature Tests

The visual examination of system components requiring a test temperature above 200°F (95°C) during the system pressure test may be conducted after the pressure holding period of IWA-5213 is satisfied, and the pressure is lowered to the level corresponding with a temperature of 200°F (95°C), in accordance with allowable cooldown rates established by fracture prevention criteria.

(15) IWA-5246 Reactor Vessel Head Flange Seal Leak Detection

In lieu of the requirements of IWB-5220, IWC-5220, or IWD-5220, the Class 1, 2, or 3 portion of the reactor vessel head flange seal leak detection system shall be examined using the VT-2 visual examination method. The test shall be conducted at ambient conditions after the refueling cavity has been filled to its normal refueling water level for at least 4 hr.

IWA-5250 CORRECTIVE ACTION

(a) The sources of leakage detected during the conduct of a system pressure test shall be located and evaluated by the Owner for corrective action as follows:

(1) Buried components with leakage losses in excess of limits acceptable for continued service shall meet the requirements of IWB-3142, IWC-3132, or IWD-3120, as applicable.

(2) If leakage occurs at a bolted connection in a system borated for the purpose of controlling reactivity, one of the bolts or studs shall be removed, VT-3 visually examined, and evaluated in accordance with IWA-3100. The bolt or stud selected shall be the one closest to the source of leakage. When the removed bolt or stud has evidence of degradation, all remaining bolts or studs in the connection shall be removed, VT-3 visually examined and evaluated in accordance with IWA-3100. If all bolts or studs in the connection are replaced in accordance with Article IWA-4000, no VT-3 visual examination of the removed bolts or studs is required.

(3) Components requiring corrective action shall have repair/replacement activities performed in accordance with Article IWA-4000 or corrective measures performed where the relevant condition can be corrected without a repair/replacement activity.

(b) If boric acid residues are detected on components, the leakage source and the areas of general corrosion shall be located. Components with local areas of general corrosion that reduce the wall thickness by more than 10% shall be evaluated to determine whether the component may be acceptable for continued service, or whether repair/replacement activities will be performed.

IWA-5251 Alternative Corrective Action for Leakage Identified at Bolted Connections

As an alternative to the requirements of IWA-5250(a)(2), the requirements of (a), (b), and (c) shall be met.

(a) The leakage shall be stopped and the bolting and component material shall be evaluated for joint integrity.

(b) If the leakage is not stopped, the Owner shall evaluate the structural integrity of the joint, the consequences of continuing operation, and the effect on system operability of continued leakage.

(c) The evaluation required by (a) and (b) shall determine the susceptibility of the bolted connection to corrosion and failure. The evaluation shall include analysis of the following:

(1) the number and service age of the bolts or studs

(2) bolt or stud and component material

(3) corrosiveness of process fluid

(4) leakage location and system function

(5) leakage history at the connection or other system components

(6) visual evidence of corrosion at the assembled connection

IWA-5260 INSTRUMENTS FOR SYSTEM HYDROSTATIC TESTS

IWA-5261 Type

Any pressure measuring instrument or sensor, analog or digital, including the pressure measuring instrument of the normal operating system instrumentation (such as control room instruments), may be used, provided the requirements of IWA-5260 are met.

IWA-5262 Accuracy

The pressure measuring instrument or sensor used in hydrostatic testing shall provide results accurate to within 0.5% of full scale for analog gages and 0.5% over the calibrated range for digital instruments.

IWA-5263 Calibration

All pressure measuring instruments shall be calibrated against a standard deadweight tester or calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is a group of tests that use the same pressure measuring instruments and that are conducted within a period not exceeding 2 weeks.

IWA-5264 Ranges

(a) Analog pressure gages used in testing shall have dials graduated over a range of at least 1.5 times, but not more than 4 times, the intended maximum test pressures.

(b) Digital pressure measuring instruments used in testing shall be selected such that the intended maximum test pressure shall not exceed 70% of the calibrated range of the instrument.

IWA-5265 Location

(a) When testing an isolated component, the pressure measuring instrument or sensor shall be connected close to the component.

(b) When testing a group of components or a multicomponent system, the pressure measuring instrument or sensor shall be connected to any point within the pressure boundary of the components or system such that the imposed pressure on any component, including static head, will not exceed 106% of the specified test pressure for the system; even though the specified test pressure may not be achieved at the highest elevations in the system.

IWA-5300 TEST RECORDS

The record of the visual examination conducted during a system pressure test shall include the procedure documenting the system test condition and system pressure boundary. Any source of leakage or other relevant conditions shall be itemized, and the location and corrective action shall be documented.

ARTICLE IWA-6000
RECORDS AND REPORTS

IWA-6100 SCOPE

This Article provides the requirements for the preparation, submittal, and retention of records and reports.

(15) IWA-6200 REQUIREMENTS

IWA-6210 RESPONSIBILITIES

IWA-6211 Owner's Responsibilities

(a) The Owner shall prepare plans and schedules for preservice and inservice examinations and tests to meet the requirements of this Division.

(b) The Owner shall prepare records of examinations, tests, and repair/replacement activities.

(c) The Owner shall complete the Owner's Activity Report Form OAR-1 for preservice and inservice examination of pressure-retaining components and their supports, and core support structures. For preservice examinations performed prior to placement of the unit into commercial service, Form OAR-1 shall be completed. For preservice and inservice examinations performed following placement of the unit into commercial service, Form OAR-1 shall include records of examinations, tests, and repair/replacement activities completed since certification of the preceding Form OAR-1. Form OAR-1 shall be completed as required by IWA-6230.

(d) The Owner shall prepare the Owner's Repair/Replacement Certification Record, Form NIS-2, upon completion of all required activities associated with the Repair/Replacement Plan necessary to place the item in service.

(e) All Form NIS-2s associated with repair/replacement activities performed since certification of the preceding Form OAR-1 shall be completed prior to the completion of Form OAR-1.

(f) When the Owner contracts a Repair/Replacement Organization to perform repair/replacement activities, the Owner shall require the Repair/Replacement Organization to provide a document certifying its repair/replacement activities. Nonmandatory Appendix T[18] provides a report form that may be used for contracted repair/replacement activities and that will assist the Owner in completing and filing Form NIS-2.

IWA-6212 Contracted Repair/Replacement Organization's Responsibilities

A contracted Repair/Replacement Organization shall prepare a document, acceptable to the Owner, certifying its repair/replacement activities. Nonmandatory Appendix T[18] provides a report form that may be used for contracted repair/replacement activities and that will assist the Owner in completing and filing Form NIS-2.

IWA-6220 OWNER'S REPAIR/REPLACEMENT CERTIFICATION RECORD

(a) A Repair/Replacement Plan shall be prepared in accordance with IWA-4150 for all repair/replacement activities, including rerating, and shall be given a unique identification number.

(b) Upon completion of all required activities associated with the Repair/Replacement Plan, the Owner shall complete Form NIS-2, as shown in Mandatory Appendix II.

(c) Form NIS-2 shall be completed after satisfying all Section XI requirements necessary to place the item in service and prior to completion of Form OAR-1.

(d) Form NIS-2 shall be certified by the Owner and presented to the Inspector for the required signature.

(e) The certified Form NIS-2 shall be retained by the Owner in accordance with IWA-6350.

(f) The Owner shall maintain an index of Repair/Replacement Plans.

IWA-6230 OWNER'S ACTIVITY REPORT

(a) Form OAR-1 for the preservice examinations shall be completed prior to the date of placement of the unit into commercial service.

(b) For preservice and inservice examinations performed following placement of the unit into commercial service, Form OAR-1, as shown in Mandatory Appendix II, shall be processed as specified below within 90 calendar days of the completion of each refueling outage.

(1) A listing of the items with flaws or relevant conditions that exceeded the acceptance criteria of Division 1 and that required evaluation to determine acceptability for continued service shall be provided with the information and format of Form OAR-1, Table 1. This information is required whether or not the flaw or relevant condition was discovered during a scheduled examination or test.

(2) An abstract for the repair/replacement activities that were required due to an item containing a flaw or relevant condition that exceeded Section XI acceptance criteria shall be provided with the information and format of Form OAR-1, Table 2. This information is required even if the discovery of the flaw or relevant condition that necessitated the repair/replacement activity did not result from an examination or test required by Section XI. If the acceptance criteria for a particular item is not specified in Section XI, the provisions of IWA-3100(b) shall be used to determine which repair/replacement activities are required to be included in the abstract.

(3) If there are multiple inspection plans with different intervals, periods, or Section XI Editions or Addenda, the different inspection intervals, periods, Editions, or Addenda shall be identified on Form OAR-1.

(4) Form OAR-1 shall be certified by the Owner and presented to the Inspector for the required signature.

(5) The completed Form OAR-1 shall be submitted to the regulatory and enforcement authorities having jurisdiction at the plant site, if required by these authorities.

IWA-6300 RETENTION

IWA-6310 MAINTENANCE OF RECORDS

The Owner shall retain records and reports identified in IWA-6330, IWA-6340, and IWA-6350. The records and reports shall be filed and maintained in a manner that will allow access by the Inspector. The Owner shall provide suitable protection from deterioration and damage for all records and reports, in accordance with the Owner's Quality Assurance Program, for the service lifetime of the component or system. Storage shall be at the plant site or at another location that will meet the access and Quality Assurance Program requirements.

IWA-6320 REPRODUCTION, DIGITIZATION, AND MICROFILMING

(a) Records and reports shall be either the original, including a digitally generated original, or a reproduced, legible copy. Records may be maintained in an electronic (i.e., digital) format using magnetic, optical, or equivalent storage media. Hard-copy records may be digitized. The Owner's Quality Assurance Program shall include a system for verifying accuracy and monitoring image legibility, storage, retrievability, and reproduction quality.

(b) Radiographs may be microfilmed or digitally reproduced. Digital reproduction shall be in accordance with Section V, Article 2, Mandatory Appendix VI, including Supplement A. The Owner's Quality Assurance Program shall include a system for monitoring the accuracy of the reproduction process so that the reproduction will provide the same information retrieval capability as the original radiograph. The accuracy of the reproduction process includes the exposure (or multiple exposures for density coverage), focusing, contrast, and resolution. The Quality Assurance Program shall also provide a system for identifying film or reproduction artifacts that might appear as material discontinuities in the reproduction.

IWA-6330 CONSTRUCTION RECORDS

Records designated by the Owner in accordance with NCA-4134.17, the Construction Code, and Owner's Requirements, as applicable, shall be retained.

IWA-6340 INSERVICE INSPECTION RECORDS

The Owner shall designate the records to be maintained. Such records shall include the following, as applicable:

(a) record index

(b) preservice and inservice inspection plans and schedules

(c) preservice and inservice inspection reports

(d) records of flaw acceptance by analytical evaluation

(e) records of regions in ferritic Class 1 components with modified acceptance standards

(f) nondestructive examination procedures

(g) nondestructive examination records

(h) pressure test procedures

(i) pressure test records

(j) for Class CC

(1) tendon force and elongation measurement records (IWL-2522)

(2) tendon wire and strand sample test results (IWL-2523)

(3) free water documentation (IWL-2524.2)

(4) corrosion protection medium and free water analysis results (IWL-2525)

IWA-6350 REPAIR/REPLACEMENT ACTIVITY RECORDS

The following records prepared in performance of a repair/replacement activity shall be retained:

(a) evaluations required by IWA-4160(a), IWA-4160(b), and IWA-4311

(b) Repair/Replacement Program and Plans

(c) records and reports of repair/replacement activities

(d) reconciliation documentation

(e) NIS-2 Form

(f) documents certifying repair/replacement activities by contracted Repair/Replacement Organizations

(15)

ARTICLE IWA-9000
GLOSSARY

analytical evaluation: a quantitative process to determine the acceptability of flaws that exceed the applicable acceptance standards, including predicted future growth, to determine whether a component is acceptable for continued service without a repair/replacement activity.

applied stress (σ): a stress resolvable into membrane and bending components and including pressure, thermal, discontinuity, and residual effects acting at the flaw location.

appurtenance: an item to be attached to a stamped component that has work performed on it requiring verification by an Inspector.

assess: to determine by evaluation of data compared with previously obtained data such as operating data or design specifications.

Authorized Inspection Agency: an organization that is empowered by an enforcement authority to provide inspection personnel and services as required by this Section.

Authorized Nuclear Inservice Inspector: a person who is employed and qualified by an Authorized Inspection Agency and who will perform the duties of the Inspector in accordance with the requirements of this Section.

Authorized Nuclear Inservice Inspector Supervisor: a person who is employed by an Authorized Inspection Agency to supervise Authorized Nuclear Inservice Inspectors and who is qualified as an Authorized Nuclear Inservice Inspector.

Authorized Nuclear Inspector: an employee of an Authorized Inspection Agency who has been qualified in accordance with Article NCA-5000.

beltline region: the region of the reactor vessel (shell material including welds, heat-affected zones, and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron radiation damage to be considered in the selection of the most limiting material with regard to radiation damage.

bending stress (σ_b): component of primary stress proportional to distance from centroid of solid section. It excludes discontinuity stresses and stress concentrations.

bobbin coil: a circular inside diameter eddy current coil wound such that the coil is concentric with the tube during examination.

buried component or support: a component or support that is buried or concrete encased.

Certificate Holder: an organization holding a Certificate of Authorization or Certificate of Accreditation issued by the Society.

Certificate of Authorization: a document issued by the Society that authorizes the use of an ASME Code Symbol Stamp for a specified time and for a specified scope of activity.

cold shutdown: See plant technical specifications.

commercial service: nuclear power plant operation commencing with the date the power unit is determined by the Owner to be available for the regular production of electricity.

component: a vessel, concrete containment, pump, valve, storage tank, piping system, or core support structure.

component standard support: a support consisting of one or more generally mass-produced units usually referred to as catalog items.

component support: a metal support designed to transmit loads from a component to the load-carrying building or foundation structure. Component supports include piping supports and encompass those structural elements relied upon to either support the weight or provide structural stability to components.

constant load type support: spring type support that produces a relatively constant supporting force throughout a specified deflection.

construction: an all-inclusive term comprising materials, design, fabrication, examination, testing, inspection, and certification required in the manufacture and installation of items.

Construction Code: nationally recognized Codes, Standards, and Specifications (e.g., ASME, ASTM, USAS, ANSI, API, AWWA, AISC, MSS, AWS) including designated Cases, providing construction requirements for an item.

core support structures: those structures or parts of structures that are designed to provide direct support or restraint of the core (fuel and blanket assemblies) within the reactor pressure vessel.

corrective action: action taken to resolve flaws and relevant conditions, including supplemental examinations, analytical evaluations, repair/replacement activities, and corrective measures.

corrective measures: actions (such as maintenance) taken to resolve relevant conditions, but not including supplemental examinations, analytical evaluations, and repair/replacement activities.

crack arrest fracture toughness (K_{Ia}): the critical value of the stress intensity factor (K_I) for crack arrest as a function of temperature.

crack tip: the extremity of the flaw. The boundary between the flaw and the adjacent material at the intersection of the two flaw faces.

critical flaw size: the flaw size that will cause failure under a specified load calculated using fracture mechanics. The minimum critical flaw size for normal or upset conditions (Service Levels A and B) is a_c; the minimum critical initiation flaw size for emergency and faulted conditions is a_i.

defect: a flaw (imperfection or unintentional discontinuity) of such size, shape, orientation, location, or properties as to be rejectable.

design life: the period of time for which a component is designed to meet the criteria set forth in the Design Specification.

design lifetime: See *design life*.

Design Report: the design document which shows that the allowable limits stated in the construction code are not exceeded for the loadings specified in the design specification.

Design Specification: a document prepared by the Owner or Owner's Designee which provides a complete basis for construction in accordance with the construction code.

discontinuity: a lack of continuity or cohesion; an interruption in the normal physical structure of material or a product.

dissimilar metal weld: a weld between

(a) carbon or low alloy steels to high alloy steels,

(b) carbon or low alloy steels to high nickel alloys, or

(c) high alloy steels to high nickel alloys.

Emergency Conditions: those operating conditions which have a low probability of occurrence (Service Level C).

enforcement authority: a regional or local governing body, such as a State or Municipality of the United States or a Province of Canada, empowered to enact and enforce Boiler and Pressure Vessel Code legislation.

engineering evaluation: an evaluation of indications that exceed allowable acceptance standards to determine if the margins required by the Design Specifications and Construction Code are maintained.

examination category: a grouping of items to be examined or tested.

explosive welding: a solid state welding process wherein coalescence is produced by the application of pressure by means of an explosive.

fabrication: actions by Repair/Replacement Organizations such as forming, machining, assembling, welding, brazing, heat treating, examination, testing, and inspection, but excluding design, required to manufacture parts, appurtenances, piping subassemblies, or supports.

Faulted Conditions: those operating conditions associated with extremely low probability postulated events (Service Level D).

flaw: an imperfection or unintentional discontinuity that is detectable by nondestructive examination.

flaw aspect ratio (a/ℓ): the ratio of flaw depth (a) for surface flaws, or one-half of the flaw depth ($2a$) for subsurface flaws, to the length of the flaw (ℓ), where a, $2a$, and ℓ are the dimensions of the rectangle circumscribing the flaw. (See Figures IWA-3310-1 through IWA-3390-1.)

flaw depth: the depth is the maximum through-thickness dimension (a or $2a$) of the rectangle circumscribing the flaw when drawn normal to the surface of the component.

fracture initiation: level at which the applied stress intensity (K_I) is equal to or exceeds the fracture toughness (K_{Ic}).

general corrosion: an approximately uniform wastage of a surface of a component, through chemical or electrochemical action, free of deep pits or cracks.

hanger: an item that carries the weight of components or piping from above with the supporting members being mainly in tension.

high energy items: items in systems with maximum operating conditions greater than 200°F (93°C) or 275 psig (1.9 MPa).

hot functional testing: a series of preoperational tests, prior to reactor criticality, to ensure that the equipment meets the design parameters at normal system temperatures and pressures.

hot standby: See plant technical specifications.

imperfection: a condition of being imperfect; a departure of a quality characteristic from its intended condition.

indication: the response or evidence from the application of a nondestructive examination.

inservice examination: the process of visual, surface, or volumetric examination performed in accordance with the rules and requirements of this Division.

inservice inspection: methods and actions for assuring the structural and pressure-retaining integrity of safety-related nuclear power plant components in accordance with the rules of this Section.

inservice life: the period of time from the initial use of an item until its retirement from service.

inspection: verification of the performance of examinations and tests by an Inspector.

Inspection Program: the plan and schedule for performing examinations or tests.

Inspector: an Authorized Nuclear Inservice Inspector, except for those instances where so designated as an Authorized Nuclear Inspector.

installation: those actions required to place and attach components to their supports and join items of a nuclear power system by welding or mechanical means.

item: a material, part, appurtenance, piping subassembly, component, or component support.

K_I: See *stress intensity factor*.

K_{Ia}: See *crack arrest fracture toughness*.

K_{Ic}: See *plane strain fracture toughness*.

K_{Id}: dynamic initiation fracture toughness obtained under fast or rapidly applied loading conditions.

K_{IR}: the crack growth resistance (fracture toughness) expressed in units corresponding to K_I. The value of K_{IR} defined in Nonmandatory Appendix G is the lesser of K_{Ic} and K_{Ia} for the material and temperature involved.

laminar flaw: planar flaws that are oriented within 10 deg of a plane parallel to the surface of the component. (See Figure IWA-3360-1.)

linear flaw: a flaw having finite length and narrow uniform width and depth. (See Figure IWA-3400-1.)

lowest service temperature: the minimum temperature of the fluid retained by a component or, alternatively, the calculated volumetric average metal temperature expected during normal operation, whenever the pressure within the component exceeds 20% of the preoperational system hydrostatic test pressure.

material: metallic materials manufactured to an SA, SB, or SFA specification or any other material specification permitted by this Section or Section III.

Material Organization (Metallic): an organization accredited by holding a Quality System Certificate issued by the Society, or qualified by an accredited Material Organization or Certificate Holder, in accordance with the requirements of NCA-3800 or qualified by an Owner in accordance with the requirements of IWA-4140.

membrane stress (σ_m): the component of normal stress which is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration.

multiple flaws: two or more proximate discontinuous flaws. They may be planar, coplanar, or separate.

neutron fluence: the number of fast neutrons per unit area received by a cross-sectional component. This is a time integral of neutron flux at a given location in a component.

nondestructive examination: an examination by the visual, surface, or volumetric method.

nonplanar flaw: a flaw oriented in more than one plane. It may be curvilinear or a combination of two or more inclined planes. (See Figure IWA-3340-1.)

normal operating conditions: the operating conditions during reactor startup, operation at power, hot standby, and reactor cooldown to cold shutdown conditions. Test conditions are excluded.

normal plant operation: the conditions of startup, hot standby, operation within the normal power range, and cooldown and shutdown of the plant.

open ended: a condition of piping or lines that permits free discharge to atmospheric or containment atmosphere.

overpressure protection: the means by which components, or groups of components, are protected from overpressure, as required by the applicable Construction Code, by the use of pressure relieving devices or other design provisions.

Owner: the organization legally responsible for the construction and/or operation of a nuclear facility including but not limited to one who has applied for, or who has been granted, a construction permit or operating license by the regulatory authority having lawful jurisdiction.

Owner's Requirements: those requirements prepared by or for the Owner that

(a) define the requirements for an item when a Construction Code is not specified;

(b) address plant-specific requirements of the Construction Code that must be identified by the Owner; or

(c) invoke plant-specific requirements that are in excess of Construction Code requirements.

planar flaw: a flat two-dimensional flaw oriented in a plane other than parallel to the surface of the component. (See Figure IWA-3310-1.)

plane strain fracture toughness (K_{Ic}): the material toughness property measured in terms of the stress intensity factor, K_I, which will lead to nonductile crack propagation.

post-tensioning: a method of prestressing concrete in which the tendons are tensioned after the concrete has cured

prestressed concrete: reinforced concrete in which there have been introduced internal stresses of such magnitude and distribution that the stresses resulting from loads are counteracted to a desired degree.

Quality System Certificate (Materials): a certificate issued by the Society that permits an organization to perform specified Material Organization activities in accordance with Section III requirements.

RT_{NDT}: the reference nil-ductility transition temperature established in NB-2330 from drop weight and Charpy V-notch tests to account for the effect of irradiation.

reconciliation: the process of evaluating and justifying use of alternative Construction Code requirements or revised Owner's Requirements.

regulatory authority: a federal government agency, such as the United States Nuclear Regulatory Commission, that is empowered to issue and enforce regulations affecting the design, construction, and operation of nuclear power plants.

reinforced concrete: concrete containing reinforcement and designed so that the two materials act together in resisting force.

relevant condition: a condition observed during a visual examination that requires supplemental examination, corrective measure, correction by repair/replacement activities, or analytical evaluation.

Repair/Replacement Organization: the organization that performs repair/replacement activities under the provisions of the Owner's Quality Assurance Program. The Owner may be the Repair/Replacement Organization.

rerating: a change to all or a portion of a component or component support by changing its design ratings (e.g., internal or external pressure or temperature), whether or not physical work is performed on the item.

safety function: a function that is necessary to ensure

(a) the integrity of the reactor coolant pressure boundary,

(b) the capability to shut down the reactor and maintain it in a safe shutdown condition, or

(c) the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the guideline exposures of 10CFR100.

seal weld: a nonstructural weld intended to prevent leakage, where the strength is provided by a separate means.

source material: metallic products used for conversion to, or qualification as, material, by a Certificate Holder, Material Organization, or Owner.

stress: the intensity of the internal forces or components of forces that act on a plane through a given point. Stress is expressed in force per unit area.

stress intensity factor (K_I): a measure of the stress-field intensity near the tip of an ideal crack in a linear elastic medium when deformed so that the crack faces are displaced apart, normal to the crack plane (opening mode or mode I deformation). K_I is directly proportional to applied load and depends on specimen geometry.

structural factor: a multiplying factor applied to load or stress in the evaluation of a degraded component or piping item for the purpose of maintaining structural integrity during continued operation for a defined period of time.

Structural Integrity Test: the initial or subsequent pressure test of a containment structure to demonstrate the ability to withstand the prescribed loads.

support: see below

(a) an item used to position components, resist gravity, resist dynamic loading, or maintain equilibrium of components;

(b) an item that carries the weight of a component or piping from below with the supporting members being mainly in compression.

support part: a part or subassembly of a component support or piping support.

surface flaw: a flaw that either penetrates the surface or is less than a given distance from the surface. (See Figure IWA-3310-1.)

tendon: an assembly of prestressing steel, anchorages, and couplings, which imparts prestressing forces to concrete.

terminal ends: the extremities of piping runs that connect to structures, components, or pipe anchors, each of which acts as a rigid restraint or provides at least 2 degrees of restraint to piping thermal expansion.

test: a procedure to obtain information through measurement or observation.

unbonded tendons: tendons in which the prestressing steel is permanently free to move relative to the concrete to which they are applying prestressing forces.

variable spring type support: a spring type support providing a variable supporting force throughout a specified deflection.

verify: to determine that a particular action has been performed in accordance with the rules and requirements of this Section either by witnessing the action or by reviewing records.

vibration control and sway brace: a spring type support providing a variable restraining force along its axis.

welded joint category: the location of a joint in a vessel used for specifying required examinations. The categories are designated as A, B, C, and D as defined in NE-3351.

yield strength (σ_y): the stress at which a material exhibits a specified limiting deviation from the linear proportionality of stress to strain. The deviation is expressed in terms of strain (generally 0.2%).

SUBSECTION IWB REQUIREMENTS FOR CLASS 1 COMPONENTS OF LIGHT-WATER-COOLED PLANTS

ARTICLE IWB-1000 SCOPE AND RESPONSIBILITY

IWB-1100 SCOPE

This Subsection provides requirements for inservice inspection of Class 1 pressure-retaining components and their welded attachments in light-water-cooled plants.

IWB-1200 COMPONENTS SUBJECT TO EXAMINATION

IWB-1210 EXAMINATION REQUIREMENTS

The examination requirements of this Subsection shall apply to Class 1 pressure-retaining components and their welded attachments.

IWB-1220 COMPONENTS EXEMPT FROM EXAMINATION

The following components[19] or portions of components are exempted from the volumetric, surface, VT-1 visual, and VT-3 visual examination requirements of IWB-2500:

(a) components that are connected to the reactor coolant system and are part of the reactor coolant pressure boundary, and that are of such a size and shape so that upon postulated rupture the resulting flow of coolant from the reactor coolant system under normal plant operating conditions is within the capacity of makeup systems that are operable from on-site emergency power. The emergency core cooling systems are excluded from the calculation of makeup capacity.

(b) See (1) through (3) below.

(1) components and piping segments NPS 1 (DN 25) and smaller, except for steam generator tubing;

(2) components and piping segments which have one inlet and one outlet, both of which are NPS 1 (DN 25) and smaller;

(3) components[20] and piping segments which have multiple inlets or multiple outlets whose cumulative pipe cross-sectional area does not exceed the cross-sectional area defined by the OD of NPS 1 (DN 25) pipe.

(c) reactor vessel head connections and associated piping, NPS 2 (DN 50) and smaller, made inaccessible by control rod drive penetrations.

(d) welds or portions of welds that are inaccessible due to being encased in concrete, buried underground, located inside a penetration, or encapsulated by guard pipe.

ARTICLE IWB-2000
EXAMINATION AND INSPECTION

IWB-2200 PRESERVICE EXAMINATION

(a) Examinations required by this Article (with the exception of Examination Category B-P, and the visual VT-3 examination of the internal surfaces of Table IWB-2500-1 (B-L-2, B-M-2) shall be completed prior to initial plant startup. In addition, these preservice examinations shall be extended to include essentially 100% of the pressure-retaining welds in all Class 1 components, except in those components exempted from examination by IWB-1220(a), IWB-1220(b), or IWB-1220(c). However, in the case of Table IWB-2500-1 (B-O), the examination shall be extended to include essentially 100% of the welds in the installed peripheral control rod drive housings only.

(b) Shop and field examinations may serve in lieu of the on-site preservice examinations provided:

(1) in the case of vessels only, the examination is performed after the hydrostatic test required by Section III has been completed;

(2) such examinations are conducted under conditions and with equipment and techniques equivalent to those that are expected to be employed for subsequent inservice examinations;

(3) the shop and field examination records are, or can be, documented and identified in a form consistent with those required in Article IWA-6000.

(c) Steam generator tube examination shall be governed by the plant Technical Specification.

IWB-2400 INSPECTION SCHEDULE

IWB-2410 INSPECTION PROGRAM

Inservice examinations and system pressure tests may be performed during plant outages such as refueling shutdowns or maintenance shutdowns.

IWB-2411 Inspection Program

(a) The required percentage of examinations in each Examination Category shall be completed in accordance with Table IWB-2411-1, with the following exceptions:

(1) Examination Categories B-N-1, B-P, and B-Q

(2) examinations partially deferred to the end of an inspection interval, as allowed by Examination Categories B-A, B-D, and B-F

(3) examinations deferred to the end of an inspection interval, as allowed by Examination Categories B-A, B-N-2, B-N-3, and B-O

(4) examinations deferred until disassembly of a component for maintenance, repair/replacement activity, or volumetric examination, as allowed by Examination Categories B-G-1, B-G-2, B-L-2, and B-M-2

(5) welded attachments examined as a result of component support deformation under Examination Category B-K

If there are less than three items or welds to be examined in an Examination Category, the items or welds may be examined in any two periods, or in any one period if there is only one item or weld, in lieu of the percentage requirements of Table IWB-2411-1.

(b) If items or welds are added to the Inspection Program, during the service lifetime of a plant, examination shall be scheduled as follows:

(1) When items or welds are added during the first period of an interval, at least 25% of the examinations required by the applicable Examination Category and Item Number for the added items or welds shall be performed during each of the second and third periods of that interval. Alternatively, if deferral of the examinations is permitted for the Examination Category and Item Number, the second period examinations may be deferred to the third period and at least 50% of the examinations required by the applicable Examination Category and Item Number for the added items or welds shall be performed during the third period.

Table IWB-2411-1
Inspection Program

Inspection Interval	Inspection Period, Calendar Years of Plant Service Within the Interval	Minimum Examinations Completed, %	Maximum Examinations Credited, %
All	3	16	50
	7	50 [Note (1)]	75
	10	100	100

NOTE:
(1) If the first period completion percentage for any examination category exceeds 34%, at least 16% of the required examinations shall be performed in the second period.

(2) When items or welds are added during the second period of an interval, at least 25% of the examinations required by the applicable Examination Category and Item Number for the added items or welds shall be performed during the third period of that interval.

(3) When items or welds are added during the third period of an interval, examinations shall be scheduled in accordance with (a) for successive intervals.

IWB-2413 Inspection Program for Steam Generator Tubing

The examinations shall be governed by the plant Technical Specification.

IWB-2420 SUCCESSIVE INSPECTIONS

(a) The sequence of component examinations which was established during the first inspection interval shall be repeated during each successive inspection interval, to the extent practical. The sequence of component examinations may be modified in a manner that optimizes scaffolding, radiological, insulation removal, or other considerations, provided that the percentage requirements of Table IWB-2411-1 are maintained.

(b) If a component is accepted for continued service in accordance with IWB-3132.3 or IWB-3142.4, the areas containing flaws or relevant conditions shall be reexamined during the next three inspection periods listed in the schedule of the Inspection Program of IWB-2400. Alternatively, acoustic emission may be used to monitor growth of existing flaws in accordance with IWA-2234. For vessel welds, the three successive inspections are not required if the following conditions are met:

(1) The flaw is characterized as subsurface in accordance with Figure IWA-3320-2.

(2) The weld containing the flaw is acceptable for continued service in accordance with IWB-3600, and the flaw is demonstrated acceptable for the intended service life of the component.

(c) If the reexaminations required by (b) reveal that the flaws or relevant conditions remain essentially unchanged, or that the flaw growth is within the growth predicted by the analytical evaluation, for three successive inspection periods, then the component examination schedule may revert to the original schedule of successive inspections or the inspection interval defined by the analytical evaluation, whichever is limiting.

(d) If the reexaminations required by (b) above reveal new flaws or relevant conditions that exceed the applicable acceptance standards of Table IWB-3410-1, or growth of existing flaws in excess of the growth predicted by the analytical evaluation, then

(1) the entire weld, area, or part[21] shall be examined during the current outage

(2) additional examinations shall be performed in accordance with IWB-2430

(e) For steam generator tubing, the successive examinations shall be governed by the plant Technical Specification.

(f) If welded attachments are examined as a result of identified component support deformation, and the results of these examinations exceed the acceptance standards of Table IWB-3410-1, successive examinations shall be performed, if determined necessary, based on an evaluation by the Owner. The evaluation shall be documented and shall include the cause of the welded attachment damage if known. If the cause of the welded attachment damage could recur or is unknown, successive examinations shall be performed in accordance with the requirements of (b) above. No successive examinations are required if either of the following applies:

(1) There are no other welded attachments subject to the same apparent or root cause conditions.

(2) The degradation mechanism no longer exists.

IWB-2430 ADDITIONAL EXAMINATIONS

(a) Examinations performed in accordance with Tables IWB-2500-1 (B-A) through IWB-2500-1 (B-O) and Table IWB-2500-1 (B-Q), that reveal flaws or relevant conditions exceeding the acceptance standards of Table IWB-3410-1 shall be extended to include additional examinations during the current outage in accordance with (1) or (2) below.

(1) Additional examinations shall be performed in accordance with the following requirements:

(-a) The additional examinations shall include an additional number of welds, areas, or parts[21] included in the inspection item[22] equal to the number of welds, areas, or parts included in the inspection item that were scheduled to be performed during the present inspection period. The additional examinations shall be selected from welds, areas, or parts of similar material and service. This additional selection may require inclusion of piping systems other than the one containing the flaws or relevant conditions.

(-b) If the additional examinations required by (-a) above reveal flaws or relevant conditions exceeding the acceptance standards of Table IWB-3410-1, the examinations shall be further extended to include additional examinations during the current outage. These additional examinations shall include the remaining number of welds, areas, or parts of similar material and service subject to the same type of flaws or relevant conditions.

(2) Additional examinations shall be performed in accordance with the following requirements:

(-a) An engineering evaluation shall be performed. Topics to be addressed in the engineering evaluation shall include the following:

(-1) a determination of the cause of the flaws or relevant conditions

(-2) an evaluation of applicable service conditions and degradation mechanisms to establish that the affected welds, areas, or parts[21] will perform their intended safety functions during subsequent operation

(-3) a determination of which additional welds, areas, or parts[21] are subject to the same service conditions and degradation mechanisms that caused the flaws or relevant conditions

(-b) Additional examinations shall be performed on all those welds, areas, or parts[21] subject to the same service conditions and degradation mechanisms that caused the flaws or relevant conditions. This additional selection might require inclusion of piping systems other than the one containing the original flaws or relevant conditions. No additional examinations are required if the engineering evaluation concludes that

(-1) there are no additional welds, areas, or parts subject to the same service conditions that caused the flaws or relevant conditions or

(-2) no degradation mechanism exists

(-c) The engineering evaluation shall be retained in accordance with Article IWA-6000.

(b) The examination method for additional examinations may be limited to the examination method that originally identified the flaws or relevant conditions, provided use of the method is supported by an engineering evaluation. The engineering evaluation shall determine the cause of the flaws or relevant conditions and the appropriate method to be used as part of the additional examination scope. The engineering evaluation shall be retained in accordance with Article IWA-6000.

(c) For the inspection period following the period in which the examinations of (a) were completed, the examinations shall be performed as originally scheduled in accordance with IWB-2400.

(d) For steam generator tubing, additional examinations shall be governed by plant Technical Specifications.

(e) If welded attachments are examined as a result of identified component support deformation, and the results of these examinations exceed the acceptance standards of Table IWB-3410-1, additional examinations shall be performed, if determined necessary, based on an evaluation by the Owner. The evaluation shall be documented and shall include the cause of the welded attachment damage if known. If the cause of the welded attachment damage could recur or is unknown, additional examinations shall be performed in accordance with the requirements of (a) above. No additional examinations are required if either of the following applies:

(1) There are no other welded attachments subject to the same apparent or root cause conditions.

(2) The degradation mechanism no longer exists.

IWB-2500 EXAMINATION AND PRESSURE TEST REQUIREMENTS

(a) Components shall be examined and tested as specified in Tables IWB-2500-1 (B-A) through IWB-2500-1 (B-Q). The method of examination for the components and parts of the pressure-retaining boundaries shall comply with those tabulated in Tables IWB-2500-1 (B-A) through IWB-2500-1 (B-Q) except where alternate examination methods are used that meet the requirements of IWA-2240.

(b) Tables IWB-2500-1 (B-A) through IWB-2500-1 (B-Q) are organized as follows.

Examination Category	Examination Area
B-A	Pressure-Retaining Welds in Reactor Vessel
B-B	Pressure-Retaining Welds in Vessels Other Than Reactor Vessels
B-D	Full Penetration Welded Nozzles in Vessels
B-F	Pressure-Retaining Dissimilar Metal Welds in Vessel Nozzles
B-G-1	Pressure-Retaining Bolting, Greater Than 2 in. (50 mm) in Diameter
B-G-2	Pressure-Retaining Bolting, 2 in. (50 mm) and Less in Diameter
B-J	Pressure-Retaining Welds in Piping
B-K	Welded Attachments for Vessels, Piping, Pumps, and Valves
B-L-2	Pump Casings
B-M-2	Valve Bodies
B-N-1	Interior of Reactor Vessel
B-N-2	Welded Core Support Structures and Interior Attachments to Reactor Vessels
B-N-3	Removable Core Support Structures
B-O	Pressure-Retaining Welds in Control Rod Drive and Instrument Nozzle Housings
B-P	All Pressure-Retaining Components
B-Q	Steam Generator Tubing

(c) Alternatively, for Examination Categories B-F and B-J, the provisions of Nonmandatory Appendix R may be applied to all Class 1 piping or to one or more individual piping systems.

(d) In lieu of the surface examination requirements for Examination Category B-F NPS 4 (DN 100) and larger piping welds, Examination Category B-J NPS 4 (DN 100) and larger piping welds, Examination Category B-F socket welds, and Examination Category B-J socket welds, the Owner may elect to perform a plant-specific review for welds susceptible to outside surface attack. All welds of the examination categories and within the size limitations of this subparagraph, determined by this review to be susceptible to outside surface attack, require surface examination each interval, in the same sequence, to the extent practical, over the lifetime of the item. The plant-specific review shall be updated each interval. The requirements of IWB-2411 shall be met. Acceptance standards shall be in accordance with IWB-3514. For any socket weld connections identified as susceptible to

thermal fatigue, VT-2 visual examination shall be performed at operating pressure during each refueling outage. Contributors to outside surface attack include proximity to nearby leak paths, proximity to chloride-bearing materials, existence of moisture- or salt-laden atmosphere, and existence of insulation or other coating or cover that traps moisture. Specific outside surface attack susceptibility criteria are as follows:

(1) austenitic stainless steel base metal, welds, or heat-affected zone (HAZ); operating temperature greater than 150°F (65°C); and piping outside surface within five pipe diameters of a probable leak path (e.g., valve stem) and covered with nonmetallic insulation not in compliance with U.S. NRC Regulatory Guide 1.36 (e.g., chloride content) or equivalent requirements

(2) austenitic stainless steel base metal, welds, or HAZ and piping outside surface exposed to wetting from a concentrated chloride-bearing environment (e.g., seawater, brackish water, brine) or

(3) items identified as susceptible to any mechanisms of outside surface attack other than external chloride stress corrosion cracking based on a review of plant experience and plant-specific processes and programs addressing chlorides and other contaminants

(e) For PWR stainless steel residual and regenerative heat exchangers, in lieu of the requirements of Examination Categories B-B, B-D, and B-J, VT-2 visual examinations may be performed in accordance with the following:

(1) These alternative examination requirements shall not be applied to any heat exchanger, nor to any heat exchanger design or configuration, that has experienced a through-wall leak, such as heat exchangers with an inner shell (inner barrel). The Owner shall evaluate industry experience to determine which heat exchanger designs or configurations have leaked. If any leakage is detected, it shall be corrected in accordance with Article IWA-4000. Any subsequent use of these alternative examination requirements shall then be discontinued. The affected heat exchanger and others of the same design or configuration shall be examined in accordance with (a).

(2) Application of these alternative examination requirements is limited to those welds that are part of the as-received heat exchanger assembly. The regenerative heat exchanger assembly may be formed from multiple smaller heat exchanger subcomponents connected by sections of piping. All of the smaller heat exchanger subcomponents and the connecting piping are within the boundary of the heat exchanger assembly.

(3) All welds, other than reinforcing plate welds, shall have received at least one volumetric examination. The preservice or Construction Code volumetric examination may be used to meet this requirement. Reinforcing plate welds shall have received at least one surface examination.

(4) The component shall be VT-2 visually examined for evidence of leakage while undergoing the system leakage test as required by Examination Category B-P, to be performed every refueling outage. IWB-3522 shall be met.

(15)

Table IWB-2500-1 (B-A)
Examination Category B-A, Pressure-Retaining Welds in Reactor Vessel

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination		Deferral of Examination to End of Interval
					First Inspection Interval	Successive Inspection Intervals	
B1.10	Shell welds		Volumetric	IWB-3510	All welds [Note (2)]	Same as for first interval	Permissible
B1.11	Circumferential	IWB-2500-1					
B1.12	Longitudinal	IWB-2500-2					
B1.20	Head welds	IWB-2500-3	Volumetric	IWB-3510	Accessible length of all welds [Note (2)]	Same as for first interval	Permissible
B1.21	Circumferential						
B1.22	Meridional						
B1.30	Shell-to-flange weld	IWB-2500-4	Volumetric	IWB-3510	Weld [Note (2)]	Same as for first interval	Permissible [Note (3)] or [Note (5)]
B1.40	Head-to-flange weld	IWB-2500-5	Volumetric and surface	IWB-3510	Weld [Note (2)]	Same as for first interval	Permissible [Note (4)] or [Note (5)]
B1.50	Repair welds [Note (1)]	IWB-2500-1 and IWB-2500-2	Volumetric	IWB-3510	All weld repair areas	Same as for first interval	Permissible
B1.51	Beltline region						

NOTES:
(1) Material (base metal) weld repairs where repair depth exceeds 10% nominal of the vessel wall. If the location of the repair is not positively and accurately known, then the individual shell plate, forging, or shell course containing the repair shall be included.
(2) Includes essentially 100% of the weld length.
(3) The shell-to-flange weld examination may be performed during the first and third periods, in which case 50% of the shell-to-flange weld shall be examined by the end of the first period, and the remainder by the end of third period. During the first period, the examination need only be performed from the flange face, provided this same portion is examined from the shell during the third period.
(4) During the first and second periods, the examination may be performed from the flange face, provided these same portions are examined from the head during the third period.
(5) Deferral in the first inspection interval is not permitted. Deferral in successive inspection intervals is permitted provided that
(a) no welded repair/replacement activities have been performed either on the shell-to-flange weld or head-to-flange weld; and
(b) neither the shell-to-flange weld nor the head-to-flange weld contains identified flaws or relevant conditions that require successive inspections in accordance with IWB-2420(b).

Table IWB-2500-1 (B-B)
Examination Category B-B, Pressure-Retaining Welds in Vessels Other Than Reactor Vessels

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination: First Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals [Note (3)]	Deferral of Examination to End of Interval
	Pressurizer		Volumetric	IWB-3510	Figure IWB-2500-20(a)	Figure IWB-2500-20(b)	Not permissible
B2.10	Shell-to-Head						
B2.11	Circumferential	IWB-2500-1			Both welds [Note (4)]	Both welds [Note (4)]	
B2.12	Longitudinal	IWB-2500-2			1 ft (300 mm) of all welds [Note (2)]	1 ft (300 mm) of one weld [Note (2)] per head	
B2.20	Head Welds	IWB-2500-3	Volumetric	IWB-3510	All welds [Note (4)]	One weld per head	Not permissible
B2.21	Circumferential						
B2.22	Meridional						
	Steam Generators (Primary Side)		Volumetric	IWB-3510	Figure IWB-2500-20(c) All welds [Note (4)]	Figure IWB-2500-20(d) One weld [Note (1)] per head	Not permissible
B2.30	Head Welds	IWB-2500-3					
B2.31	Circumferential						
B2.32	Meridional						
B2.40	Tubesheet-To-Head Weld	IWB-2500-6	Volumetric	IWB-3510	Weld [Note (4)]	Weld [Note (1)], [Note (4)]	Not permissible
	Heat Exchangers (Primary Side) — Head		Volumetric	IWB-3510	Figure IWB-2500-20(e) All welds [Note (4)]	Figure IWB-2500-20(f) One weld [Note (1)] per head	Not permissible
B2.50	Head Welds						
B2.51	Circumferential	IWB-2500-1, IWB-2500-3					
B2.52	Meridional	IWB-2500-3					
	Heat Exchangers (Primary Side) — Shell				Figure IWB-2500-20(g)	Figure IWB-2500-20(h)	
B2.60	Tubesheet-to-Head Welds	IWB-2500-6	Volumetric	IWB-3510	Weld [Note (4)]	Weld [Note (1)], [Note (4)]	Not permissible
B2.70	Longitudinal Welds	IWB-2500-2	Volumetric	IWB-3510	1 ft of all welds [Note (2)] at each end of shell	1 ft of one weld [Note (1)], [Note (2)] at each end of shell	Not permissible
B2.80	Tubesheet-to-Shell Welds	IWB-2500-6	Volumetric	IWB-3510	Welds [Note (4)] each end	Welds [Note (1)], [Note (4)] each end	Not permissible

Table IWB-2500-1 (B-B)
Examination Category B-B, Pressure-Retaining Welds in Vessels Other Than Reactor Vessels (Cont'd)

NOTES:
(1) The examination may be limited to one vessel among the group of vessels performing a similar function.
(2) The weld selected for examination is that weld intersecting the circumferential weld.
(3) The initially selected welds are to be examined in the same sequence during successive inspection intervals, to the extent practical.
(4) Includes essentially 100% of the weld length.

Table IWB-2500-1 (B-D)
Examination Category B-D, Full Penetration Welded Nozzles in Vessels

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination		Deferral of Examination to End of Interval
					First Inspection Interval	Successive Inspection Intervals	
	Reactor Vessel						
B3.90	Nozzle-to-Vessel Welds	IWB-2500-7 [Note (4)]	Volumetric	IWB-3512	All nozzles [Note (1)]	Same as for 1st Interval	See [Note (2)], [Note (3)], [Note (5)]
B3.100	Nozzle Inside Radius Section	IWB-2500-7 [Note (4)]	Volumetric	IWB-3512	All nozzles [Note (1)]	Same as for 1st Interval	See [Note (2)], [Note (5)]
	Pressurizer						
B3.110	Nozzle-to-Vessel Welds	IWB-2500-7 [Note (4)]	Volumetric	IWB-3512	All nozzles [Note (1)]	Same as for 1st Interval	Not permissible
	Steam Generators (Primary Side)						
B3.130	Nozzle-to-Vessel Welds	IWB-2500-7 [Note (4)]	Volumetric	IWB-3512	All nozzles [Note (1)]	Same as for 1st Interval	Not permissible
	Heat Exchangers (Primary Side)						
B3.150	Nozzle-to-Vessel Welds	IWB-2500-7 [Note (4)]	Volumetric	IWB-3512	All nozzles [Note (1)]	Same as for 1st Interval	Not permissible
B3.160	Nozzle Inside Radius Section	IWB-2500-7 [Note (4)]	Volumetric	IWB-3512	All nozzles [Note (1)]	Same as for 1st Interval	Not permissible

NOTES:
(1) Includes nozzles with full penetration welds to vessel shell (or head) and integrally cast nozzles, but excludes manways and handholes either welded to or integrally cast in vessel.
(2) At least 25% but not more than 50% of the nozzles shall be examined by the end of the first inspection period, and the remainder by the end of the inspection interval.
(3) If the nozzle weld is examined by the straight beam ultrasonic method from inside the nozzle bore, the remaining examinations required from the shell inside diameter may be performed at or near the end of the interval.
(4) The examination volumes shall apply to the applicable figure shown in Figures IWB-2500-7(a) through IWB-2500-7(d).
(5) For PWRs in the second and successive inspection intervals, these examinations may be deferred to the end of the interval, provided no repair/replacement activities have been performed on the examination item, and no flaws or relevant conditions requiring successive inspections in accordance with IWB-2420(b) are contained in the examination item.

Table IWB-2500-1 (B-F)
Examination Category B-F, Pressure-Retaining Dissimilar Metal Welds in Vessel Nozzles

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination		Deferral of Examination to End of Interval
					First Inspection Interval	Successive Inspection Intervals	
	Reactor Vessel						
B5.10	NPS 4 (DN 100) or Larger Nozzle-to-Safe End Butt Welds	IWB-2500-8	Volumetric and surface	IWB-3514	All welds	Same as for 1st interval	See [Note (1)], [Note (2)]
B5.11	NPS 4 (DN 100) or Larger Nozzle-to-Component Butt Welds	IWB-2500-8	Volumetric and surface	IWB-3514	All welds	Same as for 1st interval	Not permissible
B5.20	Less Than NPS 4 (DN 100) Nozzle-to-Safe End Butt Welds	IWB-2500-8	Surface	IWB-3514	All welds	Same as for 1st interval	See [Note (1)]
B5.30	Nozzle-to-Safe End Socket Welds	IWB-2500-8	Surface	IWB-3514	All welds	Same as for 1st interval	See [Note (1)]
	Pressurizer						
B5.40	NPS 4 (DN 100) or Larger Nozzle-to-Safe End Butt Welds	IWB-2500-8	Volumetric and surface	IWB-3514	All welds	Same as for 1st interval	Not permissible
B5.50	Less Than NPS 4 (DN 100) Nozzle-to-Safe End Butt Welds	IWB-2500-8	Surface	IWB-3514	All welds	Same as for 1st interval	Not permissible
B5.60	Nozzle-to-Safe End Socket Welds	IWB-2500-8	Surface	IWB-3514	All welds	Same as for 1st interval	Not permissible
	Steam Generator						
B5.70	NPS 4 (DN 100) or Larger Nozzle-to-Safe End Butt Welds	IWB-2500-8	Volumetric and surface	IWB-3514	All welds	Same as for 1st interval	Not permissible
B5.71	NPS 4 (DN 100) or Larger Nozzle-to-Component Butt Welds	IWB-2500-8	Volumetric and surface	IWB-3514	All welds	Same as for 1st interval	Not permissible
B5.80	Less Than NPS 4 (DN 100) Nozzle-to-Safe End Butt Welds	IWB-2500-8	Surface	IWB-3514	All welds	Same as for 1st interval	Not permissible
B5.90	Nozzle-to-Safe End Socket Welds	IWB-2500-8	Surface	IWB-3514	All welds	Same as for 1st interval	Not permissible
	Heat Exchangers						
B5.100	NPS 4 (DN 100) or Larger Nozzle-to-Safe End Butt Welds	IWB-2500-8	Volumetric and surface	IWB-3514	All welds	Same as for 1st interval	Not permissible
B5.110	Less Than NPS 4 (DN 100) Nozzle-to-Safe End Butt Welds	IWB-2500-8	Surface	IWB-3514	All welds	Same as for 1st interval	Not permissible
B5.120	Nozzle-to-Safe End Socket Welds	IWB-2500-8	Surface	IWB-3514	All welds	Same as for 1st interval	Not permissible

NOTES:

(1) Deferral is not permissible during the first interval. However, during successive intervals, the examinations may be performed coincident with the vessel nozzle examinations required by Examination Category B-D.

(2) For PWRs in the second and successive inspection intervals, these examinations may be deferred to the end of the interval, provided no repair/replacement activities have been performed on the examination item, and no flaws or relevant conditions requiring successive inspections in accordance with IWB-2420(b) are contained in the examination item.

(15)

Table IWB-2500-1 (B-G-1)
Examination Category B-G-1, Pressure-Retaining Bolting, Greater Than 2 in. (50 mm) in Diameter

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination: First Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals	Deferral of Examination to End of Interval
	Reactor Vessel						
B6.10	Closure Head Nuts	Surfaces	Visual, VT-1	IWB-3517	Closure head nuts	Same as for 1st interval	Permissible
B6.20	Closure Studs	IWB-2500-12(a)	Volumetric [Note (7)]	IWB-3515	Closure studs [Note (1)]		
B6.40	Threads in Flange	IWB-2500-12(a)	Volumetric	IWB-3515	Threads in flange		
B6.50	Closure Washers, Bushings	Surfaces	Visual, VT-1	IWB-3517	Closure washer and bushings [Note (2)]		
	Pressurizer						
B6.60	Bolts and Studs	IWB-2500-12(a)	Volumetric [Note (7)]	IWB-3515	Bolts and studs [Note (1)]	Same as for 1st interval	Permissible
B6.70	Flange Surface, [Note (6)] when connection disassembled	Surfaces	Visual, VT-1	IWB-3517	Flange surface		
B6.80	Nuts, Bushings, and Washers	Surfaces	Visual, VT-1	IWB-3517	Nuts, bushings, and washers [Note (2)]		
	Steam Generators						
B6.90	Bolts and Studs	IWB-2500-12(a)	Volumetric [Note (7)]	IWB-3515	Bolts and studs [Note (1)]	Same as for 1st interval	Permissible
B6.100	Flange Surface, [Note (6)] when connection disassembled	Surfaces	Visual, VT-1	IWB-3517	Flange surface		
B6.110	Nuts, Bushings, and Washers	Surfaces	Visual, VT-1	IWB-3517	Nuts, bushings, and washers [Note (2)]		
	Heat Exchangers						
B6.120	Bolts and Studs	IWB-2500-12(a)	Volumetric [Note (7)]	IWB-3515	Bolts and studs [Note (1)], [Note (3)]	Same as for 1st interval	Permissible
B6.130	Flange Surface, [Note (6)] when connection disassembled	Surfaces	Visual, VT-1	IWB-3517	Flange surface [Note (4)]		
B6.140	Nuts, Bushings, and Washers	Surfaces	Visual, VT-1	IWB-3517	Nuts, bushings, and washers [Note (2)], [Note (4)]		

Table IWB-2500-1 (B-G-1)
Examination Category B-G-1, Pressure-Retaining Bolting, Greater Than 2 in. (50 mm) in Diameter (Cont'd)

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination: First Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals	Deferral of Examination to End of Interval
	Piping						
B6.150	Bolts and Studs	IWB-2500-12(a)	Volumetric [Note (7)]	IWB-3515	Bolts and studs [Note (1)], [Note (5)]	Same as for 1st interval	Permissible
B6.160	Flange Surface, [Note (6)] when connection disassembled	Surfaces	Visual, VT-1	IWB-3517	Flange surface [Note (5)]		
B6.170	Nuts, Bushings, and Washers	Surfaces	Visual, VT-1	IWB-3517	Nuts, bushings, and washers [Note (2)], [Note (5)]		
	Pumps						
B6.180	Bolts and Studs	IWB-2500-12(a)	Volumetric [Note (7)]	IWB-3515	Bolts and studs [Note (1)], [Note (3)]	Same as for 1st interval	Permissible
B6.190	Flange Surface, [Note (6)] when connection disassembled	Surfaces	Visual, VT-1	IWB-3517	Flange surface [Note (4)]		
B6.200	Nuts, Bushings, and Washers	Surfaces	Visual, VT-1	IWB-3517	Nuts, bushings, and washers [Note (2)], [Note (4)]		
	Valves						
B6.210	Bolts and Studs	IWB-2500-12(a)	Volumetric [Note (7)]	IWB-3515	Bolts and studs [Note (1)], [Note (3)]	Same as for 1st interval	Permissible
B6.220	Flange Surface, [Note (6)] when connection disassembled	Surfaces	Visual, VT-1	IWB-3517	Flange surface [Note (4)]		
B6.230	Nuts, Bushings, and Washers	Surfaces	Visual, VT-1	IWB-3517	Nuts, bushings, and washers [Note (2)], [Note (4)]		

GENERAL NOTE: Bolting diameter is defined as the smaller of the minor thread diameter of the portion of the bolting that is under tension or the bolting shank diameter.

NOTES:
(1) Bolting may be examined:
(a) in place under tension;
(b) when the connection is disassembled;
(c) when the bolting is removed.
(2) Bushings are required to be examined only when the bolting is removed. Bushings may be examined in place.

Table IWB-2500-1 (B-G-1)
Examination Category B-G-1, Pressure-Retaining Bolting, Greater Than 2 in. (50 mm) in Diameter (Cont'd)

NOTES (CONT'D):

(3) Volumetric examination of bolts and studs for heat exchangers, pumps, or valves may be conducted on one heat exchanger, one pump, or one valve among a group of heat exchangers, pumps, or valves that are similar in design, type, and function. In addition, when the component to be examined contains a group of bolted connections of similar design and size, such as flanged connections, the examination may be conducted on one bolted connection among the group.

(4) Visual examination of nuts, bushings, washers, and flange surfaces for heat exchangers, pumps, or valves is required only when the component is examined under Examination Category B-B, B-L-2, or B-M-2. Examination of a bolted connection is required only once during the interval.

(5) The examination of flange bolting in piping systems may be limited to one bolted connection among a group of bolted connections that are similar in design, size, function, and service.

(6) Examination includes 1 in. (25 mm) annular surface of flange surrounding each stud.

(7) When bolts or studs are removed for examination, surface examination meeting the acceptance standards of IWB-3515 may be substituted for volumetric examination.

(15)

Table IWB-2500-1 (B-G-2)
Examination Category B-G-2, Pressure-Retaining Bolting, 2 in. (50 mm) and Less in Diameter

Item No.	Parts Examined [Note (1)]	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination: First Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals	Deferral of Examination to End of Interval
	Reactor Vessel						
B7.10	Bolts, Studs, and Nuts	Surface	Visual, VT-1	IWB-3517	All bolts, studs, and nuts [Note (2)]	Same as for 1st interval	Not permissible
	Pressurizer						
B7.20	Bolts, Studs, and Nuts	Surface	Visual, VT-1	IWB-3517	All bolts, studs, and nuts [Note (2)]	Same as for 1st interval	Not permissible
	Steam Generators						
B7.30	Bolts, Studs, and Nuts	Surface	Visual, VT-1	IWB-3517	All bolts, studs, and nuts [Note (2)]	Same as for 1st interval	Not permissible
	Heat Exchangers						
B7.40	Bolts, Studs, and Nuts	Surface	Visual, VT-1	IWB-3517	All bolts, studs, and nuts [Note (2)]	Same as for 1st interval	Not permissible
	Piping						
B7.50	Bolts, Studs, and Nuts	Surface	Visual, VT-1	IWB-3517	All bolts, studs, and nuts [Note (3)]	Same as for 1st interval	Not permissible
	Pumps						
B7.60	Bolts, Studs, and Nuts	Surface	Visual, VT-1	IWB-3517	All bolts, studs, and nuts [Note (2)]	Same as for 1st interval	Not permissible
	Valves						
B7.70	Bolts, Studs, and Nuts	Surface	Visual, VT-1	IWB-3517	All bolts, studs, and nuts [Note (2)]	Same as for 1st interval	Not permissible

GENERAL NOTE: Bolting diameter is defined as the smaller of the minor thread diameter of the portion of the bolting that is under tension or the bolting shank diameter.

NOTES:
(1) Bolting is required to be examined only when a connection is disassembled or bolting is removed.
(2) For components other than piping, examination of bolting is required only when the component is examined under Examination Category B-A, B-B, B-L-2, or B-M-2. Examination of bolted connection is required only once during the interval.
(3) The examination of flange bolting in piping systems may be limited to one bolted connection among a group of bolted connections that are similar in design, size, function, and service. Examination is required only when a flange is disassembled. Examination of a bolted connection is required only once during the interval.

Table IWB-2500-1 (B-J)
Examination Category B-J, Pressure-Retaining Welds in Piping

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination		Deferral of Examination to End of Interval
					First Inspection Interval	Successive Inspection Intervals [Note (1)]	
B9.10	NPS 4 or larger (DN 100)	IWB-2500-8	Surface and volumetric	IWB-3514	Welds [Note (2)], [Note (3)], [Note (4)], [Note (5)], [Note (6)]	Same as for first interval	Not permissible
B9.11	Circumferential welds						
B9.20	Less than NPS 4 (DN 100)	IWB-2500-8		IWB-3514		Same as for first interval	Not permissible
B9.21	Circumferential welds other than PWR high pressure safety injection systems		Surface		Welds [Note (2)], [Note (3)], [Note (4)]		
B9.22	Circumferential welds of PWR high pressure safety injection systems		Volumetric		Welds [Note (3)], [Note (5)], [Note (6)], [Note (7)]		
B9.30	Branch pipe connection welds					Same as for first interval	Not permissible
B9.31	NPS 4 or larger (DN 100)	IWB-2500-9, IWB-2500-10, and IWB-2500-11	Surface and volumetric	IWB-3514	Welds [Note (2)], [Note (3)], [Note (4)], [Note (5)], [Note (6)]		
B9.32	Less than NPS 4 (DN 100)		Surface		Welds [Note (2)], [Note (3)], [Note (4)]		
B9.40	Socket welds	IWB-2500-8	Surface	IWB-3514	Welds [Note (2)], [Note (3)]	Same as for first interval	Not permissible

NOTES:
(1) The initially selected welds are to be examined in the same sequence during successive inspection intervals, to the extent practical.
(2) Examinations shall include the following:
(a) All terminal ends in each pipe or branch run connected to vessels.
(b) All terminal ends and joints in each pipe or branch run connected to other components where the stress levels exceed either of the following limits under loads associated with specific seismic events and operational conditions:
(1) primary plus secondary stress intensity range of 2.4 S_m for ferritic steel and austenitic steel
(2) cumulative usage factor U of 0.4
(c) All dissimilar metal welds not covered under Category B-F.
(d) Additional piping welds so that the total number of circumferential butt welds (or branch connection or socket welds) selected for examination equals 25% of the circumferential butt welds (or branch connection or socket welds) in the reactor coolant piping system. This total does not include welds exempted by IWB-1220 or welds in Item No. B9.22. These additional welds may be located as follows:
(1) For PWR plants
(-a) one hot-leg and one cold-leg in one reactor coolant piping loop
(-b) one branch, representative of an essentially symmetric piping configuration among each group of branch runs that are connected to reactor coolant loops and that perform similar system functions

Table IWB-2500-1 (B-J)
Examination Category B-J, Pressure-Retaining Welds in Piping (Cont'd)

NOTES (CONT'D):

(-c) each piping and branch run exclusive of the categories of loop and runs that are part of system piping of (-a) and (-b) above

(2) For BWR plants

(-a) one reactor coolant recirculation loop (where a loop or run branches, only one branch)

(-b) one branch run representative of an essentially symmetric piping configuration among each group of branch runs that are connected to a loop and that perform similar system functions

(-c) one steam line run representative of an essentially symmetric piping configuration among the runs

(-d) one feedwater line run representative of an essentially symmetric piping configuration among the runs (where a loop or run branches, only one branch)

(-e) each piping and branch exclusive of the categories of loops and runs that are part of the system piping of (-a) through (-d) above

(3) Includes essentially 100% of the weld length.

(4) For circumferential welds with intersecting longitudinal welds, surface examination of the longitudinal piping welds is required for those portions of the welds within the examination boundaries of intersecting Examination Categories B-F and B-J circumferential welds.

(5) For circumferential welds with intersecting longitudinal welds, volumetric examination of the longitudinal piping welds is required for those portions of the welds within the examination boundaries of intersecting Examination Categories B-F and B-J circumferential welds. The following requirements shall also be met:

(a) When longitudinal welds are specified and locations are known, examination requirements shall be met for both transverse and parallel flaws at the intersection of the welds and for that length of longitudinal weld within the circumferential weld examination volume.

(b) When longitudinal welds are specified but locations are unknown, or the existence of longitudinal welds is uncertain, the examination requirements shall be met for both transverse and parallel flaws within the entire examination volume of intersecting circumferential welds.

(6) For welds in carbon or low alloy steels, only those welds showing reportable preservice transverse indications need to be examined by the ultrasonic method for reflectors transverse to the weld length direction except that circumferential welds with intersecting longitudinal welds shall meet [Note (5)].

(7) A 10% sample of PWR high pressure safety injection system circumferential welds in piping greater than or equal to NPS $1\frac{1}{2}$ (DN 40) and less than NPS 4 (DN 100) shall be selected for examination. This sample shall be selected from locations determined by the Owner as most likely to be subject to thermal fatigue. Thermal fatigue may be caused by conditions such as valve leakage or turbulence effects.

Table IWB-2500-1 (B-K)
Examination Category B-K, Welded Attachments for Vessels, Piping, Pumps, and Valves

Item No.	Parts Examined [Note (1)]	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent [Note (2)], [Note (3)] and Frequency [Note (6)] of Examination		Deferral of Examination to End of Interval
					First Inspection Interval	Successive Inspection Intervals	
	Pressure Vessels						
B10.10	Welded attachments	IWB-2500-13, IWB-2500-14, and IWB-2500-15	Surface [Note (7)]	IWB-3516	Each welded attachment and each identified occurrence [Note (4)]	Same as for first interval	Not permissible
	Piping						
B10.20	Welded attachments	IWB-2500-13, IWB-2500-14, and IWB-2500-15	Surface	IWB-3516	Each welded attachment and each identified occurrence [Note (5)]	Same as for first interval	Not permissible
	Pumps						
B10.30	Welded attachments	IWB-2500-13, IWB-2500-14, and IWB-2500-15	Surface	IWB-3516	Each welded attachment and each identified occurrence [Note (5)]	Same as for first interval	Not permissible
	Valves						
B10.40	Welded attachments	IWB-2500-13, IWB-2500-14, and IWB-2500-15	Surface	IWB-3516	Each welded attachment and each identified occurrence [Note (5)]	Same as for first interval	Not permissible

NOTES:

(1) Weld buildup on nozzles that is in compression under normal conditions and provides only component support is excluded from examination. Examination is limited to those welded attachments that meet the following conditions:

(a) the attachment is on the outside surface of the pressure-retaining component;

(b) the attachment provides component support as defined in NF-1110;

(c) the attachment weld joins the attachment either directly to the surface of the component or to an integrally cast or forged attachment to the component, and

(d) the attachment weld is full penetration, fillet, or partial penetration, either continuous or intermittent.

(2) The extent of the examination includes essentially 100% of the length of the attachment weld at each attachment subject to examination, except that, for the configuration shown in Figure IWB-2500-15, examination of surface areas may be limited to the portions of these areas that are accessible without removal of support members.

(3) Selected samples of welded attachments shall be examined each inspection interval.

(4) For multiple vessels of similar design, function and service, only one welded attachment of only one of the multiple vessels shall be selected for examination. For single vessels, only one welded attachment shall be selected for examination. The attachment selected for examination on one of the multiple vessels or the single vessel, as applicable, shall be an attachment under continuous load during normal system operation, or an attachment subject to a potential intermittent load (seismic, water hammer, etc.) during normal system operation if an attachment under continuous load does not exist.

(5) For piping, pumps, and valves, a sample of 10% of the welded attachments associated with the component supports selected for examination under IWF-2510 shall be examined.

(6) Examination is required whenever component support member deformation, e.g., broken, bent, or pulled out parts, is identified during operation, refueling, maintenance, examination, or testing.

Table IWB-2500-1 (B-K)
Examination Category B-K, Welded Attachments for Vessels, Piping, Pumps, and Valves (Cont'd)

NOTES (CONT'D):

(7) For the configurations shown in Figures IWB-2500-13 and IWB-2500-14, a surface examination from an accessible side of the attachment weld shall be performed. Alternatively, for the configuration shown in Figure IWB-2500-14, a volumetric examination of volume A-B-C-D from an accessible side of the attachment weld may be performed in lieu of the surface examination of surfaces A-B or C-D.

Table IWB-2500-1 (B-L-2, B-M-2)
Examination Categories B-L-2, Pump Casings; B-M-2, Valve Bodies

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination: First Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals	Deferral of Examination to End of Interval
	Pumps						
B12.20	Pump casing (B-L-2)	Internal surfaces	Visual, VT-3	IWB-3519	Internal surface [Note (1)]	Same as for first interval	See [Note (2)]
	Valves						
B12.50	Valve body, exceeding NPS 4 (DN 100) (B-M-2)	Internal surfaces	Visual, VT-3	IWB-3519	Internal surface [Note (3)]	Same as for first interval	See [Note (2)]

NOTES:

(1) Examinations are limited to at least one pump in each group of pumps performing similar functions in the system, e.g., recirculating coolant pumps.

(2) Examination is required only when a pump or valve is disassembled for maintenance, or repair. Examination of the internal pressure boundary shall include the internal pressure-retaining surfaces made accessible for examination by disassembly. If a partial examination is performed and a subsequent disassembly of that pump or valve allows a more extensive examination, an examination shall be performed during the subsequent disassembly. A complete examination is required only once during the interval.

(3) Examinations are limited to at least one valve within each group of valves that are of the same size, constructural design (such as globe, gate, or check valves), and manufacturing method, and that perform similar functions in the system (such as containment isolation and system overpressure protection).

Table IWB-2500-1 (B-N-1, B-N-2, B-N-3)
Examination Categories B-N-1, Interior of Reactor Vessel; B-N-2, Welded Core Support Structures and Interior Attachments to Reactor Vessels; B-N-3, Removable Core Support Structures

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination: First Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals	Deferral of Examination to End of Interval
	Reactor Vessel						
B13.10	Vessel interior (B-N-1)	Accessible areas [Note (1)]	Visual, VT-3	IWB-3520.2	Refueling outages [Note (3)]	Each inspection period	Not permissible
	Reactor Vessel (BWR)						
B13.20	Interior attachments within beltline region (B-N-2)	Accessible welds	Visual, VT-1	IWB-3520.1	Welds	Same as for first interval	Permissible
B13.30	Interior attachments beyond beltline region (B-N-2)	Accessible welds	Visual, VT-3	IWB-3520.2	Welds	Same as for first interval	Permissible
B13.40	Core support structure (B-N-2)	Accessible surfaces	Visual, VT-3	IWB-3520.2	Surfaces	Same as for first interval	Permissible
	Reactor Vessel (PWR)						
B13.50	Interior attachments within beltline region (B-N-2)	Accessible welds	Visual, VT-1	IWB-3520.1	Welds	Same as for first interval	Permissible
B13.60	Interior attachments beyond beltline region (B-N-2)	Accessible welds	Visual, VT-3	IWB-3520.2	Welds	Same as for first interval	Permissible
B13.70	Core support structure [Note (2)] (B-N-3)	Accessible surfaces	Visual, VT-3	IWB-3520.2	Surfaces	Same as for first interval	Permissible

NOTES:
(1) Areas to be examined shall include the spaces above and below the reactor core that are made accessible for examination by removal of components during normal refueling outages.
(2) The structure shall be removed from the reactor vessel for examination.
(3) At 1st refueling outage, and subsequent refueling outages at approximately 3-yr intervals.

(15)

Table IWB-2500-1 (B-O)
Examination Category B-O, Pressure-Retaining Welds in Control Rod Drive and Instrument Nozzle Housings

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination: First Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals	Deferral of Examination to End of Interval
	Reactor Vessel (BWR)						
B14.10	Welds in Control Rod Drive (CRD) housing	IWB-2500-18	Volumetric or surface	IWB-3523	See [Note (1)]	Same as for first interval	Permissible
	Reactor Vessel (PWR)						
B14.20	Welds in Control Rod Drive (CRD) Housings	IWB-2500-18	Volumetric or surface [Note (2)]	IWB-3523	See [Note (1)]	Same as for first interval	Permissible
B14.21	Welds in In-Core Instrumentation Nozzle (ICI) Housings > NPS 2 (DN50)	IWB-2500-18	Volumetric or surface [Note (2)]	IWB-3523	10% ICI housings	Same as for first interval	Permissible

NOTES:
(1) Examination is required on 10% of peripheral CRD housings. Alternatively, 10% of the combined length of each weld configuration (e.g., housing-to-housing and housing-to-flange) of the peripheral CRD housing welds may be examined, provided each weld selected for examination is examined to the maximum extent practicable.
(2) The surface examination method shall be performed on the inside diameter of the penetration nozzle housing welds as shown in Figure IWB-2500-18 for examination surface area C-D.

Table IWB-2500-1 (B-P)
Examination Category B-P, All Pressure-Retaining Components

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method [Note (1)]	Acceptance Standard	Extent and Frequency of Examination: First Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals	Deferral of Examination to End of Interval
B15.10	Pressure-retaining components [IWB-5222(a)]	System leakage test (IWB-5220)	Visual, VT-2	IWB-3522	Each refueling outage [Note (2)]	Same as for first interval	Not permissible
B15.20	Pressure-retaining components [IWB-5222(b)]	System leakage test (IWB-5220)	Visual, VT-2	IWB-3522	Once per interval [Note (3)]	Same as for first interval	See [Note (3)]

NOTES:
(1) Visual examination of IWA-5240.
(2) The system leakage test (IWB-5220) shall be conducted prior to plant startup following a reactor refueling outage.
(3) The system leakage test (IWB-5220) of the boundary of IWB-5222(b) shall be performed at or near the end of the interval.

Table IWB-2500-1 (B-Q)
Examination Category B-Q, Steam Generator Tubing

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination		Deferral of Examination to End of Interval
					First Inspection Interval	Successive Inspection Intervals	
B16.10	Steam Generator Tubing in Straight Tube Design	Entire length of tubing	Volumetric	[Note (2)]	[Note (1)]	[Note (1)]	
B16.20	Steam Generator Tubing in U-Tube Design	Tubing hot leg side, U- bend portion and optionally cold leg side	Volumetric	IWB-3521	[Note (1)]	[Note (1)]	

NOTES:
(1) The extent and frequency of examination shall be governed by the plant Technical Specification.
(2) In the course of preparation.

Figure IWB-2500-1
Vessel Shell Circumferential Weld Joints

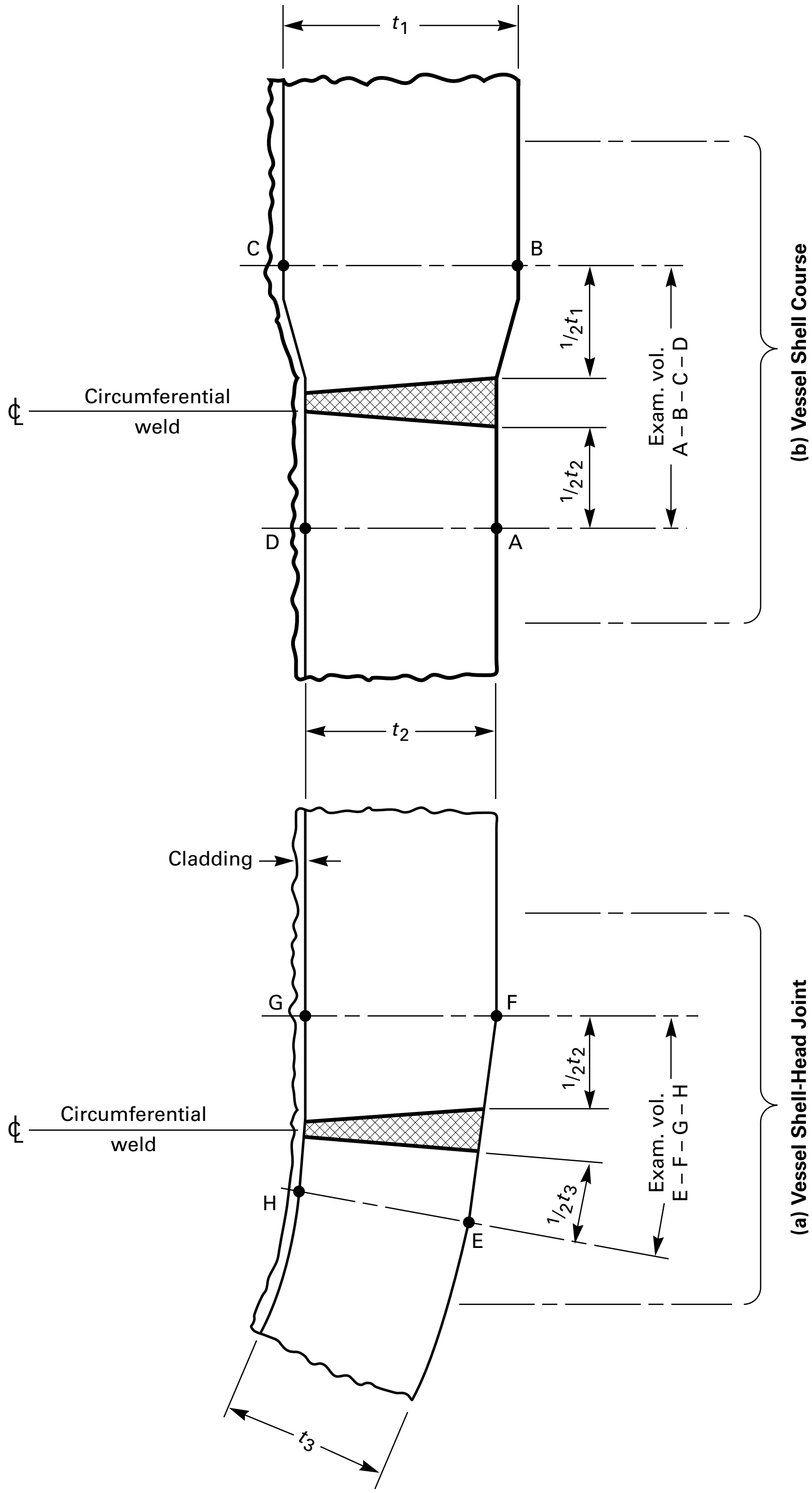


Figure IWB-2500-2
Vessel Shell Longitudinal Weld Joints

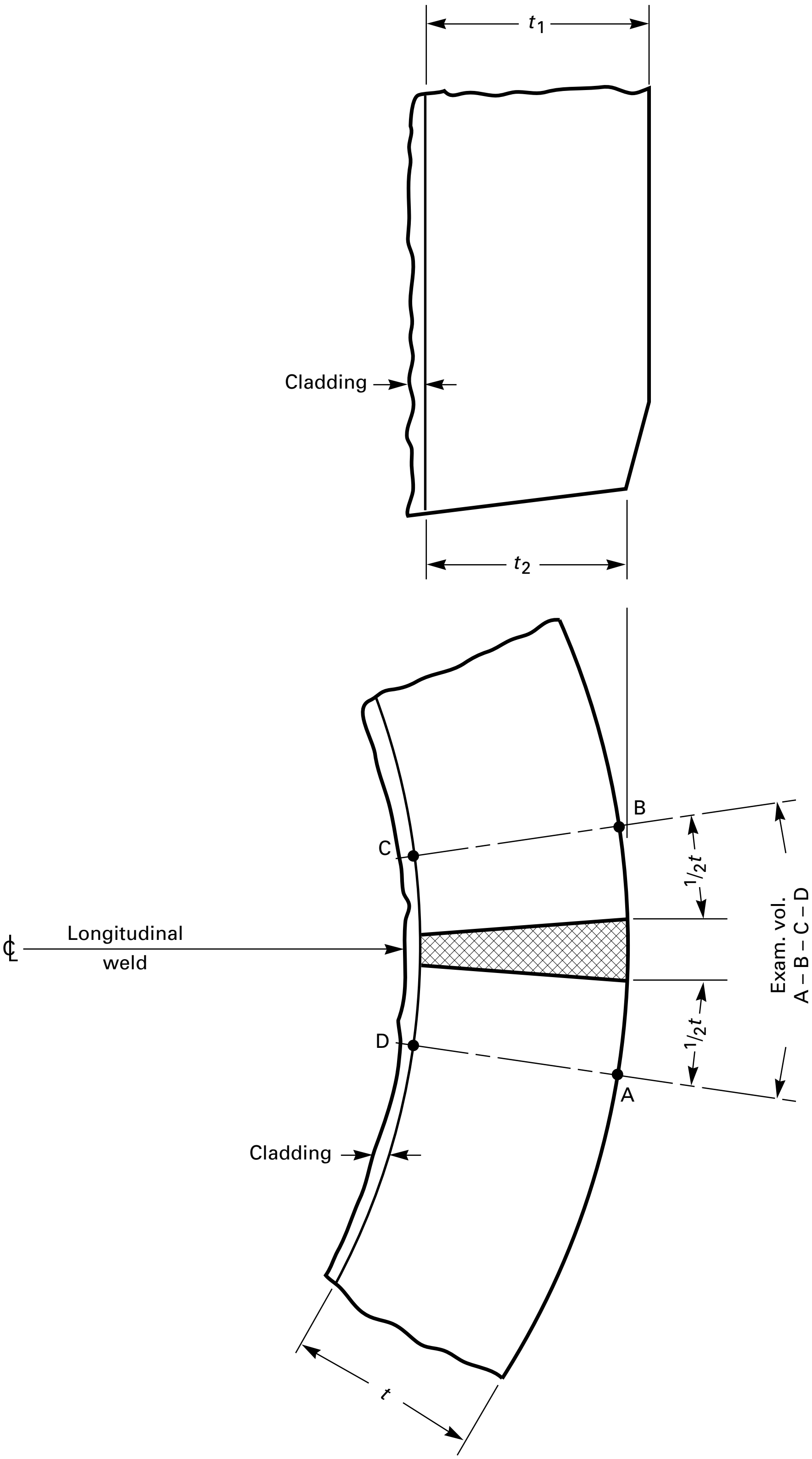


Figure IWB-2500-3
Spherical Vessel Head Circumferential and Meridional Weld Joints

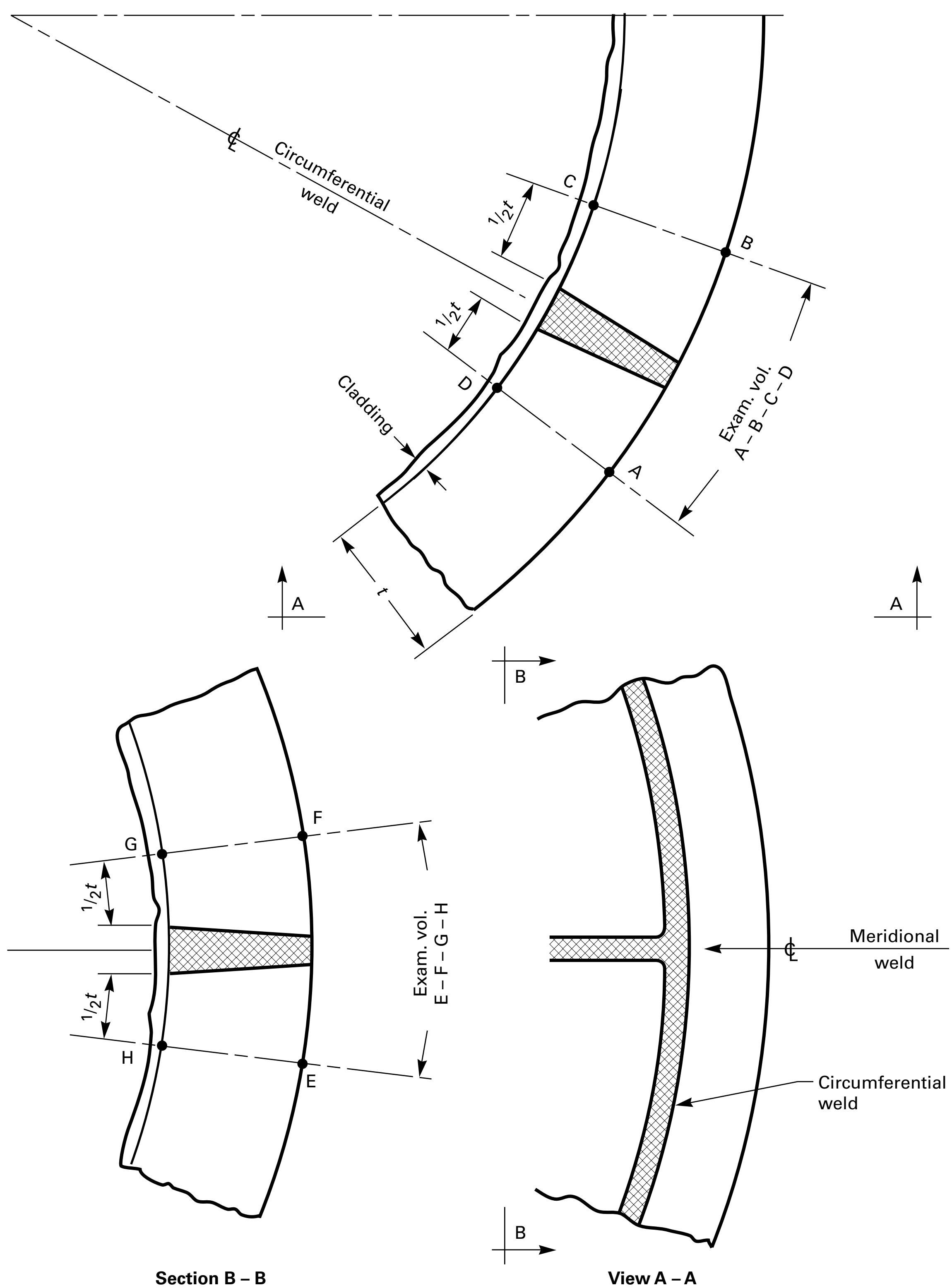


Figure IWB-2500-4
Shell-to-Flange Weld Joint

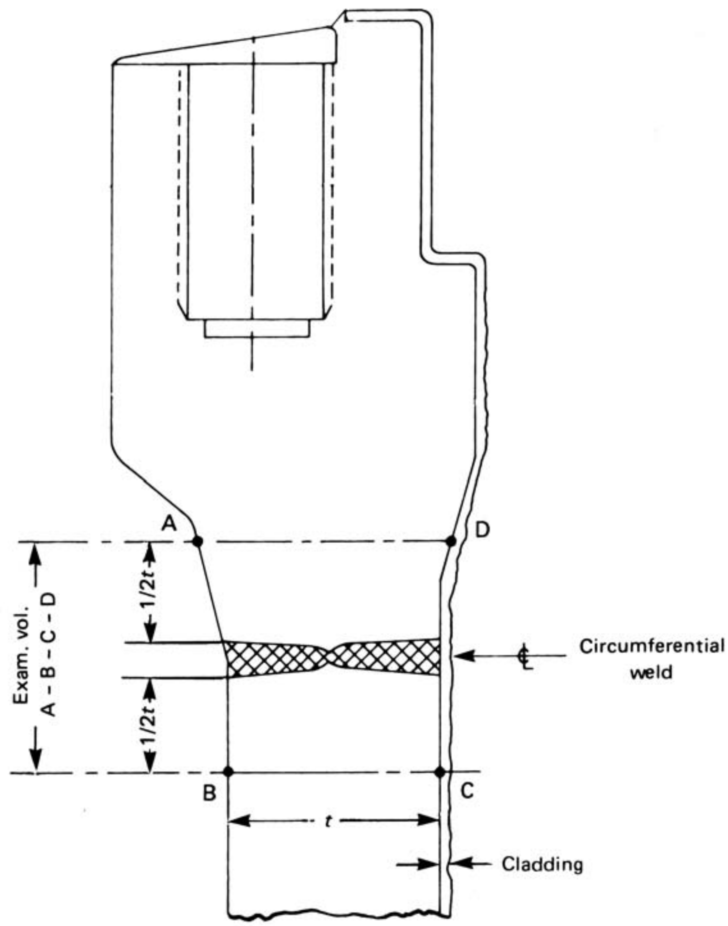


Figure IWB-2500-5
Head-to-Flange Weld Joint

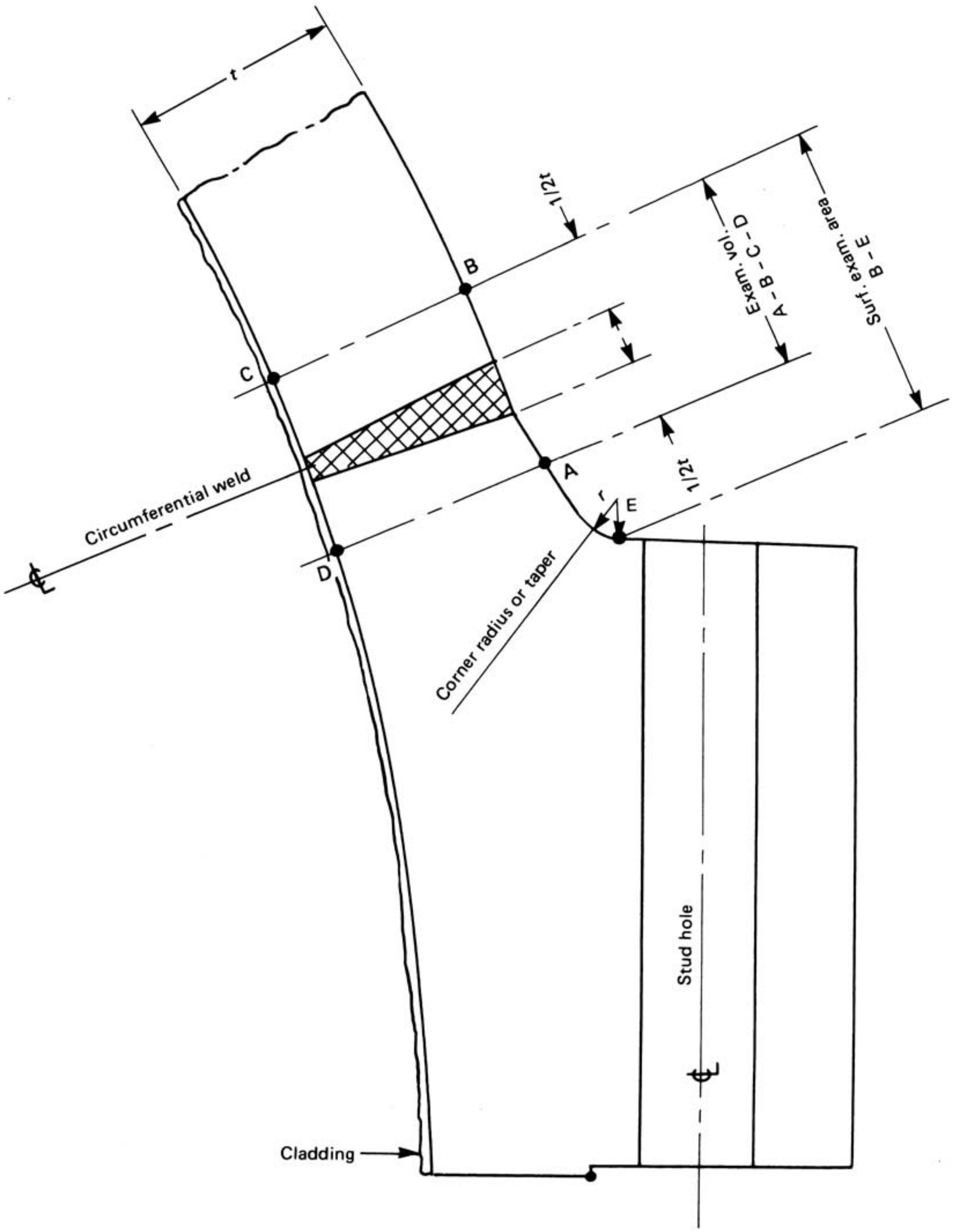
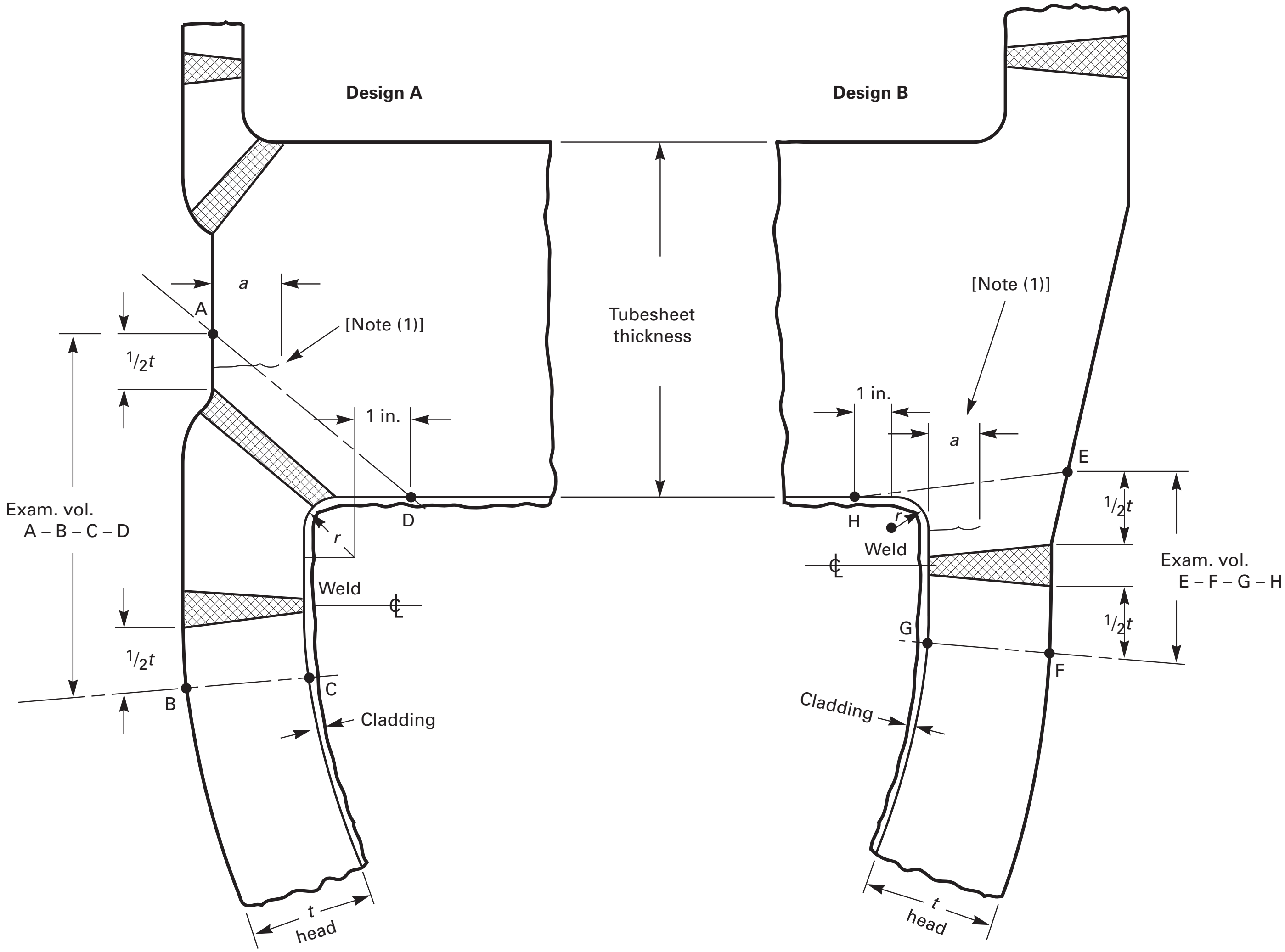


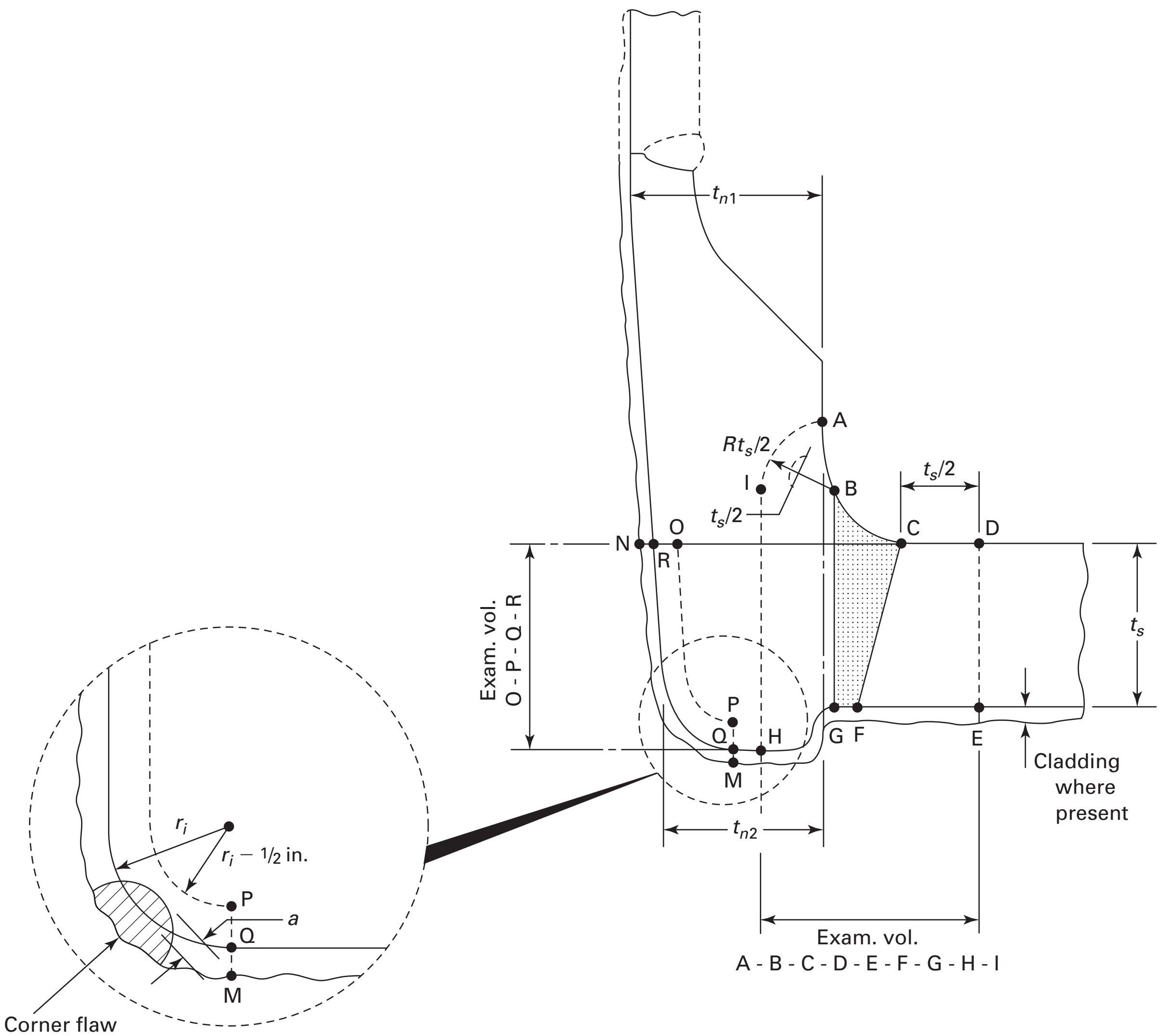
Figure IWB-2500-6
Typical Tubesheet-to-Head Weld Joints



GENERAL NOTE: All flaws are exaggerated in size and scale.

NOTE:
(1) Laminar flaws within examined volume of tubesheet are considered planar flaws.

Figure IWB-2500-7(a)
Nozzle in Shell or Head
(Examination Zones in Barrel-Type Nozzles Joined by Full Penetration Corner Welds)



EXAMINATION REGION [Note (1)]	EXAMINATION VOLUME [Notes (2) and (3)]
Shell (or head) adjoining region	C-D-E-F
Attachment weld region	B-C-F-G
Nozzle cylinder region	A-B-G-H-I
Nozzle inside corner region	O-P-Q-R

Legend:

r_i = nozzle inside corner radius

t_{n1}, t_{n2} = nozzle wall thickness

t_s = shell (or head) thickness

GENERAL NOTE: 1/2 in. = 13 mm

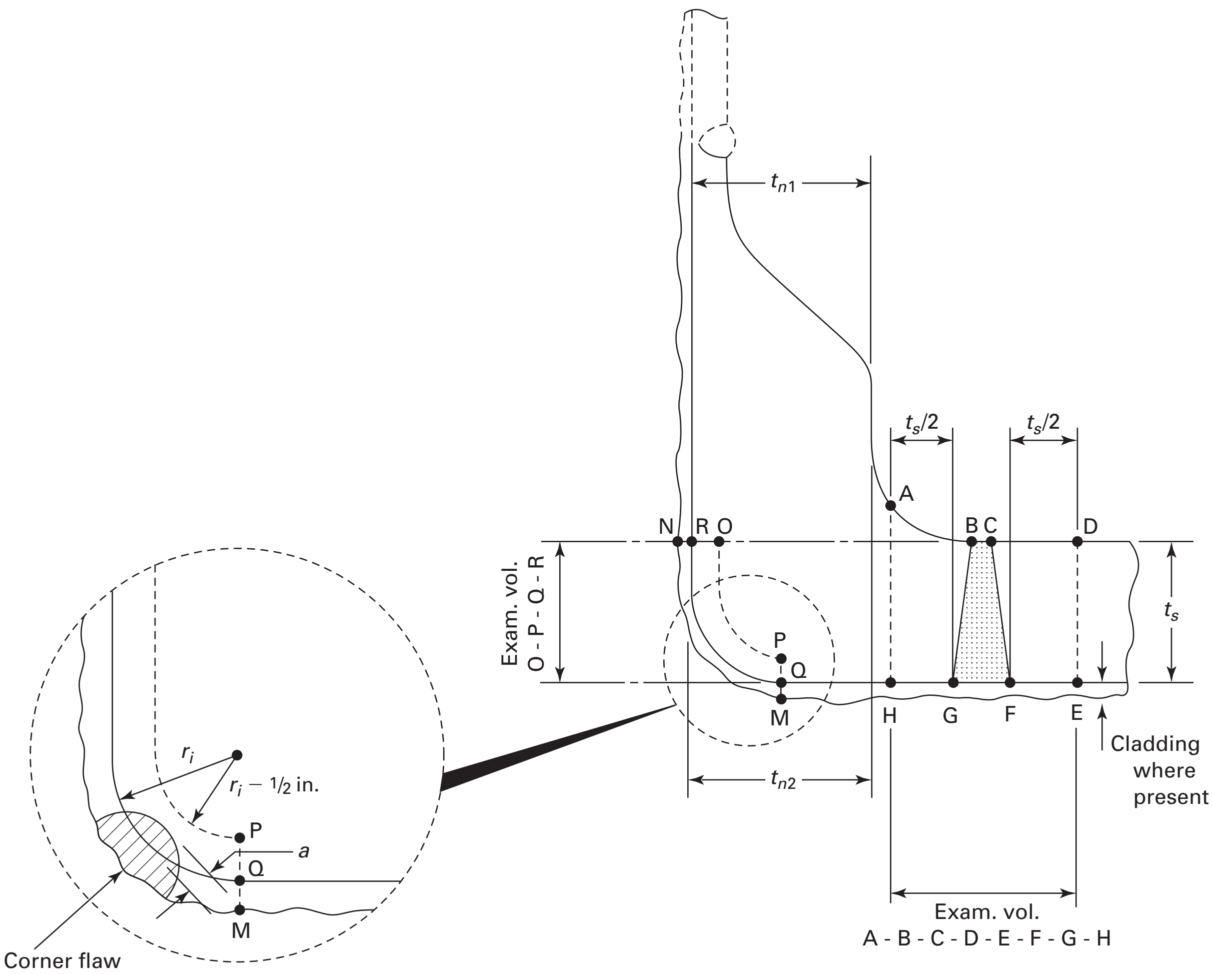
NOTES:

(1) Examination regions are identified for the purpose of differentiating the acceptance standards in IWB-3512.

(2) Examination volumes may be determined either by direct measurements on the component or by measurements based on design drawings.

(3) The dimensions for the examination volume shall be determined from the edge of the weld bevel if the weld toe extends beyond the bevel.

Figure IWB-2500-7(b) Nozzle in Shell or Head (Examination Zones in Flange Type Nozzles Joined by Full Penetration Butt Welds)



EXAMINATION REGION [Note (1)]	EXAMINATION VOLUME [Note (2)]
Shell (or head) adjoining region	C-D-E-F
Attachment weld region	B-C-F-G
Nozzle cylinder region	A-B-G-H
Nozzle inside corner region	O-P-Q-R

Legend:

r_i = nozzle inside corner radius

t_{n1}, t_{n2} = nozzle wall thickness

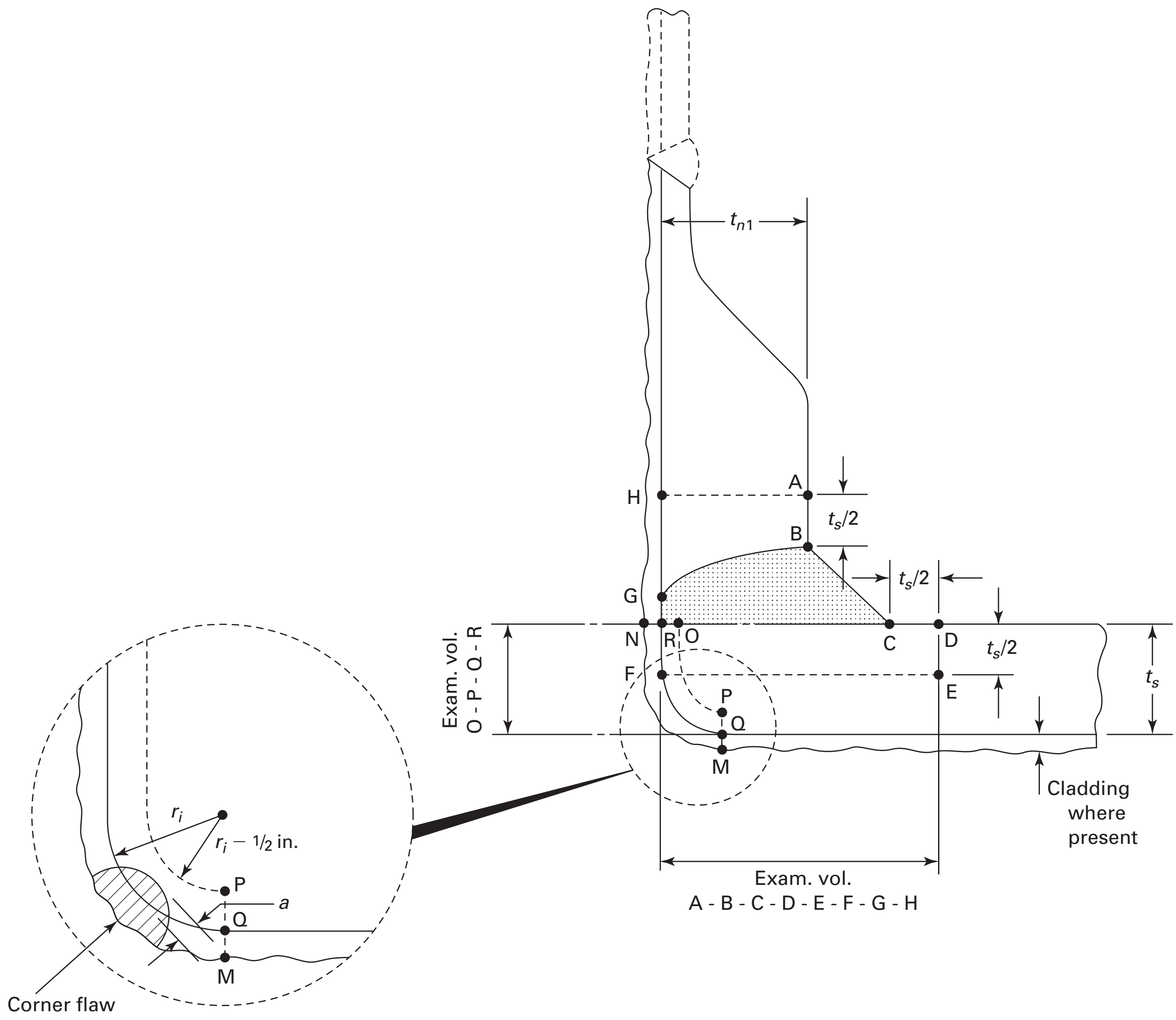
t_s = shell (or head) thickness

NOTES:

(1) Examination regions are identified for the purpose of differentiating the acceptance standards in IWB-3512.

(2) Examination volumes may be determined either by direct measurements on the component or by measurements based on design drawings.

Figure IWB-2500-7(c)
Nozzle in Shell or Head
(Examination Zones in Set-On Type Nozzles Joined by Full Penetration Corner Welds)



EXAMINATION REGION [Note (1)]	EXAMINATION VOLUME [Notes (2) and (3)]
Shell (or head) adjoining region	C-D-E-F-R
Attachment weld region	B-C-R-G
Nozzle cylinder region	A-B-G-H
Nozzle inside corner region	O-P-Q-R

Legend:

r_i = nozzle inside corner radius

t_{n1} = nozzle wall thickness

t_s = shell (or head) thickness

GENERAL NOTE: $\frac{1}{2}$ in. = 13 mm

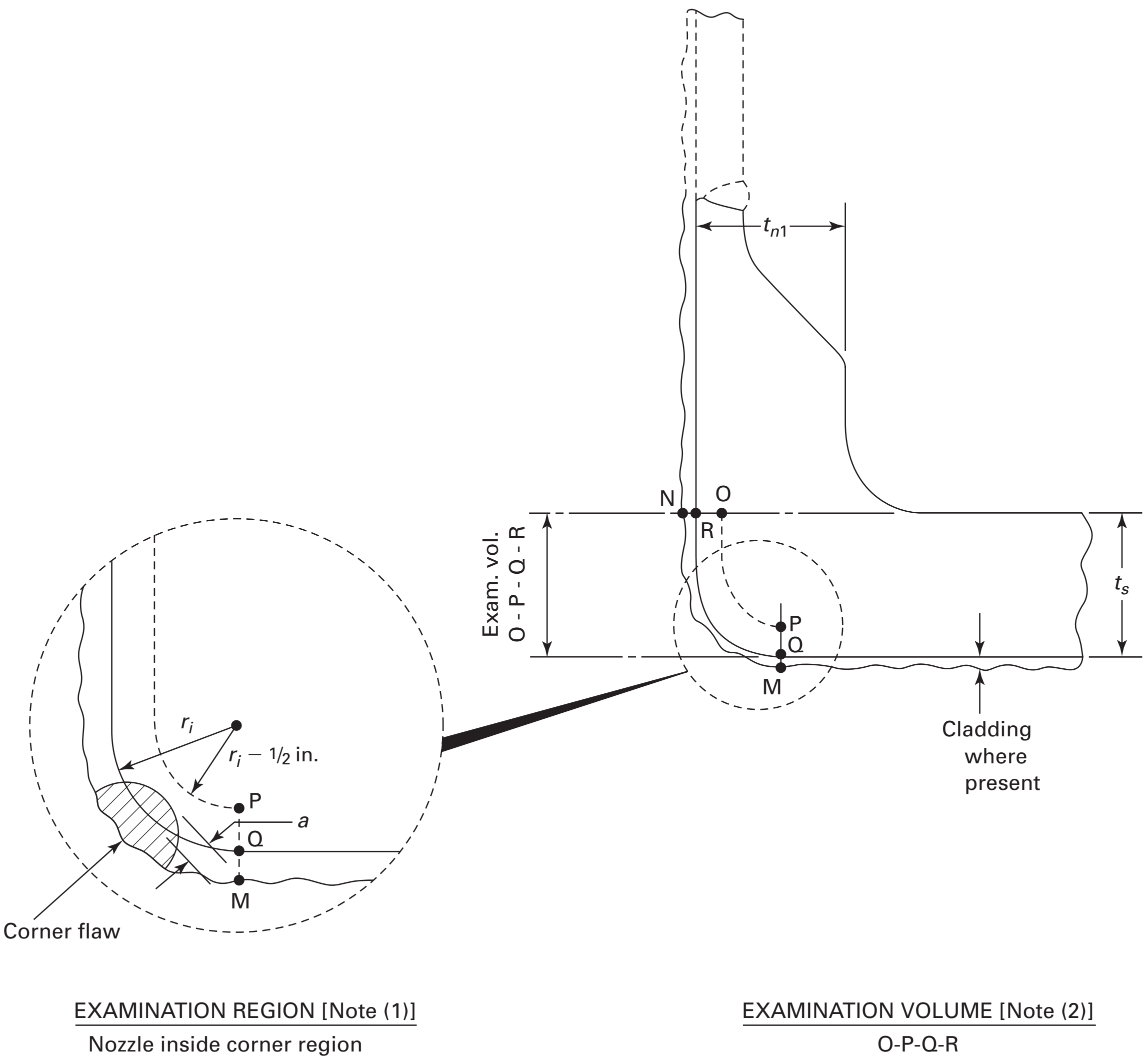
NOTES:

(1) Examination regions are identified for the purpose of differentiating the acceptance standards in IWB-3512.

(2) Examination volumes may be determined either by direct measurements on the component or by measurements based on design drawings.

(3) The dimensions for the examination volume shall be determined from the edge of the weld bevel if the weld toe extends beyond the bevel.

Figure IWB-2500-7(d) Nozzle in Shell or Head (Examination Zone in Nozzles Integrally Cast or Formed in Shell or Head)



Legend:

r_i = nozzle inside corner radius

t_{n1} = nozzle wall thickness

t_s = shell (or head) thickness

GENERAL NOTE: $^1/_2$ in. = 13 mm

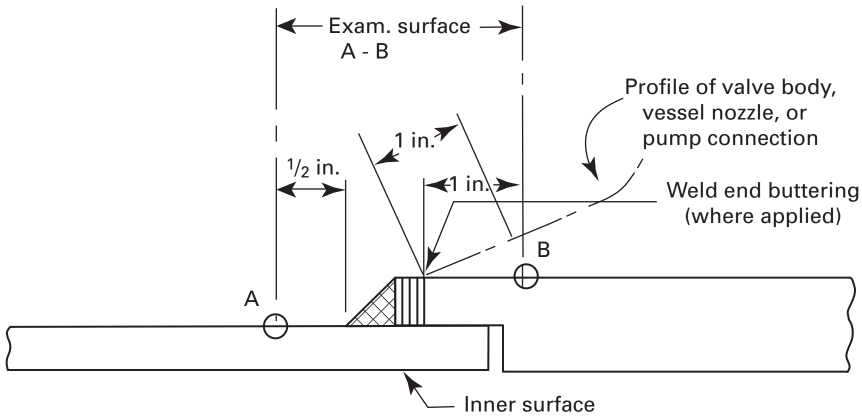
NOTES:

(1) Examination regions are identified for the purpose of differentiating the acceptance standards in IWB-3512.

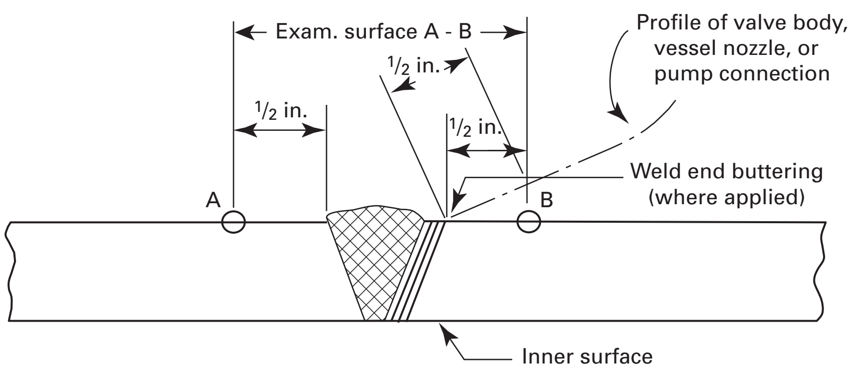
(2) Examination volumes may be determined either by direct measurements on the component or by measurements based on design drawings.

Figure IWB-2500-8 Similar and Dissimilar Metal Welds in Components, Nozzles, and Piping

(15)

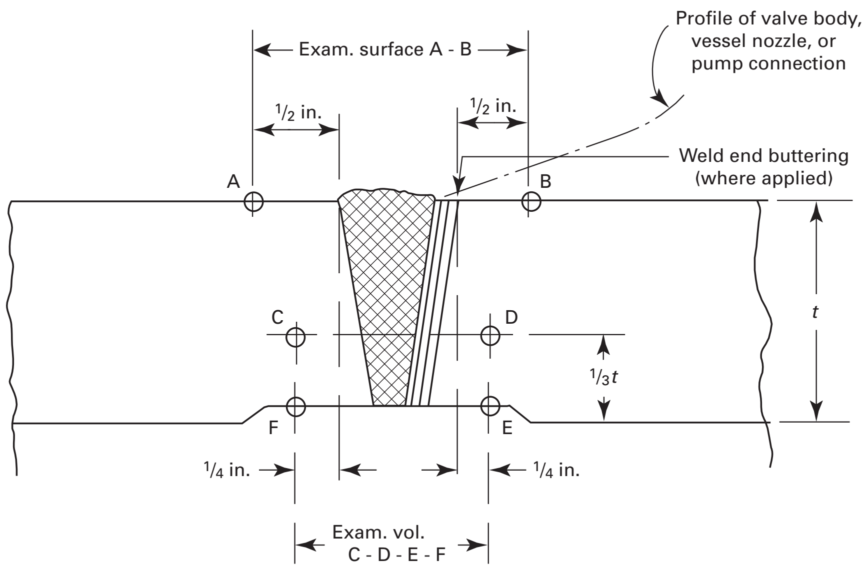


(a) Socket Welded Piping

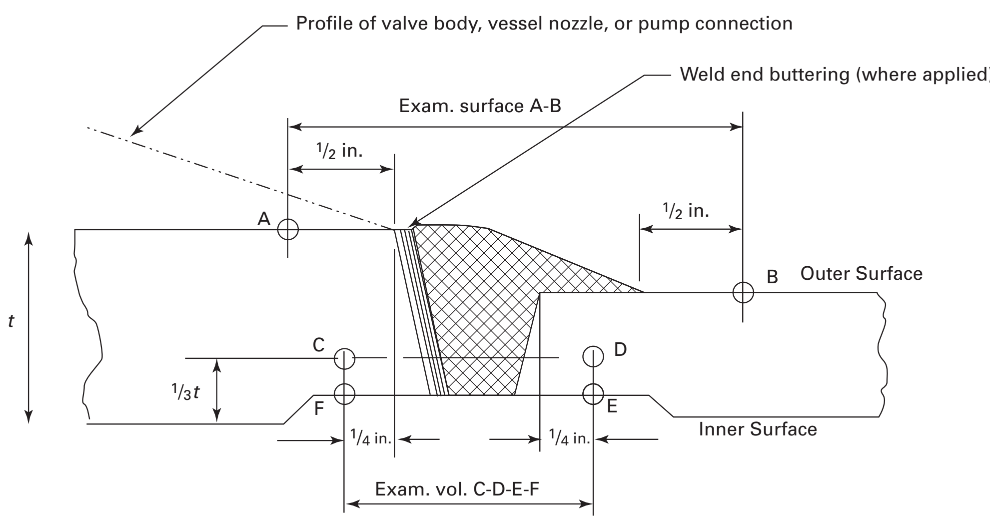


(b) Less Than NPS 4 (DN 100)

Figure IWB-2500-8
Similar and Dissimilar Metal Welds in Components, Nozzles, and Piping (Cont'd)

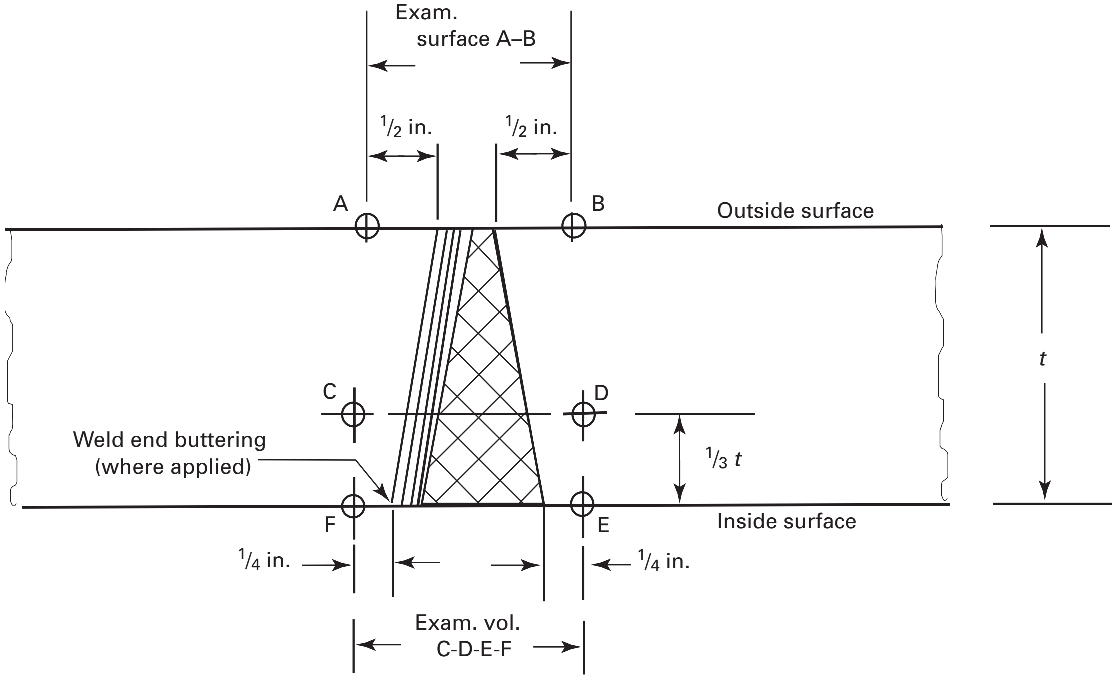


(c) NPS 4 (DN 100) or Larger

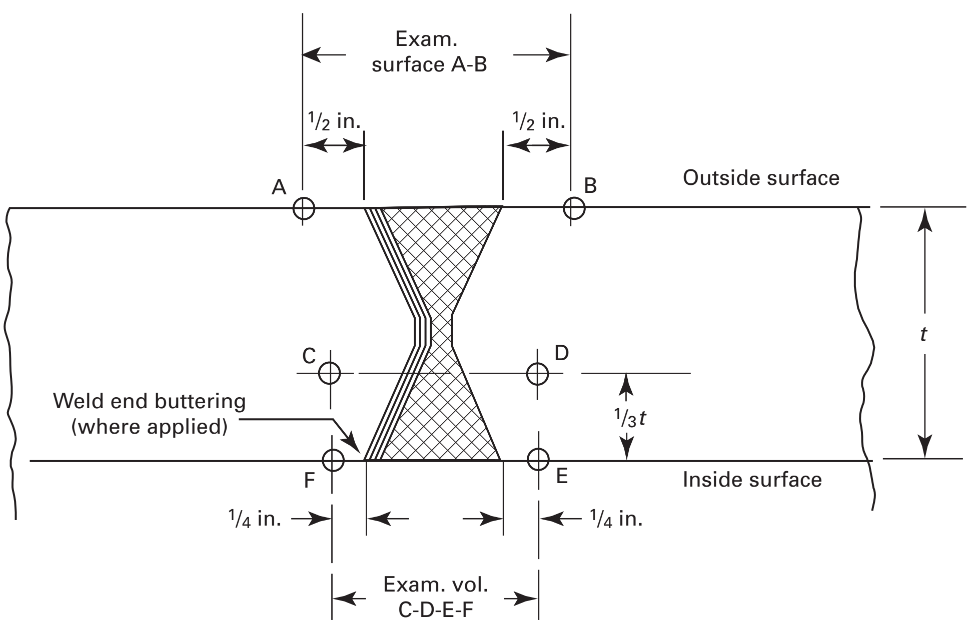


(d) NPS 4 (DN 100) or Larger

Figure IWB-2500-8
Similar and Dissimilar Metal Welds in Components, Nozzles, and Piping (Cont'd)



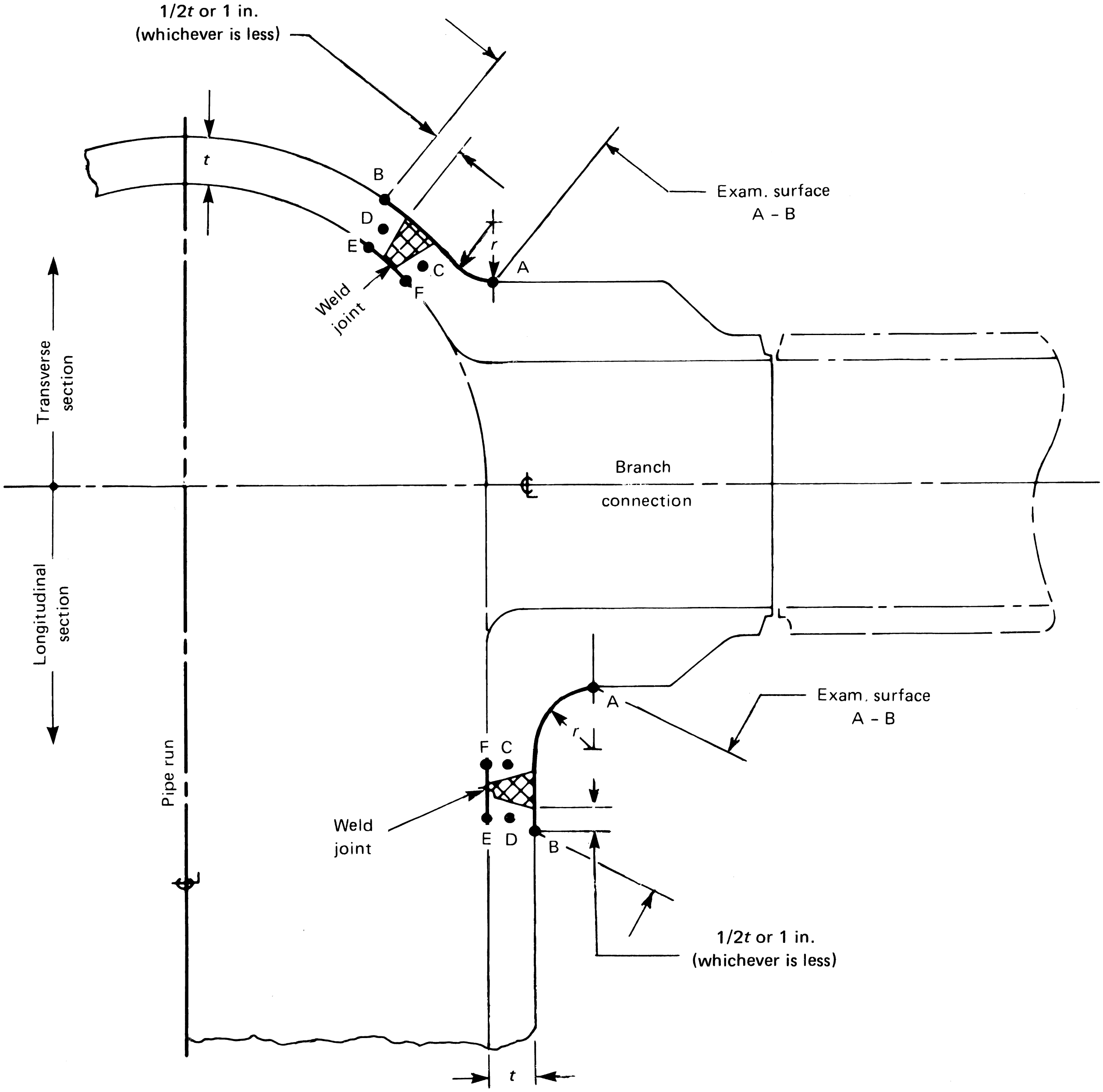
(e) Alternative Configuration for NPS 4 (DN 100) or Larger



(f) Double-Groove Alternative Configuration for NPS 4 (DN 100) or Larger

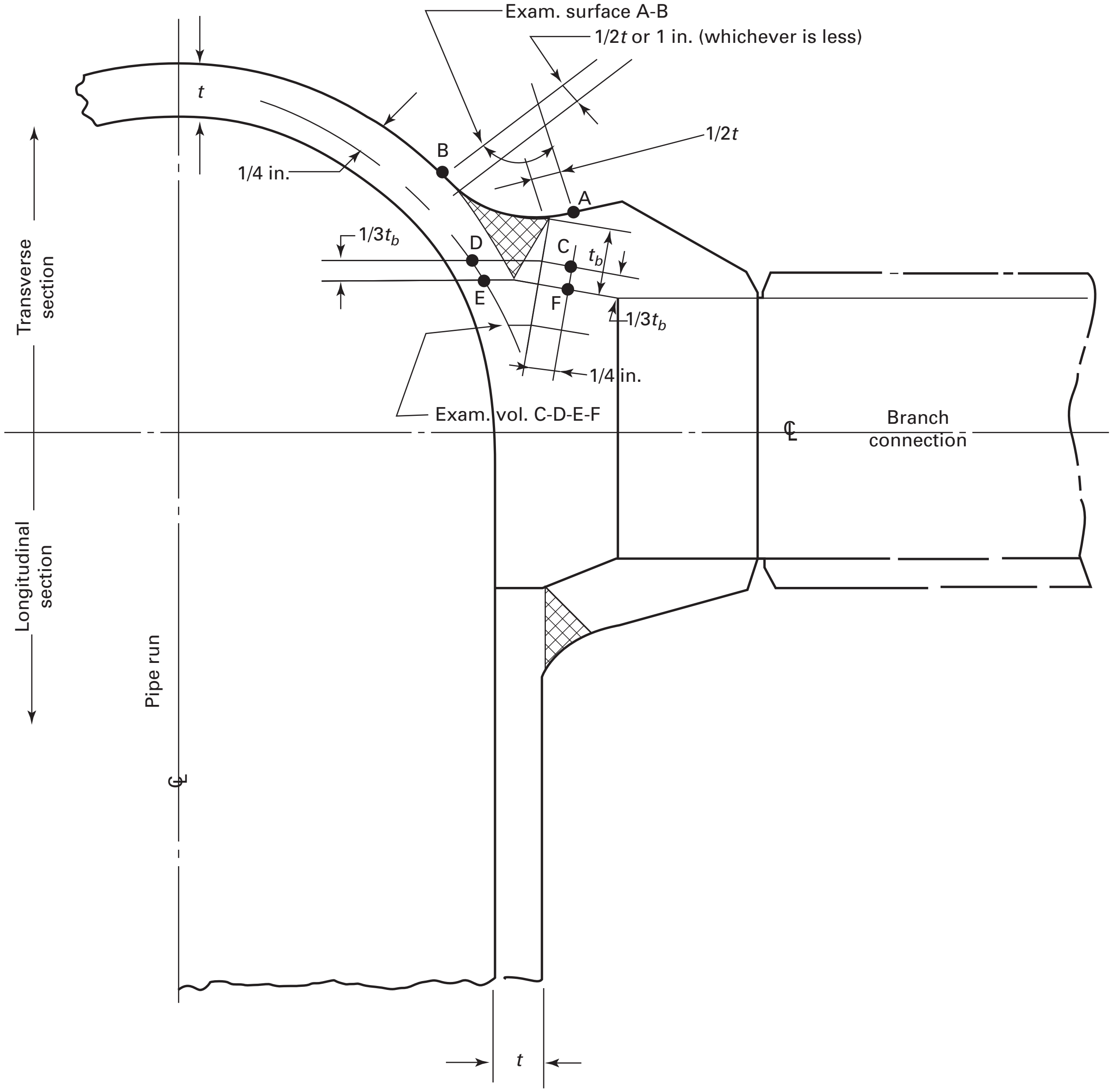
GENERAL NOTES:
(a) 1 in. = 25 mm
(b) $^1/_2$ in. = 13 mm
(c) $^1/_4$ in. = 6 mm
(d) If weld end buttering is present on both sides, the examination surface and volume shall be measured from the ends of both butterings. It might include remnants of replaced welds and might appear artificially wide on exposed surfaces due to fabrication processes. If the true dimension is unknown, buttering thickness may be determined from manufacturer's drawings or shall be assumed to be $^1/_2$ in.

Figure IWB-2500-9
Pipe Branch Connection



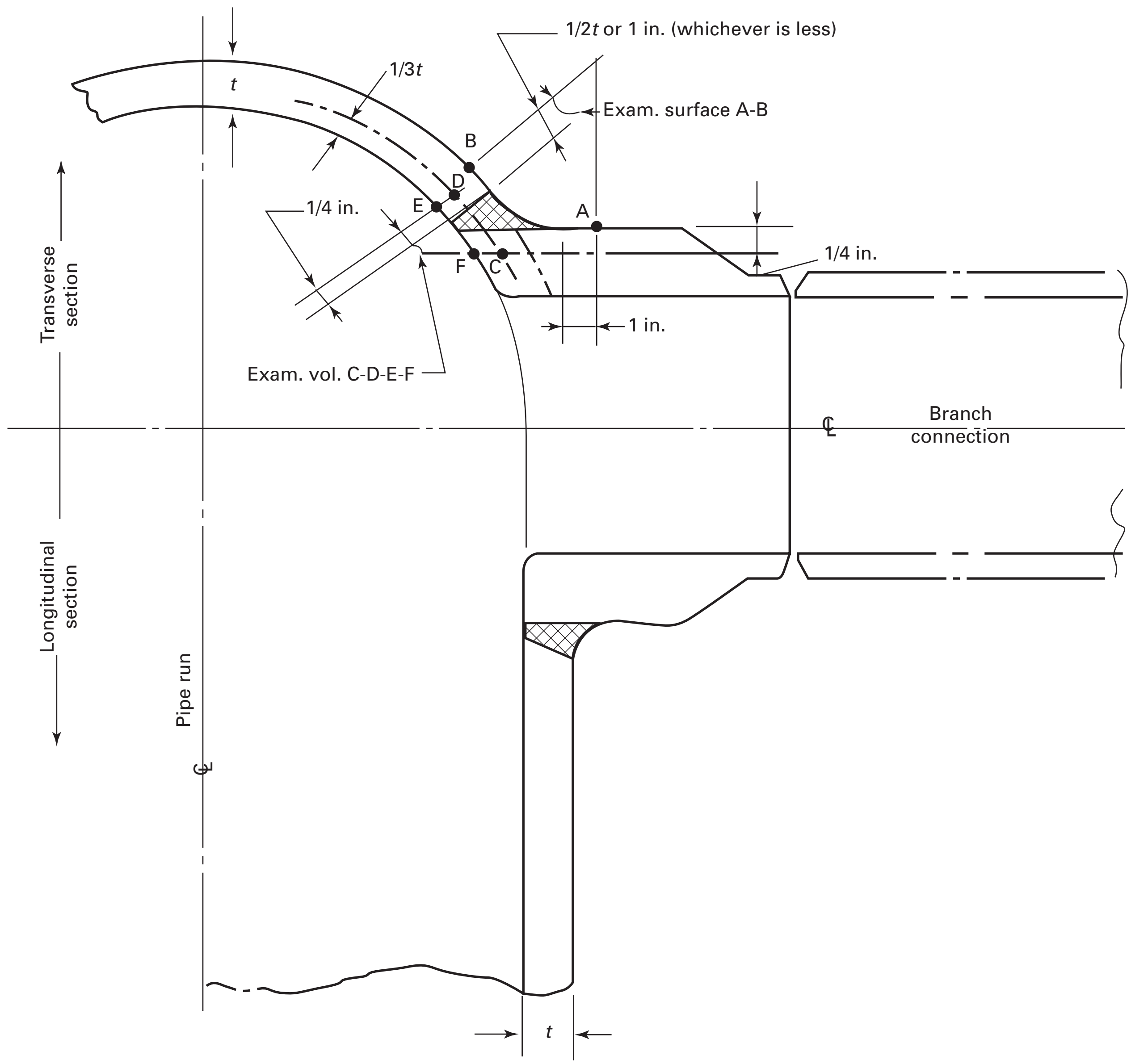
GENERAL NOTES:
(a) 1 in. = 25 mm
(b) Examination volumes C–D–E–F are defined per Figure IWB-2500-8.

Figure IWB-2500-10
Pipe Branch Connection



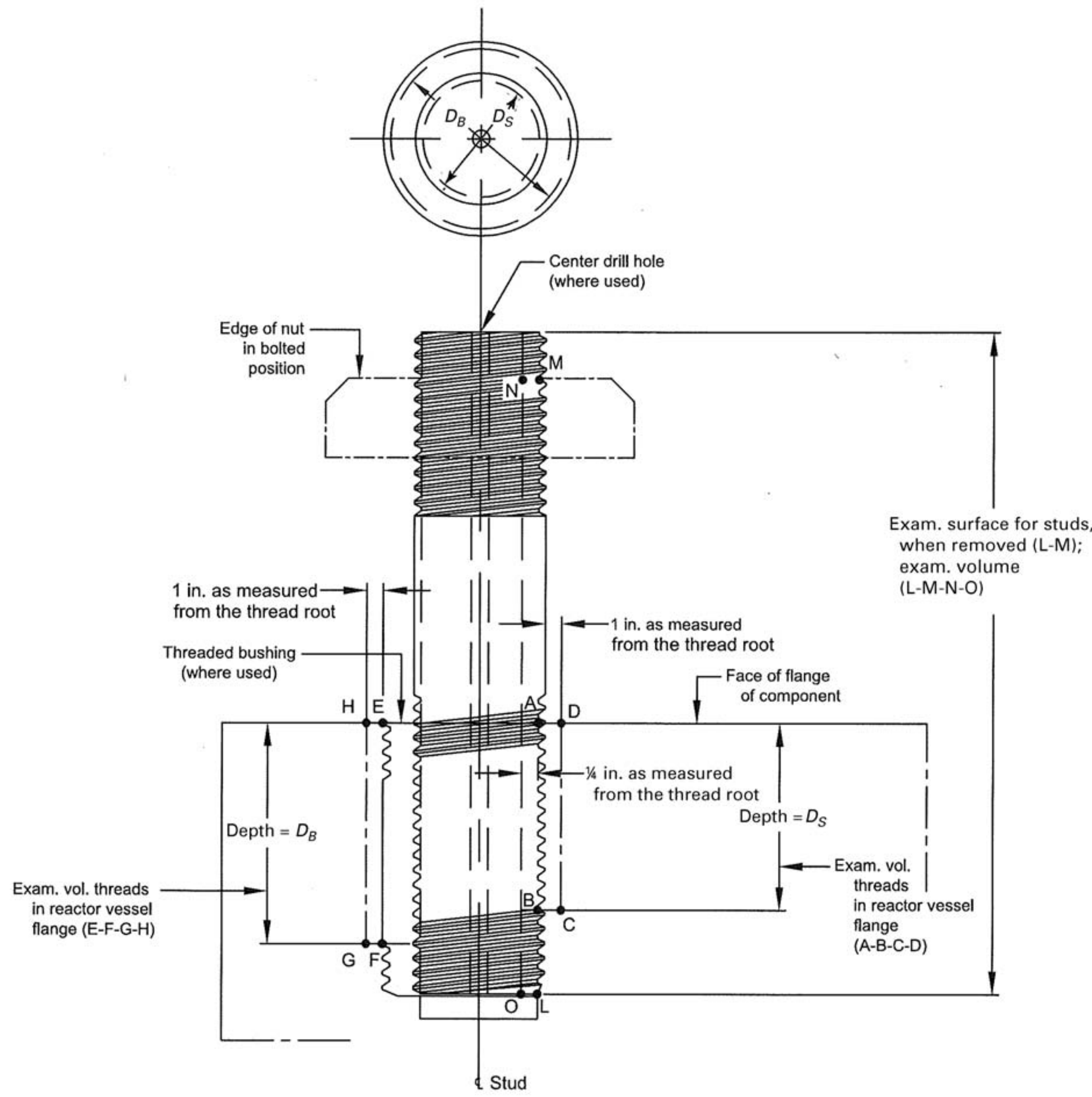
GENERAL NOTES:
(a) 1 in. = 25 mm
(b) Examination volumes C–D–E–F are defined per Figure IWB-2500-8.
(c) The dimensions for the examination volume shall be determined from the edge to the weld bevel if the weld toe extends beyond the bevel.

Figure IWB-2500-11
Pipe Branch Connection



GENERAL NOTES:
(a) 1 in. = 25 mm
(b) Examination volumes C–D–E–F are defined per Figure IWB-2500-8.
(c) The dimensions for the examination volume shall be determined from the edge of the weld bevel if the weld toe extends beyond the bevel.

Figure IWB-2500-12(a) Stud and Threads in Flange Stud Hole (15)



Legend:

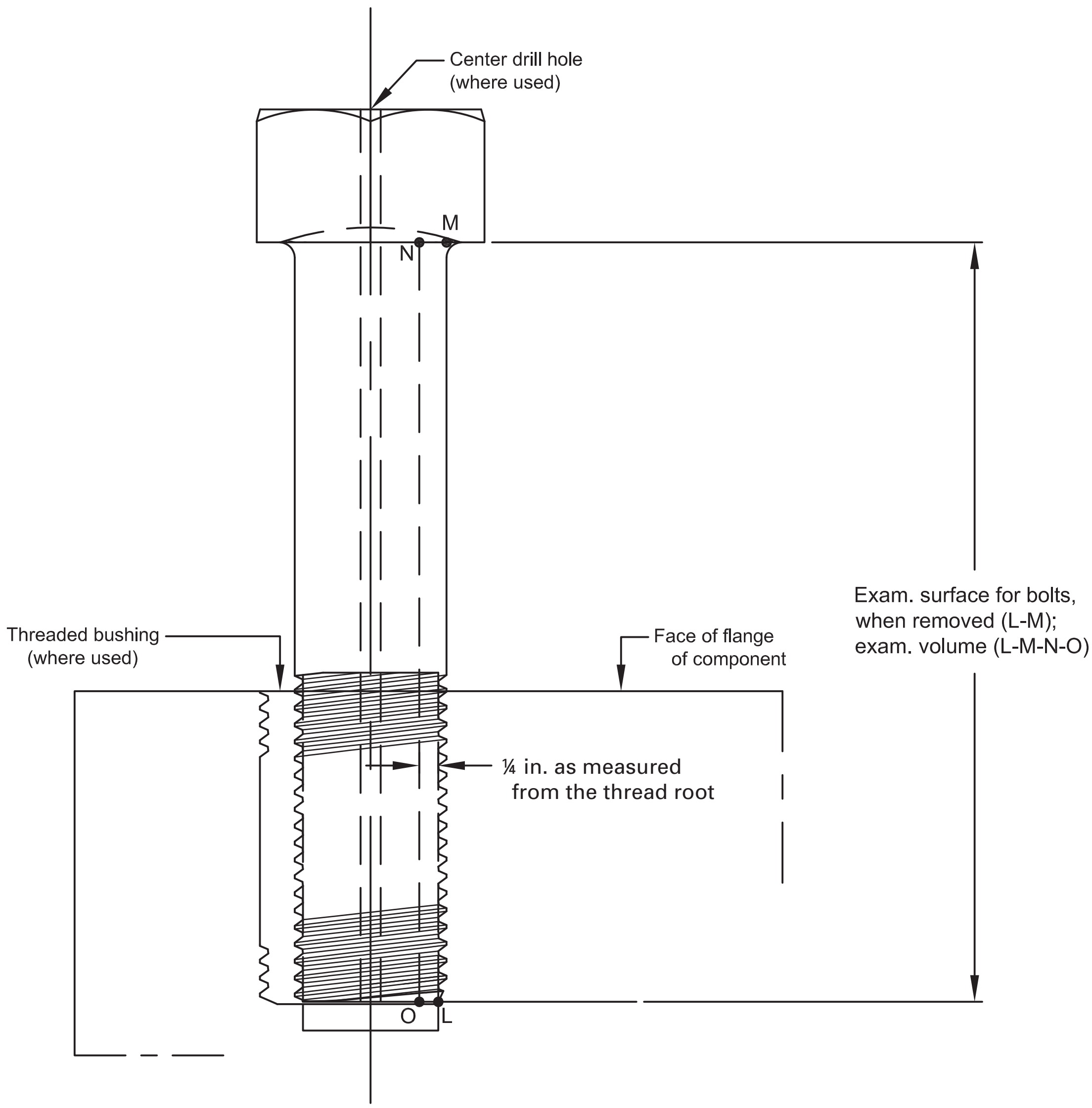
D_B = diameter of the threaded bushing

D_S = diameter of the stud

GENERAL NOTES:
(a) 1 in. = 25 mm
(b) $^1/_4$ in. = 6 mm

(15)

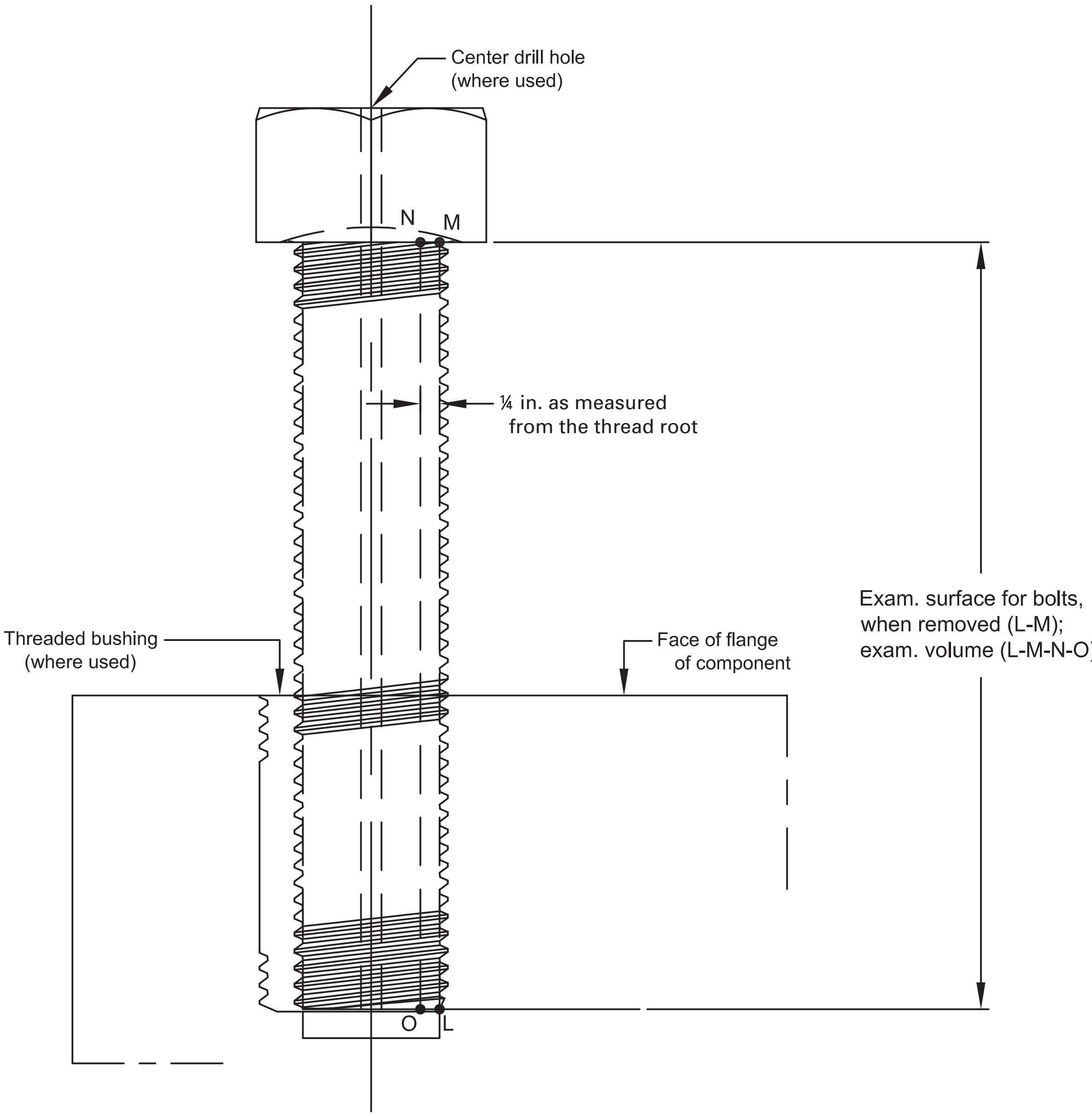
Figure IWB-2500-12(b)
Pressure-Retaining Bolts
(Integral Head With Shank)



GENERAL NOTE: $^1/_4$ in. = 6 mm

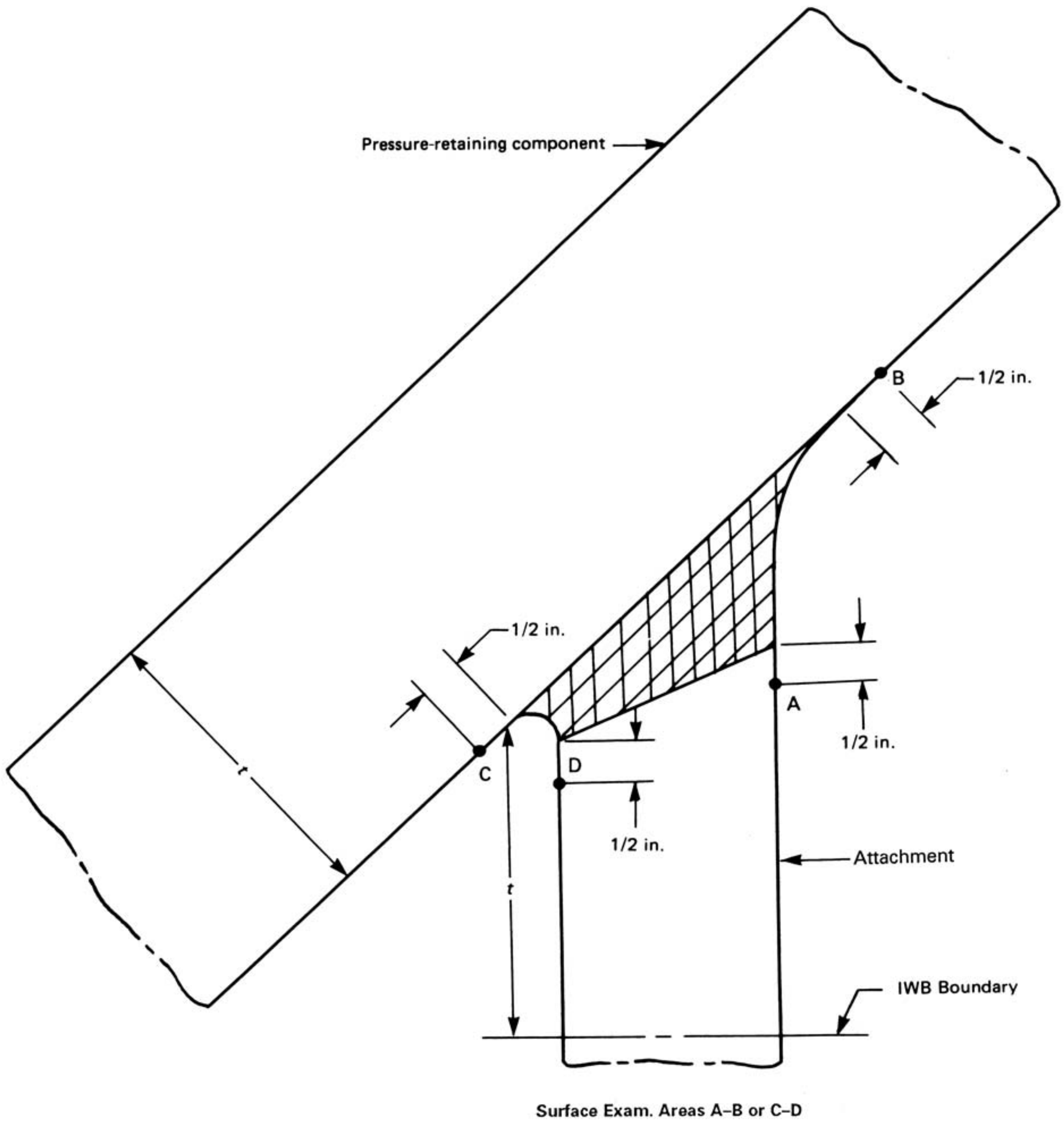
(15)

Figure IWB-2500-12(c)
Pressure-Retaining Bolts
(Integral Head Without Shank)



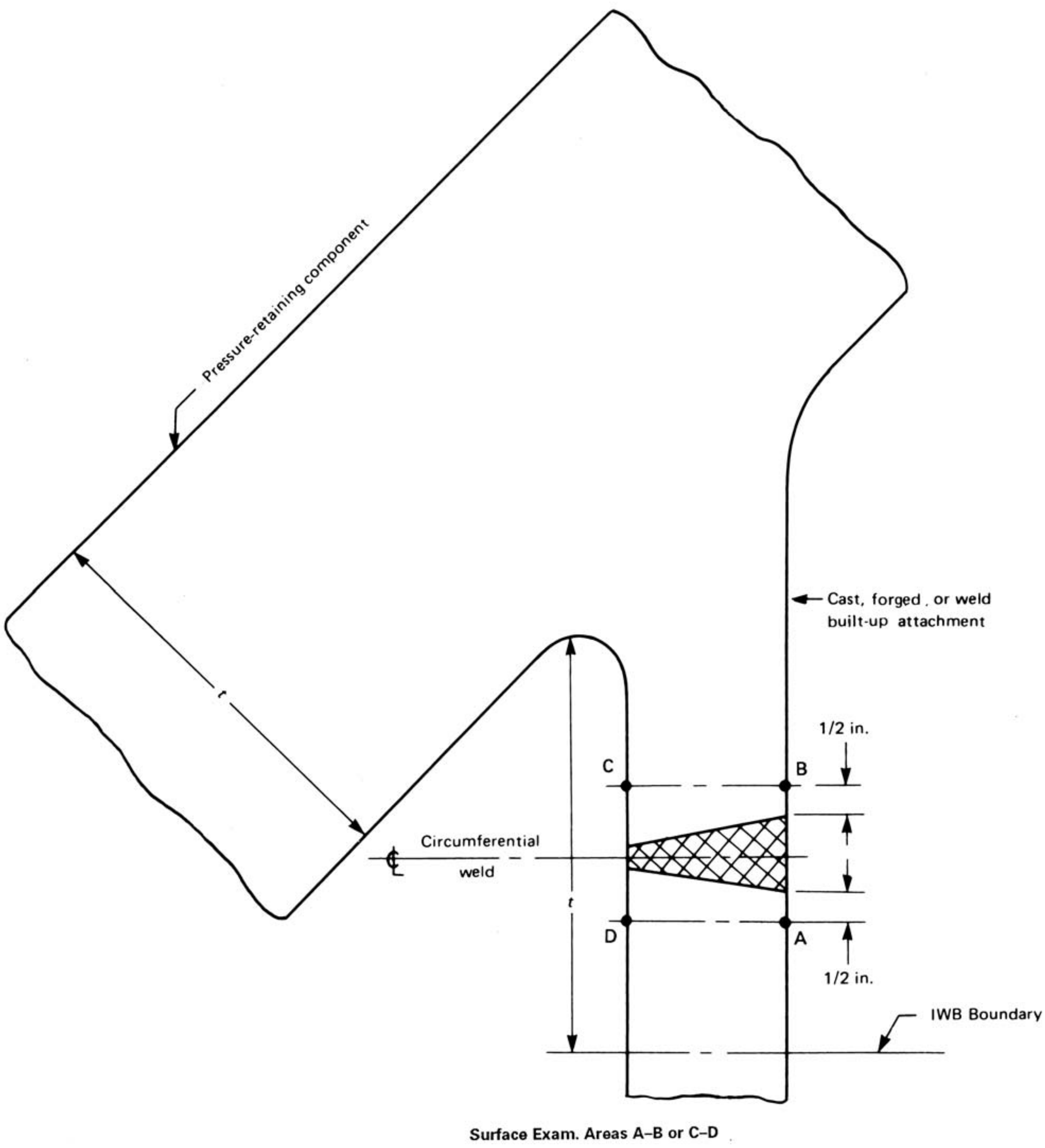
GENERAL NOTE: $^{1}/_{4}$ in. = 6 mm

Figure IWB-2500-13
Welded Attachment



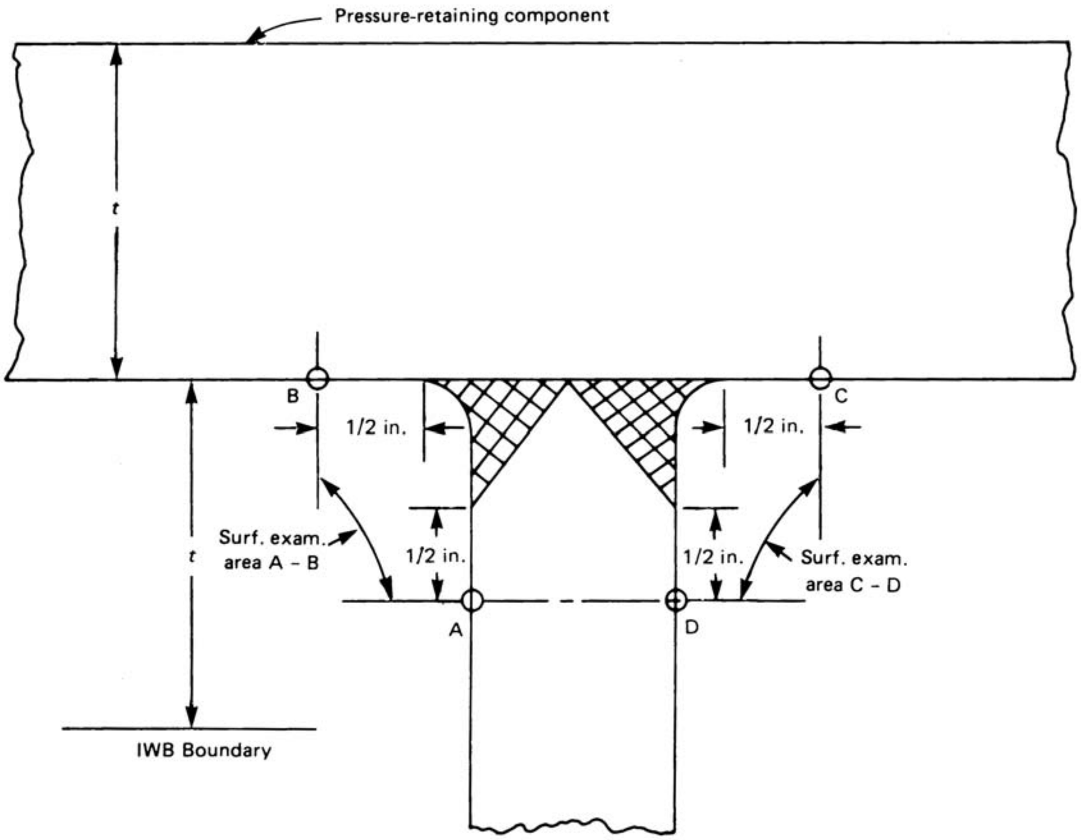
GENERAL NOTE: $\frac{1}{2}$ in. = 13 mm

Figure IWB-2500-14
Welded Attachment



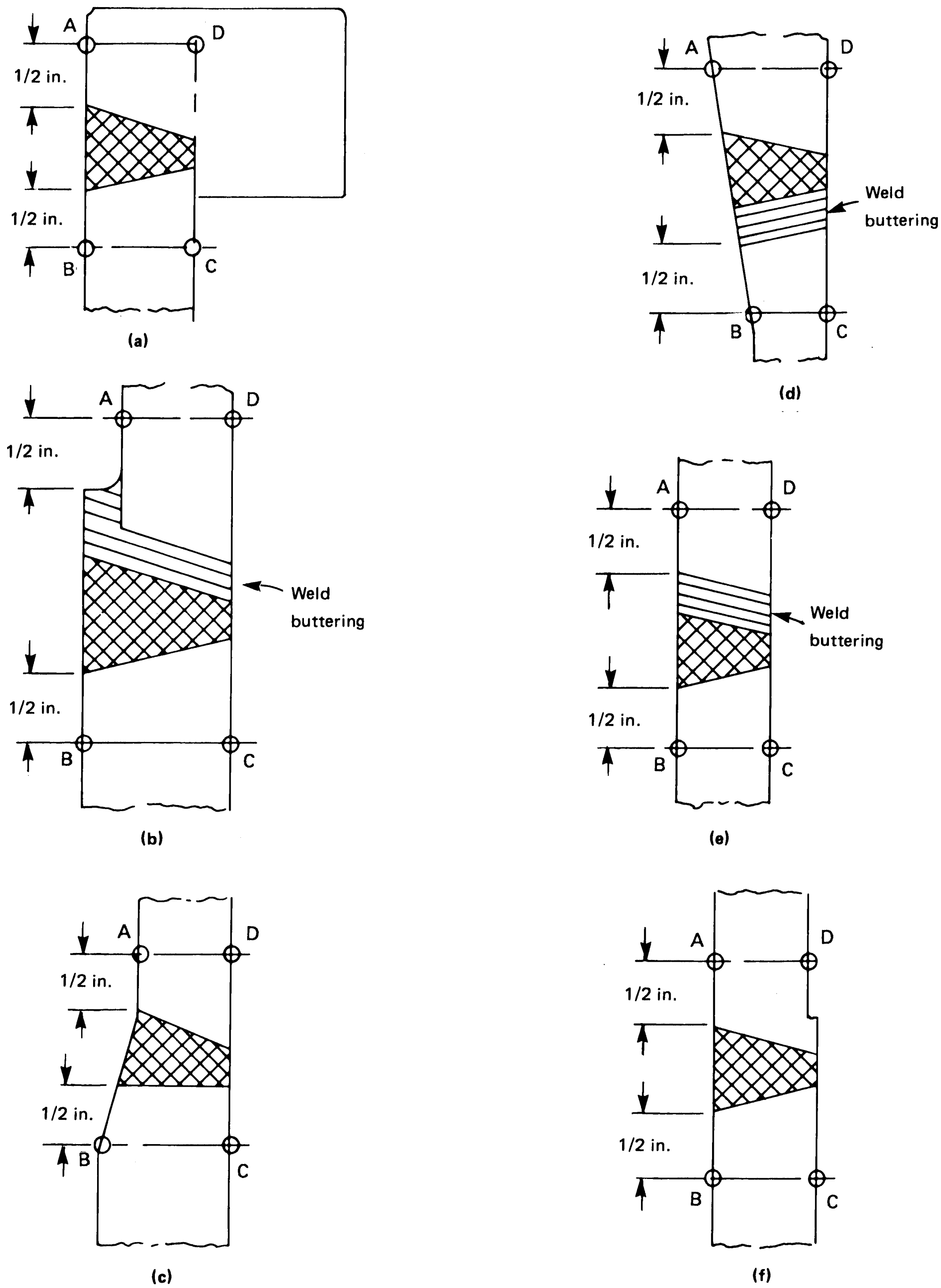
GENERAL NOTE: $\frac{1}{2}$ in. = 13 mm

Figure IWB-2500-15
Welded Attachment



GENERAL NOTES:
(a) Examination of surface areas may be limited to the portions of these areas that are accessible without removal of support members.
(b) $^1/_2$ in. = 13 mm

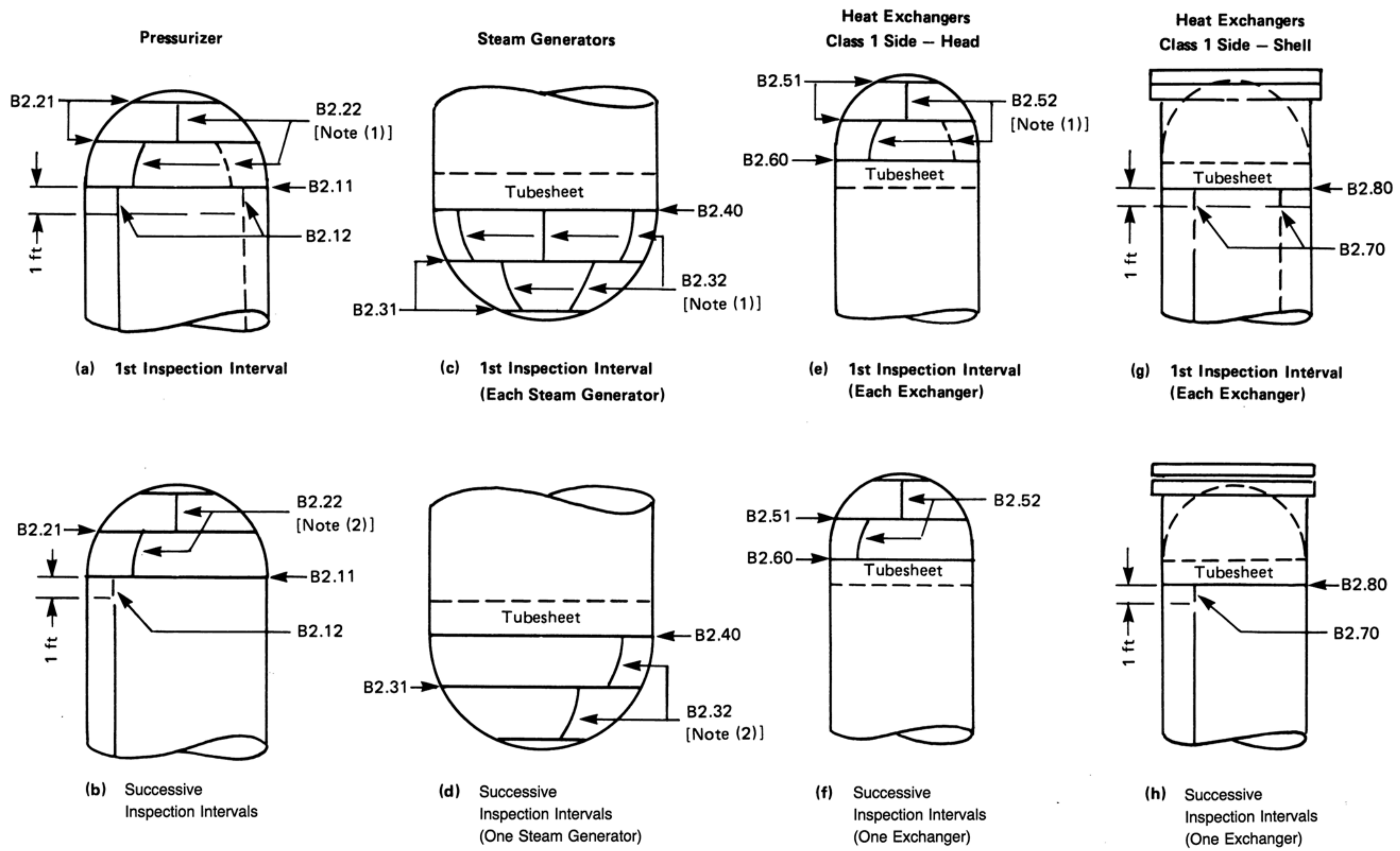
Figure IWB-2500-18
Control Rod Drive and Instrument Nozzle Housing Welds



Examination Volume A-B-C-D
Surface Examination Area A-B or C-D

GENERAL NOTE: $\frac{1}{2}$ in. = 13 mm

Figure IWB-2500-20
Extent of Weld Examination



NOTES:
(1) Includes welds within 180 deg meridian of head.
(2) Includes welds within 90 deg meridian of head.

ARTICLE IWB-3000 ACCEPTANCE STANDARDS

IWB-3100 EVALUATION OF EXAMINATION RESULTS

IWB-3110 PRESERVICE VOLUMETRIC AND SURFACE EXAMINATIONS

IWB-3111 General

(a) The preservice volumetric and surface examinations required by IWB-2200 and performed in accordance with IWA-2200 shall be evaluated by comparing the examination results with the acceptance standards specified in IWB-3112.

(b) Acceptance of components for service shall be in accordance with IWB-3112, IWB-3113, and IWB-3114.

(15) IWB-3112 Acceptance

(a) A component whose volumetric or surface examination in accordance with IWB-2200 meets (1), (2), or (3) below shall be acceptable for service, provided the verified flaws are recorded in accordance with the requirements of IWA-1400(i) and IWA-2220(b) in terms of location, size, shape, orientation, and distribution within the component.

(1) The volumetric or surface examination confirms the absence of flaws or identifies only flaws that have already been shown to meet the nondestructive examination standards of NB-2500 or NB-5300, as documented in Quality Assurance Records (NCA-4134.17).

(2) Volumetric examination detects flaws that are confirmed by surface or volumetric examination to be nonsurface-connected and that do not exceed the standards of Table IWB-3410-1.

(3) Volumetric examination detects flaws that are confirmed by surface or volumetric examination to be nonsurface-connected and that are accepted by analytical evaluation in accordance with the provisions of IWB-3132.3 to the end of the service lifetime of the component and reexamined in accordance with the requirements of IWB-2420(b) and IWB-2420(c).

(b) A component whose volumetric or surface examination detects flaws that do not meet the criteria established in (a) shall be unacceptable for service, unless the component is corrected by a repair/replacement activity in accordance with IWB-3113 to the extent necessary to meet the provisions of (a) prior to placement of the component in service.

(c) A component whose volumetric or surface examination (IWB-2200) detects flaws, other than the flaws of (b), that exceed the standards of Table IWB-3410-1 is unacceptable for service, unless the component is corrected by a repair/replacement activity to the extent necessary to meet the acceptance standards prior to placement of the component in service.

IWB-3113 Repair/Replacement Activity and Reexamination

The repair/replacement activity and reexamination shall comply with the requirements of Article IWA-4000. Reexamination shall be conducted in accordance with the requirements of IWA-2200. The recorded results shall demonstrate that the area subjected to the repair/replacement activity meets the acceptance standards of Table IWB-3410-1.

IWB-3114 Review by Authorities

(a) The Repair/Replacement Program and the reexamination results shall be subject to review by the enforcement authorities having jurisdiction at the plant site.

(b) Evaluation of examination results may be subject to review by the regulatory authority having jurisdiction at the plant site.

IWB-3120 PRESERVICE VISUAL EXAMINATIONS

IWB-3121 General

(a) The preservice visual examinations required by IWB-2200 and performed in accordance with IWA-2200 shall be evaluated by comparing the examination results with the acceptance standards specified in Table IWB-3410-1.

(b) Acceptance of components for service shall be in accordance with IWB-3122, IWB-3123, and IWB-3124.

IWB-3122 Acceptance

IWB-3122.1 Acceptance by Visual Examination.

(a) A component whose visual examination confirms the absence of the relevant conditions described in the standards of Table IWB-3410-1 shall be acceptable for service.

(b) A component whose visual examination detects the relevant conditions described in the standards of Table IWB-3410-1 shall be unacceptable for service, unless such

components meet the requirements of IWB-3122.2 or IWB-3122.3 prior to placement of the component in service.

IWB-3122.2 Acceptance by Supplemental Examination. A component containing relevant conditions shall be acceptable for service if the results of supplemental examinations (IWB-3200) meet the requirements of IWB-3110.

IWB-3122.3 Acceptance by Corrective Measures or Repair/Replacement Activity. A component containing relevant conditions is acceptable for service if the relevant conditions are corrected by a repair/ replacement activity or by corrective measures to the extent necessary to meet the acceptance standards of Table IWB-3410-1.

IWB-3123 Repair/Replacement Activity and Reexamination

The repair/replacement activity and reexamination shall comply with the requirements of Article IWA-4000. Reexamination shall be conducted in accordance with the requirements of IWA-2200; the recorded results shall demonstrate that the area subjected to the repair/replacement activity meets the acceptance standards of Table IWB-3410-1.

IWB-3124 Review by Authorities

(a) The Repair/Replacement Program and the reexamination results shall be subject to review by the enforcement authorities having jurisdiction at the plant site.

(b) Evaluation of examination results may be subject to review by the regulatory authority having jurisdiction at the plant site.

IWB-3130 INSERVICE VOLUMETRIC AND SURFACE EXAMINATIONS

IWB-3131 General

(a) The volumetric and surface examinations required by IWB-2500 and performed in accordance with IWA-2200 shall be evaluated by comparing the examination results with the acceptance standards specified in Table IWB-3410-1, except where (b) is applicable.

(b) When flaws are detected by a required volumetric or surface examination, the component is acceptable for continued service provided the requirements of IWB-3112(a) or the acceptance standards of Table IWB-3410-1 are met.

(c) Volumetric and surface examination results shall be compared with recorded results of the preservice examination and prior inservice examinations. Acceptance of the components for continued service shall be in accordance with IWB-3132, IWB-3133, and IWB-3134.

IWB-3132 Acceptance

IWB-3132.1 Acceptance by Volumetric or Surface Examination. A component whose volumetric or surface examination either reconfirms the absence of flaws or detects flaws that are acceptable under the provisions of IWB-3131(b) are acceptable for continued service. Confirmed changes in flaws from prior examinations shall be recorded in accordance with IWA-1400(i) and IWA-2220(b). A component that does not meet the acceptance standards of Table IWB-3410-1 shall be corrected in accordance with the provisions of IWB-3132.2 or IWB-3132.3. (**15**)

IWB-3132.2 Acceptance by Repair/Replacement Activity. A component whose volumetric or surface examination detects flaws that exceed the acceptance standards of Table IWB-3410-1 is unacceptable for continued service until the component is corrected by a repair/replacement activity to the extent necessary to meet the acceptance standards of IWB-3000.

IWB-3132.3 Acceptance by Analytical Evaluation. A component whose volumetric or surface examination detects flaws that exceed the acceptance standards of Table IWB-3410-1, or for which the acceptance standards are not applicable, is acceptable for continued service without a repair/replacement activity if an analytical evaluation, as described in IWB-3600, meets the acceptance criteria of IWB-3600. The area containing the flaw shall be subsequently reexamined in accordance with IWB-2420(b) and IWB-2420(c). If the subsequent IWB-2420(b) and IWB-2420(c) examinations reveal that the flaws remain essentially unchanged, or the flaw growth is within the growth predicted by the analytical evaluation, and the design inputs for the analytical evaluation have not been affected by activities such as power uprates, the existing analytical evaluation may continue to be used, provided it covers the time period until the next examination. (**15**)

IWB-3133 Repair/Replacement Activity and Reexamination

The repair/replacement activity and reexamination shall comply with the requirements of Article IWA-4000. Reexamination shall be conducted in accordance with the requirements of IWA-2200. The recorded results shall demonstrate that the area subjected to the repair/replacement activity meets the acceptance standards of Table IWB-3410-1.

IWB-3134 Review by Authorities

(a) The Repair/Replacement Program and the reexamination results shall be subject to review by the enforcement authorities having jurisdiction at the plant site.

(b) Analytical evaluation of examination results as required by IWB-3132.3 shall be submitted to the regulatory authority having jurisdiction at the plant site.

IWB-3140 INSERVICE VISUAL EXAMINATIONS

IWB-3141 General

(a) The visual examinations required by IWB-2500 and performed in accordance with IWA-2200 shall be evaluated by comparing the examination results with the acceptance standards specified in Table IWB-3410-1.

(b) Acceptance of components for continued service shall be in accordance with IWB-3142, IWB-3143, and IWB-3144.

IWB-3142 Acceptance

IWB-3142.1 Acceptance by Visual Examination.

(a) A component whose visual examination confirms the absence of the relevant conditions described in the standards of Table IWB-3410-1 shall be acceptable for continued service.

(b) A component whose visual examination detects the relevant conditions described in the standards of Table IWB-3410-1 shall be unacceptable for continued service, unless such components meet the requirements of IWB-3142.2, IWB-3142.3, or IWB-3142.4.

IWB-3142.2 Acceptance by Supplemental Examination. A component containing relevant conditions shall be acceptable for continued service if the results of supplemental examinations (IWB-3200) meet the requirements of IWB-3130.

IWB-3142.3 Acceptance by Corrective Measures or Repair/Replacement Activity. A component containing relevant conditions is acceptable for continued service if the relevant conditions are corrected by a repair/replacement activity or by corrective measures to the extent necessary to meet the acceptance standards of Table IWB-3410-1.

(15) **IWB-3142.4 Acceptance by Analytical Evaluation.**

(a) Analytical evaluation shall not be used to accept through-wall or through-weld leakage in Class 1 components.

(b) A component containing relevant conditions is acceptable for continued service if an analytical evaluation demonstrates the component's acceptability. The evaluation analysis and evaluation acceptance criteria shall be specified by the Owner. A component accepted for continued service based on analytical evaluation shall be subsequently examined in accordance with IWB-2420(b) and IWB-2420(c). If the subsequent IWB-2420(b) and IWB-2420(c) examinations reveal that the relevant conditions remain essentially unchanged, or the changes in the relevant conditions are within the limits predicted by the analytical evaluation, and the design inputs for the analytical evaluation have not been affected by activities such as power uprates, the existing analytical evaluation may continue to be used, provided it covers the time period until the next examination.

IWB-3143 Repair/Replacement Activity and Reexamination

The repair/replacement activity and reexamination shall comply with the requirements of Article IWA-4000. Reexamination shall be conducted in accordance with the requirements of IWA-2200. The recorded results shall demonstrate that the area subjected to the repair/replacement activity meets the acceptance standards of Table IWB-3410-1.

IWB-3144 Review by Authorities

(a) The Repair/Replacement Program and the reexamination results shall be subject to review by the enforcement authorities having jurisdiction at the plant site.

(b) Evaluation analyses of examination results as required by IWB-3142.4 shall be submitted to the regulatory authority having jurisdiction at the plant site.

IWB-3200 SUPPLEMENTAL EXAMINATIONS

(a) Volumetric or surface examinations that detect flaws which require evaluation in accordance with the requirements of IWB-3100 may be supplemented by other examination methods and techniques (IWA-2240) to determine the character of the flaw (i.e., size, shape, and orientation).

(b) Visual examinations that detect relevant conditions described in the standards of this Article may be supplemented by surface or volumetric examinations to determine the extent of the unacceptable conditions and the need for corrective measures, analytical evaluation or repair/replacement activities.

IWB-3400 STANDARDS

IWB-3410 ACCEPTANCE STANDARDS

The acceptance standards referenced in Table IWB-3410-1 shall be applied to determine acceptability for service. The following conditions shall apply.

IWB-3410.1 Application of Standards.

(a) The acceptance standards for ferritic steel components shall only be applicable to those components whose material properties are in accordance with those stated in the referenced table.

(b) The acceptance standards for ferritic steel components shall be applicable where the maximum postulated defect that determines the limiting operating conditions conforms with the recommendations stated in Section III Appendices.

IWB-3410.2 Modification of Standards.

(a) Where less than the maximum postulated defect is used, as permitted by Section III Appendices, Nonmandatory Appendix G, or operating conditions are modified from those originally assumed, the acceptance standards of this Article shall be modified.

Table IWB-3410-1
Acceptance Standards

Examination Category	Component and Part Examined	Acceptance Standard
B-A, B-B	Vessel welds	IWB-3510
B-D	Full penetration welded nozzles in vessels	IWB-3512
B-F, B-J	Dissimilar and similar metal welds in piping and vessel nozzles	IWB-3514
B-G-1	Bolting greater than 2 in. (50 mm) in diameter	IWB-3515, IWB-3517
B-G-2	Bolting 2 in. (50 mm) in diameter and less	IWB-3517
B-K	Welded attachments for vessels, piping, pumps, and valves	IWB-3516
B-L-2, B-M-2	Pump casings and valve bodies	IWB-3519
B-N-1, B-N-2, B-N-3	Interior surfaces and internal components of reactor vessels	IWB-3520
B-O	Control rod drive and instrument nozzle housing welds	IWB-3523
B-P	Pressure-retaining boundary	IWB-3522
B-Q	Steam generator tubing	IWB-3521

(b) The Owner shall be responsible for modification of acceptance standards as necessary to maintain the equivalent structural factors[23] of the acceptance standards of this Article.

(c) Modified standards shall not allow greater flaw sizes than those contained in this Article for the applicable examination category.

(d) Modified acceptance standards shall be filed with the regulatory and enforcement authorities having jurisdiction at the plant site.

IWB-3420 CHARACTERIZATION

Each detected flaw or group of flaws shall be characterized by the rules of IWA-3300 to establish the dimensions of the flaws. These dimensions shall be used in conjunction with the acceptance standards of IWB-3500.

IWB-3430 ACCEPTABILITY

Flaws that meet the requirements of IWB-3500 for the respective examination category shall be acceptable.

IWB-3500 ACCEPTANCE STANDARDS

IWB-3510 STANDARDS FOR EXAMINATION CATEGORY B-A, PRESSURE-RETAINING WELDS IN REACTOR VESSEL, AND EXAMINATION CATEGORY B-B, PRESSURE-RETAINING WELDS IN VESSELS OTHER THAN REACTOR VESSELS

IWB-3510.1 Allowable Planar Flaws.

(a) The size of allowable planar flaws within the boundary of the examination volumes specified in Figures IWB-2500-1 (B-Q) through IWB-2500-6 shall not exceed the limits specified in Table IWB-3510-1.

(b) Where a flaw extends or lies beyond the examination volumes as detected by the procedures used to examine the specified volumes, the overall size of the flaw shall be compared with the standards specified in Table IWB-3510-1.

(c) Any two or more coplanar aligned flaws characterized as separate flaws by IWA-3330 are allowable, provided the requirements of IWA-3390 are met.

(d) Surface flaws within cladding are acceptable.

IWB-3510.2 Allowable Laminar Flaws.

(a) The areas of allowable laminar flaws as defined by IWA-3360 within the boundary of the examination zones delineated in the applicable figures specified in IWB-3510.1(a) shall not exceed the limits specified in Table IWB-3510-2.

(b) Laminar flaws that join with a planar flaw shall be governed by the standards of Table IWB-3510-1.

IWB-3510.3 Allowable Linear Flaws.

(a) The size of allowable linear flaws as detected by a surface examination (MT/PT) or volumetric examination (RT) within the examination boundary shown in Figures IWB-2500-1 through IWB-2500-6 shall not exceed the limits specified in Table IWB-3510-3.

(b) Where a flaw extends beyond the examination boundaries, or separate linear flaws lie both within and beyond the boundaries but are characterized as a single flaw by IWA-3400, the overall flaw size shall be compared with the standards of Table IWB-3510-3.

Table IWB-3510-1
Allowable Planar Flaws
Material: Ferritic steels that meet the requirements of NB-2331 and G-2110(b) of Section III

Aspect Ratio, [Note (1)] a/ℓ	Volumetric Examination Method, Nominal Wall Thickness, [Note (1)], [Note (2)] t, in. (mm)					
	$2^1/_2$ (65) and less		4 (100) to 12 (300)		16 (400) and greater	
	Surface Flaw, [Note (5)] a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %	Surface Flaw [Note (5)], a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %	Surface Flaw, [Note (5)] a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %
0.0	3.1	$3.4Y^{1.00}$	1.9	$2.0Y^{1.00}$	1.4	$1.5Y^{1.00}$
0.05	3.3	$3.8Y^{0.96}$	2.0	$2.2Y^{0.90}$	1.5	$1.7Y^{0.91}$
0.10	3.6	$4.3Y^{0.72}$	2.2	$2.5Y^{0.69}$	1.7	$1.9Y^{0.69}$
0.15	4.1	$4.9Y^{0.48}$	2.5	$2.9Y^{0.47}$	1.9	$2.1Y^{0.43}$
0.20	4.7	$5.7Y^{0.50}$	2.8	$3.3Y^{0.47}$	2.1	$2.5Y^{0.45}$
0.25	5.5	$6.6Y^{0.65}$	3.3	$3.8Y^{0.61}$	2.5	$2.8Y^{0.57}$
0.30	6.4	$7.8Y^{0.84}$	3.8	$4.4Y^{0.77}$	2.9	$3.3Y^{0.75}$
0.35	7.4	$9.0Y^{0.99}$	4.4	$5.1Y^{0.93}$	3.3	$3.8Y^{0.90}$
0.40	8.3	$10.5Y^{1.00}$	5.0	$5.8Y^{1.00}$	3.8	$4.3Y^{1.00}$
0.45	8.5	$12.3Y^{1.00}$	5.1	$6.7Y^{1.00}$	3.9	$4.9Y^{1.00}$
0.50	8.7	$14.3Y^{1.00}$	5.2	$7.6Y^{1.00}$	4.0	$5.6Y^{1.00}$

NOTES:
(1) For intermediate flaw aspect ratios a/ℓ and thickness t, linear interpolation is permissible. Refer to IWA-3200(b).
(2) Component thickness t is measured normal to the pressure-retaining surface of the component. Where the section thickness varies, the average thickness over the length of the planar flaw is the component thickness.
(3) The total depth of a subsurface flaw is $2a$.
(4) $Y = [(S/t)/(a/t)]$ or (S/a). Y is the flaw-to-surface proximity factor, and S is defined in IWA-3310 and IWA-3320. If $S < 0.4d$, the subsurface flaw is classified as a surface flaw. If $Y > 1.0$, use $Y = 1.0$.
(5) Applicable to flaws in surface region B-E shown in Figure IWB-2500-5 only if the maximum postulated defect of Section III Appendices, Nonmandatory Appendix G, G-2120, is justified. If a smaller defect is used, Refer to IWB-3410.2.

Table IWB-3510-2
Allowable Laminar Flaws

Component Thickness, [Note (1)] t, in. (mm)	Laminar Area, [Note (2)] A, in.^{2} (mm^2)
2.5 (65)	7.5 (4 800)
4 (100)	12 (7 700)
6 (150)	18 (12 000)
8 (200)	24 (15 000)
10 (250)	30 (19 000)
12 (300)	36 (23 000)
14 (350)	42 (27 000)
16 (400) and greater	52 (34 000)

NOTES:
(1) For intermediate thicknesses, linear interpolation of area is permissible. Refer to IWA-3200(c).
(2) The area of a laminar flaw is defined in IWA-3360.

Table IWB-3510-3
Allowable Linear Flaws [Note (1)]
Material: Ferritic steels that meet the requirements of NB-2331 and G-2110(b) of Section III

Nominal Section Thickness, [Note (2)] *t*, in. (mm)	Surface Flaw, [Note (1)], [Note (3)] ℓ/t, %	Subsurface Flaw, [Note (1)] ℓ/t, %
$2^1/_2$ (65) and less	17.4	28.6
4 (100) through 12 (300)	10.4	15.2
16 (400) and greater	8.0	11.2

NOTES:
(1) Applicable to linear flaws detected by surface examination (MT/PT) or radiographic examination (RT) method where flaw depth dimension a is indeterminate. If supplemental volumetric examination (UT) is performed which determines the a and ℓ dimensions, the standards of Table IWB-3510-1 shall apply.
(2) For intermediate thickness, linear interpolation is permissible. Refer to IWA-3200.
(3) Applicable to linear flaws in surface region B-E shown in Figure IWB-2500-5 only if the maximum postulated defect of Section III Appendices, Nonmandatory Appendix G, G-2120, is justified. If a smaller defect size is used, Refer to IWB-3410.2.

IWB-3512 Standards for Examination Category B-D, Full Penetration Welds of Nozzles in Vessels

IWB-3512.1 Allowable Planar Flaws.

(a) The size of allowable planar flaws detected in the nozzle and weld areas within the boundary of the examination volume specified in Figures IWB-2500-7(a) through IWB-2500-7(d) shall not exceed the limits specified in Table IWB-3512-1.

(b) The size of allowable planar flaws detected in the vessel shell (or head) material adjoining the nozzle and weld areas and within the boundary of the examination volumes specified in Figures IWB-2500-7(a) through IWB-2500-7(d) shall not exceed the limits of Table IWB-3510-1.

(c) The component thickness t to be applied in calculating the flaw a/t ratio for comparison with the standards in Table IWB-3510-1 or IWB-3512-1, as applicable, shall be selected as specified in Table IWB-3512-2. This table lists the component thicknesses as a function of flaw location for each type nozzle configuration as shown in Figures IWB-2500-7(a) through IWB-2500-7(d).

(d) Any two or more coplanar aligned flaws characterized as separate flaws by IWA-3300 are allowable, provided the requirements of IWA-3390 are met.

IWB-3512.2 Allowable Laminar Flaws.

(a) Laminar flaws in vessel shell or head material within the boundary of the examination volumes specified in Figures IWB-2500-7(a) through IWB-2500-7(d) shall be governed by the standards of IWB-3510.2.

(b) Laminar flaws in the nozzle wall shall be considered as planar flaws and the standards of IWB-3512.1 shall apply.

IWB-3514 Standards for Examination Category B-F, Pressure-Retaining Dissimilar Metal Welds in Vessel Nozzles, and Examination Category B-J, Pressure-Retaining Welds in Piping (15)

(a) The acceptance standards of IWB-3514 do not apply to planar surface-connected flaws that are in contact with the reactor coolant environment during normal operation and are detected by inservice examination in the following materials:

(1) for PWRs, UNS N06600, N06082, or W86182 surfaces with a normal operating temperature greater than or equal to 525°F (275°C) and in contact with the reactor coolant environment

(2) for BWRs, UNS N06600, W86182, or austenitic stainless steel and associated weld surfaces, in contact with the reactor coolant environment, that are susceptible to stress corrosion cracking and not mitigated

(b) If the acceptance standards are not met or are not applicable, for acceptance by analytical evaluation, the planar surface-connected flaws in (a) shall meet the provisions of IWB-3600.

(c) Susceptible materials and mitigation criteria for BWRs are specified in NUREG 0313 Revision 2, Sections 2.1 and 2.2.

IWB-3514.1 Allowable Planar Flaws. (15)

(a) The size of allowable planar flaws within the boundary of the examination surfaces and volumes delineated in Figures IWB-2500-8 through IWB-2500-11 shall be in accordance with the standards of IWB-3514.2, IWB-3514.3, and IWB-3514.4, as applicable. In addition, the requirements of IWB-3514.8 shall be satisfied for planar surface-connected flaws that are in contact with the

Table IWB-3512-1
Allowable Planar Flaws
Material: Ferritic steels that meet the requirements of NB-2331 and G-2110(b) of Section III

	Volumetric Examination Method, Nominal Wall Thickness, [Note (1)] t, in. (mm)			
	$2\frac{1}{2}$ (65) and less		4 (100) through 12 (300)	
Aspect Ratio, [Note (1)] a/ℓ	Surface Flaw, [Note (2)] a/t, %	Subsurface Flaw, [Note (2)] – [Note (4)] a/t, %	Surface Flaw, [Note (2)] a/t, %	Subsurface Flaw, [Note (2)] – [Note (4)] a/t, %
0.00	3.1	$3.4Y^{1.00}$	1.9	$2.0Y^{1.00}$
0.05	3.3	$3.8Y^{0.96}$	2.0	$2.2Y^{0.90}$
0.10	3.6	$4.3Y^{0.72}$	2.2	$2.5Y^{0.69}$
0.15	4.1	$4.9Y^{0.48}$	2.5	$2.9Y^{0.47}$
0.20	4.7	$5.7Y^{0.50}$	2.8	$3.3Y^{0.47}$
0.25	5.5	$6.6Y^{0.65}$	3.3	$3.8Y^{0.61}$
0.30	6.4	$7.8Y^{0.84}$	3.8	$4.4Y^{0.77}$
0.35	7.4	$9.0Y^{0.99}$	4.4	$5.1Y^{0.93}$
0.40	8.3	$10.5Y^{1.00}$	5.0	$5.8Y^{1.00}$
0.45	8.5	$12.3Y^{1.00}$	5.1	$6.7Y^{1.00}$
0.50	8.7	$14.3Y^{1.00}$	5.2	$7.6Y^{1.00}$
Inside corner region	2.5	Not applicable	2.5	Not applicable

NOTES:
(1) Dimensions of a and ℓ are defined in IWA-3300. For intermediate flaw aspect ratios a/ℓ and thickness t, linear interpolation is permissible. Refer to IWA-3200(b).
(2) See Table IWB-3512-2 for the appropriate component thickness t as a function of flaw location.
(3) The total depth of a subsurface flaw is $2a$ (Figure IWA-3320-1).
(4) $Y = [(S/t)/(a/t)] = (S/a)$. If $S < 0.4d$, the flaw is classified as a surface flaw. If $Y > 1.0$, use $Y = 1.0$.

reactor coolant environment during normal operation and are detected by preservice examination in materials that are susceptible to stress corrosion cracking, as defined for PWRs in IWB-3514(a)(1) and for BWRs in IWB-3514(a)(2) and IWB-3514(c).

(b) Where flaws extend beyond the boundaries of the examination surfaces and volumes, or separate flaws are detected that lie both within and beyond the boundaries but are characterized as a single flaw by the rules of IWA-3300, the overall flaw size shall be compared with the standards of (a).

(c) Any two or more coplanar aligned flaws that are characterized as separate flaws by IWA-3300 are allowable, provided the requirements of IWA-3390 are met.

(d) Inner surface flaws detected by volumetric examination of piping components with austenitic cladding on the inner surface shall be governed by the following standards.

(1) Surface flaws that do not penetrate through the nominal clad thickness into base metal need not be compared with the standards of (a).

(2) The size of allowable surface flaws that penetrate through the cladding into base metal shall not exceed the standards of (a), except that the depth a of the flaw shall be the total depth minus the nominal clad thickness.

Table IWB-3512-2
Component Thickness Versus Flaw Location

	Component Thickness, t			
Location of Flaw [Note (1)]	Barrel Type Nozzle [Figure IWB-2500-7(a)]	Flange Type Nozzle [Figure IWB-2500-7(b)]	Set-On Type Nozzle [Figure IWB-2500-7(c)]	Integrally Cast Nozzle [Figure IWB-2500-7(d)]
Shell (or head) adjoining region	t_s	t_s	t_s	n/a
Attachment weld region	t_s	t_s	t_s	n/a
Nozzle cylinder region	$(t_{n_1} + t_{n_2})/2$	$(t_{n_1} + t_{n_2})/2$	t_{n_1}	n/a
Nozzle inside corner region	Smallest of t_{n_1}, t_{n_2}, or t_s	Smallest of t_{n_1}, t_{n_2}, or t_s	Smaller of t_{n_1} or t_s	Smaller of t_{n_1} or t_s

NOTE:
(1) See Figures IWB-2500-7(a) through IWB-2500-7(d) for definition of the examination volume for each of the examination regions.

Table IWB-3514-1
Allowable Planar Flaws
Materials: Ferritic steels that meet the requirements of NB-2300 and the specified minimum yield strength of 50 ksi (350 MPa) or less at 100°F (40°C) Austenitic steels that meet the requirements for the specified minimum yield strength of 35 ksi (240 MPa) or less at 100 °F (40 °C)

	Volumetric Examination Method, Wall Thickness, [Note (1)], [Note (2)] t, in. (mm)							
	0.312 (8)		1.0 (25)		2.0 (50)		3.0 (75) and over	
Aspect Ratio, [Note (1)] a/ℓ	Surface Flaw, a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %	Surface Flaw, a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %	Surface Flaw, a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %	Surface Flaw, a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %
Preservice and Inservice Examination								
0.00	10.0	10.0 $Y^{0.96}$	10.0	10.0 $Y^{0.96}$	10.0	10.0 $Y^{0.96}$	10.0	10.0 $Y^{0.96}$
0.05	10.0	10.0 $Y^{0.91}$	10.0	10.0 $Y^{0.73}$	10.0	10.0 $Y^{0.68}$	10.0	10.0 $Y^{0.67}$
0.10	10.0	10.0 $Y^{0.59}$	11.3	11.3 $Y^{0.65}$	11.8	11.8 $Y^{0.69}$	11.9	11.9 $Y^{0.70}$
0.15	11.1	11.1 $Y^{0.63}$	13.9	13.9 $Y^{0.87}$	14.4	14.4 $Y^{0.91}$	14.6	14.6 $Y^{0.93}$
0.20	12.8	12.8 $Y^{0.78}$	15.0	15.0 $Y^{0.96}$	15.0	15.0 $Y^{0.96}$	15.0	15.0 $Y^{0.96}$
0.25	14.3	14.3 $Y^{0.90}$	15.0	15.0 $Y^{0.96}$	15.0	15.0 $Y^{0.96}$	15.0	15.0 $Y^{0.96}$
0.30 to 0.50	15.0	15.0 $Y^{0.96}$	15.0	15.0 $Y^{0.96}$	15.0	15.0 $Y^{0.96}$	15.0	15.0 $Y^{0.96}$

GENERAL NOTE: This table is not applicable to planar surface-connected flaws that are in contact with the reactor coolant environment during normal operation and are detected by inservice examination in materials that are susceptible to stress corrosion cracking, as defined for PWRs in IWB-3514(a)(1) and for BWRs in IWB-3514(a)(2) and IWB-3514(c). For planar surface-connected flaws that are in contact with the reactor coolant environment during normal operation and are detected by preservice examination in these materials, the requirements of IWB-3514.8 shall be satisfied.

NOTES:
(1) For intermediate flaw aspect ratios a/ℓ and thickness t, linear interpolation is permissible. Refer to IWA-3200(b) and IWA-3200(c).
(2) t is nominal wall thickness or actual wall thickness if determined by UT examination.
(3) The total depth of a subsurface flaw is $2a$.
(4) $Y = (S/t)/(a/t) = S/a$. If $S < 0.4d$, the flaw is classified as a surface flaw. If $Y > 1.0$, use $Y = 1.0$.

IWB-3514.2 Allowable Flaw Standards for Ferritic Piping.

(a) The size of allowable flaws shall not exceed the limits specified in Table IWB-3514-1.

(b) Where flaws on the outer surface of piping as detected by the surface examination method during an inservice examination exceed the allowable standards of IWB-3514.7, the flaws may be examined by the volumetric method. The acceptance of these flaws shall be governed by the allowable flaw standards for the volumetric examination method in Table IWB-3514-1.

IWB-3514.3 Allowable Flaw Standards for Austenitic Piping.

(a) The size of allowable flaws shall not exceed the limits specified in Table IWB-3514-1.

(b) Where flaws on the outer surface of piping as detected by the surface examination method during an inservice examination exceed the allowable standards of IWB-3514.7, the flaws may be examined by the volumetric method. The acceptance of these flaws shall be governed by the allowable flaw standards for the volumetric examination method in Table IWB-3514-1.

IWB-3514.4 Allowable Flaw Standards for Dissimilar Metal Welds.

(a) The size of allowable flaws in the carbon or low alloy steel end of a dissimilar metal weld joint shall be governed by the standards of IWB-3514.2.

(b) The size of allowable flaws in the high alloy steel or high nickel alloy end, and the weld metal of a dissimilar metal weld joint shall be governed by the standards of IWB-3514.3.

IWB-3514.6 Allowable Laminar Flaws. The area of allowable laminar flaws, as defined by IWA-3360, within the boundary of the examination zones shown in Figures IWB-2500-8 through IWB-2500-11, shall not exceed the limits specified in Table IWB-3514-3.

IWB-3514.7 Allowable Linear Flaw Standards for Ferritic and Austenitic Piping.

(a) The size of an allowable linear flaw within the boundaries of the examination surfaces in Figures IWB-2500-8 through IWB-2500-11 shall not exceed the limits specified for ferritic piping in Table IWB-3514-4 and for austenitic piping in Table IWB-3514-2.

(b) Where a flaw extends beyond the boundaries of the examination surfaces in Figures IWB-2500-8 through IWB-2500-11, or where discontinuous linear flaws lie both within and beyond the boundaries and are characterized as a single flaw by the rules of IWA-3400, the size of allowable overall linear flaws shall not exceed the limits specified for ferritic piping in Table IWB-3514-4 and for austenitic piping in Table IWB-3514-2.

IWB-3514.8 Surface-Connected Flaws in Contact With the Reactor Coolant Environment That Are Detected by Preservice Examination in Materials Susceptible to Stress Corrosion Cracking. When a surface-connected flaw that will be in contact with the reactor coolant environment during normal operation is detected using volumetric examination, the weld shall be reexamined twice subsequent to the preservice examination. The first reexamination shall be performed after a time interval that is greater than 2 yr, and fewer than 6 yr, subsequent to plant start-up following the preservice examination. The time interval for the second reexamination shall be determined using the rules of IWB-3640 for analytical evaluation of flaws and shall not exceed 10 yr subsequent to plant start-up following the preservice examination. The time interval between the two reexaminations shall be at least 2 yr, except that it shall not extend the second reexamination beyond the end of the evaluation period. (15)

Table IWB-3514-2
Allowable Linear Flaws
Material: Austenitic steels that meet the requirements for the specified minimum yield strength of 35 ksi (240 MPa) or less at 100°F (40°C)

	Wall Thickness [Note (1)], [Note (2)], *t*, in. (mm)			
Surface Examination Method	**0.312 (8) or less**	**1.0 (25)**	**2.0 (50)**	**3.0 (75) and Over**
Preservice examination [Note (3)] Flaw length, ℓ, in. (mm)	1/8 (3)	3/16 (5)	1/4 (6)	1/4 (6)
Inservice examination [Note (3)] Flaw length, ℓ, in. (mm)	0.2 (5)	0.25 (6)	0.45 (11)	0.65 (16)

NOTES:
(1) For intermediate wall thickness, linear interpolation is permissible. Refer to IWA-3200(c).
(2) *t* is nominal wall thickness or actual wall thickness if determined by UT examination.
(3) The provisions of IWB-3514.3(b) may be applied if these standards are exceeded.

Table IWB-3514-3
Allowable Laminar Flaws

Nominal Pipe Wall Thickness, *t*, in. (mm)	Laminar Area, [Note (1)], [Note (2)] in.^{2} (mm^2)
0.625 (16) and less	7.5 (4 800)
3.5 (89)	7.5 (4 800)
6.0 (150)	12.0 (7 700)

NOTES:
(1) Area of a laminar flaw is defined in IWA-3360.
(2) Linear interpolation with respect to nominal pipe wall thickness is permissible to determine intermediate value of allowable laminar area. Refer to IWA-3200(c).

Table IWB-3514-4
Allowable Linear Flaws
Material: Ferritic steels that meet the requirements of NB-2300 and specified minimum yield strength of 50 ksi (345 MPa) or less at 100°F (40°C)

Examination	Nominal Wall Thickness, *t*, in. (mm) [Note (1)]					
	Less than 0.312 (8)	0.312 (8)	1.0 (25)	2.0 (50)	3.0 (75)	4.0 (100) and Over
Surface Examination Method, PT or MT						
Preservice Examination [Note (2)]						
Flaw length, ℓ, in. (mm)	$^1/_{16}$ (1.5)	$^1/_8$ (3)	$^1/_4$ (6)	$^1/_4$ (6)	$^1/_4$ (6)	$^1/_4$ (6)
Inservice Examination [Note (2)]						
Flaw Length, ℓ, in. (mm)	$^3/_{16}$ (5)	$^3/_{16}$ (5)	$^5/_{16}$ (8)	$^5/_8$ (16)	$^7/_8$ (22)	$^7/_8$ (22)
Volumetric Examination Method, RT						
Preservice Examination [Note (3)]						
Surface Flaw Length, ℓ, in. (mm)	...	$^1/_8$ (3)	$^1/_4$ (6)	$^1/_4$ (6)	$^1/_4$ (6)	$^1/_4$ (6)
Subsurface Flaw Length, ℓ, in. (mm)	...	$^1/_4$ (6)	$^3/_8$ (9)	$^3/_4$ (19)	1.0 (25)	1.0 (25)
Inservice Examination [Note (3)]						
Surface Flaw Length, ℓ, in. (mm)	...	$^3/_{16}$ (5)	$^5/_{16}$ (8)	$^5/_8$ (16)	$^7/_8$ (22)	$^7/_8$ (22)
Subsurface Flaw Length, ℓ, in. (mm)	...	$^1/_4$ (6)	$^3/_8$ (9)	$^3/_4$ (19)	1.2 (30)	1.4 (35)

NOTES:
(1) For intermediate nominal wall thicknesses, linear interpolation is permissible. Refer to IWA-3200(c).
(2) The provision of IWB-3514.2(b) may be applied whenever these standards are exceeded.
(3) The distinction between surface and subsurface flaws shall be determined by the rules of IWA-3320 and IWA-3370, and may require special examination techniques.

IWB-3515 Standards for Examination Category B-G-1, Pressure-Retaining Bolting Greater Than 2 in. (50 mm) in Diameter

IWB-3515.1 Allowable Flaws for Surface Examinations of Studs and Bolts. Allowable surface flaws in vessel closure studs and pressure-retaining bolting shall not exceed the following limits:

(a) nonaxial flaws, $^1/_4$ in. in (6 mm) length

(b) axial flaws, 1 in. (25 mm) in length

IWB-3515.2 Allowable Flaws for Volumetric Examinations of Studs and Bolts.

(a) The size of allowable nonaxial flaws in vessel closure studs and pressure-retaining bolting within the boundary of the examination volume shown in Figure IWB-2500-12(a) shall not exceed the limits specified in Table IWB-3515-1.

(b) Any two or more subsurface flaws, at any diameter of the stud which combine to reduce the net diameter are acceptable, provided the combined flaw depths do not exceed the sum of the allowable limits specified in Table IWB-3515-1 for the corresponding flaw aspect ratios, divided by the number of flaws.

Table IWB-3515-1
Allowable Planar Flaws
Materials: SA-193 Grade B7, SA-320 Grade L43, SA-540 Class 3 Grades B23, B24 that meet the requirements of NB-2333

Aspect Ratio, a/ℓ [Note (1)]	Subsurface Flaws, a, in. (mm) [Note (2)]
Diameter Range: Nominal Sizes Greater Than 4 in. (100 mm)	
0.0	0.10 (2.5)
0.10	0.10 (2.5)
0.20	0.15 (3.8)
0.30	0.15 (3.8)
0.40	0.20 (5.1)
0.50	0.25 (6.4)
Diameter Range: Nominal Sizes 2 in. (50 mm) and Greater, But Not Over 4 in. (100 mm)	
0.0	0.075 (1.9)
0.10	0.075 (1.9)
0.20	0.10 (2.5)
0.30	0.10 (2.5)
0.40	0.15 (3.8)
0.50	0.18 (4.6)

NOTES:
(1) Dimensions a and ℓ are defined in IWA-3300. For intermediate flaw aspect ratios a/ℓ, linear interpolation is permissible. Refer to IWA-3200(b).
(2) The total depth of an allowable subsurface flaw is twice the listed value.

(c) Any flaw detected by the volumetric examination shall be investigated by a surface examination. If confirmed to be a surface flaw, the standards of IWB-3515.1 shall apply. If not a surface flaw, the standards of (a) and (b) shall apply.

IWB-3515.3 Allowable Flaws for Volumetric Examinations of Threads in Stud Holes. The size of allowable flaws within the boundary of the examination volume in Figure IWB-2500-12(a) and oriented on a plane normal to the axis of the stud shall not exceed 0.2 in. (5 mm) as measured radially from the root of the thread.

IWB-3516 Standards for Examination Category B-K, Welded Attachments for Vessels, Piping, Pumps, and Valves

IWB-3516.1 Allowable Planar Flaws.

(a) The size of an allowable flaw within the boundary of the examination surfaces and volumes in Figures IWB-2500-13, IWB-2500-14, and IWB-2500-15 shall not exceed the allowable flaw standards of this Article for the applicable supported pressure-retaining component to which the attachment is welded. For indications located wholly on the attachment side of the line A-D in Figures IWB-2500-13, IWB-2500-14, and IWB-2500-15, the thickness and the surface of the attachment shall be considered the thickness and surface of the component for purposes of flaw indication characterization (IWA-3300) and for comparison with the allowable indication standards. For indications located in the examination volume A-B-C-D, the indication shall be characterized considering both the surface of the attachment and the surface of the pressure boundary as the surface of the component for comparison with the allowable indication standards.

(b) Where a flaw extends beyond the boundaries of the examination surfaces and volumes, or separate flaws are detected that lie both within and beyond the boundaries but are characterized as single flaws by the rules of Article IWA-3000, the overall flaw size shall be compared with the standards of (a).

(c) Where a flaw detected by a surface examination method exceeds the allowable standards of (a), an optional volumetric examination may be conducted, in which case the allowable flaw standards for the volumetric examination method shall apply.

IWB-3516.2 Allowable Laminar Flaws.

(a) The allowable area of a laminar flaw within the boundary of the examination volume of the attachment or the pressure-retaining membrane to which the support is attached shall be governed by IWB-3510 or IWB-3514, as applicable.

(b) Where laminar flaws are detected in an attachment which does not transmit tensile load in the through-thickness direction, the laminar flaw standards need not apply.

IWB-3517 Standards[24] for Examination Category B-G-1, Pressure-Retaining Bolting Greater Than 2 in. (50 mm) in Diameter, and Examination Category B-G-2, Pressure-Retaining Bolting 2 in. (50 mm) and Less in Diameter

IWB-3517.1 Visual Examination, VT-1. The following relevant conditions[25] shall require corrective action to meet the requirements of IWB-3122 prior to service or IWB-3142 prior to continued service:

(a) crack-like flaws that exceed the allowable linear flaw standards of IWB-3515;

(b) more than one deformed or sheared thread in the zone of thread engagement of bolts, studs, or nuts;

(c) localized general corrosion that reduces the bolt or stud cross-sectional area by more than 5%;

(d) bending, twisting, or deformation of bolts or studs to the extent that assembly or disassembly is impaired;

(e) missing or loose bolts, studs, nuts, or washers

(f) fractured bolts, studs, or nuts;

(g) degradation of protective coatings on bolting surfaces; or

(h) evidence of coolant leakage near bolting.

IWB-3519 Standards for Examination Category B-L-2, Pump Casings, and Examination Category B-M-2, Valve Bodies

IWB-3519.1 Visual Examination, VT-3. The following relevant conditions[26] shall require corrective action to meet the requirements of IWB-3122 prior to service or IWB-3142 prior to continued service:

(a) corrosion or erosion that reduces the pressure-retaining wall thickness[27] by more than 10%;

(b) wear of mating surfaces that may lead to loss of function or leakage; or

(c) crack-like surface flaws developed in service or grown in size beyond that recorded during preservice visual examination.

IWB-3519.2 Allowable Planar Flaws. If a supplemental examination is performed that can characterize the flaw size and shape, the following acceptance standards for allowable planar flaws shall be applied:

(a) The size of an allowable planar flaw shall not exceed the limits specified in Table IWB-3519.2-1 or Table IWB-3519.2-2, as applicable. Base metal flaws in castings that are permitted by the governing material specifications meeting the requirements of Section III are acceptable.

(b) If separate flaws are detected and are characterized as a single flaw in accordance with IWA-3300, the flaw shall meet the requirements of (a).

(c) Any two or more coplanar aligned flaws characterized as separate flaws in accordance with IWA-3300 are acceptable, provided the requirements of IWA-3390 are met.

(d) If a flaw is detected by radiographic examination and exceeds the allowable surface flaw standards of Table IWB-3519.2-1 or Table IWB-3519.2-2, as applicable, surface examination may be performed, with acceptance in accordance with Table IWB-3519.2-1 or Table IWB-3519.2-2. If acceptable by surface examination, the flaw shall meet subsurface flaw standards of Table IWB-3519.2-1 or Table IWB-3519.2-2.

(e) A surface flaw in the cladding detected by volumetric examination of austenitic clad ferritic base material shall meet the following requirements:

(1) Surface flaws that do not extend to the base material are acceptable.

(2) A surface flaw that extends into the base material shall meet the requirements of (a), considering dimension a to be the portion of the flaw depth in the base material.

IWB-3520 STANDARDS FOR EXAMINATION CATEGORY B-N-1, INTERIOR OF REACTOR VESSEL, EXAMINATION CATEGORY B-N-2, WELDED CORE SUPPORT STRUCTURES AND INTERIOR ATTACHMENTS TO REACTOR VESSELS, AND EXAMINATION CATEGORY B-N-3, REMOVABLE CORE SUPPORT STRUCTURES

IWB-3520.1 Visual Examination, VT-1. The following relevant conditions[28] shall require corrective action to meet the requirements of IWB-3122 prior to service or IWB-3142 prior to continued service:

(a) crack-like surface flaws on the welds joining the attachment to the vessel wall that exceed the allowable linear flaw standards of IWB-3510; or

(b) structural degradation of attachment welds such that the original cross-sectional area[29] is reduced by more than 10%.

IWB-3520.2 Visual Examination, VT-3. The following relevant conditions[28] shall require corrective action in meeting the requirements of IWB-3122 prior to service or IWB-3142 prior to continued service:

(a) structural distortion or displacement of parts to the extent that component function may be impaired;

(b) loose, missing, cracked, or fractured parts, bolting, or fasteners;

(c) foreign materials or accumulation of corrosion products that could interfere with control rod motion or could result in blockage of coolant flow through fuel;

(d) corrosion or erosion that reduces the nominal section thickness by more than 5%;

(e) wear of mating surfaces that may lead to loss of function; or

(f) structural degradation of interior attachments such that the original cross-sectional area is reduced more than 5%.

Table IWB-3519.2-1
Allowable Planar Flaws
Material: Ferritic steels that meet the requirements of NB-2300 and the specified minimum yield strength of 50 ksi (350 MPa) or less at 100°F (40°C) Thickness Range: 2 in. (50 mm) or greater

Volumetric (UT)			Volumetric (UT), Inservice Examination		
Aspect Ratio, a/ℓ [Note (1)]	Surface Flaw, a/t, % [Note (2)]	Subsurface Flaw, a/t, % [Note (2)], [Note (3)], [Note (4)]	Aspect Ratio, a/ℓ [Note (1)]	Surface Flaw, a/t, % [Note (2)]	Subsurface Flaw, a/t, % [Note (2)], [Note (3)], [Note (4)]
Preservice Examination			Inservice Examination		
0.00	2.6	$3.3Y^{1.00}$	0.00	3.9	$3.3Y^{1.00}$
0.05	2.8	$3.5Y^{1.00}$	0.05	4.2	$3.5Y^{1.00}$
0.10	3.1	$3.7Y^{0.79}$	0.10	4.6	$3.7Y^{0.79}$
0.15	3.5	$4.1Y^{0.74}$	0.15	5.2	$4.1Y^{0.74}$
0.20	3.9	$4.7Y^{0.89}$	0.20	5.8	$Y^{0.89}$
0.25	4.4	$5.3Y^{1.00}$	0.25	6.6	$5.3Y^{1.00}$
0.30	5.0	$5.9Y^{1.00}$	0.30	7.5	$5.9Y^{1.00}$
0.35	5.0	$6.7Y^{1.00}$	0.35	7.5	$6.7Y^{1.00}$
0.40	5.0	$7.5Y^{1.00}$	0.40	7.5	$7.5Y^{1.00}$
0.45	5.0	$8.4Y^{1.00}$	0.45	7.5	$8.4Y^{1.00}$
0.50	5.0	$9.3Y^{1.00}$	0.50	7.5	$9.3Y^{1.00}$

Nominal Wall Thickness, t, in. (mm) [Note (1)]	Volumetric (RT) and Surface Method	Volumetric (RT)	Nominal Wall Thickness, t, in. (mm) [Note (1)]	Volumetric (RT) and Surface Method	Volumetric (RT)
	Surface Flaw, Length, ℓ, in. (mm)	Subsurface Flaw, Length, ℓ, in. (mm)		Surface Flaw, Length, ℓ, in. (mm)	Subsurface Flaw, Length, ℓ, in. (mm)
Preservice Examination			Inservice Examination		
2.0 (50)	$^1/_4$ (6)	$^3/_4$ (19)	2.0 (50)	0.3 (8)	0.8 (20)
3.0 (75)	$^1/_4$ (6)	$^3/_4$ (19)	3.0 (75)	0.45 (11)	0.9 (23)
4.0 (100)	$^1/_4$ (6)	$^3/_4$ (19)	4.0 (100)	0.6 (15)	1.2 (30)
5.0 (125)	$^1/_4$ (6)	$^3/_4$ (19)	5.0 (125)	0.75 (19)	1.5 (38)
6.0 (150) and over	$^1/_4$ (6)	$^3/_4$ (19)	6.0 (150) and over	0.9 (23)	1.8 (46)

NOTES:

(1) For intermediate flaw aspect ratios a/ℓ and thickness t, linear interpolation is permissible. Refer to IWA-3200(b) and IWA-3200(c).

(2) Component thickness t is measured normal to the pressure-retaining surface of the component. Where section thickness varies, the average thickness over the length of the indication is the component thickness.

(3) The total depth of a subsurface flaw is $2a$.

(4) $Y = (S/t)(a/t) = S/a$. If $S < 0.4d$, the flaw is classified as a surface flaw. If $Y > 1.0$, use $Y = 1.0$.

Table IWB-3519.2-2
Allowable Planar Flaws
Material: Austenitic stainless steels that meet the requirements for the specified minimum yield strength of 35 ksi (240 MPa) or less at 100°F (40°C) Thickness Range: 2 in. (50 mm) and greater

Nominal Wall Thickness, t, in. (mm) [Note (1)]	Volumetric (UT) [Note (2)], [Note (3)] Surface Flaw, a, in. (mm)	Volumetric (UT) Surface Flaw, ℓ, in. (mm)	Volumetric (UT) Subsurface Flaw [Note (4)], [Note (5)], a, in. (mm)	Volumetric (UT) Subsurface Flaw, ℓ, in. (mm)	Volumetric (RT) and Surface Method Surface Flaw, Length, ℓ, in. (mm)	Volumetric (RT) Subsurface Flaw, Length, ℓ, in. (mm)
Preservice Examination						
2.0 (50)	0.17 (4.3)	1.04 (26.4)	$0.17Y^{0.96}$ ($4.3Y^{0.96}$)	1.04 (26.4)	1/4 (6)	3/4 (19)
3.0 (75) and over	0.24 (6.1)	1.44 (36.6)	$0.24Y^{0.96}$ ($6.1Y^{0.96}$)	1.44 (36.6)	1/4 (6)	3/4 (19)
Inservice Examination						
2.0 (50)	0.22 (5.5)	1.32 (33.5)	$0.22Y^{0.96}$ ($5.5Y^{0.96}$)	1.32 (33.5)	0.3 (8)	1.0 (25)
3.0 (75) and over	0.30 (7.6)	1.80 (45.7)	$0.30Y^{0.96}$ ($7.6Y^{0.96}$)	1.80 (45.7)	0.45 (11)	1.0 (25)

NOTES:
(1) t is the nominal wall thickness at the section where the flaw is detected or the actual wall thickness as determined by a UT examination. For intermediate wall thicknesses, linear interpolation is acceptable. Refer to IWA-3200(c).
(2) The allowable flaws for preservice examination are based on the following equations:

(U.S. Customary Units)

$$a/t = (10.1 - 0.7t)/100, \text{ where } t \text{ max.} = 3 \text{ in.}$$
$$\ell/t = (60.6 - 4.2t)/100, \text{ where } t \text{ max.} = 3 \text{ in.}$$

(SI Units)

$$a/t = (10.1 - 0.028t)/100, \text{ where } t \text{ max.} = 75 \text{ mm}$$
$$\ell/t = (60.6 - 0.165t)/100, \text{ where } t \text{ max.} = 75 \text{ mm}$$

(3) The allowable flaws for inservice examinations are based on the following equations:

(U.S. Customary Units)

$$a/t = (12.7 - 0.9t)/100, \text{ where } t \text{ max.} = 3 \text{ in.}$$
$$\ell/t = (75.2 - 5.4t)/100, \text{ where } t \text{ max.} = 3 \text{ in.}$$

(SI Units)

$$a/t = (12.7 - 0.035t)/100, \text{ where } t \text{ max.} = 75 \text{ mm}$$
$$\ell/t = (76.2 - 0.213t)/100, \text{ where } t \text{ max.} = 75 \text{ mm}$$

(4) $Y = (S/t)/(a/t) = S/a$. If $S < 0.4d$, the flaw is classified as a surface flaw. If $Y > 1.0$, use $Y = 1.0$
(5) The total depth of a subsurface flaw is $2a$.

IWB-3521 Standards for Examination Category B-Q, Steam Generator Tubes

IWB-3521.1 Allowable Flaws for U-Tube Steam Generators. For single or multiple flaws of cracks, wastage, or intergranular corrosion in tubing of SB-163 material meeting the requirements of NB-2550 and having an r/t ratio of less than 8.70, the depth of an allowable O.D. flaw shall not exceed 40% of the tube wall thickness.

IWB-3521.2 Allowable Flaws for Straight-Tube Steam Generators. In the course of preparation.

IWB-3522 Standards for Examination Category B-P, All Pressure-Retaining Components

IWB-3522.1 Visual Examination, VT-2. A component whose visual examination (IWA-5240) detects any of the following relevant conditions[28] shall meet IWB-3142 and IWA-5250 prior to continued service:

(a) any through-wall or through-weld, pressure-retaining material leakage from insulated and noninsulated components;

(b) leakage in excess of limits established by the Owner from mechanical connections (such as pipe caps, bolted connections, or compression fittings) or from components provided with leakage limiting devices (such as valve-packing glands or pump seals);

(c) areas of general corrosion of a component resulting from leakage;

(d) discoloration or accumulated residues on surfaces of components, insulation, or floor areas that may be evidence of borated water leakage; or

(e) leakages or flow test results from buried components in excess of limits established by the Owner.

IWB-3523 Standards for Examination Category B-O, Pressure-Retaining Welds in Control Rod Drive and Instrument Nozzle Housings

IWB-3523.1 Allowable Planar Flaws.

(a) The size of an allowable planar flaw within the boundary of the examination surfaces and volumes delineated in Figure IWB-2500-18 shall not exceed the limits specified in IWB-3523.2 and IWB-3523.3, as applicable.

(b) Where a flaw extends beyond the boundaries of the examination surfaces and volumes, or separate flaws are detected that lie both within and beyond the boundaries but are characterized as a single flaw by the rules of IWA-3300, the overall flaw size shall be compared with the standards of (a).

(c) Any two or more coplanar aligned flaws characterized as separate flaws by IWA-3300 are allowable, provided the requirements of IWA-3390 are met.

IWB-3523.2 Allowable Flaw Standards for Surface Examination.

(a) The size of allowable flaws shall not exceed $^3/_{16}$ in. (5 mm) for the preservice examination and $^1/_4$ in. (6 mm) for the inservice examination.

(b) Where a flaw on the outer surface of the housing exceeds the allowable standards, the housing may be examined using the volumetric method, and the acceptance standards of IWB-3523.3 shall apply.

IWB-3523.3 Allowable Flaw Standards for Volumetric Examination.

(a) The depth of an allowable preservice flaw shall not exceed 10% of weld thickness; the length shall not exceed 60% of weld thickness.

(b) The depth of an allowable inservice flaw shall not exceed 12.5% of weld thickness; the length shall not exceed 75% of weld thickness.

IWB-3600 ANALYTICAL EVALUATION OF PLANAR FLAWS

IWB-3610 ACCEPTANCE CRITERIA FOR FERRITIC STEEL COMPONENTS 4 in. (100 mm) AND GREATER IN THICKNESS (15)

(a) A flaw that exceeds the size of allowable flaws defined in IWB-3500 may be analytically evaluated using procedures such as described in Nonmandatory Appendix A to calculate its growth until the next inspection or the end of service lifetime of the component.

(b) For purposes of analytical evaluation, the depth of flaws in clad components shall be defined in accordance with Figure IWB-3610-1 as follows:

(1) Category 1 — A flaw that lies entirely in the cladding need not be analytically evaluated.

(2) Category 2 — A surface flaw that penetrates the cladding and extends into the ferritic steel shall be analytically evaluated on the basis of the total flaw depth in both the ferritic steel and cladding.

(3) Category 3 — A subsurface flaw that lies in both the ferritic steel and the cladding shall be treated as either a surface or a subsurface flaw depending on the relationship between S and d as shown in Figure IWB-3610-1.

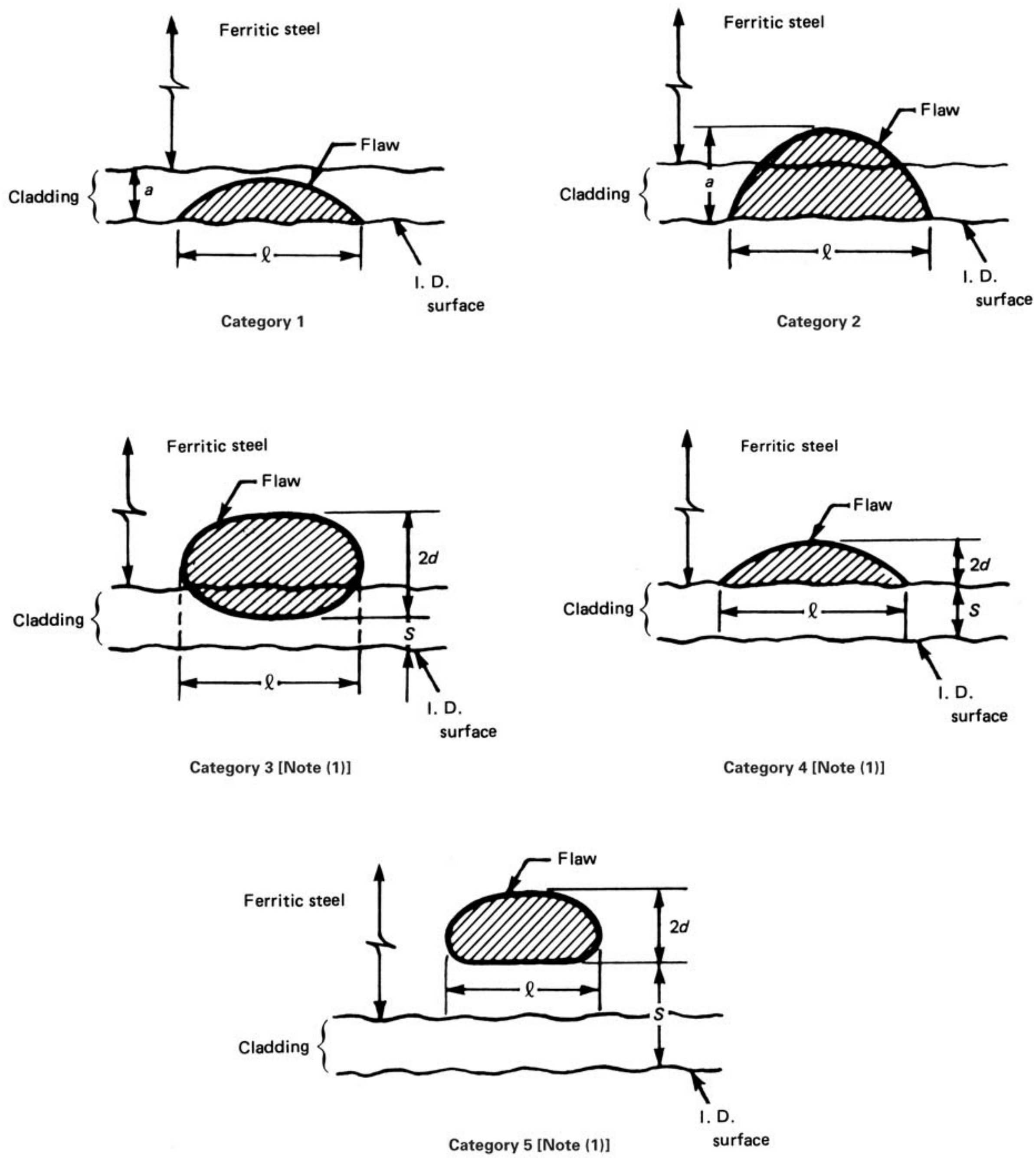
(4) Category 4 — A subsurface flaw that lies entirely in the ferritic steel and terminates at the weld metal interface shall be treated as either a surface or subsurface flaw depending on the relationship between S and d as shown in Figure IWB-3610-1.

(5) Category 5 — A subsurface flaw contained entirely in the ferritic steel shall be treated as either a surface or a subsurface flaw depending on the relationship between S and d as shown in Figure IWB-3610-1.

(c) When examination results do not permit accurate determination of the flaw category, the more conservative category shall be selected.

(15)

Figure IWB-3610-1
Characterization and Proximity Rules for Analytical Evaluation of Clad Components



NOTE:
(1) If $S > 0.4d$, then $a = d$ (subsurface flaw); if $S < 0.4d$, then $a = S + 2d$ (surface flaw).

(d) The component containing the flaw is acceptable for continued service during the evaluated time period if the following are satisfied:

(1) the criteria of IWB-3611 or IWB-3612;

(2) the primary stress limits of NB-3000, assuming a local area reduction of the pressure-retaining membrane that is equal to the area of the detected flaw(s) as determined by the flaw characterization rules of Article IWA-3000.

(e) The analytical evaluation procedures shall be the responsibility of the Owner and shall be subject to approval by the regulatory authority having jurisdiction at the plant site.

IWB-3611 Acceptance Criteria Based on Flaw Size

A flaw exceeding the limits of IWB-3500 is acceptable if the critical flaw parameters satisfy the following criteria:

$$a_f < 0.1a_c$$

$$a_f < 0.5a_i$$

where

a_f = maximum size to which the detected flaw is calculated to grow in a specified time period, which can be the next scheduled inspection of the component, or until the end of vessel design lifetime
a_c = minimum critical size of the flaw under normal operating conditions
a_i = minimum critical size of the flaw for initiation of nonarresting growth under postulated emergency and faulted conditions

IWB-3612 Acceptance Criteria Based on Applied Stress Intensity Factor

A flaw exceeding the limits of IWB-3500 is acceptable if the applied stress intensity factor for the flaw dimensions a_f and ℓ_f satisfies the following criteria.

(a) For normal conditions:

$$K_I < K_{Ic}/\sqrt{10}$$

where

K_I = applied stress intensity factor for normal conditions, including upset and test conditions for the flaw dimensions a_f and ℓ_f
K_{Ic} = fracture toughness based on crack initiation for the corresponding crack-tip temperature
a_f = end-of-evaluation-period flaw depth defined in IWB-3611
ℓ_f = end-of-evaluation-period flaw length

(b) For emergency and faulted conditions:

$$K_I < K_{Ic}/\sqrt{2}$$

where

K_I = applied stress intensity factor under emergency and faulted conditions for flaw dimensions a_f and ℓ_f

IWB-3613 Acceptance Criteria for Flanges and Shell Regions Near Structural Discontinuities (15)

The following criteria shall be used for the analytical evaluation of flaws in areas of structural discontinuity, such as vessel-flange and nozzle-to-shell regions. A flaw exceeding the limits of IWB-3500 is acceptable if the applied stress intensity factor for the dimensions a_f and ℓ_f satisfies the following limits.

(a) For conditions where pressurization does not exceed 20% of the Design Pressure, during which the minimum temperature is not less than RT_{NDT}:

$$K_I < K_{Ic}/\sqrt{2}$$

where

K_I = applied stress intensity factor for flaw dimensions a_f and ℓ_f
K_{Ic} = fracture toughness based on crack initiation for the corresponding crack-tip temperature
a_f = end-of-evaluation-period flaw depth defined in IWB-3611
ℓ_f = end-of-evaluation-period flaw length

(b) For normal conditions (including upset and test conditions), excluding those described in (a), the criteria of IWB-3611 or IWB-3612(a) shall be satisfied.

(c) For emergency and faulted conditions, the criteria of IWB-3611 or IWB-3612(b) shall be satisfied.

IWB-3620 ACCEPTANCE CRITERIA FOR FERRITIC COMPONENTS LESS THAN 4 in. (100 mm) IN THICKNESS

These criteria are in the course of preparation. In the interim, the criteria of IWB-3610 may be applied.

IWB-3630 ACCEPTANCE CRITERIA FOR STEAM GENERATOR TUBING

Evaluation of cracks, wastage, or intergranular corrosion in steam generator tubes that exceed the allowable flaw standards of IWB-3521 shall be performed by analyses acceptable to the regulatory authority having jurisdiction at the plant site.

(15) IWB-3640 ANALYTICAL EVALUATION PROCEDURES AND ACCEPTANCE CRITERIA FOR FLAWS IN AUSTENITIC AND FERRITIC PIPING

Piping containing flaws exceeding the acceptance standards of IWB-3514.1 may be analytically evaluated to determine acceptability for continued service to the next inspection or to the end of the evaluation period. A pipe containing flaws is acceptable for continued service for a specified evaluation time period if the criteria of IWB-3642, IWB-3643, or IWB-3644 are satisfied. The procedures shall be the responsibility of the Owner and shall be provided to the regulatory authority having jurisdiction at the plant site.

IWB-3641 Analytical Evaluation Procedures

Analytical evaluation procedures based on flaw size or applied stress, such as those described in Nonmandatory Appendix C or H, may be used, subject to the following:

(a) The analytical evaluation procedures and acceptance criteria in Nonmandatory Appendix C are applicable to piping NPS 1 (DN 25) and greater. The procedures and criteria in Nonmandatory Appendix H are applicable to piping NPS 4 (DN 100) and greater. Nonmandatory Appendices C and H are applicable to portions of adjoining pipe fittings within a distance of $(R_2 t)^{1/2}$ from the weld centerline, where R_2 is the outside radius and t is the nominal thickness of the pipe. The weld geometry and weld-base metal interface are defined in Nonmandatory Appendix C.

(b) The analytical evaluation procedures and acceptance criteria are applicable to seamless or welded wrought carbon steel pipe and pipe fittings, and associated weld materials that have a specified minimum yield strength not greater than 40 ksi (280 MPa).

(c) The analytical evaluation procedures and acceptance criteria are applicable to seamless or welded wrought or cast austenitic pipe and pipe fittings and associated weld materials that are made of wrought stainless steel, Ni-Cr-Fe alloy, or cast stainless steel, and have a specified minimum yield strength not greater than 45 ksi (310 MPa).

(d) A flaw growth analysis shall be performed on the detected flaw to predict its growth due to fatigue or stress corrosion cracking mechanisms, or both, when applicable, during a specified evaluation time period. The time interval selected for flaw growth analysis (i.e., evaluation period) shall be until the next inspection or until the end of the evaluation period for the item.

(e) The calculated maximum flaw dimensions at the end of the evaluation period shall be compared to the acceptance criteria for Service Levels A, B, C, and D loadings to determine the acceptability of the item for continued service.

IWB-3642 Analytical Evaluation Procedures and Acceptance Criteria Based on Failure Mode Determination

Piping containing flaws exceeding the acceptance standards of IWB-3514.1 may be analytically evaluated using procedures described in Nonmandatory Appendix C and is acceptable for continued service during the evaluated time period when the critical flaw parameters satisfy the criteria in Nonmandatory Appendix C. Flaw acceptance criteria are based on allowable flaw size or allowable stress. Flaws with depths greater than 75% of the wall thickness are unacceptable.

IWB-3643 Analytical Evaluation Procedures and Acceptance Criteria Based on Use of a Failure Assessment Diagram

Piping containing flaws exceeding the allowable flaw standards of IWB-3514.1 may be analytically evaluated using procedures based on use of a failure assessment diagram, such as described in Nonmandatory Appendix H. Such analytical evaluation procedures may be invoked in accordance with the conditions of IWB-3641. Flaws with depths greater than 75% of the wall thickness are unacceptable.

IWB-3644 Alternative Analytical Evaluation Procedure and Acceptance Criteria Based on Applied Stress

Piping containing flaws exceeding the allowable flaw standards of IWB-3514.1 is acceptable for continued service until the end of the evaluation period if the alternative analytical evaluation procedure demonstrates, at the end-of-evaluation period, structural factors, based on load, equivalent to the following:

Service Level	Structural Factor
A	2.7
B	2.4
C	1.8
D	1.4

Flaws with depths greater than 75% of the wall thickness are unacceptable.

IWB-3660 EVALUATION PROCEDURE AND ACCEPTANCE CRITERIA FOR PWR REACTOR VESSEL HEAD PENETRATION NOZZLES

PWR reactor vessel upper and lower head penetration nozzles containing flaws may be evaluated to determine acceptability for continued service in accordance with the evaluation procedure and acceptance criteria of this paragraph. The evaluation procedures and acceptance criteria shall be the responsibility of the Owner.

Note that the acceptance standards of IWB-3500 shall not be used to accept indications in this region.

IWB-3661 Evaluation Procedure

This evaluation procedure is applicable to head penetration nozzles with 8 in. (200 mm) nominal outside diameter and less. This procedure shall not be used for partial penetration nozzle to vessel (J-groove) welds.

(15) IWB-3662 Methodology for Evaluation

(a) A flaw growth analysis shall be performed on each detected flaw to determine its maximum growth due to fatigue, stress corrosion cracking or both mechanisms, when applicable, during a specified evaluation period. The minimum time interval for the flaw growth evaluation shall be until the next inspection.

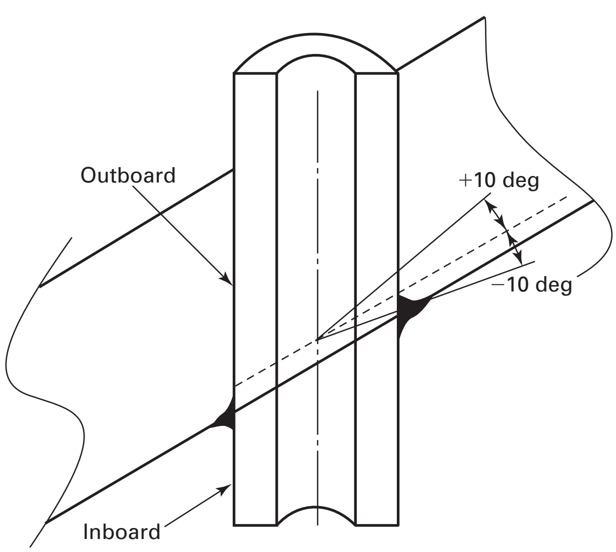
(b) All applicable loadings shall be considered, including weld residual stress, in calculating the crack growth.

(c) The flaw shall be characterized in accordance with the requirements of IWA-3400, including the proximity rules of Figure IWA-3400-1 for surface flaws.

(d) The flaw shall be projected into both axial and circumferential orientations, and each orientation shall be evaluated. The axial orientation is the same for each nozzle, but the circumferential orientation will vary depending on the angle of intersection of the penetration nozzle with the head. The circumferential orientation is defined in Figure IWB-3662-1.

(e) The location of the flaw, relative to the J-groove attachment weld, shall be determined.

Figure IWB-3662-1
Definition of Circumferential Orientation for Flaw Characterization



GENERAL NOTE: Planar flaws within 10 deg of the plane formed by the J-groove weld root, shown as the dashed line, shall be considered circumferential flaws.

(f) The flaw shall be evaluated using procedures such as those described in Nonmandatory Appendix O, to calculate the following critical flaw parameters:

a_f = the maximum depth to which the detected flaw is calculated to grow at the end of the evaluation period

l_f = the maximum length to which the detected flaw is calculated to grow at the end of the evaluation period

IWB-3663 Acceptance Criteria

The calculated maximum flaw dimensions at the end of the evaluation period shall be compared with the maximum allowable flaw dimensions in Table IWB-3663-1.

IWB-3700 EVALUATION OF PLANT OPERATING EVENTS (15)

IWB-3710 SCOPE

This Subarticle provides rules for evaluation of events and conditions for pressure boundary components and associated structures in operating plants.

IWB-3720 UNANTICIPATED OPERATING EVENTS (15)

(a) When an operating event causes an excursion outside the normal operating pressure and temperature limits defined in the plant Technical Specifications, an evaluation shall be performed to determine the effects of the out-of-limit condition on the structural integrity of the Reactor Coolant System.

(b) Nonmandatory Appendix E provides procedures and criteria that may be used to evaluate the integrity of the reactor vessel beltline for the out-of-limit condition.

(c) The evaluation procedures shall be the responsibility of the Owner and shall be subject to acceptance by the regulatory authority having jurisdiction at the plant site.

IWB-3730 FRACTURE TOUGHNESS CRITERIA FOR PROTECTION AGAINST FAILURE

(a) During reactor operation, load and temperature conditions shall be maintained to provide protection against failure due to the presence of postulated flaws in the ferritic portions of the reactor coolant pressure boundary. Nonmandatory Appendix G provides procedures that may be used to define these load and temperature conditions.

(b) For reactor vessels with material upper shelf Charpy impact energy levels less than 50 ft-lb (68 J), service and test conditions may be evaluated, using current-geometry and material properties, to provide protection against ductile failure. Nonmandatory Appendix K contains procedures that may be used to demonstrate protection against ductile failure.

Table IWB-3663-1
Reactor Vessel Head Penetration Nozzle Acceptance Criteria

Location [Note (1)], [Note (2)]	Axial		Circumferential	
	a_f	ℓ_f	a_f	ℓ_f
Inboard of Weld (I.D.) [Note (3)]	t	No Limit	t	0.75 Circ.
At and Outboard of Weld (I.D.)	0.75t	No Limit	[Note (4)]	[Note (4)]
Inboard of Weld (O.D.) [Note (3)]	t	No Limit	t	0.75 Circ.
Outboard of Weld (O.D.)	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]

GENERAL NOTES:
(a) Linear surface flaws of any size in the partial penetration nozzle to vessel (J-groove) welds are not acceptable.
(b) t = wall thickness of head penetration nozzle.

NOTES:
(1) Inboard of the weld is not part of the pressure boundary.
(2) At and outboard of the weld is part of the pressure boundary.
(3) Intersecting axial and circumferential flaws in the nozzle are not acceptable.
(4) Requires case-by-case evaluation. Acceptance criteria shall be justified by the Owner.

(c) The procedures used to define protection against failure due to the presence of postulated flaws shall be the responsibility of the Owner and shall be subject to acceptance by the regulatory authority having jurisdiction at the plant site.

IWB-3740 OPERATING PLANT FATIGUE ASSESSMENTS

(a) Nonmandatory Appendix L provides procedures that may be used to assess the effects of thermal and mechanical fatigue concerns on component acceptability for continued service.

(b) Nonmandatory Appendix L provides procedures that may also be used when the calculated fatigue usage exceeds the fatigue usage limit defined in the original Construction Code.

ARTICLE IWB-5000
SYSTEM PRESSURE TESTS

IWB-5200 SYSTEM TEST REQUIREMENTS

IWB-5210 TEST

(a) Pressure-retaining components shall be tested at the frequency stated in, and visually examined by the method specified in Table IWB-2500-1 (B-P).

(b) The system pressure tests and visual examinations shall be conducted in accordance with Article IWA-5000 and this Article. The contained fluid in the system shall serve as the pressurizing medium.

IWB-5220 SYSTEM LEAKAGE TEST

IWB-5221 Pressure

(a) The system leakage test shall be conducted at a pressure not less than the pressure corresponding to 100% rated reactor power.

(b) The system test pressure and temperature shall be attained at a rate in accordance with the heat-up limitations specified for the system.

IWB-5222 Boundaries

(a) The pressure-retaining boundary during the system leakage test shall correspond to the reactor coolant boundary, with all valves in the position required for normal reactor operation startup. The visual examination shall, however, extend to and include the second closed valve at the boundary extremity.

(b) The Class 1 pressure-retaining boundary which is not pressurized when the system valves are in the position required for normal reactor startup shall be pressurized and examined at or near the end of the inspection interval. This boundary may be tested in its entirety or in portions and testing may be performed during the testing of the boundary of (a).

IWB-5230 HYDROSTATIC TEST

(a) The hydrostatic test may be conducted at any test pressure specified in Table IWB-5230-1 corresponding to the selected test temperature, provided the requirements of IWB-5240 are met for all ferritic steel components within the boundary of the system (or portion of system) subject to the test pressure (see IWA-5245).

(b) Whenever a hydrostatic test is conducted in which the reactor vessel contains nuclear fuel and the vessel is within the system test boundary, the test pressure shall not exceed the limiting conditions specified in the plant Technical Specifications.

IWB-5240 TEMPERATURE

(a) The minimum test temperature for either the system leakage or system hydrostatic test shall not be lower than the minimum temperature for the associated pressure specified in the plant Technical Specifications.

(b) The system test temperature shall be modified as required by the results obtained from each set of material surveillance specimens withdrawn from the reactor vessel during the service lifetime.

(c) For tests of systems or portions of systems constructed entirely of austenitic steel, test temperature limitations are not required to meet fracture prevention criteria. In cases where the components of the system are constructed of ferritic and austenitic steels that are nonisolable from each other during a system leakage or system hydrostatic test, the test temperature shall be in accordance with IWB-5230(a).

Table IWB-5230-1
Test Pressure

Test Temperature, °F (°C)	Test Pressure [Note (1)], [Note (2)]
100 (40) or less	$1.10P_o$
200 (95)	$1.08P_o$
300 (150)	$1.06P_o$
400 (200)	$1.04P_o$
500 (260) or greater	$1.02P_o$

NOTES:
(1) P_o is the reactor pressure corresponding to 100% rated reactor power.
(2) Linear interpolation at intermediate test temperatures is permissible.

SUBSECTION IWC
REQUIREMENTS FOR CLASS 2 COMPONENTS OF LIGHT-WATER-COOLED PLANTS

ARTICLE IWC-1000
SCOPE AND RESPONSIBILITY

IWC-1100 SCOPE

This Subsection provides requirements for inservice inspection of Class 2 pressure-retaining components and their welded attachments in light-water-cooled plants.

IWC-1200 COMPONENTS SUBJECT TO EXAMINATION

IWC-1210 EXAMINATION REQUIREMENTS

The examination requirements of this Subsection shall apply to Class 2 pressure-retaining components and their welded attachments.

IWC-1220 COMPONENTS EXEMPT FROM EXAMINATION

The following components or portions of components are exempted from the volumetric and surface examination requirements of IWC-2500.

(15) **IWC-1221 Components Within RHR, ECC, and CHR Systems or Portions of Systems**[30]

(a) For systems, except high pressure safety injection systems in pressurized water reactor plants:

(1) components and piping segments NPS 4 (DN 100) and smaller

(2) components and piping segments which have one inlet and one outlet, both of which are NPS 4 (DN 100) and smaller

(3) components[20] and piping segments which have multiple inlets or multiple outlets, whose cumulative pipe cross-sectional area does not exceed the cross-sectional area defined by the O.D. of NPS 4 (DN 100) pipe

(b) For high pressure safety injection systems in pressurized water reactor plants:

(1) components and piping segments NPS $1^1/_2$ (DN 40) and smaller

(2) components and piping segments which have one inlet and one outlet, both of which are NPS $1^1/_2$ (DN 40) and smaller

(3) components[20] and piping segments which have multiple inlets or multiple outlets whose cumulative pipe cross-sectional area does not exceed the cross-sectional area defined by the O.D. of NPS $1^1/_2$ (DN 40) pipe

(c) Vessels, piping, pumps, valves, other components, and component connections of any size in statically pressurized, passive (i.e., no pumps) safety injection systems[31] of pressurized water reactor plants.

(d) Piping and other components of any size beyond the last shutoff valve in open-ended suction or discharge portions of systems that do not contain water during normal plant operating conditions.

IWC-1222 Components Within Systems or Portions of Systems Other Than RHR, ECC, and CHR Systems[30] (15)

(a) For systems, except auxiliary feedwater systems in pressurized water reactor plants:

(1) components and piping segments NPS 4 (DN 100) and smaller

(2) components and piping segments which have one inlet and one outlet, both of which are NPS 4 (DN 100) and smaller

(3) components[20] and piping segments which have multiple inlets or multiple outlets whose cumulative pipe cross-sectional area does not exceed the cross-sectional area defined by the O.D. of NPS 4 (DN 100) pipe.

(b) For auxiliary feedwater systems in pressurized water reactor plants:

(1) components and piping segments NPS $1^1/_2$ (DN 40) and smaller

(2) components and piping segments which have one inlet and one outlet, both of which are NPS $1^1/_2$ (DN 40) and smaller

(3) components[20] and piping segments which have multiple inlets or multiple outlets whose cumulative pipe cross-sectional area does not exceed the cross-sectional area defined by the O.D. of NPS 1½ (DN 40) pipe.

(c) Vessels, piping, pumps, valves, other components, and component connections of any size in systems or portions of systems that operate (when the system function is required) at a pressure equal to or less than 275 psig (1,900 kPa) and at a temperature equal to or less than 200°F (95°C).

(d) Piping and other components of any size beyond the last shutoff valve in open-ended suction or discharge portions of systems that do not contain water during normal plant operating conditions.

IWC-1223 Inaccessible Welds

Welds or portions of welds that are inaccessible due to being encased in concrete, buried underground, located inside a penetration, or encapsulated by guard pipe.

ARTICLE IWC-2000
EXAMINATION AND INSPECTION

IWC-2200 PRESERVICE EXAMINATION

(a) All examinations required by this Article (with the exception of Table IWC-2500-1 (C-H)) for those components initially selected for examination in accordance with the Inspection Program and not exempt from inservice examinations by IWC-1220 shall be completed prior to initial plant startup.

(b) Shop and field examinations may serve in lieu of the on-site preservice examinations, provided

(1) in the case of vessels only, the hydrostatic test required by Section III has been completed

(2) such examinations are conducted under conditions and with equipment and techniques equivalent to those which are expected to be employed for subsequent inservice examinations

(3) the shop and field examination records are, or can be, documented and identified in a form consistent with those required in Article IWA-6000

IWC-2400 INSPECTION SCHEDULE

IWC-2410 INSPECTION PROGRAM

Inservice examinations and system pressure tests may be performed during either system operation or plant outages.

IWC-2411 Inspection Program

(a) The required examinations in each examination category shall be completed during each inspection interval in accordance with Table IWC-2411-1, with the exceptions of Category C-H and of welded attachments examined as a result of component support deformation under Examination Category C-C. If there are less than three items or welds to be examined in an Examination Category, the items or welds may be examined in any two periods, or in any one period if there is only one item or weld, in lieu of the percentage requirements of Table IWC-2411-1.

(b) If items or welds are added to the Inspection Program, during the service lifetime of a plant, examination shall be scheduled as follows:

(1) When items or welds are added during the first period of an interval, at least 25% of the examinations required by the applicable Examination Category and Item Number for the added items or welds shall be performed during each of the second and third periods of that interval.

(2) When items or welds are added during the second period of an interval, at least 25% of the examinations required by the applicable Examination Category and Item Number for the added items or welds shall be performed during the third period of that interval.

(3) When items or welds are added during the third period of an interval, examinations shall be scheduled in accordance with (a) for successive intervals.

IWC-2420 SUCCESSIVE INSPECTIONS

(a) The sequence of component examinations which was established during the first inspection interval shall be repeated during each successive inspection interval, to the extent practical. The sequence of component examinations may be modified in a manner that optimizes scaffolding, radiological, insulation removal, or other considerations, provided that the percentage requirements of Table IWC-2411-1 are maintained.

(b) If a component is accepted for continued service in accordance with IWC-3122.3 or IWC-3132.3(a), the areas containing flaws or relevant conditions shall be reexamined during the next inspection period listed in the schedule of the Inspection Program of IWC-2400. Alternatively, acoustic emission may be used to monitor growth of existing flaws in accordance with IWA-2234. For vessel welds, the successive inspection is not required if the following conditions are met:

(1) The flaw is characterized as subsurface in accordance with Figure IWA-3320-2.

Table IWC-2411-1
Inspection Program

Inspection Interval	Inspection Period, Calendar Years of Plant Service Within the Interval	Minimum Examinations Completed, %	Maximum Examinations Credited, %
All	3	16	50
	7	50 [Note (1)]	75
	10	100	100

NOTE:
(1) If the first period completion percentage for any examination category exceeds 34%, at least 16% of the required examinations shall be performed in the second period.

(2) The weld containing the flaw is acceptable for continued service in accordance with IWC-3600, and the flaw is demonstrated acceptable for the intended service life of the component.

(c) If the reexaminations required by (b) above reveal that the flaws or relevant conditions remain essentially unchanged, or that the flaw growth is within the growth predicted by the analytical evaluation, for the next inspection period, then the component examination schedule may revert to the original schedule of successive inspections or the inspection interval defined by the analytical evaluation, whichever is limiting.

(d) If the reexaminations required by (b) above reveal new flaws or relevant conditions that exceed the applicable acceptance standards of Table IWC-3410-1, or growth of existing flaws in excess of the growth predicted by the analytical evaluation, then

(1) the entire weld, area, or part[32] shall be examined during the current outage

(2) additional examinations shall be performed in accordance with IWC-2430

(e) If welded attachments are examined as a result of identified component support deformation and the results of these examinations exceed the acceptance standards of Table IWC-3410-1 successive examinations shall be performed, if determined necessary, based on an evaluation by the Owner. The evaluation shall be documented and shall include the cause of the welded attachment damage if known. If the cause of the welded attachment damage could recur or is unknown, successive examinations shall be performed in accordance with the requirements of (b) above. No successive examinations are required if either of the following applies:

(1) There are no other welded attachments subject to the same apparent or root cause conditions.

(2) The designation mechanism no longer exists.

IWC-2430 ADDITIONAL EXAMINATIONS

(a) Examinations performed in accordance with Tables IWC-2500-1 (C-A) through IWC-2500-1 (C-F-2) that reveal flaws or relevant conditions exceeding the acceptance standards of Table IWC-3410-1 shall be extended to include additional examinations during the current outage in accordance with (1) or (2) below.

(1) Additional examinations shall be performed in accordance with the following requirements:

(-a) The additional examinations shall include an additional number of welds, areas, or parts[32] included in the inspection item[33] equal to 20% of the number of welds, areas, or parts included in the inspection item that are scheduled to be performed during the interval. The additional examinations shall be selected from welds, areas, or parts of similar material and service. This additional selection may require inclusion of piping systems other than the one containing the flaws or relevant conditions.

(-b) If the additional examinations required by (-a) above reveal flaws or relevant conditions exceeding the acceptance standards of Table IWC-3410-1, the examinations shall be further extended to include additional examinations during the current outage. These additional examinations shall include the remaining number of welds, areas, or parts of similar material and service subject to the same type of flaws or relevant conditions.

(2) Additional examinations shall be performed in accordance with the following requirements:

(-a) An engineering evaluation shall be performed. Topics to be addressed in the engineering evaluation shall include the following:

(-1) a determination of the cause of the flaws or relevant conditions

(-2) an evaluation of applicable service conditions and degradation mechanisms to establish that the affected welds, areas, or parts[32] will perform their intended safety functions during subsequent operation

(-3) a determination of which additional welds, areas, or parts[32] are subject to the same service conditions and degradation mechanisms that caused the flaws or relevant conditions

(-b) Additional examinations shall be performed on all those welds, areas, or parts[32] subject to the same service conditions and degradation mechanisms that caused the flaws or relevant conditions. This additional selection might require inclusion of piping systems other than the one containing the original flaws or relevant conditions. No additional examinations are required if the engineering evaluation concludes that

(-1) there are no additional welds, areas, or parts subject to the same service conditions that caused the flaws or relevant conditions or

(-2) no degradation mechanism exists

(-c) The engineering evaluation shall be retained in accordance with Article IWA-6000.

(b) The examination method for additional examinations may be limited to the examination method that originally identified the flaws or relevant conditions, provided use of the method is supported by an engineering evaluation. The engineering evaluation shall determine the cause of the flaws or relevant conditions and the appropriate method to be used as part of the additional examination scope. The engineering evaluation shall be retained in accordance with Article IWA-6000.

(c) For the inspection period following the period in which the examinations of (a) were completed, the examinations shall be performed as originally scheduled in accordance with IWC-2400.

(d) If welded attachments are examined as a result of identified component support deformation and the results of these examinations exceed the acceptance standards of Table IWC-3410-1 additional examinations shall be performed, if determined necessary, based on an evaluation by the Owner. The evaluation shall be documented and shall include the cause of the welded

attachment damage if known. If the cause of the welded attachment damage could recur or is unknown, additional examinations shall be performed in accordance with the requirements of (a) above. No additional examinations are required if either of the following applies:

(1) There are no other welded attachments subject to the same apparent or root cause conditions.

(2) The degradation mechanism no longer exists.

IWC-2500 EXAMINATION AND PRESSURE TEST REQUIREMENTS

(a) Components shall be examined and pressure tested as specified in Tables IWC-2500-1 (C-A) through IWC-2500-1 (C-H). The method of examination for the components and parts of the pressure-retaining boundaries shall comply with those tabulated in Tables IWC-2500-1 (C-A) through IWC-2500-1 (C-H), except where alternate examination methods are used that meet the requirements of IWA-2240.

(b) Tables IWC-2500-1 (C-A) through IWC-2500-1 (C-H) are organized as follows.

Examination Category	Examination Area
C-A	Pressure-Retaining Welds in Pressure Vessels
C-B	Pressure-Retaining Nozzle Welds in Pressure Vessels
C-C	Welded Attachments for Pressure Vessels, Piping, Pumps, and Valves
C-D	Pressure-Retaining Bolting Greater Than 2 in. (50 mm) in Diameter
C-F-1	Pressure-Retaining Welds in Austenitic Stainless Steel or High Alloy Piping
C-F-2	Pressure-Retaining Welds in Carbon or Low Alloy Steel Piping
C-H	All Pressure-Retaining Components

(c) Alternatively, for Examination Categories C-F-1 and C-F-2, the provisions of Nonmandatory Appendix R may be applied to all Class 2 piping or to one or more individual piping systems.

(d) In lieu of the surface examination requirements for Examination Categories C-F-1 and C-F-2 welds (all diameters and thicknesses, circumferential and socket), the Owner may elect to perform a plant-specific review for welds susceptible to outside surface attack. All welds of the examination categories and within the size limitations of this subparagraph, determined by this review to be susceptible to outside surface attack, require surface examination each interval, in the same sequence, to the extent practical, over the lifetime of the item. The plant-specific review shall be updated each interval. The requirements of IWC-2411 shall be met. Acceptance standards shall be in accordance with IWC-3514. Contributors to outside surface attack include proximity to nearby leak paths, proximity to chloride-bearing materials, existence of moisture- or salt-laden atmosphere, and existence of insulation or other coating or cover that traps moisture. Specific outside surface attack susceptibility criteria are the following:

(1) austenitic stainless steel base metal, welds, or heat-affected zone (HAZ); operating temperature greater than 150°F (65°C); and piping outside surface within five page diameters of a probable leak path (e.g., valve stem) and covered with nonmetallic insulation not in compliance with U.S. NRC Regulatory Guide 1.36 (e.g., chloride content) or equivalent requirements

(2) austenitic stainless steel base metal, welds, or HAZ and piping outside surface exposed to wetting from a concentrated chloride-bearing environment (e.g., seawater, brackish water, brine) or

(3) items identified as susceptible to any mechanisms of outside surface attack other than external chloride stress corrosion cracking based on a review of plant experience and plant-specific processes and programs addressing chlorides and other contaminants

(e) For PWR stainless steel residual and regenerative heat exchangers, in lieu of the requirements of Examination Categories C-A, C-B, and C-F-1, VT-2 visual examinations may be performed in accordance with the following:

(1) These alternative examination requirements shall not be applied to any heat exchanger, nor to any heat exchanger design or configuration, that has experienced a through-wall leak, such as heat exchangers with an inner shell (inner barrel). The Owner shall evaluate industry experience to determine which heat exchanger designs or configurations have leaked. If any leakage is detected, it shall be corrected in accordance with Article IWA-4000. Any subsequent use of these alternative examination requirements shall then be discontinued. The affected heat exchanger and others of the same design or configuration shall be examined in accordance with (a).

(2) Application of these alternative examination requirements is limited to those welds that are part of the as-received heat exchanger assembly. The regenerative heat exchanger assembly may be formed from multiple smaller heat exchanger subcomponents connected by sections of piping. All of the smaller heat exchanger subcomponents and the connecting piping are within the boundary of the heat exchanger assembly.

(3) All welds, other than reinforcing plate welds, shall have received at least one volumetric examination. The preservice or Construction Code volumetric examination may be used to meet this requirement. Reinforcing plate welds shall have received at least one surface examination.

(4) The component shall be VT-2 visually examined for evidence of leakage while undergoing the system leakage test as required by Examination Category C-H, to be performed every inspection period. IWC-3516 shall be met.

Table IWC-2500-1 (C-A)
Examination Category C-A, Pressure-Retaining Welds in Pressure Vessels [Note (1)]

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method [Note (2)]	Acceptance Standard	Extent of Examination [Note (3)], [Note (4)]	Frequency of Examination [Note (5)]
C1.10	Shell Circumferential Welds	IWC-2500-1	Volumetric	IWC-3510	Cylindrical-shell-to-conical-shell-junction welds and shell (or head)-to-flange welds	Each inspection interval
C1.20	Head Circumferential Welds	IWC-2500-1	Volumetric	IWC-3510	Head-to-shell weld and welds in the knuckle, including knuckle-to-crown welds, of an ellipsoidal or torispherical head	Each inspection interval
C1.30	Tubesheet-to-Shell Weld	IWC-2500-2	Volumetric	IWC-3510	Tubesheet-to-shell weld	Each inspection interval

NOTES:

(1) These requirements do not apply to atmospheric or 0 psig to 15 psig (0 kPa to 100 kPa) storage tanks.

(2) For welds in vessels with nominal wall thickness of 0.2 in. (5 mm) or less, a surface examination may be applied in lieu of a volumetric examination. The examination shall include the weld and 0.5 in. (13 mm) on either side of the weld. The acceptance standards for the examination shall be those specified for piping in IWC-3514.

(3) Includes essentially 100% of the weld length.

(4) In the case of multiple vessels of similar design, size, and service (such as steam generators, heat exchangers), the required examinations may be limited to one vessel or distributed among the vessels.

(5) The vessel areas selected for the initial examination shall be reexamined in the same sequence over the service lifetime of the component, to the extent practical.

Table IWC-2500-1 (C-B)
Examination Category C-B, Pressure-Retaining Nozzle Welds in Pressure Vessels [Note (1)]

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent of Examination [Note (2)]	Frequency of Examination [Note (3)]
C2.10	Nozzles in Vessels ≤ 1/2 in. (13 mm) Nominal Thickness					
C2.11	Nozzle-to-Shell (Nozzle-to-Head or Nozzle-to-Nozzle) Weld in Nozzles Without Reinforcing Plate	IWC-2500-3	Surface	IWC-3511	All nozzles at terminal ends [Note (4)] of piping runs [Note (5)]	Each inspection interval
C2.12	Nozzle-to-Shell (Nozzle-to-Head or Nozzle-to-Nozzle) Weld in Nozzles With Reinforcing Plate	IWC-2500-4(c)	Surface	IWC-3511	All nozzles at terminal ends [Note (4)] of piping runs [Note (5)]	Each inspection interval
C2.20	Nozzles Without Reinforcing Plate in Vessels > 1/2 in. (13 mm) Nominal Thickness					
C2.21	Nozzle-to-Shell (Nozzle to Head or Nozzle to Nozzle) Weld	IWC-2500-4(a), (b), or (d)	Surface and volumetric	IWC-3511	All nozzles at terminal ends [Note (4)] of piping runs [Note (5)]	Each inspection interval
C2.22	Nozzle Inside Radius Section	IWC-2500-4(a), (b), or (d)	Volumetric	IWC-3511	All nozzles at terminal ends [Note (4)] of piping runs [Note (5)]	Each inspection interval
C2.30	Nozzles With Reinforcing Plate in Vessels > 1/2 in. (13 mm) Nominal Thickness					
C2.31	Reinforcing Plate Welds to Nozzle and Vessel	IWC-2500-4(c)	Surface	IWC-3511	All nozzles at terminal ends [Note (4)] of piping runs [Note (5)]	Each inspection interval
C2.32	Nozzle-to-Shell (Nozzle to Head or Nozzle to Nozzle) Welds When Inside of Vessel is Accessible	IWC-2500-4(c)	Volumetric	IWC-3511	All nozzles at terminal ends [Note (4)] of piping runs [Note (5)]	Each inspection interval
C2.33	Nozzle-to-Shell (Nozzle to Head or Nozzle to Nozzle) Welds When Inside of Vessel Is Inaccessible	[Note (6)]	Visual, VT-2	No leakage	All nozzles at terminal ends [Note (4)] of piping runs [Note (5)]	Each inspection period

NOTES:
(1) These requirements do not apply to atmospheric or 0 psig to 15 psig (0 kPa to 100 kPa) storage tanks.
(2) In the case of multiple vessels of similar design, size, and service (such as steam generators, heat exchangers), the required examinations may be limited to one vessel or distributed among the vessels.
(3) The nozzles selected initially for examination shall be reexamined in the same sequence over the service lifetime of the component, to the extent practical.
(4) Includes nozzles welded to or integrally cast in vessels that connect to piping runs (manways and handholes are excluded).
(5) Includes only those piping runs selected for examination under Examination Category C-F.
(6) The telltale hole in the reinforcing plate shall be examined for evidence of leakage while vessel is undergoing the system leakage test (IWC-5220) as required by Examination Category C-H.

Table IWC-2500-1 (C-C)
Examination Category C-C, Welded Attachments for Pressure Vessels [Note (1)], Piping, Pumps, and Valves

Item No.	Parts Examined [Note (2)]	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent of Examination [Note (3)], [Note (4)]	Frequency of Examination [Note (5)]
	Pressure Vessels					
C3.10	Welded Attachments	IWC-2500-5	Surface	IWC-3512	100% of required areas of each welded attachment	Each identified occurrence and each inspection interval [Note (6)]
	Piping					
C3.20	Welded Attachments	IWC-2500-5	Surface	IWC-3512	100% of required areas of each welded attachment	Each identified occurrence and each inspection interval [Note (7)]
	Pumps					
C3.30	Welded Attachments	IWC-2500-5	Surface	IWC-3512	100% of required areas of each welded attachment	Each identified occurrence and each inspection interval [Note (7)]
	Valves					
C3.40	Welded Attachments	IWC-2500-5	Surface	IWC-3512	100% of required areas of each welded attachment	Each identified occurrence and each inspection interval [Note (7)]

NOTES:
(1) These requirements do not apply to atmospheric or 0 psig to 15 psig (0 kPa to 100 kPa) storage tanks.
(2) Examination is limited to those welded attachments that meet the following conditions:
(a) the attachment is on the outside surface of the pressure-retaining component;
(b) the attachment provides component support as defined in NF-1110;
(c) the attachment weld joins the attachment either directly to the surface of the component or to an integrally cast or forged attachment to the component; and
(d) the attachment weld is full penetration, fillet, or partial penetration, either continuous or intermittent.
(3) The extent of the examination includes essentially 100% of the length of the attachment weld at each attachment subject to examination, except that, for the configuration shown in Figure IWC-2500-5, examination of surface areas may be limited to the portions of these areas that are accessible without removal of support members.
(4) Selected samples of welded attachments shall be examined each inspection interval.
(5) Examination is required whenever component support member deformation, e.g., broken, bent, or pulled out parts, is identified during operation, refueling, maintenance, examination, or testing.
(6) For multiple vessels of similar design, function, and service, only one welded attachment of only one of the multiple vessels shall be selected for examination. For single vessels, only one welded attachment shall be selected for examination. The attachment selected for examination on one of the multiple vessels or the single vessel, as applicable, shall be an attachment under continuous load during normal system operation, or an attachment subject to a potential intermittent load (seismic, water hammer, etc.) during normal system operation if an attachment under continuous load does not exist.
(7) For piping, pumps, and valves, a sample of 10% of the welded attachments associated with the component supports selected for examination under IWF-2510 shall be examined.

(15)

Table IWC-2500-1 (C-D)
Examination Category C-D, Pressure-Retaining Bolting Greater Than 2 in. (50 mm) in Diameter

Item No.	Parts Examined [Note (1)]	Examination Requirements/ Figure No.	Examination Method [Note (2)]	Acceptance Standard	Extent of Examination [Note (1)]	Frequency of Examination [Note (5)]
	Pressure Vessels [Note (6)]					
C4.10	Bolts and Studs	IWC-2500-6(a)	Volumetric	IWC-3513	100% bolts and studs at each bolted connection of components required to be inspected [Note (3)]	Each inspection interval
	Piping					
C4.20	Bolts and Studs	IWC-2500-6(a)	Volumetric	IWC-3513	100% bolts and studs at each bolted connection of components required to be inspected [Note (4)]	Each inspection interval
	Pumps					
C4.30	Bolts and Studs	IWC-2500-6(a)	Volumetric	IWC-3513	100% bolts and studs at each bolted connection of components required to be inspected [Note (3)]	Each inspection interval
	Valves					
C4.40	Bolts and Studs	IWC-2500-6(a)	Volumetric	IWC-3513	100% bolts and studs at each bolted connection of components required to be inspected [Note (3)]	Each inspection interval

GENERAL NOTE: Bolting diameter is defined as the smaller of the minor thread diameter of the portion of the bolting that is under tension or the bolting shank diameter.

NOTES:
(1) The examination may be performed on bolting in place under load or upon disassembly of the connection.
(2) When bolts or studs are removed for examination, surface examination meeting the acceptance standards of IWB-3515 may be substituted for volumetric examination.
(3) The examination of bolting for vessels, pumps, or valves may be conducted on one vessel, one pump, or one valve among a group of vessels, pumps, or valves that are similar in design, size, function, and service. In addition, when the component to be examined contains a group of bolted connections of similar design and size (such as flanged connections or manway covers), the examination may be conducted on one bolted connection among the group.
(4) The examination of flange bolting in piping systems may be limited to one bolted connection among a group of bolted connections that are similar in design, size, function, and service.
(5) The areas selected for the initial examination shall be reexamined in the same sequence over the service lifetime of the component, to the extent practical.
(6) These requirements do not apply to atmospheric or 0 psig to 15 psig (0 kPa to 100 kPa) storage tanks.

Table IWC-2500-1 (C-F-1)
Examination Category C-F-1, Pressure-Retaining Welds in Austenitic Stainless Steel or High Alloy Piping

Item No.	Parts Examined [Note (1)]	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent of Examination [Note (2)]	Frequency of Examination [Note (4)]
C5.10	Piping Welds ≥ $^3/_8$ in. (10 mm) Nominal Wall Thickness for Piping > NPS 4 (DN 100)					
C5.11	Circumferential Weld	IWC-2500-7	Surface and Volumetric	IWC-3514	100% of each weld requiring examination [Note (5)], [Note (6)]	Each inspection interval
C5.20	Piping Welds > $^1/_5$ in. (5 mm) Nominal Wall Thickness for Piping ≥ NPS 2 (DN 50) and ≤ NPS 4 (DN 100)					
C5.21	Circumferential Weld	IWC-2500-7	Surface and volumetric	IWC-3514	100% of each weld requiring examination [Note (5)], [Note (6)]	Each inspection interval
C5.30	Socket Welds	IWC-2500-7	Surface	IWC-3514	100% of each weld requiring examination	Each inspection interval
C5.40	Pipe Branch Connections of Branch Piping ≥ NPS 2 (DN 50)					
C5.41	Circumferential Weld	IWC-2500-9 to IWC-2500-13, inclusive	Surface	IWC-3514	100% of each weld requiring examination [Note (5)]	Each inspection interval

NOTES:

(1) Requirements for examination of welds in piping ≤ NPS 4 (DN 100) apply to PWR high pressure safety injection and auxiliary feedwater systems in accordance with the exemption criteria of IWC-1220.

(2) The welds selected for examination shall include 7.5%, but not less than 28 welds, of all dissimilar metal, austenitic stainless steel or high alloy welds not exempted by IWC-1220. (Some welds not exempted by IWC-1220 are not required to be nondestructively examined per Examination Category C-F-1. These welds, however, shall be included in the total weld count to which the 7.5% sampling rate is applied.) The examinations shall be distributed as follows:

(a) the examinations shall be distributed among the Class 2 systems prorated, to the degree practicable, on the number of nonexempt dissimilar metal, austenitic stainless steel, or high alloy welds in each system (i.e., if a system contains 30% of the nonexempt welds, then 30% of the nondestructive examinations required by Examination Category C-F-1 should be performed on that system);

(b) within a system, the examinations shall be distributed among terminal ends, dissimilar metal welds, and structural discontinuities [See [Note (3)]] prorated, to the degree practicable, on the number of nonexempt terminal ends, dissimilar metal welds, and structural discontinuities in that system; and

(c) within each system, examinations shall be distributed between line sizes prorated to the degree practicable.

(3) Structural discontinuities include pipe weld joints to vessel nozzles, valve bodies, pump casings, pipe fittings (such as elbows, tees, reducers, flanges, etc., conforming to ANSI B16.9), and pipe branch connections and fittings.

(4) The welds selected for examination shall be reexamined in the same sequence, during subsequent inspection intervals over the service lifetime of the piping component, to the extent practical.

(5) For circumferential welds with intersecting longitudinal welds, surface examination of the longitudinal piping welds is required for those portions of the welds within the examination boundaries of intersecting circumferential welds.

(6) For circumferential welds with intersecting longitudinal welds, volumetric examination of the longitudinal piping welds is required for those portions of the welds within the examination boundaries of intersecting circumferential welds. The following requirements shall also be met:

(a) When longitudinal welds are specified and locations are known, examination requirements shall be met for both transverse and parallel flaws at the intersection of the welds and for that length of longitudinal weld within the circumferential weld examination volume.

(b) When longitudinal welds are specified but locations are unknown, or the existence of longitudinal welds is uncertain, the examination requirements shall be met for both transverse and parallel flaws within the entire examination volume of intersecting circumferential welds.

Table IWC-2500-1 (C-F-2)
Examination Category C-F-2, Pressure-Retaining Welds in Carbon or Low Alloy Steel Piping

Item No.	Parts Examined [Note (1)]	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent of Examination [Note (2)]	Frequency of Examination [Note (4)]
C5.50	Piping Welds ≥ $^3/_8$ in. (10 mm) Nominal Wall Thickness for Piping > NPS 4 (DN 100)					
C5.51	Circumferential Weld	IWC-2500-7	Surface and volumetric	IWC-3514	100% of each weld requiring examination [Note (5)], [Note (6)], [Note (7)]	Each inspection interval
C5.60	Piping Welds > $^1/_5$ in. (5 mm) Nominal Wall Thickness for Piping ≥ NPS 2 (DN 50) and ≤ NPS 4 (DN 100)					
C5.61	Circumferential Weld	IWC-2500-7	Surface and volumetric	IWC-3514	100% of each weld requiring examination [Note (5)], [Note (6)], [Note (7)]	Each inspection interval
C5.70	Socket Welds	IWC-2500-7	Surface	IWC-3514	100% of each weld requiring examination	Each inspection interval
C5.80	Pipe Branch Connections of Branch Piping ≥ NPS 2 (DN 50)					
C5.81	Circumferential Weld	IWC-2500-9 to IWC-2500-13, inclusive	Surface	IWC-3514	100% of each weld requiring examination [Note (6)]	Each inspection interval

NOTES:

(1) Requirements for examination of welds in piping ≤ NPS 4 (DN 100) apply to PWR high pressure safety injection and auxiliary feedwater systems in accordance with the exemption criteria of IWC-1220.

(2) The welds selected for examination shall include 7.5%, but not less than 28 welds, of all carbon and low alloy steel welds not exempted by IWC-1220. (Some welds not exempted by IWC-1220 are not required to be nondestructively examined per Examination Category C-F-2. These welds, however, shall be included in the total weld count to which the 7.5% sampling rate is applied.) The examinations shall be distributed as follows:

(a) the examinations shall be distributed among the Class 2 systems prorated, to the degree practicable, on the number of nonexempt carbon and low alloy steel welds in each system (i.e., if a system contains 30% of the nonexempt welds, then 30% of the nondestructive examinations required by Examination Category C-F-2 should be performed on that system);

(b) within a system, the examinations shall be distributed among terminal ends, dissimilar metal welds, and structural discontinuities [See [Note (3)]] prorated, to the degree practicable, on the number of nonexempt terminal ends, dissimilar metal welds, and structural discontinuities in that system; and

(c) within each system, examinations shall be distributed between line sizes prorated to the degree practicable.

(3) Structural discontinuities include pipe weld joints to vessel nozzles, valve bodies, pump casings, pipe fittings (such as elbows, tees, reducers, flanges, etc., conforming to ANSI B16.9), and pipe branch connections and fittings.

(4) The welds selected for examination shall be reexamined in the same sequence, during subsequent inspection intervals over the service lifetime of the piping component, to the extent practical.

(5) Only those welds showing reportable preservice transverse indications need to be examined by the ultrasonic method for reflectors transverse to the weld length direction, except that circumferential welds with intersecting longitudinal weld shall meet [Note (7)].

(6) For circumferential welds with intersecting longitudinal welds, surface examination of the longitudinal piping welds is required for those portions of the welds within the examination boundaries of intersecting circumferential welds.

Table IWC-2500-1 (C-F-2)
Examination Category C-F-2, Pressure-Retaining Welds in Carbon or Low Alloy Steel Piping (Cont'd)

NOTES (CONT'D):

(7) For circumferential welds with intersecting longitudinal welds, volumetric examination of the longitudinal piping welds is required for those portions of the welds within the examination boundaries of intersecting circumferential welds. The following requirements shall also be met:

(a) When longitudinal welds are specified and locations are known, examination requirements shall be met for both transverse and parallel flaws at the intersection of the welds and for that length of longitudinal weld within the circumferential weld examination volume.

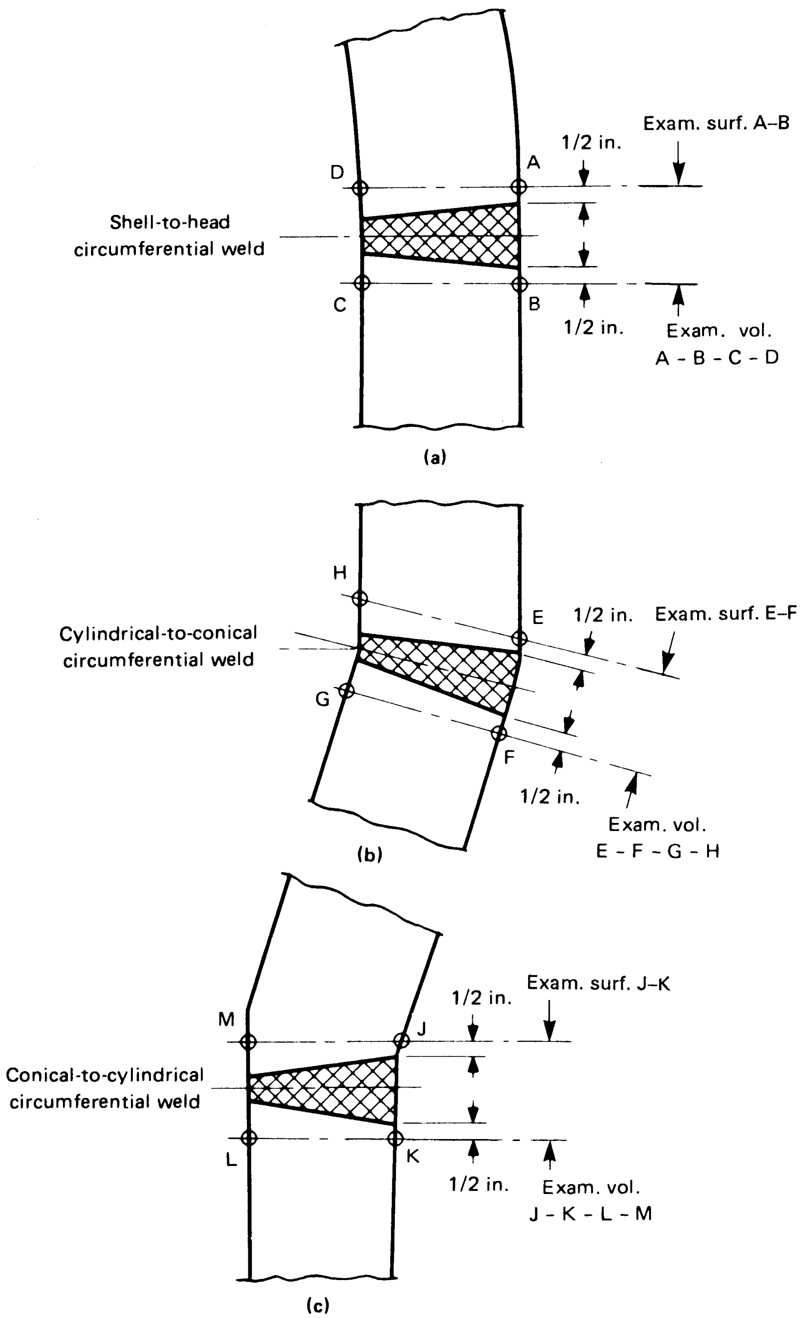
(b) When longitudinal welds are specified but locations are unknown, or the existence of longitudinal welds is uncertain, the examination requirements shall be met for both transverse and parallel flaws within the entire examination volume of intersecting circumferential welds.

Table IWC-2500-1 (C-H)
Examination Category C-H, All Pressure-Retaining Components

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method [Note (1)]	Acceptance Standard	Extent of Examination	Frequency of Examination
C7.10	Pressure-retaining components	System leakage test (IWC-5220)	Visual, VT-2	IWC-3516	Pressure-retaining boundary	Each inspection period

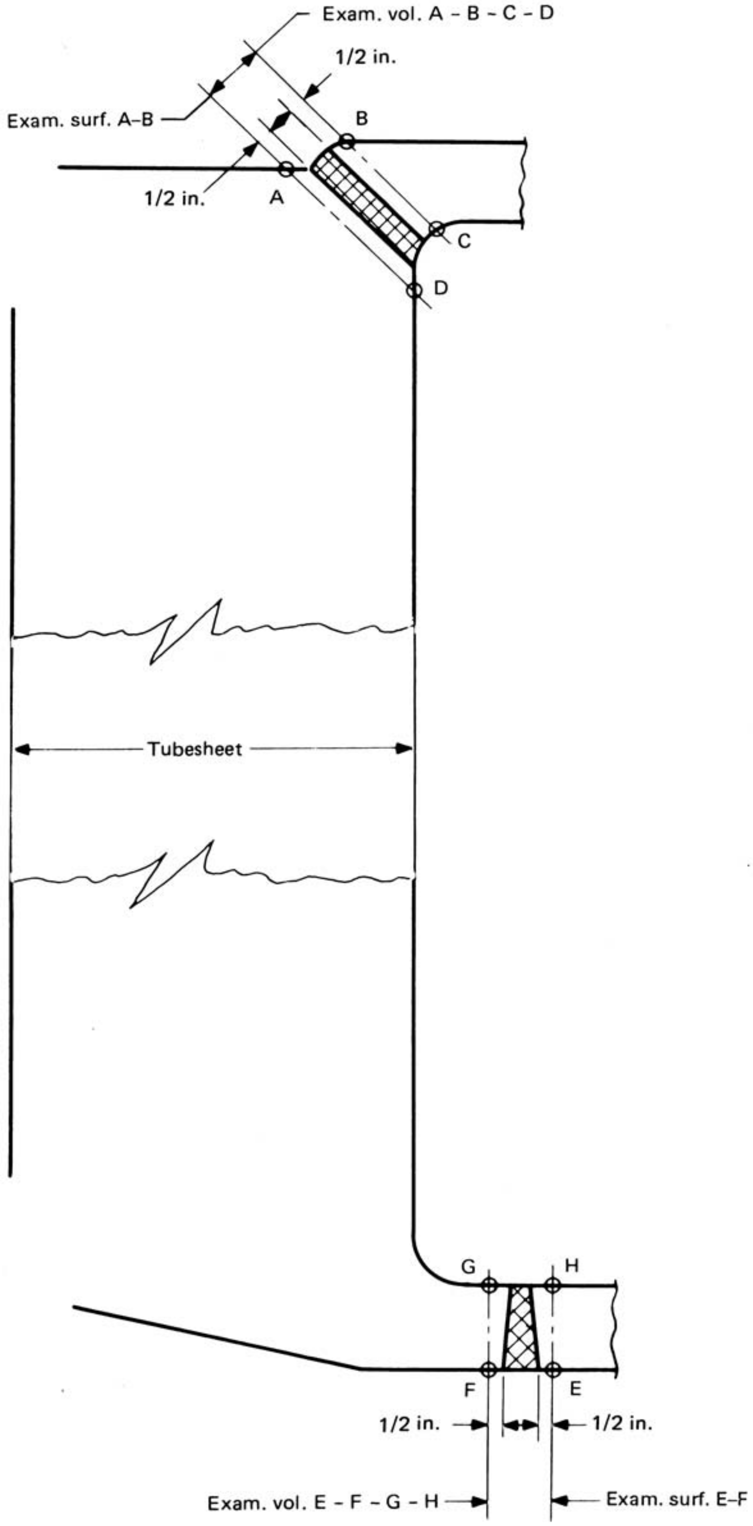
NOTE:
(1) Visual examination of IWA-5240.

Figure IWC-2500-1
Vessel Circumferential Welds



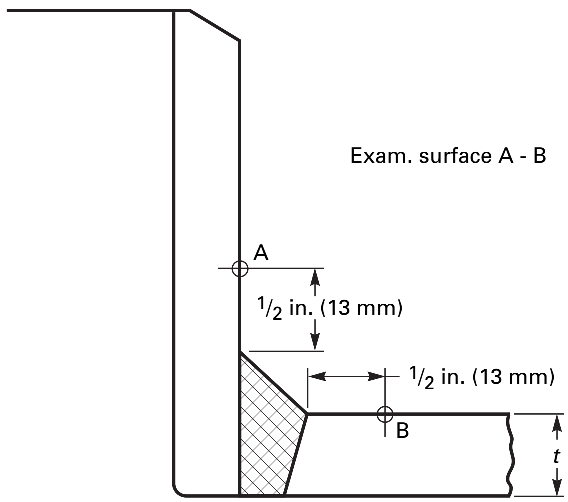
GENERAL NOTE: $^1\!/_2$ in. = 13 mm

Figure IWC-2500-2
Typical Tubesheet-to-Shell Circumferential Welds
(Steam Generator Designs)

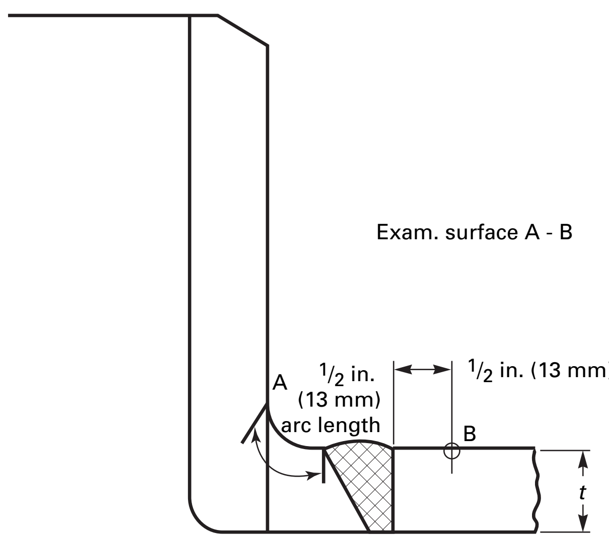


GENERAL NOTE: $^{1}/_{2}$ in. = 13 mm

Figure IWC-2500-3
Nozzle-to-Vessel Welds



(a)

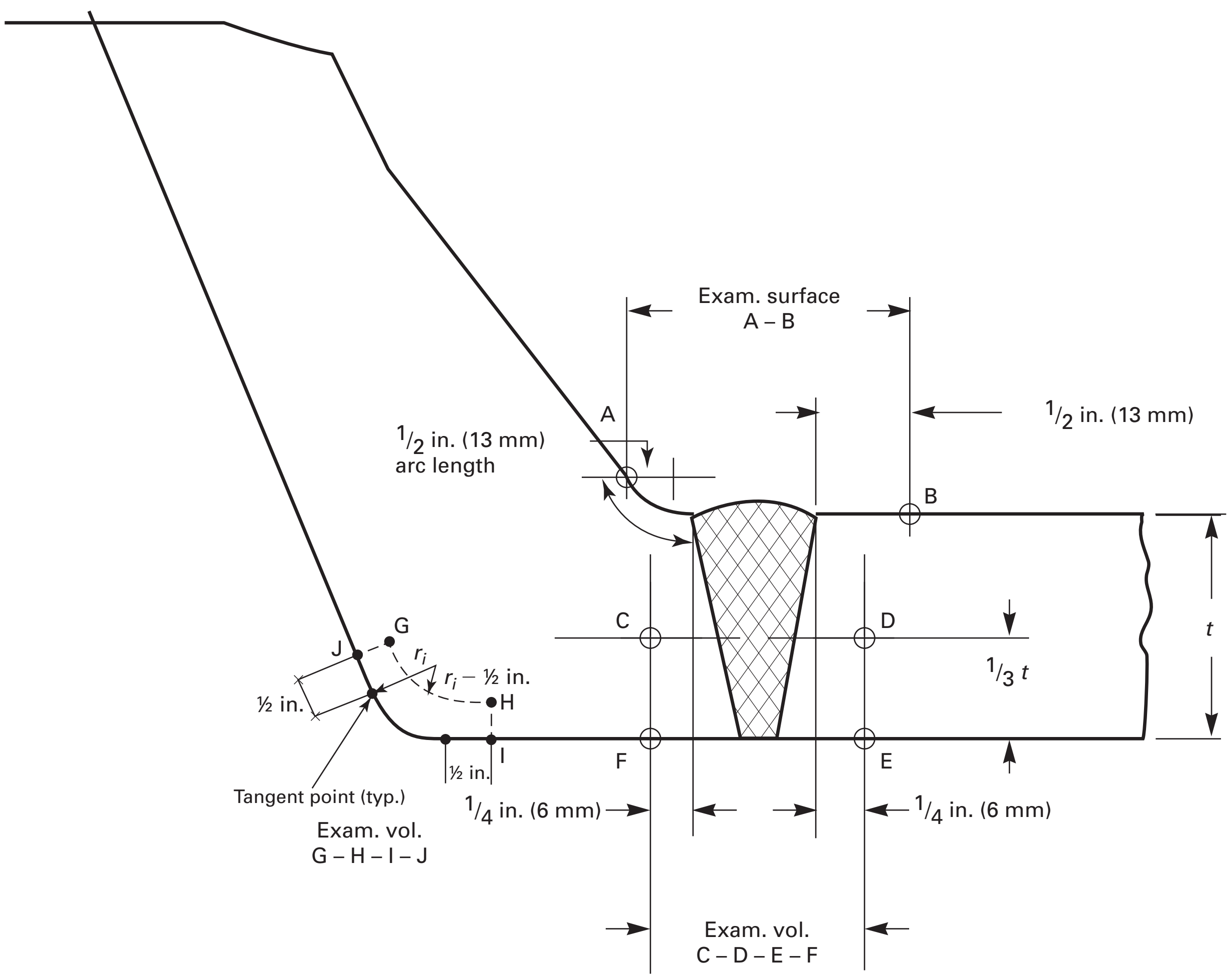


(b)

GENERAL NOTES:
(a) $\frac{1}{2}$ in. = 13 mm
(b) Nozzle sizes over NPS 4 (DN 100); vessel thickness ± ≤ $\frac{1}{2}$ in. (13 mm).

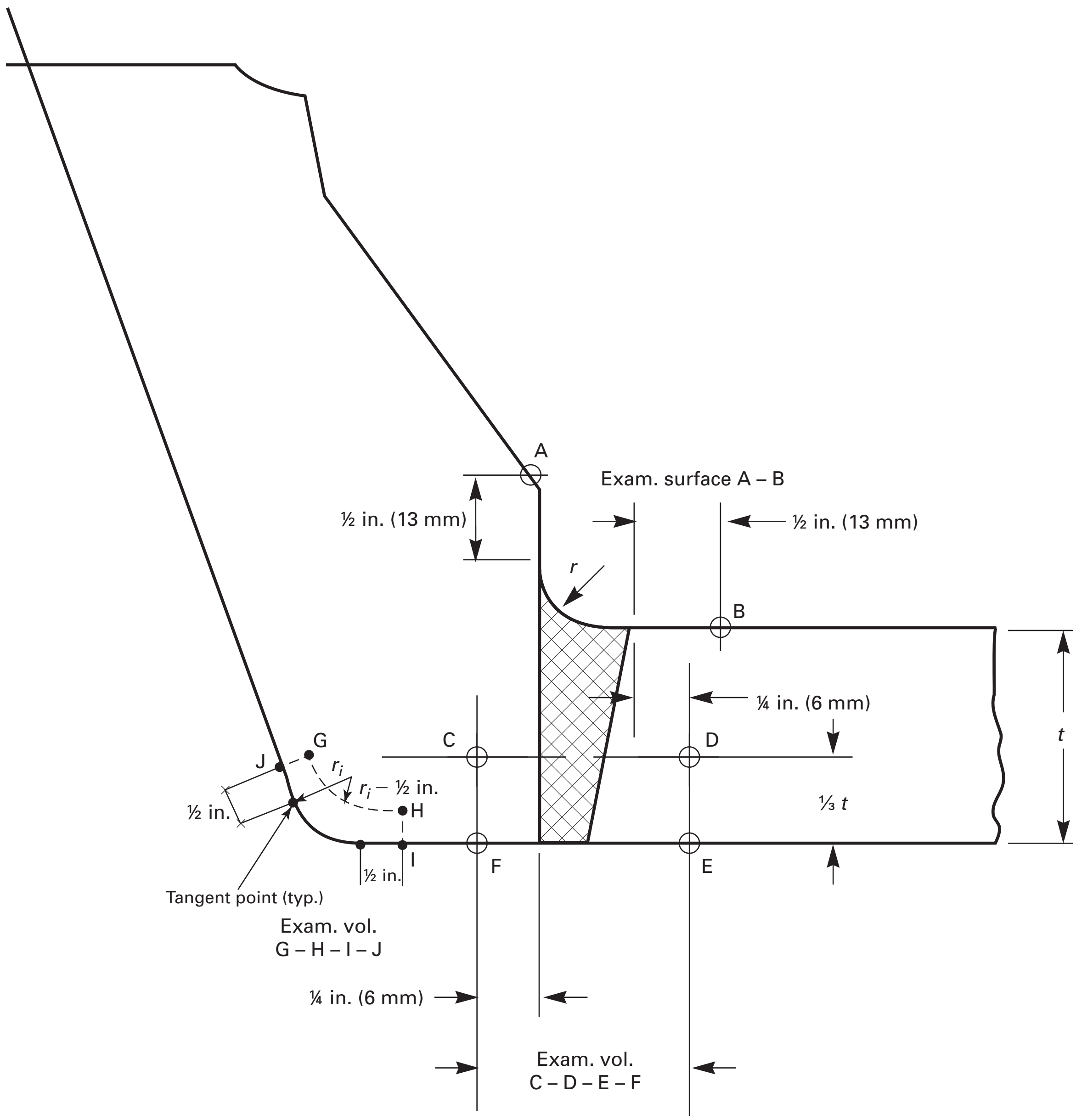
(15)

Figure IWC-2500-4
Nozzle-to-Vessel Welds



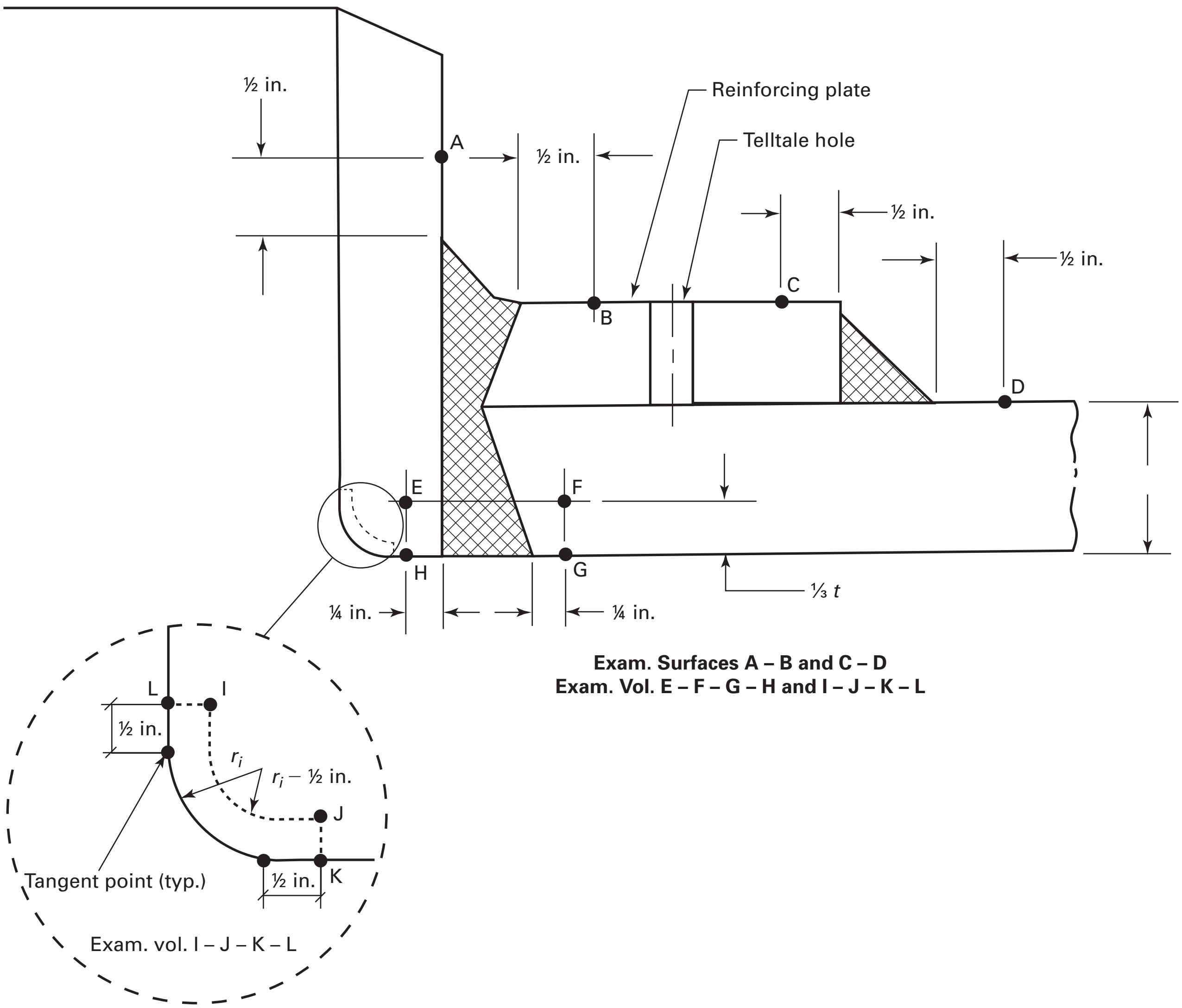
(a) See Notes (1), (2), and (3)

Figure IWC-2500-4
Nozzle-to-Vessel Welds (Cont'd)



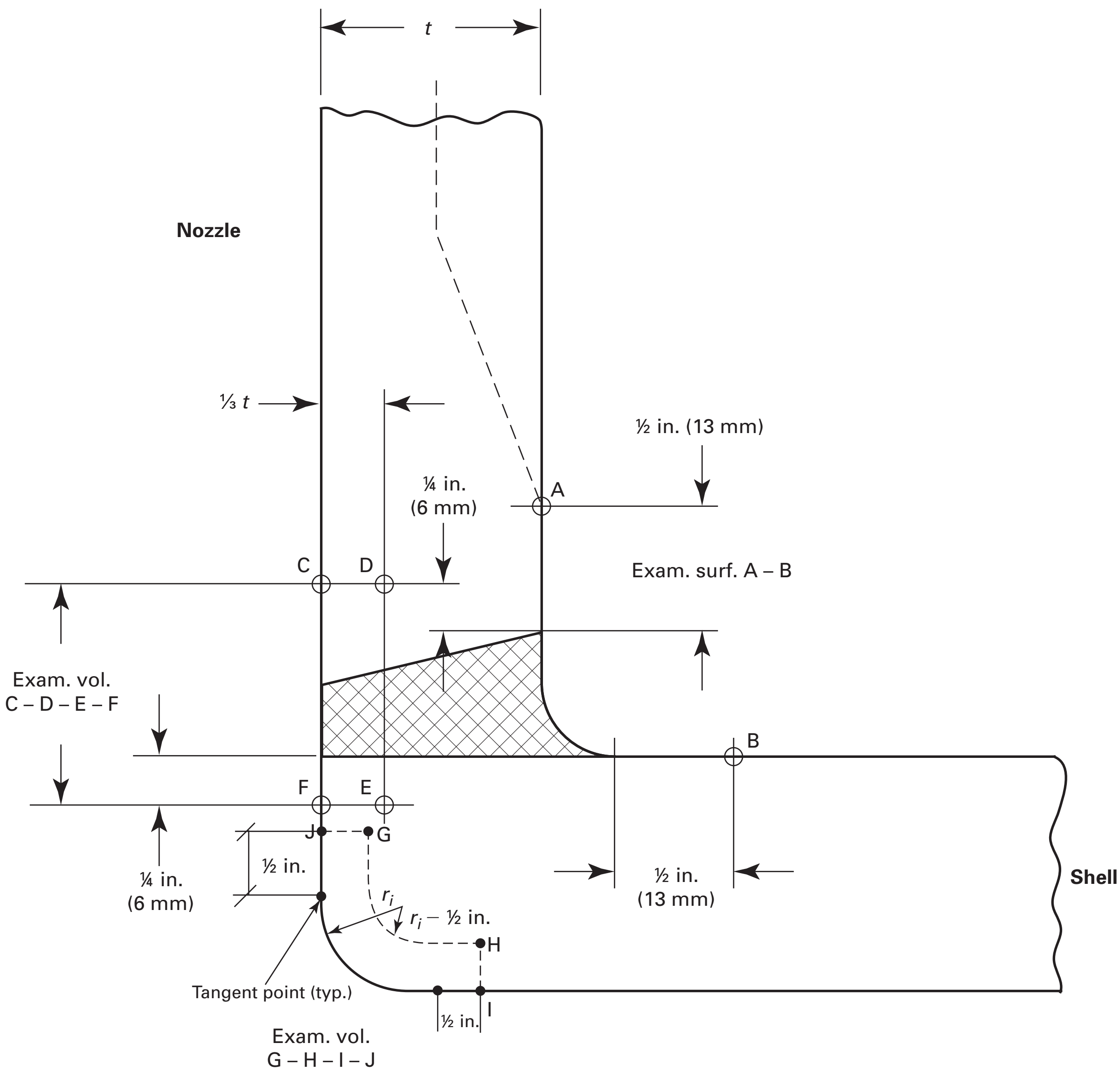
(b) See Notes (1), (2), and (3)

Figure IWC-2500-4
Nozzle-to-Vessel Welds (Cont'd)



(c) See Note (3)

Figure IWC-2500-4
Nozzle-to-Vessel Welds (Cont'd)



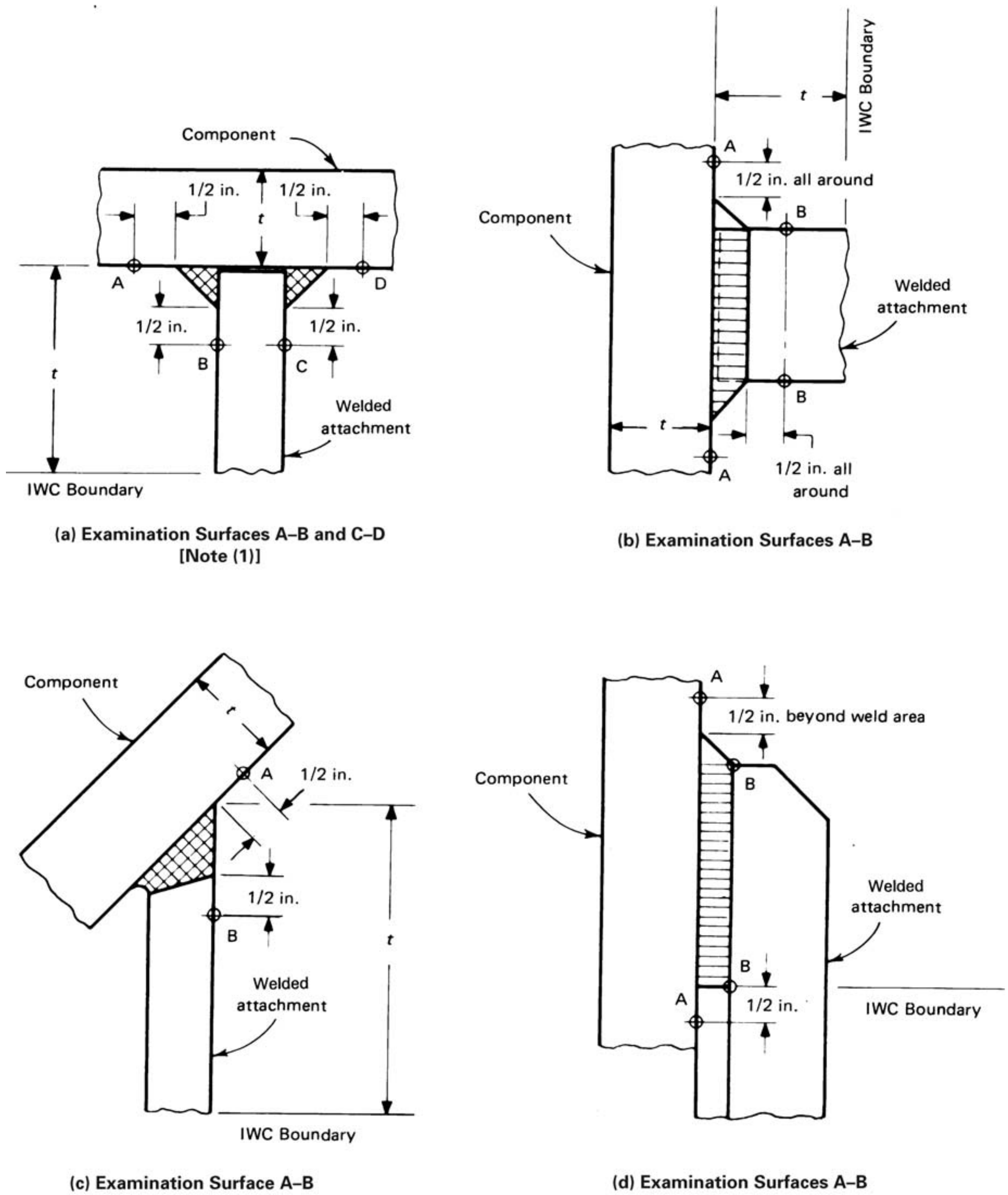
(d) See Notes (1) – (4)

GENERAL NOTES:
(a) $^{1}/_{4}$ in. = 6 mm
(b) $^{1}/_{2}$ in. = 13 mm
(c) NPS 12 = DN 300

NOTES:
(1) Nozzle sizes over NPS 4 (DN 100); vessel thickness over $^{1}/_{2}$ in. (13 mm).
(2) The dimensions for the examination volume shall be determined from the edge of the weld bevel if the weld toe extends beyond the bevel.
(3) Examination of inner radius volume is required only for nozzles greater than NPS 12 and may be limited to inner radius at vessel I.D.
(4) Configurations may include nozzle-to-shell or reinforcing-plate-to-nozzle welds that are other than full-penetration welds.

(15)

Figure IWC-2500-5
Welded Attachments

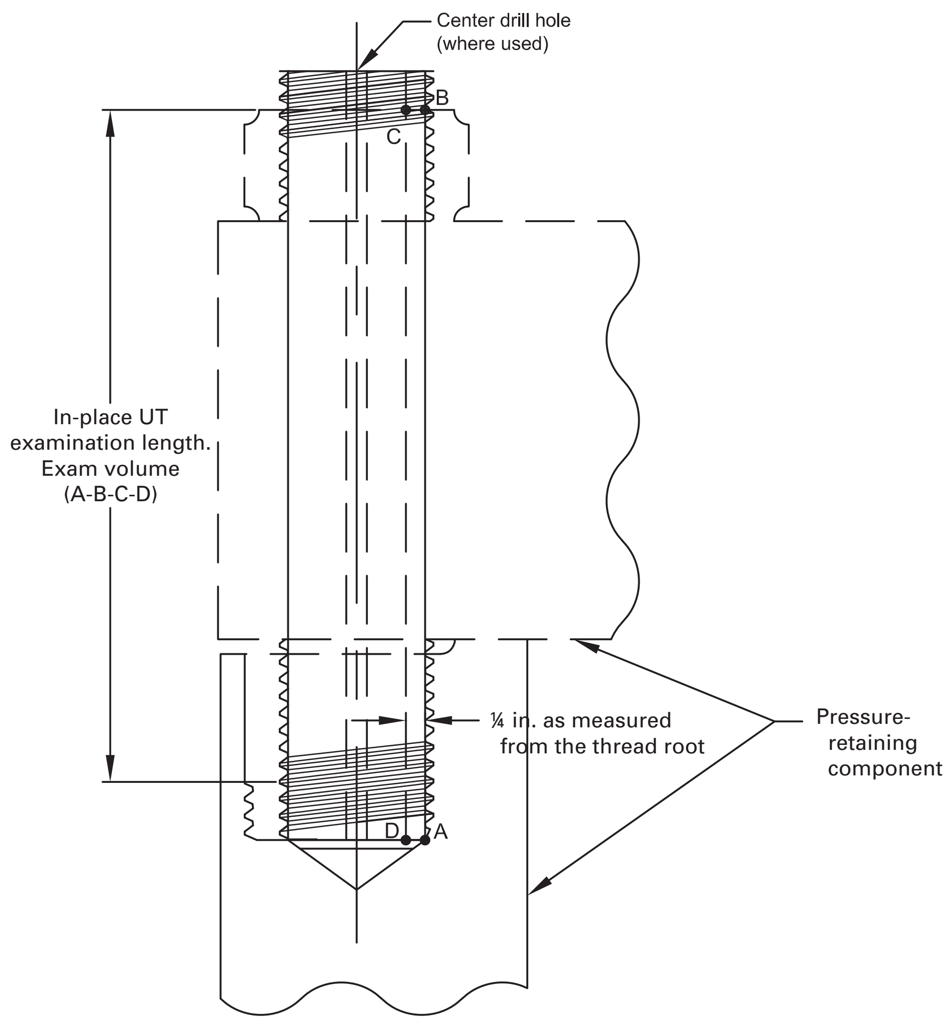


GENERAL NOTES:
(a) Examination of surface areas may be limited to the portions of these areas that are accessible without removal of support members.
(b) $^1/_2$ in. = 13 mm

NOTE:
(1) For entire length of weld plus $^1/_2$ in. at each end.

(15)

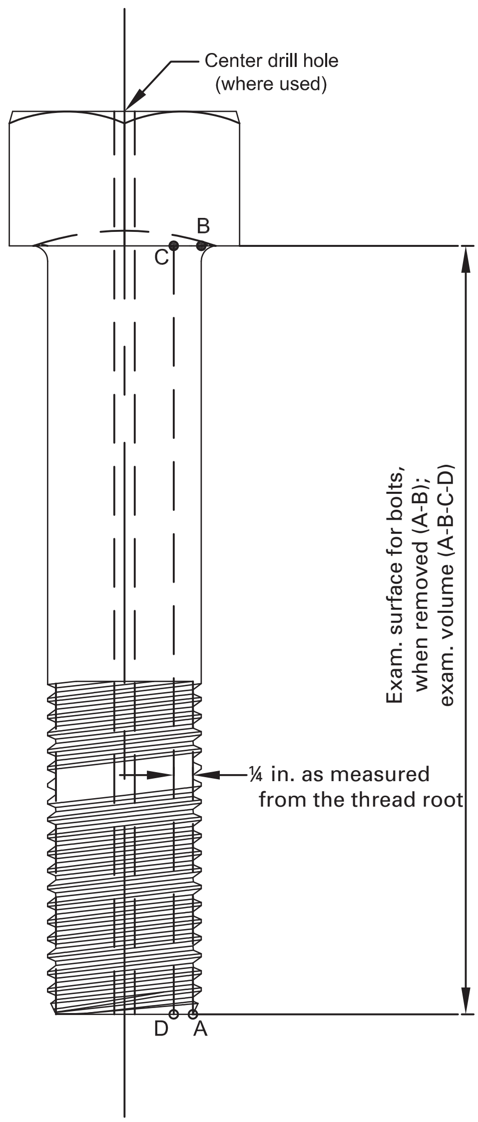
Figure IWC-2500-6(a)
Pressure-Retaining Bolting



GENERAL NOTE: $^1/_4$ in. = 6 mm

(15)

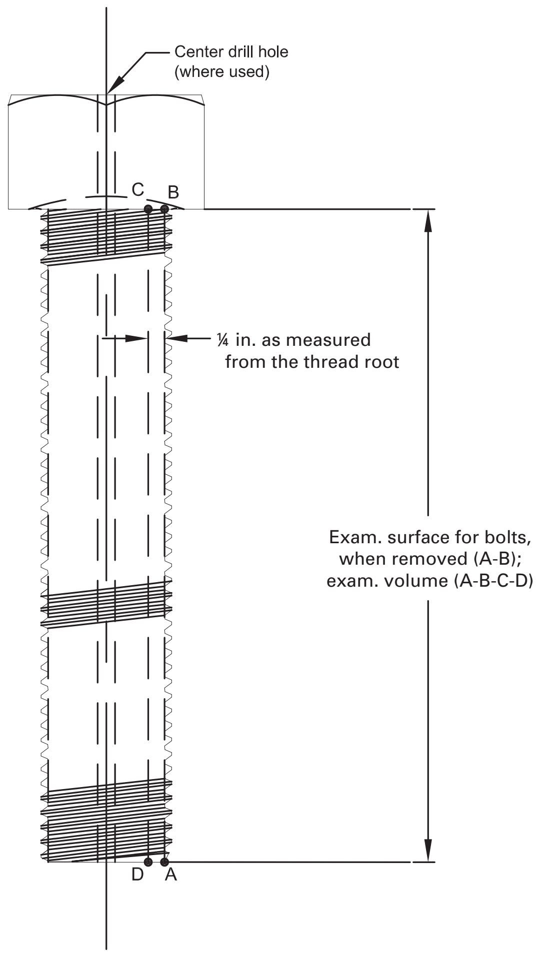
**Figure IWC-2500-6(b)
Pressure-Retaining Bolting
(Integral Head With Shank)**



GENERAL NOTE: $^1/_4$ in. = 6 mm

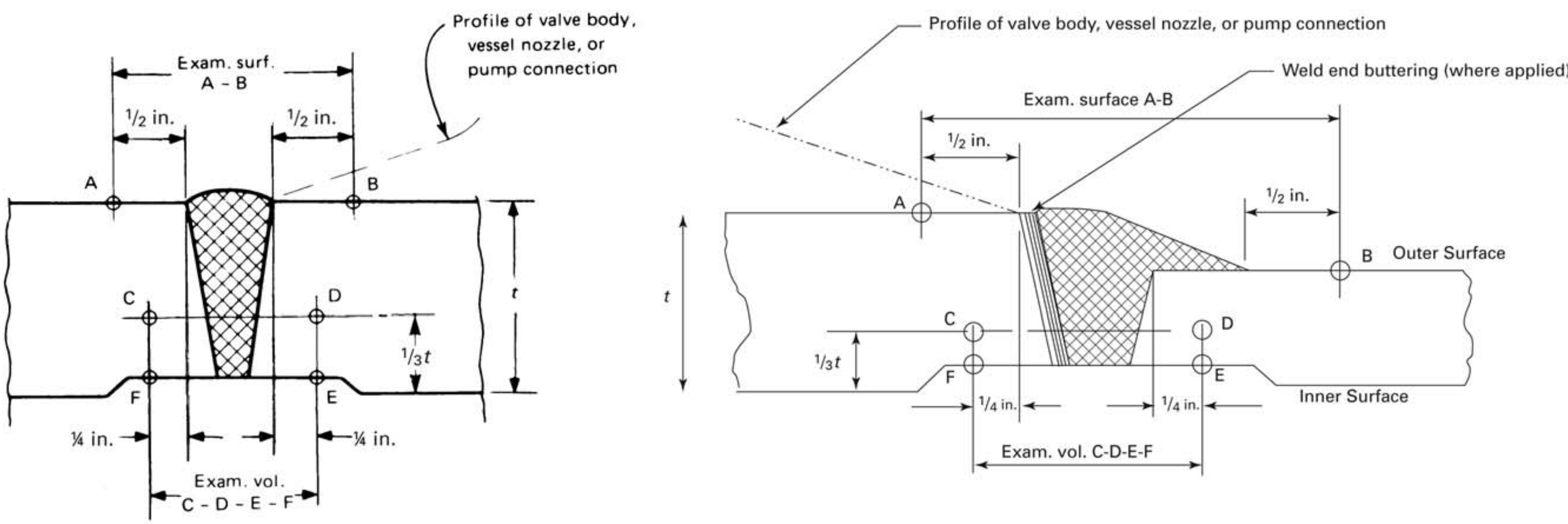
(15)

Figure IWC-2500-6(c)
Pressure-Retaining Bolting
(Integral Head Without Shank)



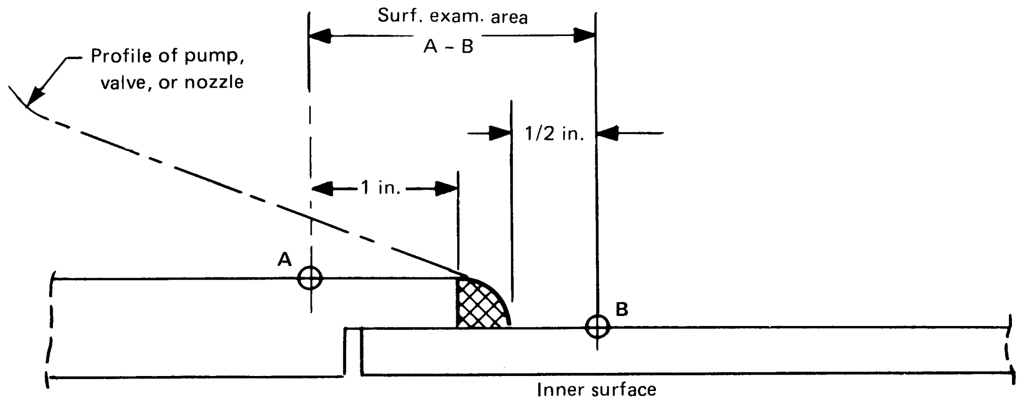
GENERAL NOTE: $^{1}/_{4}$ in. = 6 mm

Figure IWC-2500-7
Welds in Piping



(a) Full Penetration Welds

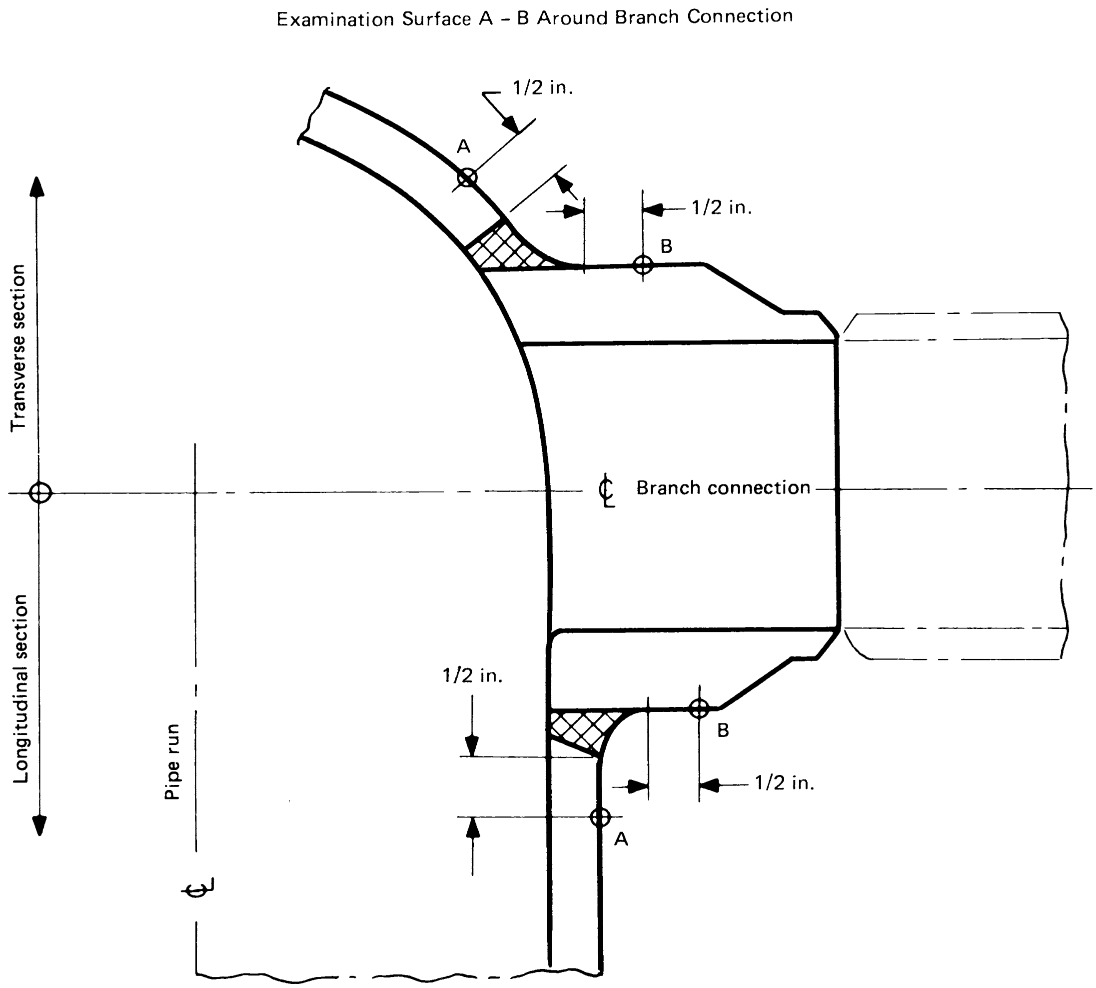
Figure IWC-2500-7
Welds in Piping (Cont'd)



(b) Socket Welded Piping

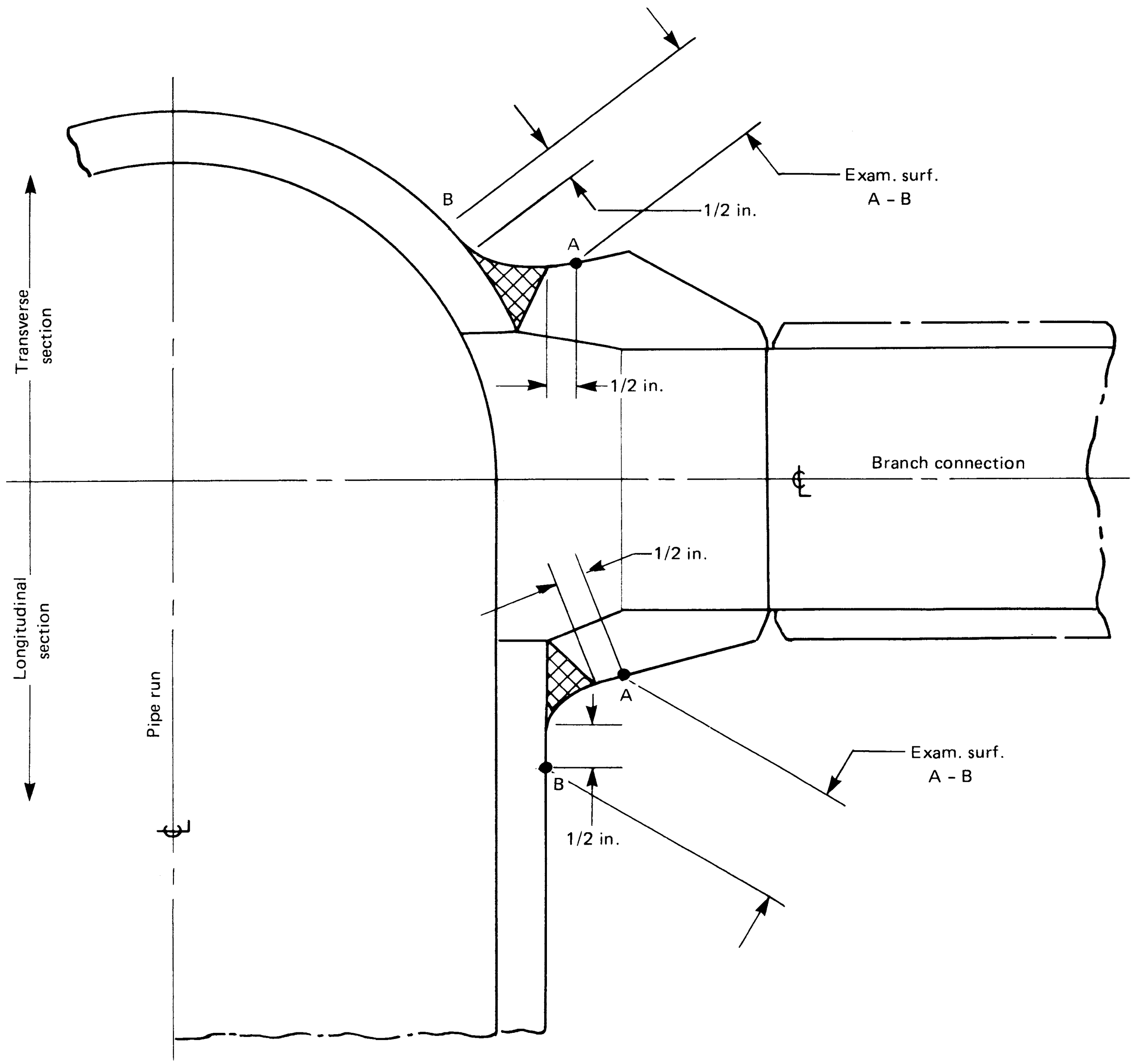
GENERAL NOTE: $^1\!/_4$ in. = 6 mm, $^1\!/_2$ in. = 13 mm, 1 in. = 25 mm

Figure IWC-2500-9
Branch Connection Welds



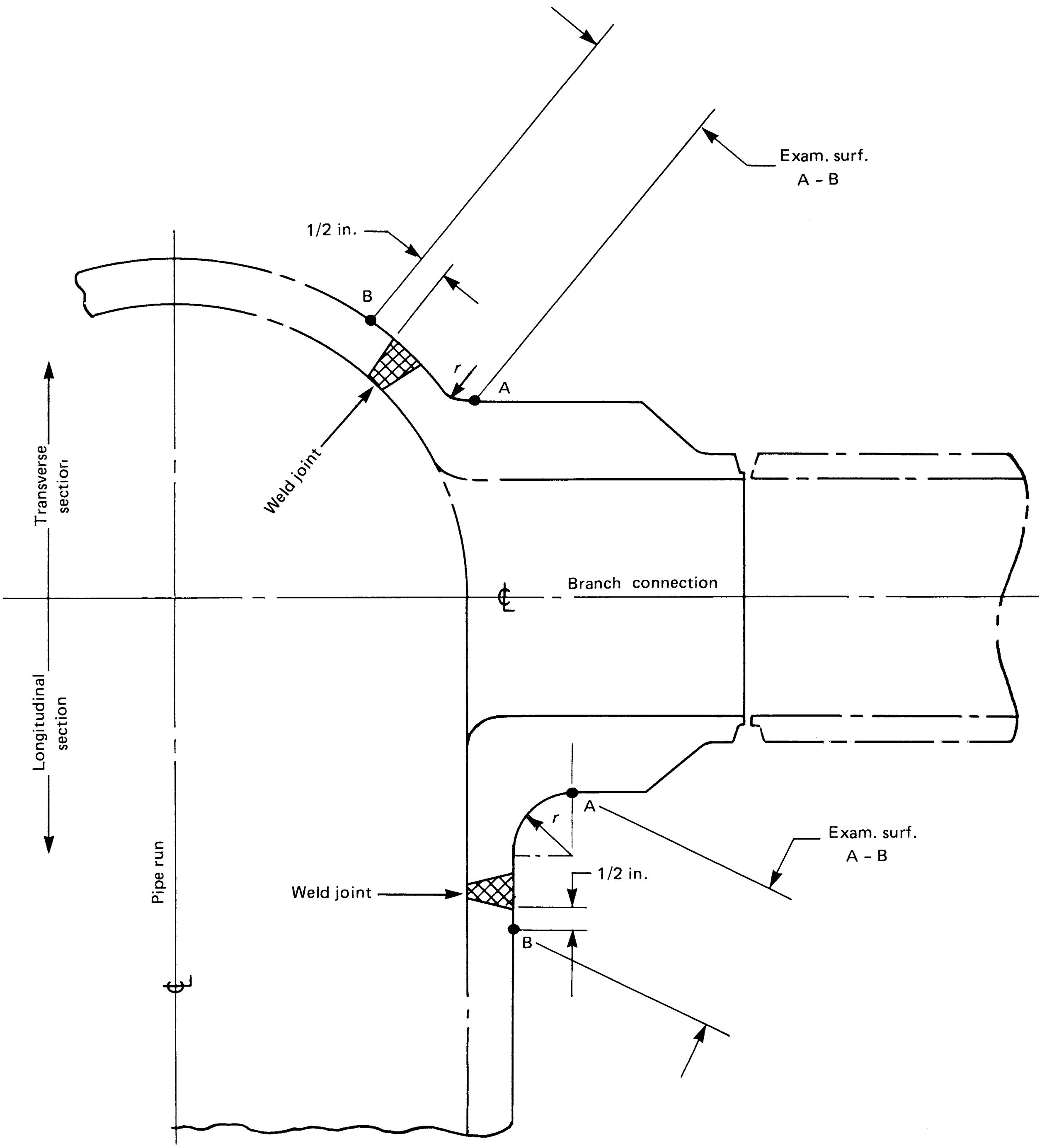
GENERAL NOTE: $\frac{1}{2}$ in. = 13 mm

Figure IWC-2500-10
Pipe Branch Connection



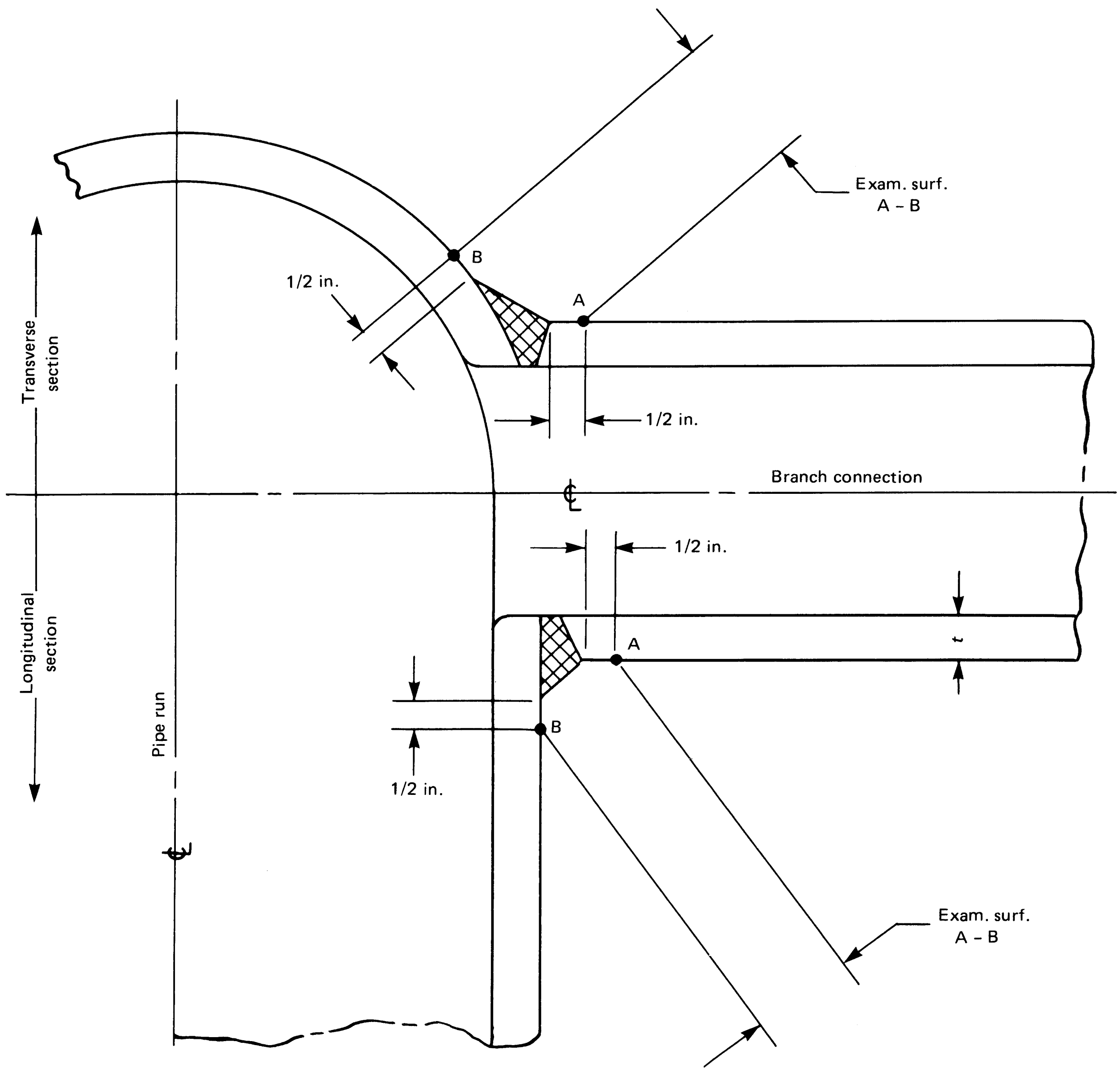
GENERAL NOTE: $\frac{1}{2}$ in. = 13 mm

Figure IWC-2500-11
Pipe Branch Connection



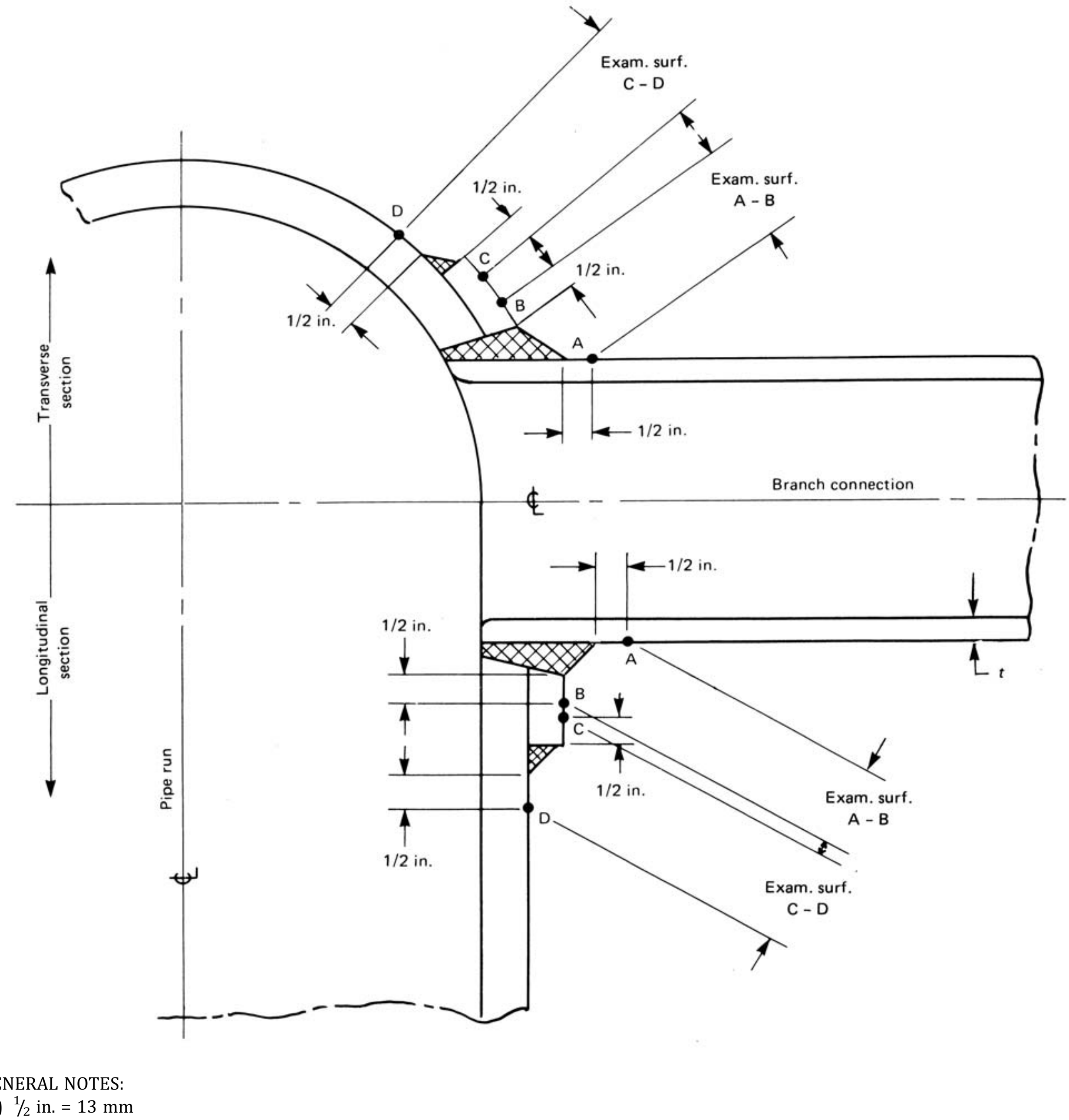
GENERAL NOTE: $\frac{1}{2}$ in. = 13 mm

Figure IWC-2500-12
Pipe Branch Connection



GENERAL NOTE: $\frac{1}{2}$ in. = 13 mm

Figure IWC-2500-13
Pipe Branch Connection



GENERAL NOTES:
(a) $^1/_2$ in. = 13 mm
(b) Configurations may include nozzle-to-shell or reinforcing-plate-to-nozzle welds that are other than full-penetration welds.

ARTICLE IWC-3000
ACCEPTANCE STANDARDS

IWC-3100 EVALUATION OF EXAMINATION RESULTS

IWC-3110 PRESERVICE VOLUMETRIC AND SURFACE EXAMINATIONS

IWC-3111 General

(a) The preservice volumetric and surface examinations required by IWC-2200 and performed in accordance with IWA-2200 shall be evaluated by comparing the examination results with the acceptance standards specified in IWC-3112.

(b) Acceptance of components for service shall be in accordance with IWC-3112, IWC-3113, and IWC-3114.

(**15**) ### IWC-3112 Acceptance

(a) A component whose volumetric or surface examination in accordance with IWC-2200 meets (1), (2), or (3) below shall be acceptable for service, provided the verified flaws are recorded in accordance with the requirements of IWA-1400(i) and IWA-2220(b) in terms of location, size, shape, orientation, and distribution within the component.

(1) Volumetric or surface examination confirms the absence of flaws or identifies only flaws that have already been shown to meet the nondestructive examination standards of NC-2500 or NC-5300, as documented in Quality Assurance Records (NCA-4134.17).

(2) Volumetric examination detects flaws that are confirmed by surface or volumetric examination to be nonsurface-connected and that do not exceed the standards of Table IWC-3410-1.

(3) Volumetric examination detects flaws that are confirmed by surface or volumetric examination to be nonsurface-connected that are accepted by analytical evaluation in accordance with the provisions of IWC-3132.3 to be acceptable to the end of the service lifetime of the component and reexamined in accordance with the requirements of IWB-2420(b) and IWB-2420(c), in lieu of IWC-2420(b) and IWC-2420(c).

(b) A component whose volumetric or surface examination detects flaws that do not meet the criteria established in (a) shall be unacceptable for service, unless the component is corrected by a repair/replacement activity in accordance with IWC-3113 to the extent necessary to meet the provisions of (a) prior to placement of the component in service.

(c) A component whose examination detects flaws other than the flaws of (b) that exceed the standards of Table IWC-3410-1 is unacceptable for service unless the component is corrected by a repair/replacement activity to the extent necessary to meet the acceptance standards prior to placement of the component in service.

IWC-3113 Repair/Replacement Activity and Reexamination

The repair/replacement activity and reexamination shall comply with the requirements of Article IWA-4000. Reexamination shall be conducted in accordance with the requirements of IWA-2200. The recorded results shall demonstrate that the area subjected to the repair/replacement activity meets the acceptance standards of Table IWC-3410-1.

IWC-3114 Review by Authorities

(a) The Repair/Replacement Program and the reexamination results shall be subject to review by the enforcement authorities having jurisdiction at the plant site.

(b) Evaluation of examination results may be subject to review by the regulatory authority having jurisdiction at the plant site.

IWC-3120 INSERVICE VOLUMETRIC AND SURFACE EXAMINATIONS

IWC-3121 General

(a) The examination results shall be compared with the recorded results of the preservice and prior inservice examinations. Acceptance of the components for continued service shall be in accordance with the acceptance alternatives of IWC-3122.

(b) Where a required inservice examination detects flaws that are acceptable under IWC-3112(a), the component shall remain acceptable for service provided the flaws satisfy the acceptance standards of NC-2500 and NC-5300 or the acceptance standards of Table IWC-3410-1.

IWC-3122 Acceptance

IWC-3122.1 Acceptance by Examination. A component whose examination reconfirms the absence of flaws, detects flaws that do not exceed the acceptance standards listed in Table IWC-3410-1, or detects flaws that are acceptable in accordance with IWC-3121(b) shall be acceptable for continued service. Confirmed changes in flaws (**15**) from prior examinations shall be recorded in accordance with IWA-1400(i) and IWA-2220(b). A component that does not meet the acceptance standards of IWC-3410 shall be corrected in accordance with the provisions shown in IWC-3122.2 or IWC-3122.3.

IWC-3122.2 Acceptance by Repair/Replacement Activity. A component whose examination detects flaws that exceed the acceptance standards of Table IWC-3410-1 is unacceptable for continued service until the component is corrected by a repair/replacement activity to the extent necessary to meet the acceptance standards of Article IWC-3000.

IWC-3122.3 Acceptance by Analytical Evaluation. A component whose examination detects flaws that exceed the acceptance standards of Table IWC-3410-1 is acceptable for continued service without a repair/replacement activity if an analytical evaluation, as described in IWC-3600, meets the acceptance criteria of IWC-3600. The area containing the flaw shall be subsequently reexamined in accordance with IWC-2420(b) and IWC-2420(c). If the subsequent IWC-2420(b) and IWC-2420(c) examinations reveal that the flaws remain essentially unchanged, or the flaw growth is within the growth predicted by the analytical evaluation, and the design inputs for the analytical evaluation have not been affected by activities such as power uprates, the existing analytical evaluation may continue to be used, provided it covers the time period until the next examination.

IWC-3124 Repair/Replacement Activity and Reexamination

The repair/replacement activity and reexamination shall comply with the requirements of Article IWA-4000. Reexamination shall be conducted in accordance with the requirements of IWA-2200; the recorded results shall demonstrate that the area subjected to the repair/replacement activity meets the acceptance standards of Table IWC-3410-1.

IWC-3125 Review by Authorities

(a) The Repair/Replacement Program and the reexamination results shall be subject to review by the enforcement authorities having jurisdiction at the plant site.

(b) Evaluation analyses of examination results as required by IWC-3122.3 shall be submitted to the regulatory authority having jurisdiction at the plant site.

IWC-3130 INSERVICE VISUAL EXAMINATIONS

IWC-3131 General

The visual examinations required by IWC-2500 and performed in accordance with the procedures of IWA-2200 shall be evaluated by comparing the examination results with the acceptance standards specified in Table IWC-3410-1. Acceptance of components for continued service shall be in accordance with IWC-3132, IWC-3133, and IWC-3134.

IWC-3132 Acceptance

(a) A component whose examination confirms the absence of relevant conditions described in the standards of Table IWC-3410-1 shall be acceptable for continued service.

(b) A component whose examination detects relevant conditions described in the standards of Table IWC-3410-1 shall be unacceptable for continued service unless such components meet the requirement of IWC-3132.1, IWC-3132.2, or IWC-3132.3.

IWC-3132.1 Acceptance by Supplemental Examination. Components containing relevant conditions shall be acceptable for continued service if the results of supplemental examination (IWC-3200) meet the requirements of IWC-3120.

IWC-3132.2 Acceptance by Corrective Measures or Repair/Replacement Activity. A component containing relevant conditions is acceptable for continued service if the relevant conditions are corrected by a repair/replacement activity or by corrective measures to the extent necessary to meet the acceptance standards of Table IWC-3410-1.

IWC-3132.3 Acceptance by Evaluation. A component containing relevant conditions is acceptable for continued service if an evaluation demonstrates the component's acceptability in accordance with (a) or (b) below.

(a) The evaluation analysis and evaluation acceptance criteria shall be specified by the Owner. Components accepted for continued service based on evaluation shall be subsequently examined in accordance with IWC-2420(b) and IWC-2420(c). If the subsequent IWC-2420(b) and IWC-2420(c) examinations reveal that the relevant conditions remain essentially unchanged, or the changes in the relevant conditions are within the limits predicted by the evaluation, and the design inputs for the evaluation have not been affected by activities such as power uprates, the existing evaluation may continue to be used, provided it covers the time period until the next examination.

(b) Temporary acceptance of flaws in moderate energy piping may be performed in accordance with Nonmandatory Appendix U, Supplement U-S1, and temporary acceptance of degradation in moderate energy vessels and tanks may be performed in accordance with Nonmandatory Appendix U, Supplement U-S2.

IWC-3133 Repair/Replacement Activity and Reexamination

The repair/replacement activity and reexamination shall comply with the requirements of Article IWA-4000.

IWC-3134 Review by Authorities

(a) The Repair/Replacement Program and the reexamination results shall be subject to review by the enforcement authorities having jurisdiction at the plant site.

(b) Evaluation analyses of examination results as required by IWC-3132.3(a) shall be submitted to the regulatory authority having jurisdiction at the plant site.

IWC-3200 SUPPLEMENTAL EXAMINATIONS

(a) Examinations that detect flaws that require evaluation in accordance with the requirements of IWC-3100 may be supplemented by other examination methods and techniques (IWA-2240) to determine the character of the flaw (i.e., size, shape, and orientation).

(b) Visual examinations that detect relevant conditions may be supplemented by other examinations (IWA-2220, IWA-2230, or IWA-2240) to determine the need for corrective measures, analytical evaluation, or repair/replacement activities.

IWC-3400 STANDARDS

IWC-3410 ACCEPTANCE STANDARDS

The acceptance standards referenced in Table IWC-3410-1 shall be applied to determine acceptability for service. The following condition applies.

IWC-3410.1 Applications of Standards. The acceptance standards for ferritic steel components shall only be applicable to those components whose material properties are in accordance with those stated in the referenced table.

IWC-3420 CHARACTERIZATION

Each detected flaw or group of flaws shall be characterized by the rules of IWA-3300 to establish the dimensions of the flaws. These dimensions shall be used in conjunction with the acceptance standards of IWC-3500.

IWC-3430 ACCEPTABILITY

Flaws that meet the requirements of IWC-3500 for the respective examination category shall be acceptable.

IWC-3500 ACCEPTANCE STANDARDS

IWC-3510 STANDARDS FOR EXAMINATION CATEGORY C-A, PRESSURE-RETAINING WELDS IN PRESSURE VESSELS

IWC-3510.1 Allowable Planar Flaws.

(a) The size of allowable planar flaws within the boundary of the examination volumes specified in Figures IWC-2500-1 and IWC-2500-2 shall not exceed the following limits:

(1) for ferritic steels, those specified in Table IWC-3510-1

(2) for austenitic steels, those specified in Table IWC-3514-1

(b) Where a flaw extends beyond the examination volumes, or separate flaws lie both within and beyond the boundaries but are characterized as a single flaw by IWA-3400, the overall size of the flaw shall not exceed the following limits:

(1) for ferritic steels, those specified in Table IWC-3510-1

(2) for austenitic steels, those specified in Table IWC-3514-1

(c) Any two or more coplanar aligned flaws characterized as separate flaws by IWA-3330 are allowable, provided the requirements of IWA-3390 are met.

IWC-3510.2 Allowable Laminar Flaws. The areas of allowable laminar flaws within the boundary of the examination zone delineated in the applicable figures specified in IWC-3510.1(a) shall not exceed the limits specified in Table IWC-3510-2.

Table IWC-3410-1
Acceptance Standards

Examination Category	Component and Part Examined	Acceptance Standard
C-A	Welds in pressure vessels	IWC-3510
C-B	Vessel nozzle welds	IWC-3511
C-C	Welded attachments for vessels, piping, pumps, and valves	IWC-3512
C-D	Bolting	IWC-3513
C-F-1, C-F-2	Welds in piping	IWC-3514
C-H	Pressure-retaining components	IWC-3516

Table IWC-3510-1
Allowable Planar Flaws
Material: Ferritic Steels That Meet the Requirements of NC-2300 and With Specified Minimum Yield Strength of 50 ksi (350 MPa) or less at 100°F (40°C)

Aspect Ratio, [Note (1)] a/ℓ	Thickness, t, in. (mm) [Note (1)], [Note (2)]					
	≤0.5 (13)	2.5 (65)	≥4.0 (100)	≤0.5 (13)	2.5 (65)	≥4.0 (100)
	Surface Flaw, a/t, %	Surface Flaw, a/t, %	Surface Flaw, a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %
0.00	5.4	3.1	1.9	$5.9Y^{1.00}$	$3.4Y^{1.00}$	$2.0Y^{1.00}$
0.05	5.7	3.3	2.0	$6.6Y^{0.96}$	$3.8Y^{0.96}$	$2.2Y^{0.90}$
0.10	6.2	3.6	2.2	$7.4Y^{0.71}$	$4.3Y^{0.72}$	$2.5Y^{0.69}$
0.15	7.1	4.1	2.5	$8.5Y^{0.48}$	$4.9Y^{0.48}$	$2.9Y^{0.47}$
0.20	8.1	4.7	2.8	$9.9Y^{0.51}$	$5.7Y^{0.50}$	$3.3Y^{0.47}$
0.25	9.5	5.5	3.3	$11.4Y^{0.66}$	$6.6Y^{0.65}$	$3.8Y^{0.61}$
0.30	11.1	6.4	3.8	$13.5Y^{0.84}$	$7.8Y^{0.84}$	$4.4Y^{0.77}$
0.35	12.8	7.4	4.4	$15.0Y^{0.96}$	$9.0Y^{0.99}$	$5.1Y^{0.93}$
0.40	14.4	8.3	5.0	$15.0Y^{0.96}$	$10.5Y^{1.00}$	$5.8Y^{1.00}$
0.45	14.7	8.5	5.1	$15.0Y^{0.96}$	$12.3Y^{1.00}$	$6.7Y^{1.00}$
0.50	15.0	8.7	5.2	$15.0Y^{0.96}$	$14.3Y^{1.00}$	$7.6Y^{1.00}$

NOTES:
(1) Dimensions of a and ℓ are defined in IWA-3300. For intermediate flaw aspect ratios a/ℓ and thickness t, linear interpolation is permissible. Refer to IWA-3200(b).
(2) Component thickness, t, is measured normal to the pressure-retaining surface of the component. Where the section thickness varies, the average thickness over the length of the planar flaw is the component thickness.
(3) The total depth of a subsurface flaw is $2a$.
(4) $Y = (S/t)/(a/t) = S/a$. If $Y \leq 0.4$, the flaw is classified as a surface flaw. If $Y > 1.0$, use $Y = 1.0$.

IWC-3510.3 Conditionally Allowable Laminar Flaws.

(a) Laminar flaws that exceed the standards specified in IWC-2500-1 (C-A) shall be considered conditionally allowable laminar flaws. In such cases, these laminar flaws shall be included as additional areas of the component subject to examination under Table IWC-2500-1 (C-A).

(b) Laminar flaws that join with a planar flaw shall be governed by the standards of IWC-3510.1.

Table IWC-3510-2
Allowable Laminar Flaws

Component Thickness, [Note (1)] t, in. (mm)	Laminar Area, [Note (2)] A, in.^{2} (mm^2)
2.5 (65) and less	7.5 (4 800)
4 (100)	12 (7 700)
6 (152)	18 (12 000)

NOTES:
(1) For intermediate thicknesses, linear interpolation of area is permissible. Refer to IWA-3200(c).
(2) The area of a laminar flaw is defined in IWA-3360.

IWC-3510.4 Allowable Linear Flaws.

(a) The size of allowable linear flaws as detected by either a surface examination (MT/PT) or volumetric examination (RT) within the boundary of the examination volumes shown in Figures IWC-2500-1 and IWC-2500-2 and within the boundaries of the examination surfaces shown in Figure IWC-2500-5 [see IWC-3512.1(a)] shall not exceed the following limits:

(1) for ferritic steels, those specified in Table IWC-3510-3

(2) for austenitic steels, those specified in Table IWB-3514-2

(b) Where a flaw extends beyond the examination boundaries, or separate linear flaws lie both within and beyond the boundaries but are characterized as a single flaw by IWA-3400, the overall flaw size shall not exceed the following limits:

(1) for ferritic steels, those specified in Table IWC-3510-3

(2) for austenitic steels, those specified in Table IWB-3514-2

Table IWC-3510-3
Allowable Linear Flaws [Note (1)]
Material: Ferritic steels that meet the requirements of NC-2300 and the specified minimum yield strength of 50 ksi (350 MPa) or less at 100°F (40°C)

Surface Examination Method (PT/MT) and Volumetric Examination Method (RT)	
Nominal Section Thickness, [Note (2)] t, in. (mm)	Flaw Length, ℓ, in. (mm)
≤$^1/_2$ (13)	$^3/_{16}$ (5)
2$^1/_2$ (65)	$^1/_4$ (6)
≥4.0 (100)	$^3/_8$ (9)

NOTES:
(1) Applicable to linear flaws detected by an examination method where flaw depth dimension a is indeterminate.
(2) For intermediate thickness, linear interpolation is permissible. Refer to IWA-3200.

IWC-3511 Standards for Examination Category C-B, Pressure-Retaining Welds of Nozzles in Vessels

IWC-3511.1 Allowable Planar Flaws.

(a) The size of allowable planar flaws in the nozzle and weld areas within the boundary of the examination volume specified in Figure IWC-2500-4 shall not exceed the following limits:

(1) for ferritic steels, those specified in Table IWC-3511-1

(2) for austenitic steels, those specified in Table IWC-3514-1

(b) The size of allowable planar flaws in the vessel shell (or head) material adjoining the nozzle and weld areas and within the boundary of the examination volumes specified in Figure IWC-2500-4 shall not exceed the following limits:

(1) for ferritic steels, those specified in Table IWC-3510-1

(2) for austenitic steels, those specified in Table IWC-3514-1

(c) Any two or more coplanar aligned flaws characterized as separate flaws by IWA-3300 are allowable, provided the requirements of IWA-3390 are met.

IWC-3511.2 Allowable Linear Flaws.

(a) The size of allowable linear flaws, as detected by either a surface (PT/MT) or volumetric examination (RT), within the boundary of the examination surfaces and volumes shown in Figures IWC-2500-3 and IWC-2500-4 shall not exceed the following limits:

(1) for ferritic steels, those specified in Table IWC-3511-2

(2) for austenitic steels, those specified in Table IWB-3514-2

(b) Where a flaw extends beyond the examination boundaries, or separate linear flaws lie both within and beyond the boundaries but are characterized as a single flaw by IWA-3400, the overall flaw size shall not exceed the following limits:

(1) for ferritic steels, those specified in Table IWC-3511-2

(2) for austenitic steels, those specified in Table IWB-3514-2

IWC-3511.3 Allowable Laminar Flaws.

(a) Laminar flaws in vessel shell or head material within the boundary of the examination volumes specified in Figure IWC-2500-4 shall be governed by the standards of Table IWC-3510-2.

(b) Laminar flaws in the nozzle wall shall be considered as planar flaws and the standards of IWC-3511.1 shall apply.

IWC-3512 Standards for Examination Category C-C, Welded Attachments for Vessels, Piping, Pumps, and Valves

IWC-3512.1 Allowable Linear Flaws.

(a) The size of an allowable flaw within the boundary of the examination surfaces in Figure IWC-2500-5 shall not exceed the allowable flaw standards of this Article for the applicable supported pressure-retaining component to which the attachment is welded.

(b) Where a flaw extends beyond the boundaries of the examination surfaces, or separate flaws are detected that lie both within and beyond the boundaries but are characterized as a single flaw by the rules of Article IWA-3000, the overall flaw size shall be compared with the standards of (a).

(c) Where a flaw detected by a surface examination method exceeds the allowable standards of (a), an optional volumetric examination may be conducted, in which case the allowable flaw standards for the volumetric examination method for the applicable supported pressure-retaining component to which the attachment is welded shall apply.

IWC-3513 Standards for Examination Category C-D, Pressure-Retaining Bolting Greater Than 2 in. (50 mm) in Diameter

IWC-3513.1 Allowable Flaws for Volumetric Examinations of Studs and Bolts.

(a) The size of allowable nonaxial flaws in pressure-retaining bolting within the boundary of the examination volume shown in Figure IWC-2500-6(a) shall not exceed the limits specified in Table IWC-3513-1.

(b) Any two or more subsurface flaws, at any cross section, which combine to reduce the net area are acceptable provided the combined flaw depths do not exceed the

Table IWC-3511-1
Allowable Planar Flaws
Material: Ferritic Steels That Meet the Requirements of NC-2300 and With Specified Minimum Yield Strength of 50 ksi (350 MPa) or Less at 100°F (40°C)

	Thickness, t, in. (mm) [Note (1)], [Note (2)]					
	≤0.5 (13)	2.5 (65)	≥4.0 (100)	≤0.5 (13)	2.5 (65)	≥4.0 (100)
Aspect Ratio, [Note (1)] a/ℓ	Surface Flaw, [Note (5)] a/t, %	Surface Flaw, [Note (5)] a/t, %	Surface Flaw, [Note (5)] a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %
0.00	5.4	3.1	1.9	5.9 $Y^{1.00}$	3.4 $Y^{1.00}$	2.0 $Y^{1.00}$
0.05	5.7	3.3	2.0	6.6 $Y^{0.96}$	3.8 $Y^{0.96}$	2.2 $Y^{0.90}$
0.10	6.2	3.6	2.2	7.4 $Y^{0.71}$	4.3 $Y^{0.72}$	2.5 $Y^{0.69}$
0.15	7.1	4.1	2.5	8.5 $Y^{0.48}$	4.9 $Y^{0.48}$	2.9 $Y^{0.47}$
0.20	8.1	4.7	2.8	9.9 $Y^{0.51}$	5.7 $Y^{0.50}$	3.3 $Y^{0.47}$
0.25	9.5	5.5	3.3	11.4 $Y^{0.66}$	6.6 $Y^{0.65}$	3.8 $Y^{0.61}$
0.30	11.1	6.4	3.8	13.5 $Y^{0.84}$	7.8 $Y^{0.84}$	4.4 $Y^{0.77}$
0.35	12.8	7.4	4.4	15.0 $Y^{0.96}$	9.0 $Y^{0.99}$	5.1 $Y^{0.93}$
0.40	14.4	8.3	5.0	15.0 $Y^{0.96}$	10.5 $Y^{1.00}$	5.8 $Y^{1.00}$
0.45	14.7	8.5	5.1	15.0 $Y^{0.96}$	12.3 $Y^{1.00}$	6.7 $Y^{1.00}$
0.50	15.0	8.7	5.2	15.0 $Y^{0.96}$	14.3 $Y^{1.00}$	7.6 $Y^{1.00}$
Inside corner region [Note (5)]	$r_n/60$ in. ($r_n/1500$ mm)	$r_n/60$ in. ($r_n/1500$ mm)	$r_n/60$ in. ($r_n/1500$ mm)	Not applicable	Not applicable	Not applicable

NOTES:
(1) Dimensions of a and ℓ are defined in IWA-3300. For intermediate flaw aspect ratios a/ℓ and thickness t, linear interpolation is permissible. Refer to IWA-3200(b).
(2) See Figure IWC-2500-4 for the appropriate component thickness, t.
(3) The total depth of a subsurface flaw is $2a$.
(4) $Y = (S/t)/(a/t) = S/a$. If $Y \leq 0.4$, the flaw is classified as a surface flaw. If $Y > 1.0$, use $Y = 1.0$.
(5) r_n is the radius of the nozzle bore.

Table IWC-3511-2
Allowable Linear Flaws [Note (1)]
Material: Ferritic steels that meet the requirements of NC-2300 and the specified minimum yield strength of 50 ksi (350 MPa) or less at 100°F (40°C)

Surface Examination Method (PT/MT) and Volumetric Examination Method (RT)	
Nominal Section Thickness, [Note (2)] t, in. (mm)	Flaw Length, ℓ, in. (mm)
≤1/2 (13)	3/16 (5)
2 1/2 (65)	1/4 (6)
≥4 (100)	3/8 (9)

NOTES:
(1) Applicable to linear flaws detected by an examination method where flaw depth dimension a is indeterminate.
(2) For intermediate thickness, linear interpolation is permissible. Refer to IWA-3200.

Table IWC-3513-1
Allowable Planar Flaws
Material: SA-193, SA-320, SA-354, SA-540 that meet the requirements of NC-2333 and the specified minimum yield strength between 95 ksi (655 MPa) and 130 ksi (900 MPa) at 100°F (40°C)

Diameter Range: Nominal Sizes Greater Than 2 in. (50 mm)	
Aspect Ratio, [Note (1)] a/ℓ	Subsurface [Note (2)] Flaws, a, in. (mm)
0.0	0.075 (1.9)
0.10	0.075 (1.9)
0.20	0.10 (2.5)
0.30	0.10 (2.5)
0.40	0.15 (3.8)
0.50	0.18 (4.6)

NOTES:
(1) Dimensions a and ℓ are defined in IWA-3300. For intermediate flaw aspect ratios a/ℓ, linear interpolation is permissible. Refer to IWA-3200(b).
(2) The total depth of an allowable subsurface flaw is twice the listed value.

sum of the allowable limits specified in Table IWC-3513-1 for the corresponding flaw aspect ratios, divided by the number of flaws.

(c) Any flaw detected by the volumetric examination shall be investigated by a surface examination. If confirmed to be a surface flaw, the standards of IWC-3513.2 shall apply. If not a surface flaw, the standards of (a) and (b) shall apply.

IWC-3513.2 Allowable Flaws for Surface Examinations of Studs and Bolts. Allowable surface flaws in pressure-retaining bolting shall not exceed the following limits:

(a) nonaxial flaws, $^1/_4$ in. (6 mm) in length

(b) axial flaws, 1 in. (25 mm) in length

(15) IWC-3514 Standards for Examination Category C-F-1, Pressure-Retaining Welds in Austenitic Stainless Steel or High Alloy Piping, and C-F-2, Pressure-Retaining Welds in Carbon or Low Alloy Steel Piping

(a) The acceptance standards of IWC-3514 do not apply to planar surface-connected flaws that are in contact with the reactor coolant environment during normal operation and are detected by inservice examination in the following materials:

(1) for PWRs, UNS N06600, N06082, or W86182 surfaces with a normal operating temperature greater than or equal to 525°F (275°C) and in contact with the reactor coolant environment

(2) for BWRs, UNS N06600, W86182, or austenitic stainless steel and associated weld surfaces, in contact with the reactor coolant environment, that are susceptible to stress corrosion cracking and not mitigated

(b) If the acceptance standards are not met or are not applicable, for acceptance by analytical evaluation, the planar surface-connected flaws in (a) shall meet the provisions of IWC-3600.

(c) Susceptible materials and mitigation criteria for BWRs are specified in NUREG 0313 Revision 2, Sections 2.1 and 2.2.

(15) **IWC-3514.1 Allowable Planar Flaws.**

(a) The size of allowable planar flaws within the boundary of the examination surfaces and volumes delineated in Figures IWC-2500-7 and IWC-2500-9 through IWC-2500-13 shall be in accordance with the standards of IWC-3514.2 and IWC-3514.3, as applicable. In addition, the requirements of IWC-3514.6 shall be satisfied for planar surface-connected flaws that are in contact with the reactor coolant environment during normal operation and are detected by preservice examination in materials that are susceptible to stress corrosion cracking, as defined for PWRs in IWC-3514(a)(1), and for BWRs in IWC-3514(a)(2) and IWC-3514(c).

(b) Where flaws extend beyond the boundaries of the examination surfaces and volumes, or separate flaws are detected that lie both within and beyond the boundaries but are characterized as a single flaw by the rules of IWA-3300, the overall flaw size shall be compared with standards of (a) above.

(c) Any two or more coplanar-aligned flaws that are characterized as separate flaws by IWA-3300 are allowable, provided the requirements of IWA-3390 are met.

(d) Inner surface flaws detected by volumetric examination of piping components with austenitic cladding on the inner surface shall be governed by the following standards:

(1) Surface flaws that do not penetrate through the nominal clad thickness into base metal need not be compared with the standards of (a) above.

(2) The size of allowable surface flaws that penetrate through the cladding into base metal shall not exceed the standards of (a) above, except that the depth a of the flaw shall be the total depth minus the nominal clad thickness.

IWC-3514.2 Allowable Flaw Standards for Ferritic Piping. The standards are in the course of preparation. The standards of IWB-3514 may be applied.

IWC-3514.3 Allowable Flaw Standards for Austenitic or High Alloy Piping.

(a) The size of allowable flaws shall not exceed the limits specified in Table IWC-3514-1.

(b) Where flaws on the outer surface of piping as detected by the surface examination method during an inservice examination exceed the allowable standards of IWC-3514.5, the flaws may be examined by the volumetric method. The acceptance of these flaws shall be governed by the allowable flaw standards for the volumetric examination method in Table IWC-3514-1.

IWC-3514.4 Allowable Laminar Flaws for Austenitic Piping. The area of allowable laminar flaws, as defined by IWA-3360, within the boundary of the examination zones shown in Figures IWC-2500-7 and IWC-2500-9 through IWC-2500-13 shall not exceed the limits specified in Table IWB-3514-3.

IWC-3514.5 Allowable Linear Flaw Standards for Austenitic or High Alloy Piping.

(a) The size of an allowable linear flaw within the boundaries of the examination surfaces in Figures IWC-2500-7 and IWC-2500-9 through IWC-2500-13 shall not exceed the limits specified in Table IWB-3514-2.

(b) Where a flaw extends beyond the boundaries of the examination surfaces in Figures IWC-2500-7 and IWC-2500-9 through IWC-2500-13, or where discontinuous linear flaws lie both within and beyond the boundaries and are characterized as a single flaw by the rules of IWA-3400, the size of allowable overall linear flaws shall not exceed the limits specified in Table IWB-3514-2.

Table IWC-3514-1
Allowable Planar Flaws
Material: Austenitic steels that meet the requirements for the specified minimum yield strength of 35 ksi (240 MPa) or less at 100°F (40°C)

	Volumetric Examination Method, Wall Thickness, [Note (1)], [Note (2)] t, in. (mm)					
	0.312 (8)		1.0 (25)		2.0 (50) and over	
Aspect Ratio, [Note (1)] a/ℓ	**Surface Flaw, a/t, %**	**Subsurface Flaw, [Note (3)], [Note (4)] a/t, %**	**Surface Flaw, a/t, %**	**Subsurface Flaw, [Note (3)], [Note (4)] a/t, %**	**Surface Flaw, a/t, %**	**Subsurface Flaw, [Note (3)], [Note (4)] a/t, %**
Preservice and Inservice Examination						
0.00	10.0	$10.0Y^{0.96}$	10.0	$10.0Y^{0.96}$	10.0	$10.0Y^{0.96}$
0.05	10.0	$10.0Y^{0.91}$	10.0	$10.0Y^{0.73}$	10.0	$10.0Y^{0.68}$
0.10	10.0	$10.0Y^{0.59}$	11.3	$11.3Y^{0.65}$	11.8	$11.8Y^{0.69}$
0.15	11.1	$11.1Y^{0.63}$	13.9	$13.9Y^{0.87}$	14.4	$14.4Y^{0.91}$
0.20	12.8	$12.8Y^{0.78}$	15.0	$15.0Y^{0.96}$	15.0	$15.0Y^{0.96}$
0.25	14.3	$14.3Y^{0.90}$	15.0	$15.0Y^{0.96}$	15.0	$15.0Y^{0.96}$
0.30 to 0.50	15.0	$15.0Y^{0.96}$	15.0	$15.0Y^{0.96}$	15.0	$15.0Y^{0.96}$

GENERAL NOTE: This table is not applicable to planar surface-connected flaws that are in contact with the reactor coolant environment during normal operation and are detected by in-service examination in materials that are susceptible to stress corrosion cracking, as defined for PWRs in IWC-3514(a)(1) and for BWRs in IWC-3514(a)(2) and IWC-3514(c). For planar surface-connected flaws that are in contact with the reactor coolant environment during normal operation and are detected by preservice examination in these materials, the requirements of IWC-3514.6 shall be satisfied.

NOTES:
(1) For intermediate flaw aspect ratios a/ℓ and thickness t, linear interpolation is permissible. Refer to IWA-3200(b) and IWA-3200(c).
(2) t is nominal wall thickness or actual wall thickness if determined by UT examination.
(3) The total depth of a subsurface flaw is $2a$.
(4) $Y = (S/t)/(a/t) = S/a$. If $S < 0.4d$, the flaw is classified as a surface flaw. If $Y > 1.0$, use $Y = 1.0$.

(15) **IWC-3514.6 Surface-Connected Flaws in Contact With the Reactor Coolant Environment That Are Detected by Preservice Examination in Materials Susceptible to Stress Corrosion Cracking.** When a surface-connected flaw that will be in contact with the reactor coolant environment during normal operation is detected using volumetric examination, the weld shall be reexamined twice subsequent to the preservice examination. The first reexamination shall be performed after a time interval that is greater than 2 yr, and fewer than 6 yr, subsequent to plant start-up following the preservice examination. The time interval for the second reexamination shall be determined using the rules of IWC-3640 for analytical evaluation of flaws and shall not exceed 10 yr subsequent to plant start-up following the preservice examination. The time interval between the two reexaminations shall be at least 2 yr, except that it shall not extend the second reexamination beyond the end of the evaluation period.

IWC-3516 Standards for Examination Category C-H, All Pressure-Retaining Components

IWC-3516.1 Visual Examination, VT-2. A component whose visual examination (IWA-5240) detects any of the following relevant conditions[34] shall meet IWC-3132 and IWA-5250 prior to continued service:

(a) any through-wall or through-weld, pressure-retaining material leakage from insulated and noninsulated components

(b) leakage in excess of limits established by the Owner from mechanical connections (such as pipe caps, bolted connections, or compression fittings) or from components provided with leakage limiting devices (such as valve packing glands or pump seals)

(c) areas of general corrosion of a component resulting in leakage

(d) discoloration or accumulated residues on surfaces of components, insulation, or floor areas that may be evidence of leakage

(e) leakages or flow test results from buried components in excess of limits established by the Owner

(15) IWC-3600 ANALYTICAL EVALUATION OF PLANAR FLAWS

IWC-3610 ACCEPTANCE CRITERIA FOR FERRITIC COMPONENTS

These criteria are in the course of preparation. In the interim, the criteria of IWB-3610 may be applied.

IWC-3640 ANALYTICAL EVALUATION PROCEDURES AND ACCEPTANCE CRITERIA FOR FLAWS IN AUSTENITIC AND FERRITIC PIPING

Piping containing flaws exceeding the acceptance standards of IWC-3514 may be analytically evaluated to determine acceptability for continued service to the next inspection or to the end of the evaluation period. A pipe containing flaws is acceptable for continued service for a specified evaluation time period if the criteria of IWC-3642, IWC-3643, or IWC-3644 are satisfied. The procedures shall be the responsibility of the Owner and shall be provided to the regulatory authority having jurisdiction at the plant site.

IWC-3641 Analytical Evaluation Procedures

Analytical evaluation procedures based on flaw size or applied stress, such as those described in Nonmandatory Appendix C or H, may be used, subject to the following:

(a) The analytical evaluation procedures and acceptance criteria in Nonmandatory Appendix C are applicable to piping NPS 1 (DN 25) and greater. The procedures and criteria in Nonmandatory Appendix H are applicable to piping NPS 4 (DN 100) and greater. Nonmandatory Appendices C and H are applicable to portions of adjoining pipe fittings within a distance of $(R_2t)^{1/2}$ from the weld centerline, where R_2 is the outside radius and t is the nominal thickness of the pipe. The weld geometry and weld-base metal interface are defined in Nonmandatory Appendix C.

(b) The analytical evaluation procedures and acceptance criteria are applicable to seamless or welded wrought carbon steel pipe and pipe fittings, and associated weld materials that have a specified minimum yield strength not greater than 40 ksi (280 MPa).

(c) The analytical evaluation procedures and acceptance criteria are applicable to seamless or welded wrought or cast austenitic pipe and pipe fittings and associated weld materials that are made of wrought stainless steel, Ni-Cr-Fe alloy, or cast stainless steel, and have a specified minimum yield strength not greater than 45 ksi (310 MPa).

(d) A flaw growth analysis shall be performed on the detected flaw to predict its growth due to fatigue or stress corrosion cracking mechanisms, or both, when applicable, during a specified evaluation time period. The time interval selected for flaw growth analysis (i.e., evaluation period) shall be until the next inspection or until the end of the evaluation period for the item.

(e) The calculated maximum flaw dimensions at the end of the evaluation period shall be compared to the acceptance criteria for Service Levels A, B, C, and D loadings to determine the acceptability of the item for continued service.

IWC-3642 Analytical Evaluation Procedures and Acceptance Criteria Based on Failure Mode Determination

Piping containing flaws exceeding the acceptance standards of IWC-3514 may be analytically evaluated using procedures described in Nonmandatory Appendix C and is acceptable for continued service during the evaluated time period when the critical flaw parameters satisfy the criteria in Nonmandatory Appendix C. Flaw acceptance criteria are based on allowable flaw size or allowable stress. Flaws with depths greater than 75% of the wall thickness are unacceptable.

IWC-3643 Analytical Evaluation Procedure and Acceptance Criteria Based on Use of a Failure Assessment Diagram

Piping containing flaws exceeding the allowable flaw standards of IWC-3514 may be analytically evaluated using procedures based on use of a failure assessment diagram, such as described in Nonmandatory Appendix H. Such analytical evaluation procedures may be invoked in accordance with the conditions of IWC-3641. Flaws with depths greater than 75% of the wall thickness are unacceptable.

IWC-3644 Alternative Analytical Evaluation Procedure and Acceptance Criteria Based on Applied Stress

Piping containing flaws exceeding the allowable flaw standards of IWC-3514 is acceptable for continued service until the end of the evaluation period if the alternative analytical evaluation procedure demonstrates, at the end-of-evaluation period, structural factors, based on load, equivalent to the following:

Service Level	Structural Factor
A	2.7
B	2.4
C	1.8
D	1.4

Flaws with depths greater than 75% of the wall thickness are unacceptable.

ARTICLE IWC-5000
SYSTEM PRESSURE TESTS

IWC-5200 SYSTEM TEST REQUIREMENTS

IWC-5210 TEST

(a) Pressure-retaining components shall be tested at the frequency stated in, and visually examined by the methods specified in Table IWC-2500-1 (C-H).

(b)

(1) The system pressure tests and visual examinations shall be conducted in accordance with Article IWA-5000 and this Article. The contained fluid in the system shall serve as the pressurizing medium.

(2) Alternatively, steam systems may use either water or gas as the pressurizing medium. When gas is the pressurizing medium, the test procedure shall include methods for detection and location of through-wall leakage from components of the system tested.

IWC-5220 SYSTEM LEAKAGE TEST

IWC-5221 Pressure

The system leakage test shall be conducted at the system pressure obtained while the system, or portion of the system, is in service performing its normal operating function or at the system pressure developed during a test conducted to verify system operability (e.g., to demonstrate system safety function or satisfy technical specification surveillance requirements). If portions of a system are subject to system pressure tests associated with more than one safety function, the visual examination need only be performed during the test conducted at the higher of the test pressures for the respective system safety function, except as permitted in IWA-5222.

(15) IWC-5222 Boundaries

(a) The pressure-retaining boundary for closed systems includes only those portions of the system required to operate or support the safety function up to and including the first normally closed valve (including a safety or relief valve) or valve capable of automatic closure when the safety function is required.

(b) The pressure-retaining boundary for nonclosed systems includes only those portions of the system required to operate or support the safety function up to and including the first normally closed valve, including a safety or relief valve, or valve capable of automatic closure when the safety function is required. Open-ended piping that is periodically pressurized to conditions described in IWC-5221 shall be included in the test boundary.

(c) Portions of systems that are associated with a spray header or containment sump, or are normally submerged in the process fluid such that the external surfaces of the pressure-retaining boundary are normally wetted during pressurized conditions, are excluded from the test boundary.

IWC-5230 HYDROSTATIC TEST

(a) The hydrostatic test pressure shall be at least 1.10 times the system pressure P_{sv} for systems with Design Temperature of 200°F (95°C) or less, and at least 1.25 times the system pressure P_{sv} for systems with Design Temperature above 200°F (95°C). The system pressure P_{sv} shall be the lowest pressure setting among the number of safety or relief valves provided for overpressure protection within the boundary of the system to be tested. For systems (or portions of systems) not provided with safety or relief valves, the system design pressure P_d shall be substituted for P_{sv}.

(b) The test pressure for a pneumatic test conducted in accordance with IWA-5211(c) shall be the system leakage test pressure of IWC-5221.

(c) In the case of atmospheric storage tanks, the nominal hydrostatic pressure, developed with the tank filled to its design capacity, shall be acceptable as the system test pressure.

(d) For 0–15 psi (0–100 kPa) storage tanks, the test pressure shall be 1.1 P_G, Design Pressure of vapor or gas space above liquid level for which overpressure protection is provided by relief valves.

(e) The hydrostatic test of the Class 2 portion of the Main Steam System in Boiling Water Reactor (BWR) plants may be performed in conjunction with the hydrostatic test of the Class 1 portion, when the Class 2 portion is not capable of being isolated from the Class 1 portion by the boundary valve. The hydrostatic test of the Class 2 portion shall meet the requirements of Article IWA-5000 and IWB-5230.

(f) For the purpose of the test, open ended portions of a suction or drain line from a storage tank extending to the first shutoff valve shall be considered as an extension of the storage tank.

(g) For open ended portions of discharge lines beyond the last shutoff valve in nonclosed systems (e.g., containment spray header), demonstration of an open flow path test shall be performed in lieu of the system hydrostatic test. Test personnel need not be qualified for VT-2 visual examination.

(h) Open ended vent and drain lines extending beyond the last shutoff valve and open ended safety or relief valve discharge lines are exempt from hydrostatic testing.

(i) The pressure measuring instrument used for measuring system hydrostatic or pneumatic test pressure shall meet the requirements of IWA-5260.

IWC-5240 TEMPERATURE

(a) The system test temperature during a system hydrostatic test in systems containing ferritic steel components shall meet the requirements specified by fracture prevention criteria.

(b) In systems containing ferritic steel components for which fracture toughness requirements were neither specified nor required in the construction of the components, the system test temperature shall be determined by the Owner.

(c) No limit on system test temperature is required for systems comprised of components constructed entirely of austenitic steel materials.

SUBSECTION IWD
REQUIREMENTS FOR CLASS 3 COMPONENTS OF LIGHT-WATER-COOLED PLANTS

ARTICLE IWD-1000
SCOPE AND RESPONSIBILITY

IWD-1100 SCOPE

This Subsection provides requirements for inservice inspection of Class 3 pressure-retaining components and their welded attachments in light-water-cooled plants.

IWD-1200 COMPONENTS SUBJECT TO EXAMINATION

IWD-1210 EXAMINATION REQUIREMENTS

The examination requirements of this Subsection shall apply to pressure-retaining components and their welded attachments on Class 3 systems in support of the following functions:

(a) reactor shutdown

(b) emergency core cooling

(c) containment heat removal

(d) atmosphere cleanup

(e) reactor residual heat removal

(f) residual heat removal from spent fuel storage pool

IWD-1220 COMPONENTS EXEMPT FROM EXAMINATION

The following components or portions of components are exempted from the VT-1 visual examination requirements of IWD-2500:

(a) components and piping segments NPS 4 (DN 100) and smaller

(b) components and piping segments which have one inlet and one outlet, both of which are NPS 4 (DN 100) and smaller

(c) components[20] and piping segments which have multiple inlets or multiple outlets whose cumulative pipe cross-sectional area does not exceed the cross-sectional area defined by the O.D. of NPS 4 (DN 100) pipe.

(d) components that operate at a pressure of 275 psig (1,900 kPa) or less and at a temperature of 200°F (95°C) or less in systems (or portions of systems) whose function is not required in support of reactor residual heat removal, containment heat removal, and emergency core cooling;

(e) welds or portions of welds that are inaccessible due to being encased in concrete, buried underground, located inside a penetration, or encapsulated by guard pipe.

ARTICLE IWD-2000
EXAMINATION AND INSPECTION

IWD-2200 PRESERVICE EXAMINATION

All examinations required by this Article (with the exception of Table IWD-2500-1 (D-B)) shall be performed completely, once, as a preservice examination requirement prior to initial plant startup.

IWD-2400 INSPECTION SCHEDULE

IWD-2410 INSPECTION PROGRAM

Inservice examinations and system pressure tests may be performed during either system operation or plant outages.

IWD-2411 Inspection Program

(a) The required examinations in each examination category shall be completed during each inspection interval in accordance with Table IWD-2411-1, with the exceptions of Category D-B and of welded attachments examined as a result of component support deformation under Examination Category D-A. If there are less than three items to be examined in an Examination Category, the items may be examined in any two periods, or in any one period if there is only one item, in lieu of the percentage requirements of Table IWD-2411-1.

(b) If items are added to the Inspection Program, during the service lifetime of a plant, examination shall be scheduled as follows:

Table IWD-2411-1
Inspection Program

Inspection Interval	Inspection Period, Calendar Years of Plant Service Within the Interval	Minimum Examinations Completed, %	Maximum Examinations Credited, %
All	3	16	50
	7	50 [Note (1)]	75
	10	100	100

NOTE:
(1) If the first period completion percentage for any examination category exceeds 34%, at least 16% of the required examinations shall be performed in the second period.

(1) When items are added during the first period of an interval, at least 25% of the examinations required by the applicable Examination Category and Item Number for the added items shall be performed during each of the second and third periods of that interval.

(2) When items are added during the second period of an interval, at least 25% of the examinations required by the applicable Examination Category and Item Number for the added items shall be performed during the third period of that interval.

(3) When items are added during the third period of an interval, examinations shall be scheduled in accordance with (a) for successive intervals.

IWD-2420 SUCCESSIVE INSPECTIONS

(a) The sequence of component examinations which was established during the first inspection interval shall be repeated during each successive inspection interval, to the extent practical. The sequence of component examinations may be modified in a manner that optimizes scaffolding, radiological, insulation removal, or other considerations, provided that the percentage requirements of Table IWD-2411-1 are maintained.

(b) If components are accepted for continued service by evaluation in accordance with IWD-3132.3(a), the areas containing flaws or relevant conditions shall be reexamined during the next inspection period listed in the schedule of the Inspection Program of IWD-2400.

(c) If the reexaminations required by (b) above reveal that the flaws or relevant conditions remain essentially unchanged, or that the flaw growth is within the growth predicted by the analytical evaluation, for the next inspection period, then the component examination schedule may revert to the original schedule of successive inspections or the inspection interval defined by the analytical evaluation, whichever is limiting.

(d) If the reexaminations required by (b) above reveal new flaws or relevant conditions that exceed the applicable acceptance standards of IWD-3400, or growth of existing flaws in excess of the growth predicted by the analytical evaluation, then

(1) the entire weld, area, or part[35] shall be examined during the current outage

(2) additional examinations shall be performed in accordance with IWD-2430

(e) If welded attachments are examined as a result of identified component support deformation and the results of these examinations exceed the acceptance

standards of Article IWD-3000, successive examinations shall be performed, if determined necessary based on an evaluation by the Owner. The evaluation shall be documented and shall include the cause of the welded attachment damage if known. If the cause of the welded attachment damage could recur or is unknown, successive examinations shall be performed in accordance with the requirements of (b) above. No successive examinations are required if either of the following applies:

(1) There are no other welded attachments subject to the same apparent or root cause conditions.

(2) The degradation mechanism no longer exists.

IWD-2430 ADDITIONAL EXAMINATIONS

(a) Examinations performed in accordance with Table IWD-2500-1 (D-A) that reveal flaws or relevant conditions exceeding the acceptance standards of Article IWD-3000 shall be extended to include additional examinations during the current outage in accordance with (1) or (2) below.

(1) Additional examinations shall be performed in accordance with the following requirements:

(-a) The additional examinations shall include an additional number of welds, areas, or parts[35] included in the inspection item[36] equal to 20% of the number of welds, areas, or parts included in the inspection item that are scheduled to be performed during the interval. The additional examinations shall be selected from welds, areas, or parts of similar material and service. This additional selection may require inclusion of piping systems other than the one containing the flaws or relevant conditions.

(-b) If the additional examinations required by (-a) above reveal flaws or relevant conditions exceeding the acceptance standards of Article IWD-3000, the examinations shall be further extended to include additional examinations during the current outage. These additional examinations shall include the remaining number of welds, areas, or parts of similar material and service subject to the same type of flaws or relevant conditions.

(2) Additional examinations shall be performed in accordance with the following requirements:

(-a) An engineering evaluation shall be performed. Topics to be addressed in the engineering evaluation shall include the following:

(-1) a determination of the cause of the flaws or relevant conditions

(-2) an evaluation of applicable service conditions and degradation mechanisms to establish that the affected welds, areas, or parts[35] will perform their intended safety functions during subsequent operation

(-3) a determination of which additional welds, areas, or parts[35] are subject to the same service conditions and degradation mechanisms that caused the flaws or relevant conditions

(-b) Additional examinations shall be performed on all those welds, areas, or parts[35] subject to the same service conditions and degradation mechanisms that caused the flaws or relevant conditions. This additional selection might require inclusion of piping systems other than the one containing the original flaws or relevant conditions. No additional examinations are required if the engineering evaluation concludes that

(-1) there are no additional welds, areas, or parts subject to the same service conditions that caused the flaws or relevant conditions or

(-2) no degradation mechanism exists

(-c) The engineering evaluation shall be retained in accordance with Article IWA-6000.

(b) The examination method for additional examinations may be limited to the examination method that originally identified the flaws or relevant conditions, provided use of the method is supported by an engineering evaluation. The engineering evaluation shall determine the cause of the flaws or relevant conditions and the appropriate method to be used as part of the additional examination scope. The engineering evaluation shall be retained in accordance with Article IWA-6000.

(c) For the inspection period following the period in which the examinations of (a) were completed, the examinations shall be performed as originally scheduled in accordance with IWD-2400.

(d) If welded attachments are examined as a result of identified component support deformation, and the results of these examinations exceed the acceptance standards of Article IWD-3000, additional examinations shall be performed, if determined necessary, based on an evaluation by the Owner. The evaluation shall be documented and shall include the cause of the welded attachment damage if known. If the cause of the welded attachment damage could recur or is unknown, additional examinations shall be performed in accordance with the requirements of (a) above. No additional examinations are required if either of the following applies:

(1) There are no other welded attachments subject to the same apparent or root cause conditions.

(2) The degradation mechanism no longer exists.

IWD-2500 EXAMINATION AND PRESSURE TEST REQUIREMENTS

(a) Components shall be examined and pressure tested as specified in Tables IWD-2500-1 (D-A) and IWD-2500-1 (D-B). The method of examination for the components and parts of the pressure-retaining boundaries shall comply with those tabulated in Tables IWD-2500-1 (D-A) and IWD-2500-1 (D-B) except where alternate examination methods are used that meet the requirements of IWA-2240.

(b) Tables IWD-2500-1 (D-A) and IWD-2500-1 (D-B) are organized as follows.

Examination Category	Examination Area
D-A	Welded Attachments for Pressure Vessels, Piping, Pumps, and Valves
D-B	All Pressure-Retaining Components

Table IWD-2500-1 (D-A)
Examination Category D-A, Welded Attachments for Pressure Vessels [Note (1)], Piping, Pumps, and Valves

Item No.	Parts Examined [Note (2)]	Examination Requirements/ Fig. No.	Examination Method	Acceptance Standard	Extent of Examination [Note (3)], [Note (4)]	Frequency of Examination [Note (4)], [Note (5)], [Note (6)], [Note (7)]
	Pressure Vessels					
D1.10	Welded Attachments	IWD-2500-1 (D-A)	Visual, VT-1	IWD-3000	100% of required areas of each welded attachment	Each identified occurrence and each inspection interval
	Piping					
D1.20	Welded Attachments	IWD-2500-1 (D-A)	Visual, VT-1	IWD-3000	100% of required areas of each welded attachment	Each identified occurrence and each inspection interval
	Pumps					
D1.30	Welded Attachments	IWD-2500-1 (D-A)	Visual, VT-1	IWD-3000	100% of required areas of each welded attachment	Each identified occurrence and each inspection interval
	Valves					
D1.40	Welded Attachments	IWD-2500-1 (D-A)	Visual, VT-1	IWD-3000	100% of required areas of each welded attachment	Each identified occurrence and each inspection interval

NOTES:

(1) These requirements do not apply to atmospheric or 0 psig to 15 psig (0 kPa to 100 kPa) storage tanks.

(2) Examination is limited to those welded attachments that meet the following conditions:

(a) the attachment is on the outside surface of the pressure-retaining component;

(b) the attachment provides component support as defined in NF-1110;

(c) the attachment weld joins the attachment either directly to the surface of the component or to an integrally cast or forged attachment to the component; and

(d) the attachment weld is full penetration, fillet, or partial penetration, either continuous or intermittent.

(3) The extent of the examination includes essentially 100% of the length of the attachment weld at each attachment subject to examination, except that examination of surface areas may be limited to the portions of these areas that are accessible without removal of support members.

(4) Selected samples of welded attachments shall be examined each inspection interval.

(5) Examination is required whenever component support member deformation, e.g., broken, bent, or pulled out parts, is identified during operation, refueling, maintenance, examination, or testing.

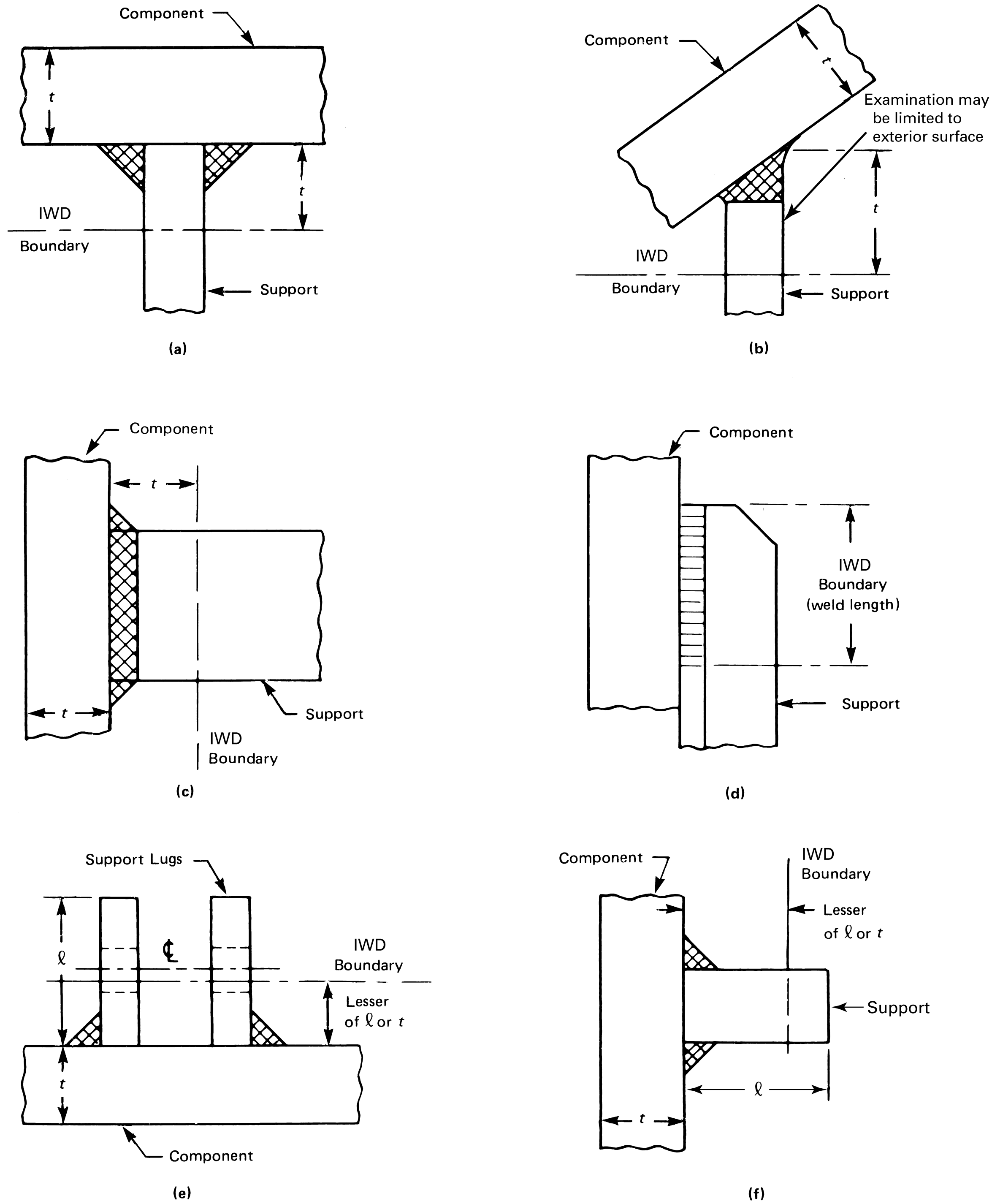
(6) For multiple vessels of similar design, function, and service, in systems the Owner has determined the welded attachments to be subject to corrosion, such as the welded attachments to the Service Water or Emergency Service Water Systems, one welded attachment of only one of the multiple vessels shall be selected for examination. For single vessels in systems that the Owner has determined the welded attachments to be subject to corrosion, such as the welded attachments to the Service Water or Emergency Service Water Systems, one welded attachment shall be selected for examination. The attachment selected for examination, on one of the multiple vessels or the single vessel, as applicable, shall be an attachment under continuous load during normal system operation or an attachment subject to potential intermittent load (seismic, water hammer, etc.) during normal system operation if an attachment under continuous load does not exist.

(7) For piping, pumps, and valves, a sample of 10% of the welded attachments in systems the Owner has determined the welded attachments to be subject to corrosion, such as the welded attachments to the Service Water or Emergency Service Water Systems, shall be selected for examination.

Table IWD-2500-1 (D-B)
Examination Category D-B, All Pressure-Retaining Components

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent of Examination	Frequency of Examination
D2.10	Pressure-retaining components	System leakage test (IWD-5220)	Visual, VT-2	IWD-3000	Pressure-retaining boundary	Each inspection period

Figure IWD-2500-1
Welded Attachments



GENERAL NOTE: Examination of surface areas may be limited to the portions of these areas that are accessible without removal of support members

ARTICLE IWD-3000 ACCEPTANCE STANDARDS

IWD-3100 EVALUATION OF EXAMINATION RESULTS

IWD-3110 PRESERVICE EXAMINATIONS

In the course of preparation. The requirements of IWC-3100 may be used.

IWD-3120 INSERVICE VOLUMETRIC AND SURFACE EXAMINATIONS

In the course of preparation. The requirements of IWC-3120 may be used.

IWD-3130 INSERVICE VISUAL EXAMINATIONS

IWD-3131 General

The visual examinations required by IWD-2500 and performed in accordance with the procedures of IWA-2200 shall be evaluated by comparing the examination results with the acceptance standards specified in Table IWD-3410-1. Acceptance of components for continued service shall be in accordance with IWD-3132, IWD-3133, and IWD-3134.

IWD-3132 Acceptance

(a) A component whose examination confirms the absence of relevant conditions described in the standards of Table IWD-3410-1 shall be acceptable for continued service.

(b) A component whose examination detects relevant conditions described in the standards of Table IWD-3410-1 shall be unacceptable for continued service unless such components meet the requirements of IWD-3132.1, IWD-3132.2, or IWD-3132.3.

IWD-3132.1 Acceptance by Supplemental Examination. Components containing relevant conditions shall be acceptable for continued service if the results of supplemental examination (IWD-3200) meet the requirements of IWD-3120.

IWD-3132.2 Acceptance by Corrective Measures or Repair/Replacement Activity. A component containing relevant conditions is acceptable for continued service if the relevant conditions are corrected by a repair/replacement activity or by corrective measures to the extent necessary to meet the acceptance standards of Table IWD-3410-1.

IWD-3132.3 Acceptance by Evaluation. A component containing relevant conditions is acceptable for continued service if an evaluation demonstrates the component's acceptability in accordance with (a) or (b) below.

(a) The evaluation analysis and evaluation criteria shall be specified by the Owner. Components accepted for continued service based on evaluation shall be subsequently examined in accordance with IWD-2420(b) and IWD-2420(c). If the subsequent IWD-2420(b) and IWD-2420(c) examinations reveal that the relevant conditions remain essentially unchanged, or the changes in the relevant conditions are within the limits predicted by the evaluation, and the design inputs for the evaluation have not been affected by activities such as power uprates, the existing evaluation may continue to be used, provided it covers the time period until the next examination.

(b) Temporary acceptance of flaws in moderate energy piping may be performed in accordance with Nonmandatory Appendix U, Supplement U-S1, and temporary acceptance of degradation in moderate energy vessels and tanks may be performed in accordance with Nonmandatory Appendix U, Supplement U-S2.

IWD-3133 Repair/Replacement Activity and Reexamination

The repair/replacement activity and reexamination shall comply with the requirements of Article IWA-4000.

IWD-3134 Review by Authorities

(a) The Repair/Replacement Program and the reexamination results shall be subject to review by the enforcement authorities having jurisdiction at the plant site.

(b) Evaluation analyses of examination results as required by IWD-3132.3(a) shall be submitted to the regulatory authority having jurisdiction at the plant site.

IWD-3200 SUPPLEMENTAL EXAMINATIONS

Visual examinations that detect relevant conditions may be supplemented by other examinations (IWA-2220, IWA-2230, or IWA-2240) to determine the need for corrective measures, analytical evaluation, or repair/replacement activities.

IWD-3400 STANDARDS

IWD-3410 ACCEPTANCE STANDARDS

The acceptance standards referenced in Table IWD-3410-1 shall be applied to determine acceptability for service.

IWD-3500 ACCEPTANCE STANDARDS

IWD-3510 STANDARDS FOR EXAMINATION CATEGORY D-A, WELDED ATTACHMENTS FOR VESSELS, PIPING, PUMPS, AND VALVES

In the course of preparation. The requirements of IWC-3500 may be used.

IWD-3511 Standards for Examination Category D-B, All Pressure-Retaining Components

IWD-3511.1 Visual Examination, VT-2. A component whose visual examination (IWA-5240) detects any of the following relevant conditions[34] shall meet IWD-3132 and IWA-5250 prior to continued service:

(a) any through-wall or through-weld, pressure-retaining material leakage from insulated and noninsulated components

(b) leakage in excess of limits established by the Owner from mechanical connections (such as pipe caps, bolted connections, or compression fittings) or from components provided with leakage-limiting devices (such as valve-packing glands or pump seals)

(c) areas of general corrosion of a component resulting in leakage

(d) discoloration or accumulated residues on surfaces of components, insulation, or floor areas that may be evidence of leakage or

(e) leakages or flow test results from buried components in excess of limits established by the Owner

IWD-3600 ANALYTICAL EVALUATION OF PLANAR FLAWS (15)

IWD-3610 ACCEPTANCE CRITERIA FOR FERRITIC COMPONENTS

In the course of preparation. The requirements of IWC-3610 may be used.

IWD-3640 ANALYTICAL EVALUATION PROCEDURES AND ACCEPTANCE CRITERIA FOR FLAWS IN AUSTENITIC AND FERRITIC PIPING

Piping containing flaws exceeding the acceptance standards of IWD-3500 may be analytically evaluated to determine acceptability for continued service to the next inspection or to the end of the evaluation period. A pipe containing flaws is acceptable for continued service for a specified evaluation time period if the criteria of IWD-3642, IWD-3643, or IWD-3644 are satisfied. The procedures shall be the responsibility of the Owner and shall be provided to the regulatory authority having jurisdiction at the plant site.

IWD-3641 Analytical Evaluation Procedures

Analytical evaluation procedures based on flaw size or applied stress, such as those described in Nonmandatory Appendix C or Nonmandatory Appendix H may be used subject to the following:

(a) The analytical evaluation procedures and acceptance criteria in Nonmandatory Appendix C are applicable to piping NPS 1 (DN 25) and greater. The procedures and criteria in Nonmandatory Appendix H are applicable to piping NPS 4 (DN 100) and greater. Nonmandatory Appendices C and H are applicable to portions of adjoining pipe fittings within a distance of $(R_2 t)^{1/2}$ from the weld centerline, where R_2 is the outside radius and t is the thickness of the pipe. The weld geometry and weld-base metal interface are defined in Nonmandatory Appendix C.

(b) The analytical evaluation procedures and acceptance criteria are applicable to seamless or welded wrought carbon steel piping and pipe fittings, and associated weld materials, that have a specified minimum yield strength not greater than 40 ksi (280 MPa).

(c) The analytical evaluation procedures and acceptance criteria are applicable to seamless or welded, wrought or cast, austenitic pipe and pipe fittings and

Table IWD-3410-1
Acceptance Standards (15)

Examination Category	Component and Part Examined	Acceptance Standard
D-A	Welded attachments for vessels, piping, pumps, and valves	IWD-3510
D-B	Pressure-retaining components	IWD-3511

associated weld materials that are made of wrought stainless steel, Ni-Cr-Fe alloy, or cast stainless steel, and have a specified minimum yield strength not greater than 45 ksi (310 MPa).

(d) A flaw growth analysis shall be performed on the detected flaw to predict its growth due to fatigue or stress corrosion cracking mechanisms, or both, when applicable, during a specified evaluation time period. The time interval selected for flaw growth analysis (i.e., evaluation period) shall be until the next inspection or until the end of the evaluation period for the item.

(e) The calculated maximum flaw dimensions at the end of the evaluation period shall be compared with the acceptance criteria for Service Levels A, B, C, and D loadings to determine the acceptability of the item for continued service.

IWD-3642 Analytical Evaluation Procedures and Acceptance Criteria Based on Failure Mode Determination

Piping containing flaws exceeding the acceptance standards of IWD-3500 may be analytically evaluated using procedures described in Nonmandatory Appendix C and is acceptable for continued service during the evaluated time period when the critical flaw parameters satisfy the criteria in Nonmandatory Appendix C. Flaw acceptance criteria are based on allowable flaw size or allowable stress. Flaws with depths greater than 75% of the wall thickness are unacceptable.

IWD-3643 Analytical Evaluation Procedure and Acceptance Criteria Based on Use of a Failure Assessment Diagram

Piping containing flaws exceeding the acceptance standards of Article IWD-3000 may be analytically evaluated using procedures based on use of a failure assessment diagram, such as described in Nonmandatory Appendix H. Such analytical evaluation procedures may be invoked in accordance with the conditions of IWD-3641. Flaws with depths greater than 75% of the wall thickness are unacceptable.

IWD-3644 Alternative Analytical Evaluation Procedure and Acceptance Criteria Based on Applied Stress

Piping containing flaws exceeding the allowable flaw standards of IWD-3500 is acceptable for continued service until the end of the evaluation period if the alternative analytical evaluation procedure demonstrates, at the end-of-evaluation period, structural factors, based on load, equivalent to those given below:

Service Level	Structural Factor
A	2.7
B	2.4
C	1.8
D	1.4

Flaws with depths greater than 75% of the wall thickness are unacceptable.

ARTICLE IWD-5000
SYSTEM PRESSURE TESTS

IWD-5200 SYSTEM TEST REQUIREMENTS

IWD-5210 TEST

(a) Pressure-retaining components shall be tested at the frequency stated in, and visually examined by the methods specified in Table IWD-2500-1 (D-B).

(b)

(1) The system pressure tests and visual examinations shall be conducted in accordance with Article IWA-5000 and this Article. The contained fluid in the system shall serve as the pressurizing medium.

(2) Alternatively, steam systems may use either water or gas as the pressurizing medium. When gas is the pressurizing medium, the test procedure shall include methods for detection and location of through-wall leakage from components of the system tested.

(c) Portions of systems that are normally submerged in its process fluid such that the external surfaces of the pressure-retaining boundary are normally wetted during its pressurized conditions are excluded from the test boundary.

IWD-5220 SYSTEM LEAKAGE TEST

IWD-5221 Pressure

The system leakage test shall be conducted at the system pressure obtained while the system, or portion of the system, is in service performing its normal operating function or at the system pressure developed during a test conducted to verify system operability (e.g., to demonstrate system safety function or satisfy technical specification surveillance requirements). If portions of a system are subject to system pressure tests associated with more than one safety function, the visual examination need only be performed during the test conducted at the higher of the test pressures for the respective system safety function, except as permitted in IWA-5222.

(15) IWD-5222 Boundaries

(a) The pressure-retaining boundary for closed systems includes only those portions of the system required to operate or support the safety-related function up to and including the first normally closed valve (including a safety or relief valve) or valve capable of automatic closure when the safety function is required.

(b) The pressure-retaining boundary for nonclosed systems includes only those portions of the system required to operate or support the safety function up to and including the first normally closed valve, including a safety or relief valve, or valve capable of automatic closure when the safety function is required. Open-ended piping that is periodically pressurized to conditions described in IWD-5221 shall be included in the test boundary.

IWD-5230 HYDROSTATIC TEST

(a) The system hydrostatic test pressure shall be at least 1.10 times the system pressure P_{sv} for systems with Design Temperature of 200°F (95°C) or less, and at least 1.25 times the system pressure P_{sv} for systems with Design Temperature above 200°F (95°C). The system pressure P_{sv} shall be the lowest pressure setting among the number of safety or relief valves provided for overpressure protection within the boundary of the system to be tested. For systems (or portions of systems) not provided with safety or relief valves, the system design pressure P_d shall be substituted for P_{sv}.

(b) The test pressure for a pneumatic test conducted in accordance with IWA-5211(c) shall be the system leakage test pressure of IWD-5221.

(c) In the case of atmospheric storage tanks, the hydrostatic head, developed with the tank filled to its design capacity, shall be acceptable as the test pressure.

(d) For 0 psi to 15 psi (0 kPa to 100 kPa) storage tanks, the test pressure shall be $1.1P_G$, Design Pressure of vapor or gas space above liquid level for which overpressure protection is provided by relief valve.

(e) For the purpose of the test, open ended[37] portions of suction or drain lines from a storage tank extending to the first shutoff valve shall be considered as an extension of the storage tank.

(f) For open ended portions of discharge lines beyond the last shutoff valve in nonclosed systems (e.g., service water systems), confirmation of adequate flow during system operation shall be acceptable in lieu of system hydrostatic test. Test personnel need not be qualified for VT-2 visual examination.

(g) Open ended vent and drain lines from components extending beyond the last shutoff valve and open ended safety or relief valve discharge lines, including safety or relief valve piping which discharges into the containment pressure suppression pool, shall be exempt from hydrostatic test.

(h) The pressure measuring instrument used for measuring system hydrostatic or pneumatic test pressure shall meet the requirements of IWA-5260.

IWD-5240 TEMPERATURE

(a) The system test temperature during a system hydrostatic test in systems constructed of ferritic steel components shall satisfy either the requirements of fracture prevention criteria, as applicable, or the test temperature determined by the Owner.

(b) For tests of systems or portions of systems constructed entirely of austenitic steel, test temperature limitations are not required to meet fracture prevention criteria.

SUBSECTION IWE
REQUIREMENTS FOR CLASS MC AND METALLIC LINERS OF CLASS CC COMPONENTS OF LIGHT-WATER-COOLED PLANTS

ARTICLE IWE-1000
SCOPE AND RESPONSIBILITY

IWE-1100 SCOPE

This Subsection provides requirements for inservice inspection of Class MC pressure-retaining components and their integral attachments, and of metallic shell and penetration liners of Class CC pressure-retaining components and their integral attachments in light-water-cooled plants.

IWE-1200 COMPONENTS SUBJECT TO EXAMINATION

IWE-1210 EXAMINATION REQUIREMENTS

The examination requirements of this Subsection shall apply to Class MC pressure-retaining components and their integral attachments and to metallic shell and penetration liners of Class CC pressure-retaining components and their integral attachments. These examinations shall apply to surface areas, including welds and base metal.

IWE-1220 COMPONENTS EXEMPTED FROM EXAMINATION

The following components (or parts of components) are exempted from the examination requirements of Article IWE-2000:

(a) vessels, parts, and appurtenances outside the boundaries of the containment system as defined in the Design Specifications.

(b) embedded or inaccessible portions of containment vessels, parts, and appurtenances that met the requirements of the original Construction Code.

(c) portions of containment vessels, parts, and appurtenances that become embedded or inaccessible as a result of vessel repair/replacement activities if the conditions of IWE-1232(a) and IWE-1232(b) and IWE-5220 are met.

(d) piping, pumps, and valves that are part of the containment system, or which penetrate or are attached to the containment vessel. These components shall be examined in accordance with the requirements of Subsection IWB or Subsection IWC, as appropriate to the classification defined by the Design Specifications.

IWE-1230 ACCESSIBILITY FOR EXAMINATION

IWE-1231 Accessible Surface Areas

(a) As a minimum, the following portions of Class MC containment vessels, parts and appurtenances, and Class CC metallic shell and penetration liners shall remain accessible for either direct or remote visual examination, from at least one side of the vessel, for the life of the plant:

(1) openings and penetrations;

(2) structural discontinuities;

(3) 80% of the pressure-retaining boundary (excluding attachments, structural reinforcement, and areas made inaccessible during construction); and

(4) surface areas identified in IWE-1240

(b) The requirements of IWE-1232 shall be met when accessibility for visual examination is only from the interior surface.

IWE-1232 Inaccessible Surface Areas

(a) Portions of Class MC containment vessels, parts, and appurtenances that are embedded in concrete or otherwise made inaccessible during construction of the vessel or as a result of vessel repair/replacement activities are exempted from examination, provided:

(1) no openings or penetrations are embedded in the concrete;

(2) all welded joints that are inaccessible for examination are double butt welded and are fully radiographed and, prior to being covered, are tested for leak tightness using a gas medium test, such as Halide Leak Detector Test; and

(3) the vessel is leak rate tested after completion of construction or repair/replacement activities to the leak rate requirements of the Design Specifications.

(b) Portions of Class CC metallic shell and penetration liners that are embedded in concrete or otherwise made inaccessible during construction or as a result of repair/replacement activities are exempted from examination, provided:

(1) all welded joints that are inaccessible for examination are examined in accordance with CC-5520 and, prior to being covered or otherwise obstructed by adjacent structures, components, parts, or appurtenances, are tested for leak tightness in accordance with CC-5536; and

(2) the containment is leak rate tested after completion of construction or repair/replacement activities to the leak rate requirements of the Design Specifications;

(c) Surface areas of Class MC containment vessels, parts and appurtenances, and surface areas of Class CC metallic shell and penetration liners are considered inaccessible if visual access by line of sight from permanent vantage points is obstructed by permanent plant structures, equipment, or components, provided these surface areas do not require examination in accordance with the inspection plan or IWE-1240.

IWE-1240 SURFACE AREAS REQUIRING AUGMENTED EXAMINATION

IWE-1241 Examination Surface Areas

Surface areas subject to accelerated degradation and aging require the augmented examinations identified in Table IWE-2500-1 (E-C). Such areas include the following:

(a) interior and exterior containment surface areas that are subject to accelerated corrosion with no or minimal corrosion allowance or areas where the absence or repeated loss of protective coatings has resulted in substantial corrosion and pitting. Typical locations of such areas are those exposed to standing water, repeated wetting and drying, persistent leakage, and those with geometries that permit water accumulation, condensation, and microbiological attack. Such areas may include penetration sleeves, stiffeners, surfaces wetted during refueling, concrete-to-steel shell or liner interfaces, embedment zones, leak chase channels, drain areas, or sump liners.

(b) interior and exterior containment surface areas that are subject to excessive wear from abrasion or erosion that causes a loss of protective coatings, deformation, or material loss. Typical locations of such areas are those subject to substantial traffic, sliding pads or supports, pins or clevises, shear lugs, seismic restraints, surfaces exposed to water jets from testing operations or safety relief valve discharges, and areas that experience wear from frequent vibrations.

(c) interior and exterior containment surface areas identified in accordance with IWE-2420(b).

IWE-1242 Identification of Examination Surface Areas

Surface areas requiring augmented examination shall be determined in accordance with IWE-1241, and shall be identified in the Owner's Inspection Program.

Examination methods shall be in accordance with IWE-2500(b).

ARTICLE IWE-2000
EXAMINATION AND INSPECTION

IWE-2100 GENERAL

(a) The requirements of Article IWA-2000 apply except as follows:

(1) The requirements of IWA-2210 and IWA-2300 do not apply to general visual examination, except as required by IWE-2330(b).

(2) The requirements of IWA-2500 and IWA-2600 do not apply.

IWE-2200 PRESERVICE EXAMINATION

(a) Examinations listed in Tables IWE-2500-1 (E-A), IWE-2500-1 (E-C), and IWE-2500-1 (E-G) shall be completed prior to initial plant startup. These preservice examinations shall include the pressure-retaining portions of components not exempted by IWE-1220.

(b) When visual examinations are required, these examinations shall be performed in accordance with IWE-2600, following the completion of the pressure test required by the Construction Code and after application of protective coatings (e.g., paint) when such coatings are required.

(c) When a vessel or liner is subjected to a repair/replacement activity during the service lifetime of a plant, the preservice examination requirements for the portion of the vessel or liner affected by the repair/replacement activity shall be met as follows:

(1) The examination requirements of Tables IWE-2500-1 (E-A), IWE-2500-1 (E-C), and IWE-2500-1 (E-G) apply.

(2) The preservice examination shall be performed upon completion of the repair/replacement activity. If the plant is not in service, the preservice examination shall be performed prior to resumption of service.

(3) When a system pressure test is required by IWE-5220 following completion of the repair/replacement activity, the preservice examination shall be performed during, or upon completion of, the pressure test.

(d) Welds made as part of repair/replacement activities shall be examined in accordance with the requirements of Article IWA-4000, except that for welds joining Class MC or Class CC components to items designed, constructed, and installed to the requirements of Section III, Class 1, 2, or 3, the examination requirements of Article IWB-2000, Article IWC-2000, or Article IWD-2000, as applicable, shall also apply.

(e) Preservice examination for a repair/replacement activity may be conducted prior to installation provided:

(1) the examination is performed after the pressure test required by the Construction Code has been completed;

(2) the examination is conducted under conditions and with equipment and techniques equivalent to those that are expected to be employed for subsequent inservice examinations; and

(3) the shop or field examination records are, or can be, documented and identified in a form consistent with that required by Article IWA-6000.

IWE-2300 VISUAL EXAMINATION, PERSONNEL QUALIFICATION, AND RESPONSIBLE INDIVIDUAL

IWE-2310 VISUAL EXAMINATIONS

The following requirements apply to IWE-2311, IWE-2312, and IWE-2313.

(a) Painted or coated areas shall be visually examined for evidence of flaking, blistering, peeling, discoloration, and other signs of distress.

(b) Noncoated areas shall be examined for evidence of cracking, discoloration, wear, pitting, corrosion, gouges, surface discontinuities, dents, and other signs of surface irregularities.

(c) Visual examinations shall be performed, either directly or remotely, by line of sight from floors, platforms, walkways, ladders, or other permanent vantage points, unless temporary access is required by the inspection plan.

IWE-2311 General Visual Examinations

General visual examinations shall be performed in accordance with IWE-2500 and Table IWE-2500-1 (E-A) to determine the general condition of containment surfaces and detect evidence of degradation.

IWE-2312 VT-3 Visual Examinations

VT-3 visual examinations shall be performed in accordance with IWE-2500 and Table IWE-2500-1 (E-A) to determine the condition of wetted surfaces of submerged areas and determine the condition of vent system surfaces of BWR containments.

IWE-2313 VT-1 Visual Examinations

VT-1 visual examinations shall be performed

(a) in accordance with IWE-2500 and Table IWE-2500-1 (E-C),

(1) to assess the initial condition of surfaces requiring augmented examinations in accordance with IWE-1241 and to determine the magnitude and extent of any deterioration and distress of these surfaces during subsequent augmented examinations;

(2) to determine the condition of inaccessible areas [IWE-1232(c)] when conditions are initially detected in accessible areas that could indicate the presence of, or result in, degradation to such inaccessible areas; and

(b) in accordance with IWE-2500 and Table IWE-2500-1 (E-G), to assess the condition of containment pressure-retaining bolting.

IWE-2320 RESPONSIBLE INDIVIDUAL

(a) The Responsible Individual shall be knowledgeable in the requirements for design, inservice inspection, and testing of Class MC and metallic liners of Class CC components.

(b) The Responsible Individual shall be responsible for the following:

(1) development of plans and procedures for general visual examination of containment surfaces

(2) instruction, training, and approval of general visual examination personnel

(3) performance or direction of general visual examinations

(4) evaluation of general visual examination results and documentation

IWE-2330 PERSONNEL QUALIFICATION

(a) Personnel performing VT-1 and VT-3 visual examinations shall meet the qualification requirements of IWA-2300.

(b) Personnel performing general visual examinations shall meet the vision test requirements of IWA-2321(a).

IWE-2400 INSPECTION SCHEDULE

IWE-2410 INSPECTION PROGRAM

Inservice examinations and system pressure tests may be performed during plant outages such as refueling shutdowns or maintenance shutdowns. The requirements of the Inspection Program shall be met.

IWE-2411 Inspection Program

(a) Examinations specified in Tables IWE-2500-1 (E-A), IWE-2500-1 (E-C), and IWE-2500-1 (E-G) shall be completed during each successive inspection interval, in accordance with Table IWE-2411-1.

(b) If items are added to the Inspection Program, examination shall be scheduled as follows.

Table IWE-2411-1
Inspection Program

Inspection Interval	Inspection Period, Calendar Years of Plant Service Within the Interval
All	3
	7
	10

(1) When an item is added during the first period of an interval, the examinations required by the applicable Examination Category and Item Number for the added item shall be performed during each of the second and third periods of that interval. Alternatively, if deferral of the examinations is permitted for the Examination Category and Item Number, the required examinations shall be performed during either the second or third period of that interval.

(2) When an item is added during the second period of an interval, the examinations required by the applicable Examination Category and Item Number for the added item shall be performed during the third period of that interval.

(3) When an item is added during the third period of an interval, examinations shall be scheduled in accordance with (a) above for successive intervals.

IWE-2420 SUCCESSIVE INSPECTIONS

(a) The sequence of component examinations established during the first inspection interval shall be repeated during each successive inspection interval, to the extent practical. The sequence of component examinations may be modified in a manner that optimizes scaffolding, radiological, insulation removal, or other considerations.

(b) When examination results detect flaws, areas of degradation, or conditions that require an engineering evaluation in accordance with Article IWE-3000 or IWE-2500(d), and the component is acceptable for continued service, the areas containing such flaws, areas of degradation, or conditions shall be reexamined during the next inspection period listed in the schedule of the Inspection Program of IWE-2411, in accordance with Table IWE-2500-1 (E-C).

(c) When the evaluation of examination results identifies conditions that could indicate the presence of, or result in, flaws or degradation in inaccessible areas [as defined in IWE-1232(c)], the inaccessible areas shall be examined, to the extent possible, for evidence of flaws and degradation. If the examination results detect flaws or areas of degradation requiring engineering evaluation

in accordance with Article IWE-3000, and the component is acceptable for continued service, the requirement of (b) shall be met.

(d) When the reexaminations required by (b) reveal that the flaws or areas of degradation remain essentially unchanged for the next inspection period, these areas no longer require augmented examination in accordance with Table IWE-2500-1 (E-C).

IWE-2500 EXAMINATION AND PRESSURE TEST REQUIREMENTS

(a) Examination methods shall comply with those tabulated in Tables IWE-2500-1 (E-A), IWE-2500-1 (E-C), and IWE-2500-1 (E-G) except when alternate examination methods are used that meet the requirements of IWA-2240.

(b) Methods for augmented examination of surface areas identified in IWE-1242 shall comply with the following criteria:

(1) Surface areas requiring augmented examination that are accessible for visual examination shall be visually examined using a VT-1 visual examination method.

(2) Surface areas requiring augmented examination that are not accessible for visual examination on the side requiring augmented examination shall be examined for wall thinning using an ultrasonic thickness measurement method in accordance with Mandatory Appendix I.

(3) When ultrasonic thickness measurements are performed, grids not exceeding one foot square shall be used. The number and location of the grids shall be determined by the Owner.

(4) Ultrasonic thickness measurements shall be used to determine the minimum wall thickness within each grid. The location of the minimum wall thickness within each grid shall be marked or recorded such that periodic reexamination can be performed in accordance with the requirements of Table IWE-2500-1 (E-C). A sampling plan may be used to determine the number and location of ultrasonic thickness measurement grids within each contiguous examination area provided.

(-a) Acceptance of the examination area is based on a statistical confidence level of at least 95% that 95% of all grids within the examination area will meet the acceptance standards of IWE-3500.

(-b) Grid locations are initially selected at random from within each examination area.

(c) Pressure test requirements for components and parts of the pressure-retaining boundary shall comply with the requirements of Article IWE-5000.

(d) When conditions exist in accessible areas that could indicate the presence of, or result in, degradation in an inaccessible area, an engineering evaluation shall be performed to determine the acceptability of the inaccessible area. Such areas are subject to the requirements of IWE-2420(b) and IWE-2420(c).

IWE-2600 CONDITION OF SURFACE TO BE EXAMINED

(a) When a containment vessel or liner is painted or coated to protect surfaces from corrosion, preservice and inservice visual examinations shall be performed without the removal of the paint or coating.

(b) When removal of paint or coating is required, it shall be removed in a manner that will not reduce the base metal or weld thickness below the design thickness.

Table IWE-2500-1 (E-A)
Examination Category E-A, Containment Surfaces

Item No.	Parts Examined	Examination Requirements/ Fig. No. [Note (1)]	Examination Method	Acceptance Standard	Extent and Frequency of Examination: 1st Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals	Deferral of Inspection to End of Interval
E1.10	Containment Vessel Pressure-Retaining Boundary [Note (1)]	IWE-2310	General visual	IWE-3510	100% During each Inspection Period	100% During each Inspection Period	N/A
E1.11	Accessible Surface Areas						
E1.12	Wetted Surfaces of Submerged Areas	IWE-2310	VT-3	IWE-3510	100%	100%	See [Note (2)]
E1.20	BWR Vent System Accessible Surface Areas [Note (1)], [Note (3)]	IWE-2310	VT-3	IWE-3510	100%	100%	See [Note (2)]
E1.30	Moisture Barriers [Note (4)]	IWE-2310, Figure IWE-2500-1	General visual	IWE-3510	100% During each Inspection Period	100% During each Inspection Period	N/A

NOTES:
(1) Examination shall include all accessible interior and exterior surfaces of Class MC components, parts, and appurtenances, and metallic shell and penetration liners of Class CC components. The following items shall be examined:
(a) integral attachments and structures that are parts of reinforcing structure, such as stiffening rings, manhole frames, and reinforcement around openings.
(b) surfaces of attachment welds between structural attachments and the pressure-retaining boundary or reinforcing structure, except for nonstructural or temporary attachments as defined in NE-4435 and minor permanent attachments as defined in CC-4543.4.
(c) surfaces of containment structural and pressure boundary welds, including longitudinal welds (Category A), circumferential welds (Category B), flange welds (Category C), and nozzle-to-shell welds (Category D) as defined in NE-3351 for Class MC and CC-3840 for Class CC; and surfaces of Flued Head and Bellows Seal Circumferential Welds joined to the Penetration.
(d) pressure-retaining bolted connections, including bolts, studs, nuts, bushings, washers, and threads in base material and flange ligaments between fastener holes. Bolted connections need not be dissassembled for performance of examinations.
(2) Examinations may be performed at any time during the interval, provided successive examinations are performed no less frequently than every third period.
(3) Includes flow channeling devices within containment vessels.
(4) Examination shall include moisture barrier materials intended to prevent intrusion of moisture against inaccessible areas of the pressure-retaining metal containment shell or liner at concrete-to-metal interfaces and at metal-to-metal interfaces which are not seal-welded. Containment moisture barrier materials include caulking, flashing, and other sealants used for this application.

Table IWE-2500-1 (E-C)
Examination Category E-C, Containment Surfaces Requiring Augmented Examination

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination: 1st Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals	Deferral of Inspection to End of Interval
E4.10	Containment Surface Areas [Note (1)]	IWE-2310, IWE-2500(b)(1)	VT-1	IWE-3520	100% of surface areas identified by IWE-1242 [Note (1)] during each inspection period	100% of surface areas identified by IWE-1242 [Note (1)] during each inspection period	Not permissible
E4.11	Visible Surfaces						
E4.12	Surface Area Grid Minimum Wall Thickness Locations	IWE-2500(b)(2), (b)(3), (b)(4)	Ultrasonic thickness	IWE-3520	100% of minimum wall thickness locations during each inspection period, established in accordance with IWE-2500(b)(3) and (b)(4)	100% of minimum wall thickness locations during each inspection period, established in accordance with IWE-2500(b)(3) and (b)(4)	Not permissible

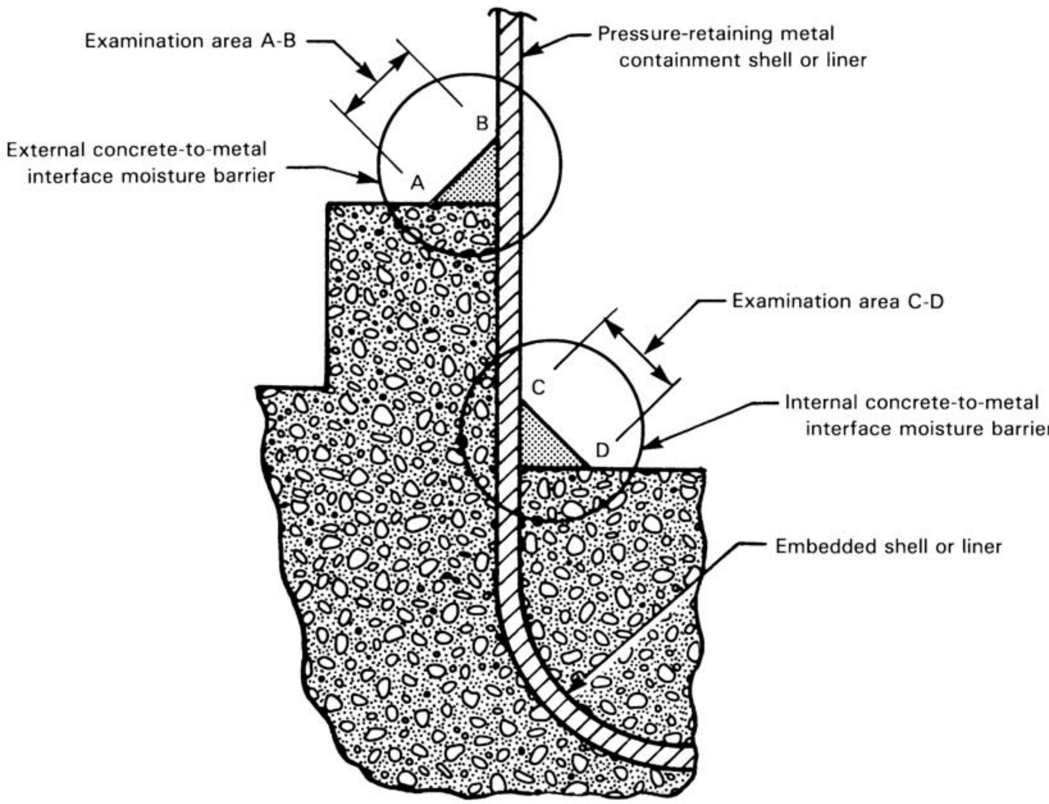
NOTE:
(1) Containment surface areas requiring augmented examination are those identified in IWE-1240.

Table IWE-2500-1 (E-G)
Examination Category E-G, Pressure-Retaining Bolting

Item No.	Parts Examined	Examination Requirements/ Figure No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination: 1st Inspection Interval	Extent and Frequency of Examination: Successive Inspection Intervals	Deferral of Inspection to End of Interval
E8.10	Bolted Connections [Note (1)]	IWE-2310	VT-1	IWE-3530	100% of each bolted connection [Note (2)]	100% of each bolted connection [Note (2)]	Permissible

NOTES:
(1) Examination shall include bolts, studs, nuts, bushings, washers, and threads in base material and flange ligaments between fastener holes.
(2) Examination may be performed with the connection assembled and bolting in place under tension, provided the connection is not dissassembled during the interval. If the bolted connection is dissassembled for any reason during the interval, the examination shall be performed with the connection dissassembled.

Figure IWE-2500-1
Examination Areas for Moisture Barriers



ARTICLE IWE-3000 ACCEPTANCE STANDARDS

IWE-3100 EVALUATION OF EXAMINATION RESULTS

IWE-3110 PRESERVICE EXAMINATIONS

IWE-3111 General

The preservice examination required by IWE-2200 and performed in accordance with the procedures of IWA-2200 shall be evaluated by the acceptance standards specified in IWE-3500. Acceptance of components for service shall be in accordance with IWE-3112 and IWE-3114.

IWE-3112 Acceptance

(a) A component whose examination either confirms the absence of or detects flaws or areas of degradation that do not exceed the acceptance standards of IWE-3500 is acceptable for service, provided the flaws or areas of degradation are recorded in accordance with the requirements of IWA-1400(i) in terms of location, size, shape, orientation, and distribution within the component.

(b) A component whose examination detects flaws or areas of degradation that do not meet the acceptance standards of IWE-3500 is unacceptable for service unless the component is corrected by a repair/replacement activity, to the extent necessary to meet the acceptance standards, prior to placement of the component in service.

IWE-3114 Repair/Replacement Activity and Reexamination

The repair/replacement activity and reexamination shall comply with the requirements of Article IWA-4000. Reexamination shall be conducted in accordance with the requirements of IWA-2200. The recorded results shall demonstrate that the area subjected to the repair/replacement activity meets the acceptance standards of IWE-3500.

IWE-3120 INSERVICE EXAMINATIONS

IWE-3121 General

Inservice examination results shall be compared with recorded results of the preservice examination and prior inservice examinations. Acceptance of the components for continued service shall be in accordance with IWE-3122.

IWE-3122 Acceptance

IWE-3122.1 Acceptance by Examination. A component whose examination results meet the acceptance standards of IWE-3500 shall be acceptable for continued service. Confirmed changes in flaws or areas of degradation from prior examinations shall be recorded in accordance with IWA-1400(i). A component that does not meet the acceptance standards of IWE-3500 shall be corrected in accordance with the provisions shown in IWE-3122.2 or IWE-3122.3.

IWE-3122.2 Acceptance by Corrective Measures or Repair/Replacement Activity. A component containing flaws or areas of degradation is acceptable for continued service if the flaws or areas of degradation are corrected by a repair/ replacement activity or by corrective measures to the extent necessary to meet the acceptance standards of IWE-3500.

IWE-3122.3 Acceptance by Engineering Evaluation.

(a) A component whose examination detects flaws or areas of degradation that do not meet the acceptance standards of IWE-3500 is acceptable for continued service without a repair/replacement activity if an engineering evaluation indicates that the flaw or area of degradation is nonstructural in nature or has no unacceptable effect on the structural integrity of the containment. If either the thickness of the base metal in local areas is reduced by no more than 10% of the nominal plate thickness or the reduced thickness can be shown by analysis to satisfy the requirements of the Design Specifications, the component is acceptable by engineering evaluation.

(b) When flaws or areas of degradation are accepted by engineering evaluation, the area containing the flaw or degradation shall be reexamined in accordance with IWE-2420(b), IWE-2420(c), and IWE-2420(d). If the subsequent IWE-2420(b), IWE-2420(c), and IWE-2420(d) examinations reveal that the flaws or areas of degradation remain essentially unchanged, or the changes in the flaws or areas of degradation are within the limits predicted by the engineering evaluation, and the design inputs for the engineering evaluation have not been affected by activities such as power uprates, the existing engineering evaluation may continue to be used, provided it covers the time period until the next examination.

(c) When portions of later editions or addenda of the Construction Code or Section III are used, all related portions shall be met.

IWE-3124 Repair/Replacement Activity and Reexamination

The repair/replacement activity and reexamination shall comply with the requirements of Article IWA-4000. Reexamination shall be conducted in accordance with the requirements of IWA-2200. The recorded results shall demonstrate that the area subject to the repair/replacement activity meets the acceptance standards of IWE-3500.

IWE-3130 INSERVICE VISUAL EXAMINATIONS

A component whose visual examination as specified in Tables IWE-2500-1 (E-A), IWE-2500-1 (E-C), and IWE-2500-1 (E-G) detects areas that are suspect, shall be unacceptable for continued service unless, following verification of the suspect areas by the supplemental examination as required by IWE-3200, the requirements of IWE-3120 are satisfied.

IWE-3200 SUPPLEMENTAL EXAMINATIONS

Examinations that detect flaws or evidence of degradation that require evaluation in accordance with the requirements of IWE-3100 may be supplemented by other examination methods and techniques (IWA-2240) to determine the character of the flaw (i.e., size, shape, and orientation) or degradation. Visual examinations that detect surface flaws or areas that are suspect shall be supplemented by either surface or volumetric examination, when specified as a result of the engineering evaluation performed in IWE-3122.3

IWE-3400 STANDARDS

IWE-3410 ACCEPTANCE STANDARDS

The acceptance standards of IWE-3500 shall be applied to evaluate the acceptability of the component for service following the preservice examination and each inservice examination.

IWE-3430 ACCEPTABILITY

Flaws or areas of degradation that do not exceed the allowable acceptance standards of IWE-3500 for the respective examination category shall be acceptable.

IWE-3500 ACCEPTANCE STANDARDS

IWE-3510 STANDARDS FOR EXAMINATION CATEGORY E-A, CONTAINMENT SURFACES

IWE-3511 General Visual Examination of Coated and Noncoated Areas

The condition of the examined area is acceptable if the Responsible Individual determines that there is no evidence of damage or degradation requiring further evaluation or performance of a repair/replacement activity. Suspect conditions shall be evaluated to the extent necessary to determine that the component function is not impaired.

IWE-3512 General Visual Examination of Moisture Barriers

Moisture barriers with wear, damage, erosion, tear, surface cracks, or other defects that permit intrusion of moisture against inaccessible areas of the pressure-retaining surfaces of the metal containment shell or liner shall be corrected by corrective measures. Corrective measures may be deferred until the next regularly scheduled outage if an engineering evaluation (IWE-3122.3) demonstrates that degradation from any moisture intrusion would not reduce the thickness of the base metal in local areas by more than 10% of the nominal plate thickness, or the degradation-reduced thickness can be shown by analysis to satisfy the requirements of the Design Specifications.

IWE-3513 Visual Examination, VT-3

The following relevant conditions[25] shall require correction or evaluation to meet the requirements of IWE-3122 prior to continued service:

(a) pressure-retaining component corrosion or erosion that exceeds 10% of the nominal wall thickness;

(b) loose, missing, cracked, or fractured parts, bolting, or fasteners; or

(c) structural distortion or displacement of parts to the extent that the component function is impaired.

IWE-3520 STANDARDS FOR EXAMINATION CATEGORY E-C, CONTAINMENT SURFACES REQUIRING AUGMENTED EXAMINATION

IWE-3521 Visual Examination, VT-1

The following relevant conditions[25] shall require correction or evaluation to meet the requirements of IWE-3122 prior to continued service:

(a) pressure-retaining component corrosion or erosion that exceeds 10% of the nominal wall thickness

(b) loose, missing, cracked, or fractured parts

(c) bolting or fastener relevant conditions listed in IWB-3517.1

(d) structural distortion or displacement of parts to the extent that component function is impaired

(e) moisture barrier conditions that fail to meet the acceptance standards of IWE-3512

IWE-3522 Ultrasonic Examination

Examinations of Class MC pressure-retaining components and of metallic shell and penetration liners of Class CC pressure-retaining components that detect material loss in a local area exceeding 10% of the nominal wall thickness, or material loss in a local area projected to exceed 10% of the nominal wall thickness prior to the next examination, shall be documented. Such local areas shall be accepted by engineering evaluation or corrected by repair/replacement activities in accordance with IWE-3122. Supplemental examinations in accordance with IWE-3200 shall be performed when specified as a result of the engineering evaluation.

IWE-3530 STANDARDS[38] FOR EXAMINATION CATEGORY E-G, PRESSURE-RETAINING BOLTING

IWE-3531 Visual Examination, VT-1

Relevant conditions[25] listed in IWB-3517.1 shall require correction or evaluation to meet the requirements of IWE-3122 prior to continued service.

ARTICLE IWE-5000
SYSTEM PRESSURE TESTS

IWE-5200 SYSTEM TEST REQUIREMENTS

IWE-5210 GENERAL

The requirements of Article IWA-5000 are not applicable to Class MC or Class CC components.

IWE-5220 TESTS FOLLOWING REPAIR/ REPLACEMENT ACTIVITIES

IWE-5221 General

(a) Except as noted in IWE-5224, a pneumatic leakage test shall be performed in accordance with IWE-5223 following repair/replacement activities performed by welding or brazing, prior to returning the component to service.

(b) The following are exempt from the requirements of this Article:

(1) attachments (e.g., as defined in NE-1132) and nonpressure-retaining items

(2) welding or brazing on pressure-retaining portions of components, when the remaining wall thickness after metal removal is at least 90% of the minimum design wall thickness

IWE-5222 Personnel Qualification

Personnel performing tests in accordance with IWE-5223.4(a) and IWE-5224 shall meet the qualification requirements of Section V, Article 1, or IWA-2300.

IWE-5223 Pneumatic Leakage Test

IWE-5223.1 Pressure. The pneumatic leakage test shall be conducted at a pressure between $0.96P_a$ and $1.10P_a$, except when otherwise limited by plant technical specifications, where P_a is the design basis accident pressure.

IWE-5223.2 Boundaries. The test boundary may be limited to brazed joints and welds affected by the repair/replacement activity.

IWE-5223.3 Test Medium and Temperature.

(a) The test medium shall be nonflammable.

(b) The test may be conducted with the vessel partially filled with water, provided the vessel stresses resulting from the test do not exceed the limits of the Construction Code.

(c) The test shall be conducted at a temperature that will preclude brittle fracture of the component.

IWE-5223.4 Examination. During the pneumatic leakage test, the leak tightness of brazed joints and welds affected by the repair/replacement activity shall be verified by performing one of the following:

(a) a bubble test — direct pressure technique in accordance with Section V, Article 10, Mandatory Appendix I, or any other Section V, Article 10 leak test that can be performed in conjunction with the pneumatic leakage test

(b) a Type A, B, or C Test, as applicable, in accordance with 10CFR50, Appendix J

IWE-5223.5 Leakage. The test area is acceptable if the acceptance standards of Section V, Article 10 are met or if the measured leakage is less than can be detected by the bubble test-direct pressure technique.

IWE-5224 Bubble Test-Vacuum Box Technique

(a) As an alternative to the requirements of IWE-5223, a bubble test-vacuum box technique may be performed following repair/replacement activities performed by welding or brazing on the following:

(1) metallic shell and penetration liners of Class CC components

(2) nonstructural pressure-retaining metallic liners of Class MC components embedded in, or backed by, concrete

(b) The bubble test shall be performed in accordance with Section V, Article 10, Mandatory Appendix II at a partial vacuum of at least 5 psi (35 kPa) below atmospheric pressure.

(c) Only brazed joints and welds made in the course of the repair/replacement activity require testing.

IWE-5240 VISUAL EXAMINATION

The visual examination requirements of IWE-2200(c) shall be met.

IWE-5250 CORRECTIVE ACTION

If the leakage test requirements of IWE-5220 cannot be satisfied, the source of leakage shall be located and the area shall be examined to the extent necessary to establish the requirements for corrective action. Repair/replacement activities shall be performed in accordance with the requirements of Article IWA-4000. Leakage testing shall be reperformed as required by IWE-5220, prior to returning the component to service.

SUBSECTION IWF REQUIREMENTS FOR CLASS 1, 2, 3, AND MC COMPONENTS SUPPORTS OF LIGHT-WATER-COOLED PLANTS

ARTICLE IWF-1000 SCOPE AND RESPONSIBILITY

IWF-1100 SCOPE

This Subsection provides the requirements for inservice inspection of Class 1, 2, 3, and MC component supports.

IWF-1200 COMPONENT SUPPORTS SUBJECT TO EXAMINATION AND TEST

IWF-1210 EXAMINATION REQUIREMENTS

The examination requirements shall apply to the following:

(a) piping supports

(b) supports other than piping supports

IWF-1220 SNUBBER INSPECTION REQUIREMENTS[39]

The inservice inspection requirements for snubbers are outside the scope of this Division.

(15) IWF-1230 SUPPORTS EXEMPT FROM EXAMINATION

Supports exempt from the examination requirements of Article IWF-2000 are those connected to piping and other items exempted from volumetric, surface, or VT-1 or VT-3 or general visual examination by IWB-1220(a) through IWB-1220(c); IWC-1221, IWC-1222; IWD-1220(a) through IWD-1220(d); and IWE-1220(a), IWE-1220(c), and IWE-1220(d). In addition, portions of supports that are inaccessible by being encased in concrete, buried underground, or encapsulated by guard pipe are also exempt from the examination requirements of Article IWF-2000.

IWF-1300 SUPPORT EXAMINATION BOUNDARIES (15)

The support examination boundaries for both integral and nonintegral supports are shown in Figure IWF-1300-1. The following definitions apply.

(a) The boundary of an integral support (B) connected to a pressure-retaining component (A) is the distance from the pressure-retaining component (A) as indicated in Subsection IWB, Subsection IWC, Subsection IWD, and Subsection IWE.

(b) The boundary of an integral support (C) connected to a building structure (E) is the surface of the building structure.

(c) The boundary of a nonintegral support (D) connected to a pressure-retaining component (A) is the contact surface between the component and the support.

(d) The boundary of a nonintegral support (D) connected to a building structure (E) is the surface of the building structure.

(e) Where the mechanical connection of a nonintegral support is buried within the component insulation, the support boundary may extend from the surface of the component insulation, provided the support is under continuous tension or compression load.

(f) The examination boundary of an intervening element shall include the attachment portion[40] of the intervening element to pressure-retaining components, integral and nonintegral attachments of pressure-retaining components, and integral and nonintegral supports. The examination boundary does not include the attachment of the intervening element to the building structure.

(15)

Figure IWF-1300-1
Illustrations of Typical Support Examination Boundaries

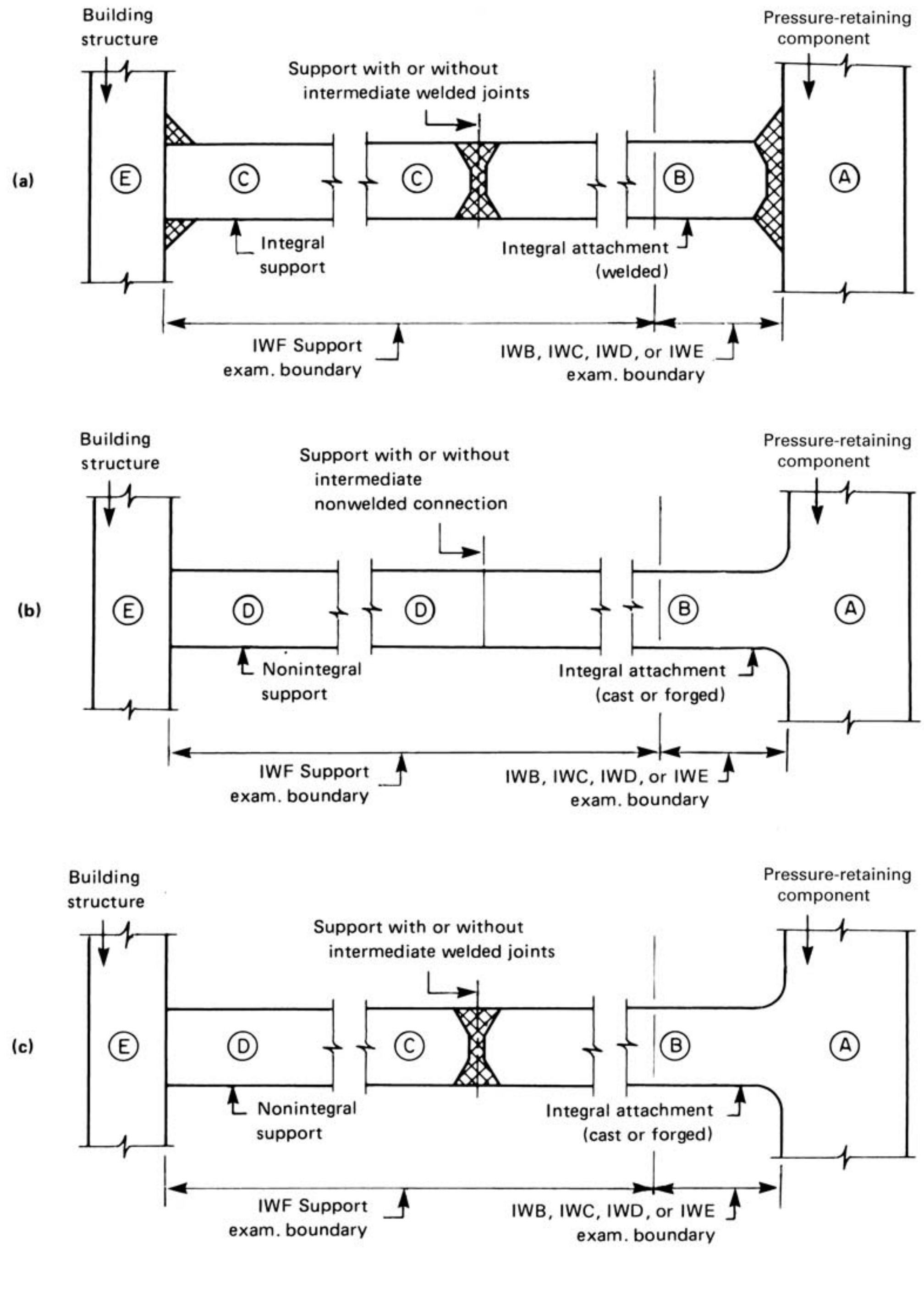
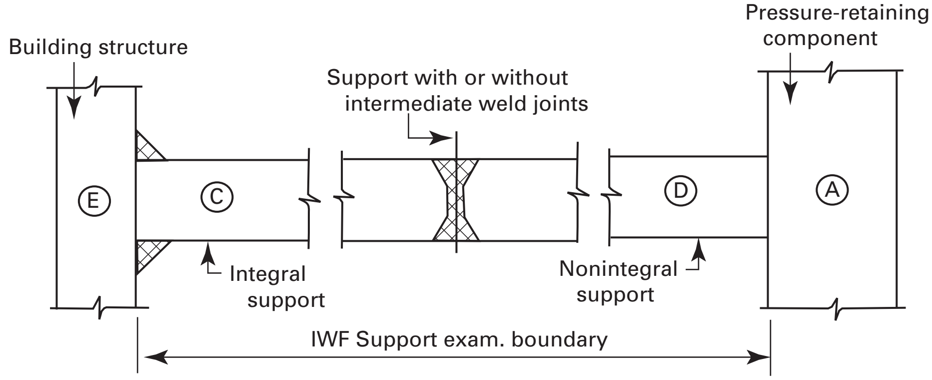
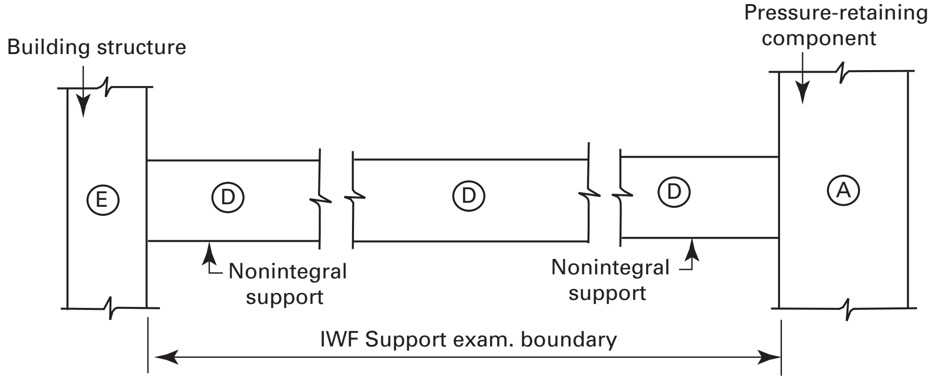


Figure IWF-1300-1
Illustrations of Typical Support Examination Boundaries (Cont'd)

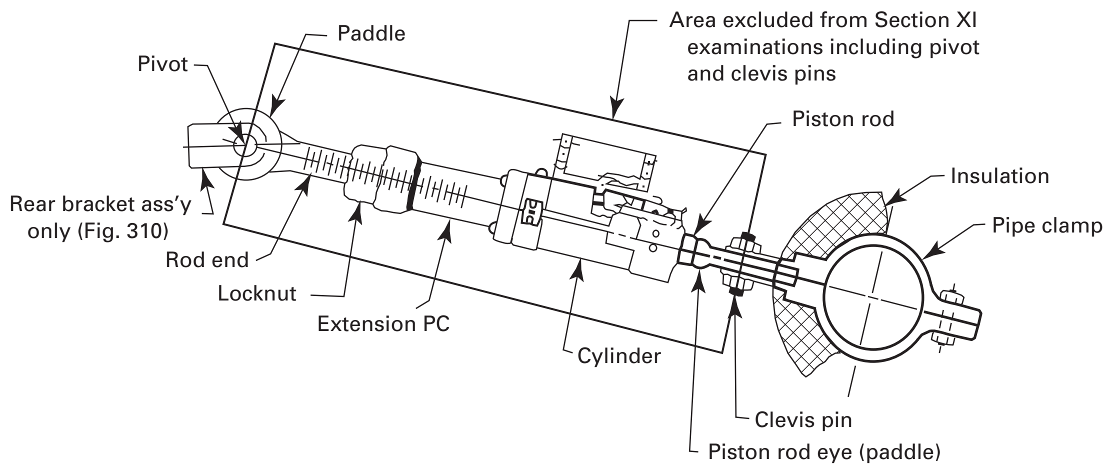
(d)



(e)



(f)



(g) All integral and nonintegral connections within the boundary governed by Subsection IWF rules and requirements are included.

(h) The examination boundary of a support containing a snubber shall not include the connections to the snubber assembly (pins).

ARTICLE IWF-2000
EXAMINATION AND INSPECTION

IWF-2100 SCOPE

The requirements of this Article apply to the examination and inspection of component supports.

IWF-2200 PRESERVICE EXAMINATION

IWF-2210 INITIAL EXAMINATION

(a) All examinations listed in Table IWF-2500-1 (F-A) shall be performed completely, once, as a preservice examination. These preservice examinations shall be extended to include 100% of all supports not exempted by IWF-1230.

(b) Examinations for systems that operate at a temperature greater than 200°F (95°C) during normal plant operation shall be performed during or following initial system heatup and cooldown. Other examinations may be performed prior to initial system heatup and cooldown.

IWF-2220 ADJUSTMENT AND REPAIR/ REPLACEMENT ACTIVITIES

(a) Prior to return of the system to service, the applicable examinations listed in Table IWF-2500-1 (F-A) shall be performed on component supports that have been adjusted in accordance with Article IWF-3000 or corrected by repair/replacement activities.

(b) For systems that operate at a temperature greater than 200°F (95°C) during normal plant operation, the Owner shall perform an additional preservice examination on the affected component supports during or following the subsequent system heatup and cooldown cycle unless determined unnecessary by evaluation. This examination shall be performed during operation or at the next refueling outage.

IWF-2400 INSPECTION SCHEDULE

IWF-2410 INSPECTION PROGRAM

(a) Inservice examinations shall be performed either during normal system operation or plant outages.

(b) The required examinations shall be completed in accordance with the inspection schedule provided in Table IWF-2410-1.

(c) If component supports are added to the Inspection Program during the service lifetime of a plant, examination shall be scheduled as follows:

(1) When component supports are added during the first period of an interval, at least 25% of the examinations required by the applicable Examination Category and Item Number for the added component supports shall be performed during each of the second and third periods of that interval.

(2) When component supports are added during the second period of an interval, at least 25% of the examinations required by the applicable Examination Category and Item Number for the added component supports shall be performed during the third period of that interval.

(3) When component supports are added during the third period of an interval, examinations shall be scheduled in accordance with (b) for successive intervals.

IWF-2420 SUCCESSIVE INSPECTIONS

(a) The sequence of component support examinations established during the first inspection interval shall be repeated during each successive inspection interval, to the extent practical. The sequence of component support examinations may be modified in a manner that optimizes scaffolding, radiological, insulation removal, or other considerations, provided that the percentage requirements of Table IWF-2410-1 are maintained.

Table IWF-2410-1
Inspection Program

Inspection Interval	Inspection Period, Calendar Years of Plant Service, Within the Interval	Minimum Examinations Completed, %	Maximum Examinations Credited, %
All	3	16	50
	7	50 [Note (1)]	75
	10	100	100

NOTE:
(1) If the first period completion percentage for any examination category exceeds 34%, at least 16% of the required examinations shall be performed in the second period.

(b) When a component support is accepted for continued service in accordance with IWF-3112.2 or IWF-3122.2, the component support shall be reexamined during the next inspection period listed in the schedule of the Inspection Programs of IWF-2410.

(c) When the examinations required by (b) do not require additional corrective measures during the next inspection period, the inspection schedule may revert to the requirements of (a).

IWF-2430 ADDITIONAL EXAMINATIONS

(a) Component support examinations performed in accordance with Table IWF-2500-1 (F-A) that reveal flaws or relevant conditions exceeding the acceptance standards of IWF-3400, and that require corrective measures, shall be extended, during the current outage in accordance with (1) or (2) below.

(1) Additional examinations shall be performed in accordance with the following requirements:

(-a) Examinations shall be extended to include the component supports immediately adjacent to those component supports for which corrective measures are required. If one or more of these adjacent supports contains a snubber, the Owner shall evaluate the need to perform an examination or test of the snubber in accordance with the ASME OM Code. The additional examinations shall be extended, during the current outage, to include additional supports within the system, equal in number and of the same type and function as those scheduled for examination during the inspection period.

(-b) When the additional examinations required by (-a) above reveal flaws or relevant conditions exceeding the acceptance standards of IWF-3400, and that require corrective measures, the examinations shall be further extended to include additional examinations during the current outage. These additional examinations shall include the remaining component supports within the system of the same type and function.

(-c) When the additional examinations required by (-b) above reveal flaws or relevant conditions exceeding the acceptance standards of IWF-3400, and that require corrective measures, the examinations shall be extended, during the current outage, to include all nonexempt supports potentially subject to the same failure modes that required corrective measures in accordance with (-a) and (-b) above. Also, these additional examinations shall include nonexempt component supports in other systems when the support failures requiring corrective actions indicate non-system-related support failure modes.

(-d) When the additional examinations required by (-c) above reveal flaws or relevant conditions exceeding the acceptance standards of IWF-3400, and that require corrective measures, the Owner shall examine, during the current outage, those exempt component supports that could be affected by the same observed failure modes and could affect nonexempt components.

(2) Additional examinations shall be performed in accordance with the following requirements:

(-a) An engineering evaluation shall be performed. Topics to be addressed in the engineering evaluation shall include the following:

(-1) a determination of the cause of the flaws or relevant conditions

(-2) an evaluation of applicable service conditions and degradation mechanisms to establish that the affected supports will perform their intended safety functions during subsequent operation

(-3) a determination of which additional supports are subject to the same service conditions and degradation mechanisms that caused the flaws or relevant conditions

(-b) Examinations shall be extended to include the component supports immediately adjacent to those component supports for which corrective measures are required. If one or more of these adjacent supports contains a snubber, the Owner shall evaluate the need to perform an examination or test of the snubber in accordance with the ASME OM Code.

(-c) Additional examinations shall be performed on all those supports subject to the same service conditions and degradation mechanisms that caused the flaws or relevant conditions. This additional selection may require inclusion of piping systems other than the one containing the original flaws or relevant conditions. No additional examinations are required if the engineering evaluation concludes that either

(-1) there are no supports subject to the same service conditions that caused the flaws or relevant conditions or

(-2) no degradation mechanism exists

(-d) The engineering evaluation shall be retained in accordance with Article IWA-6000.

(b) The examination method for additional examinations may be limited to the examination method that originally identified the flaws or relevant conditions, provided use of the method is supported by an engineering evaluation. The engineering evaluation shall determine the cause of the flaws or relevant conditions and the appropriate method to be used as part of the additional examination scope. The engineering evaluation shall be retained in accordance with Article IWA-6000.

IWF-2500 EXAMINATION REQUIREMENTS

The following shall be examined in accordance with Table IWF-2500-1 (F-A):

(a) mechanical connections[41] to pressure-retaining components and building structure

(b) weld connections to building structure

(c) weld and mechanical connections at intermediate joints in multiconnected integral and nonintegral supports

(d) clearances of guides and stops, alignment of supports, and assembly of support items
(e) hot or cold settings of spring supports and constant load supports
(f) accessible sliding surfaces

IWF-2510 SUPPORTS SELECTED FOR EXAMINATION

Supports not exempted by IWF-1230 shall be examined in accordance with Table IWF-2500-1 (F-A).

IWF-2520 METHOD OF EXAMINATION

The methods of examination shall comply with those in Table IWF-2500-1 (F-A). Alternative methods of examination meeting the requirements of IWA-2240 may be used.

Table IWF-2500-1 (F-A)
Examination Category F-A, Supports

Item No. [Note (1)]	Support Types Examined	Examination Requirements [Note (2)]/ Fig. No.	Examination Method	Acceptance Standard	Extent and Examination	Frequency of Examination [Note (3)]
F1.10	Class 1 Piping Supports	IWF-1300-1	Visual, VT-3	IWF-3410	25% of Class 1 [Note (4)]	Each inspection interval
F1.20	Class 2 Piping Supports	IWF-1300-1	Visual, VT-3	IWF-3410	15% of Class 2 [Note (4)]	Each inspection interval
F1.30	Class 3 Piping Supports	IWF-1300-1	Visual, VT-3	IWF-3410	10% of Class 3 [Note (4)]	Each inspection interval
F1.40	Supports Other Than Piping Supports (Class 1, 2, 3, and MC)	IWF-1300-1	Visual, VT-3	IWF-3410	100% of the supports [Note (5)]	Each inspection interval

NOTES:
(1) Item numbers shall be categorized to identify support types by component support function (e.g., A = supports such as one directional rod hangers; B = supports such as multi-directional restraints; and C = supports that allow thermal movement, such as springs).
(2) Examination may be limited to portions of supports that are accessible for examination without disassembly or removal of support members.
(3) To the extent practical, the same supports selected for examination during the first inspection interval shall be examined during each successive inspection interval.
(4) The total percentage sample shall be comprised of supports from each system (such as Main Steam, Feedwater, or RHR), where the individual sample sizes are proportional to the total number of non-exempt supports of each type and function within each system.
(5) For multiple components other than piping, within a system of similar design, function, and service, the supports of only one of the multiple components are required to be examined.

ARTICLE IWF-3000
STANDARDS FOR EXAMINATION EVALUATIONS

IWF-3100 EVALUATION OF EXAMINATION RESULTS

IWF-3110 PRESERVICE EXAMINATIONS

IWF-3111 General

The preservice examinations performed to meet the requirements of IWF-2200 shall be evaluated by comparing the examination results with the acceptance standards specified in IWF-3400.

IWF-3112 Acceptance

IWF-3112.1 Acceptance by Examination. Component supports whose examinations do not reveal conditions described in IWF-3410(a) shall be acceptable for service.

IWF-3112.2 Acceptance by Corrective Measures or Repair/Replacement Activity. A support whose examination detects conditions described in IWF-3410(a) is unacceptable for service until such conditions are corrected by one or more of the following:

(a) adjustment and reexamination in accordance with IWF-2200 for conditions such as

(1) detached or loosened mechanical connections;

(2) improper hot or cold settings of spring supports and constant load supports;

(3) misalignment of supports; or

(4) improper displacement settings of guides and stops

(b) repair/replacement activities in accordance with Article IWA-4000 and reexamination in accordance with IWF-2200.

IWF-3112.3 Acceptance by Evaluation or Test.

(a) As an alternative to the requirements of IWF-3112.2, a component support or a portion of a component support containing relevant conditions that do not meet the acceptance standards of IWF-3410 shall be acceptable for service without corrective actions if an evaluation or test demonstrates that the component support is acceptable for service.

(b) If a component support or a portion of a component support has been evaluated or tested and determined to be acceptable for service in accordance with (a), the Owner may perform corrective measures to restore the component support to its original design condition. The requirements of IWF-2220 are not applicable after corrective measures of IWF-3112.2(a) are performed.

(c) Records and reports shall meet the requirements of Article IWA-6000.

IWF-3120 INSERVICE EXAMINATIONS

IWF-3121 General

Inservice nondestructive examinations performed during or at the end of successive inspection intervals to meet the requirements of Table IWF-2500-1 (F-A) and conducted in accordance with the procedures of IWA-2200 shall be evaluated by comparing the results of examinations with the acceptance standards specified in IWF-3400.

IWF-3122 Acceptance

IWF-3122.1 Acceptance by Examination. Component supports whose examinations do not reveal conditions described in IWF-3410(a) shall be acceptable for continued service. Confirmed changes in conditions from prior examinations shall be recorded in accordance with IWA-1400(i). (**15**)

IWF-3122.2 Acceptance by Corrective Measures or Repair/Replacement Activity. A support whose examination detects conditions described in IWF-3410(a) is unacceptable for continued service until such conditions are corrected by one or more of the following:

(a) adjustment and reexamination in accordance with IWF-2200 for conditions such as

(1) detached or loosened mechanical connections;

(2) improper hot or cold settings of spring supports and constant load supports;

(3) misalignment of supports; or

(4) improper displacement settings of guides and stops.

(b) repair/replacement activities in accordance with Article IWA-4000 and reexamination in accordance with IWF-2200.

IWF-3122.3 Acceptance by Evaluation or Test.

(a) As an alternative to the requirements of IWF-3122.2, a component support or a portion of a component support containing relevant conditions that do not meet the acceptance standards of IWF-3410 shall be acceptable for service without corrective actions if an evaluation or test demonstrates that the component support is acceptable for service.

(b) If a component support or a portion of a component support has been evaluated or tested and determined to be acceptable for service in accordance with (a), the Owner may perform corrective measures to restore the

component support to its original design condition. The requirements of IWF-2220 are not applicable after corrective measures of IWF-3122.2(a) are performed.

(c) Records and reports shall meet the requirements of Article IWA-6000.

IWF-3200 SUPPLEMENTAL EXAMINATIONS

Examinations that detect conditions that require evaluation in accordance with the requirements of IWF-3100 may be supplemented by other examination methods and techniques (Article IWA-2000) to determine the character of the flaw (that is, size, shape, and orientation). Visual examinations that detect surface flaws that exceed IWF-3400 criteria may be supplemented by either surface or volumetric examinations.

IWF-3400 ACCEPTANCE STANDARDS

IWF-3410 ACCEPTANCE STANDARDS — COMPONENT SUPPORT STRUCTURAL INTEGRITY

(a) Component support conditions which are unacceptable for continued service shall include the following:

(1) deformations or structural degradations of fasteners, springs, clamps, or other support items;

(2) missing, detached, or loosened support items;

(3) arc strikes, weld spatter, paint, scoring, roughness, or general corrosion on close tolerance machined or sliding surfaces;

(4) improper hot or cold settings of spring supports and constant load supports;

(5) misalignment of supports;

(6) improper clearances of guides and stops.

(b) Except as defined in (a), the following are examples of nonrelevant conditions:

(1) fabrication marks (e.g., from punching, layout, bending, rolling, and machining);

(2) chipped or discolored paint;

(3) weld spatter on other than close tolerance machined or sliding surfaces;

(4) scratches and surface abrasion marks;

(5) roughness or general corrosion which does not reduce the load bearing capacity of the support;

(6) general conditions acceptable by the material, Design, and/or Construction Specifications.

SUBSECTION IWL
REQUIREMENTS FOR CLASS CC CONCRETE COMPONENTS OF LIGHT-WATER-COOLED PLANTS

ARTICLE IWL-1000
SCOPE AND RESPONSIBILITY

IWL-1100 SCOPE

(a) This Subsection provides requirements for preservice examination, inservice inspection, and repair/replacement activities of the reinforced concrete and the post-tensioning systems of Class CC components, herein referred to as concrete containments as defined by CC-1000.

(b) The rules and requirements of this Subsection do not apply to the following:

(1) steel portions not backed by concrete;

(2) shell metallic liners;

(3) penetration liners extending the containment liner through the surrounding shell concrete.

IWL-1200 ITEMS SUBJECT TO EXAMINATION

IWL-1210 EXAMINATION REQUIREMENTS

The examination requirements of this Subsection shall apply to concrete containments.

IWL-1220 ITEMS EXEMPT FROM EXAMINATION

The following items are exempt from the examination requirements of Article IWL-2000:

(a) tendon end anchorages that are inaccessible, subject to the requirements of IWL-2521.1

(b) portions of the concrete surface that are covered by the liner

(c) portions of the concrete surface obstructed by adjacent structures, components, parts, or appurtenances, unless the Responsible Engineer determines that examination is required as a result of conditions identified in accessible areas

(d) portions of the concrete surface made inaccessible by foundation material or backfill, subject to the provisions of IWL-2512

ARTICLE IWL-2000
EXAMINATION AND INSPECTION

IWL-2100 GENERAL

The requirements of Article IWA-2000 apply, except that

(a) the requirements of IWA-2210, IWA-2500, and IWA-2600 do not apply

(b) except as noted in IWL-2320, the requirements of IWA-2300 do not apply

IWL-2200 PRESERVICE EXAMINATION

Preservice examination shall be performed in accordance with the following requirements.

IWL-2210 EXAMINATION SCHEDULE

Preservice examination shall be completed prior to initial plant startup.

IWL-2220 EXAMINATION REQUIREMENTS

IWL-2221 Concrete

(a) Preservice examination shall be performed in accordance with IWL-2510.

(b) The preservice examination shall be performed following completion of the containment Structural Integrity Test.

IWL-2222 Unbonded Post-Tensioning Systems

The following information shall be documented in the preservice examination records. This information may be extracted from construction records.

(a) Date on which each tendon was tensioned.

(b) Initial seating force in each tendon.

(c) For each tendon anchorage, the location of all missing or broken wires or strands and unseated wires.

(d) For each tendon anchorage, the location of all missing or detached buttonheads or missing wedges.

(e) The product designation for the corrosion protection medium used to fill the tendon duct.

IWL-2230 PRESERVICE EXAMINATION OF REPAIR/REPLACEMENT ACTIVITIES

(a) When a concrete containment or a portion thereof is affected by repair/replacement activities during the service lifetime of a plant, the preservice examination requirements shall be met for the repair/replacement activity.

(b) When the repair/replacement activity is performed while the plant is not in service, the preservice examination shall be performed prior to resumption of service.

(c) When the repair/replacement activity is performed while the plant is in service, the preservice examination may be deferred to the next scheduled outage.

IWL-2300 VISUAL EXAMINATION, PERSONNEL QUALIFICATION, AND RESPONSIBLE ENGINEER

IWL-2310 VISUAL EXAMINATIONS

(a) General visual examinations of concrete surfaces shall be performed to determine the structural condition of containments. The general visual examination shall be performed to identify areas of concrete deterioration and distress, such as described in ACI 201.1R and ACI 349.3R.

(b) Detailed visual examinations shall be performed to determine:

(1) the magnitude and extent of deterioration and distress initially detected by general visual examinations of concrete surfaces

(2) the magnitude and extent of deterioration and distress initially detected by general visual examinations of concrete surfaces, at tendon anchorage areas

(3) the condition (e.g., cracks, wear, or corrosion) of tendon wires or strands, and anchorage hardware, as described in IWL-2524.1

(4) the condition of concrete surfaces affected by repair/replacement activities, in accordance with IWL-5250

(5) the condition of reinforcing steel exposed as a result of removal of defective concrete as described in IWL-4220(c)

IWL-2320 PERSONNEL QUALIFICATIONS

(a) Personnel performing general or detailed visual examinations shall be approved by the Responsible Engineer and shall be qualified by satisfying the following requirements:

(1) at least 10 hr plant experience, such as that gained by plant personnel involved in inspection, maintenance, or repair/replacement activities in each of the following:

(-a) structural concrete and reinforcing steel;

(-b) post-tensioning system components (for plants with post-tensioning systems only);

(2) at least 4 hr of training in Subsection IWL requirements and at least 2 hr of training in plant-specific procedures for Subsection IWL visual examinations. Training shall include requirements for inservice and preservice examinations and reporting criteria for the following:

(-a) concrete (applicable conditions such as those described in ACI 201.1R should be included)

(-b) reinforcing steel

(-c) post-tensioning system items (e.g., wires, strands, anchorage hardware, corrosion protection medium, and free water) [for plants with post-tensioning systems only]

(3) training proficiency shall be demonstrated by administering a qualification examination consisting of the following:

(-a) a written examination covering Subsection IWL requirements and plant-specific procedure requirements for visual examination, containing at least 15 questions in each of the following:

(-1) concrete and reinforcing steel;

(-2) post-tensioning system components (i.e., wires, strands, anchorage hardware, corrosion protection medium, and free water) [for plants with post-tensioning systems only].

(-b) a practical examination using test specimens with flaws or indications to be detected by the following visual examination techniques:

(-1) general and detailed visual examination of concrete

(-2) detailed visual examination of reinforcing steel

(-3) detailed visual examination of post-tensioning system components (i.e., wires, strands, and anchorage hardware) [for plants with post-tensioning systems only]

(-c) passing grades for visual examinations shall be as follows:

(-1) an average combined grade of 80% for written and practical examinations, and

(-2) a minimum grade of 70% for each written and practical examination

(-d) individuals failing to attain the required passing grades shall receive additional training as determined by the Responsible Engineer before reexamination. The written reexamination questions shall be selected at random from a bank of questions containing at least twice the number of examination questions, or the written examination shall contain at least 30% different or recorded questions. The practical reexamination test shall contain at least 50% different test specimens or shall contain specimens with at least 50% different flaws or indications from those used during the most recent practical examination that was not passed by the candidate. No individual shall be reexamined more than twice within any consecutive 12 month period.

(4) training proficiency shall be demonstrated by administering subsequent examinations at a frequency not exceeding 5 yr

(5) the vision test requirements of IWA-2321

(b) The preceding qualification requirements shall be described in the Employer's written practice.

IWL-2330 RESPONSIBLE ENGINEER

The Responsible Engineer shall be a Registered Professional Engineer experienced in evaluating the condition of structural concrete. The Responsible Engineer shall have knowledge of the design and Construction Codes and other criteria used in design and construction of concrete containments in nuclear power plants.

The Responsible Engineer shall be responsible for the following:

(a) development of plans and procedures for examination of concrete surfaces

(b) approval, instruction, and training of personnel performing general and detailed visual examination

(c) evaluation of examination results

(d) preparation or review of Repair/Replacement Plans and procedures

(e) review of procedures for pressure tests following repair/replacement activities

(f) submittal of a report to the Owner documenting results of examinations, repair/replacement activities, and pressure tests

IWL-2400 INSERVICE INSPECTION SCHEDULE

IWL-2410 CONCRETE

(a) Concrete shall be examined in accordance with IWL-2510 at 1, 3, and 5 yr following the completion of the containment Structural Integrity Test CC-6000 and every 5 yr thereafter.

(b) The 1-, 3-, and 5-yr examinations shall commence not more than 6 months prior to the specified dates and shall be completed not more than 6 months after such dates. If plant operating conditions are such that examination of portions of the concrete cannot be completed within this stated time interval, examination of those portions may be deferred until the next regularly scheduled plant outage.

(c) The 10-yr and subsequent examinations shall commence not more than 1 yr prior to the specified dates and shall be completed not more than 1 yr after such dates. If plant operating conditions are such that examination of portions of the concrete cannot be completed within this stated time interval, examination of those portions may be deferred until the next regularly scheduled plant outage.

(d) Concrete surface areas affected by a repair/replacement activity shall be examined in accordance with the requirements of IWL-2510 at 1 yr (±3 months) following

completion of repair/replacement activity. If plant operating conditions are such that examination of portions of the concrete cannot be completed within this time interval, examination of those portions may be deferred until the next regularly scheduled plant outage.

IWL-2420 UNBONDED POST-TENSIONING SYSTEMS

(a) Unbonded post-tensioning systems shall be examined in accordance with IWL-2520 at 1, 3, and 5 yr following the completion of the containment Structural Integrity Test and every 5 yr thereafter.

(b) The 1-, 3-, and 5-yr examinations shall commence not more than 6 months prior to the specified dates and shall be completed not more than 6 months after such dates. If plant operating conditions are such that examination of portions of the post-tensioning system cannot be completed within this stated time interval, examination of those portions may be deferred until the next regularly scheduled plant outage.

(c) The 10-yr and subsequent examinations shall commence not more than 1 yr prior to the specified dates and shall be completed not more than 1 yr after such dates. If plant operating conditions are such that examination of portions of the post-tensioning system cannot be completed within this stated time interval, examination of those portions may be deferred until the next regularly scheduled plant outage.

(d) Tendons affected by repair/replacement activities shall be examined in accordance with the requirements of IWL-2521.2.

IWL-2421 Sites With Multiple Plants

(a) For sites with multiple plants, the requirements of IWL-2420 may be modified if the containments utilize the same prestressing system and are essentially identical in design, if post-tensioning operations for each subsequent containment constructed at the site were completed not more than 2 yr apart, and if the containments are similarly exposed to or protected from the outside environment.

(b) When the conditions of (a) are met, the inspection dates and examination requirements may be as follows.

(1) For the containment with the first Structural Integrity Test, all examinations required by IWL-2520 shall be performed at 1, 3, and 10 yr and every 10 yr thereafter. In addition, the examinations required by IWL-2524 and IWL-2525 shall be performed at 5 and 15 yr and every 10 yr thereafter.

(2) For each subsequent containment constructed at the site, all examinations required by IWL-2520 shall be performed at 1, 5, and 15 yr and every 10 yr thereafter. In addition, the examinations required by IWL-2524 and IWL-2525 shall be performed at 3 and 10 yr and every 10 yr thereafter.

IWL-2500 EXAMINATION REQUIREMENTS

Examination shall be performed in accordance with the requirements of Tables IWL-2500-1 (L-A) and IWL-2500-1 (L-B).

Table IWL-2500-1 (L-A) Examination Category L-A, Concrete

Item No.	Parts Examined	Test or Examination Requirement	Test or Examination Method	Acceptance Standard	Extent of Examination	Frequency of Examination	Deferral of Examination
L1.10	Concrete surface	IWL-2510	General visual	IWL-3210	IWL-2510	IWL-2410	NA
L1.11	All accessible surface areas [Note (1)]						
L1.12	Suspect areas	IWL-2510	Detailed visual	IWL-3210	IWL-2510	IWL-2410	NA
L1.13	Inaccessible Below-Grade Areas [Note (2)]	IWL-2512(c)	IWL-2512(c) [Note (3)]	IWL-3210	IWL-2512(a)	IWL-2512(c)	NA

NOTES:
(1) Includes concrete surfaces at tendon anchorage areas not selected by IWL-2521 or exempted by IWL-1220(a).
(2) Concrete surfaces exposed to foundation soil, backfill, or ground water.
(3) Method of examination as defined by the Responsible Engineer, based on IWL-2512(b) evaluation.

Table IWL-2500-1 (L-B)
Examination Category L-B, Unbound Post-Tensioning System

Item No.	Parts Examined	Test or Examination Requirement	Test or Examination Method	Acceptance Standard	Extent of Examination	Frequency of Examination	Deferral of Examination
L2.10	Tendon	IWL-2522	IWL-2522	IWL-3221.1	IWL-2521	IWL-2420	NA
L2.20	Wire or strand	IWL-2523	IWL-2523.2	IWL-3221.2	IWL-2523.1	IWL-2420	NA
L2.30	Anchorage hardware and surrounding concrete	IWL-2524	Detailed visual	IWL-3221.3	IWL-2524.1	IWL-2420	NA
L2.40	Corrosion protection medium	IWL-2525, IWL-2526	IWL-2525.2(a), IWL-2526	IWL-3221.4	IWL-2525.1(a), IWL-2526	IWL-2420	NA
L2.50	Free water	IWL-2525	IWL-2525.2(b)		IWL-2525.1(b)	IWL-2420	NA

IWL-2510 SURFACE EXAMINATION

IWL-2511 Accessible Areas

(a) Concrete surface areas, including coated areas, except those exempted by IWL-1220(b) through IWL-1220(d), shall be visually examined in accordance with IWL-2310(a) for evidence of conditions indicative of damage or degradation, such as described in ACI 201.1R and ACI 349.3R. Areas not meeting the criteria established in concrete surface examination procedures [IWL-2330(a)] shall be visually examined in accordance with IWL-2310(b). If the Responsible Engineer determines that observed suspect conditions indicate the presence of, or could result in, degradation of inaccessible areas, the requirements of IWL-2512(a) shall be met.

(b) Concrete surfaces at tendon anchorage areas, including coated areas, except those exempted by IWL-1220(a), shall be visually examined in accordance with IWL-2310(a) for evidence of conditions indicating damage or degradation, such as described in ACI 201.1R and ACI 349.3R. Areas not meeting the criteria established in concrete surface examination procedures [IWL-2330(a)] shall be visually examined in accordance with IWL-2310(b).

(c) For containments with unbonded post-tensioning systems, the concrete surfaces and tendon end anchorage areas shall be examined for corrosion protection medium leakage, and the tendon end caps shall be examined for deformation. Tendon end caps shall be removed for this examination if there is evidence of tendon end cap deformation.

(d) The examinations shall be performed by, or under the direction of, the Responsible Engineer.

(e) Visual examinations may be performed from floors, roofs, platforms, walkways, ladders, ground surface, or other permanent vantage points, unless temporary close-in access is required by the inspection plan.

IWL-2512 Inaccessible Areas

(a) The Responsible Engineer shall evaluate suspect conditions and shall specify the type and extent of examinations, if any, required to be performed on inaccessible surface areas exempted by IWL-1220(c) and IWL-1220(d).

(b) Concrete surfaces exposed to foundation soil, backfill, or ground water shall be evaluated to determine susceptibility of the concrete to deterioration and the ability to perform the intended design function under conditions anticipated until the structure no longer is required to fulfill its intended design function. The technical evaluation shall be performed and documented by or under the direction of the Responsible Engineer, at periodic intervals not to exceed 10 yr. The evaluation shall include the following:

(1) existing subgrade conditions, including ground water presence, chemistry, and dynamics; aggressive below-grade environment,[42] or other plant-specific conditions that could cause accelerated aging and degradation

(2) existing or potential concrete degradation mechanisms, including, but not limited to, aggressive chemical attack, erosion and cavitation, corrosion of embedded steel, freeze-thaw, settlement, leaching of calcium hydroxide, reaction with aggregates, increase in permeability or porosity, and combined effects

(3) design and construction criteria associated with the inaccessible concrete, including structural design, detail and reinforcement, design recommendations implemented with regard to environmental exposure conditions, materials used, mixture proportioning, concrete production and placement, design and construction codes used, conformance of the structure to original design, and performance of any reanalysis

(4) condition of installed protective barrier systems, such as membranes, coatings, grout curtains, special drainage systems, and dewatering systems

(5) any condition-monitoring programs being implemented, such as settlement monitoring, ground water monitoring, condition surveys, and nondestructive examinations

(6) requirement for the examination of representative samples of below-grade concrete, if excavated for any reason, when an aggressive below-grade environment is present

(c) Based upon the evaluation of (b) above, the Responsible Engineer shall define and document the condition-monitoring program, including required examinations and frequencies, to be implemented for the management of deterioration and aging effects of the subgrade concrete surface. This program shall be incorporated into the plans and schedules required by IWA-1400(c) and IWA-6211(a).

IWL-2520 EXAMINATION OF UNBONDED POST-TENSIONING SYSTEMS

IWL-2521 Tendon Selection

(a) Tendons to be examined during an inspection shall be selected on a random basis except as noted in (b), (c), and (d), and IWL-2521.2. The population from which the random sample is drawn shall consist of all tendons of a particular type (as defined in Table IWL-2521-1) not examined during earlier inspections. The number of tendons to be examined during an inspection shall be as specified in Table IWL-2521-1 and Table IWL-2521-2.

(b) One tendon of each type (as defined in Table IWL-2521-1) shall be selected from the first year inspection sample and designated as a common tendon. Each common tendon shall be examined during each

inspection. A common tendon shall not be detensioned unless required by IWL-3300. If a common tendon is detensioned, another common tendon of the same type shall be selected from the first year inspection sample.

(c) If a containment with a stranded post-tensioning system is constructed with a predesignated number of detensionable tendons, one tendon of each type shall be selected from among those that are detensionable. The remaining tendons shall be selected from among those that cannot be detensioned.

(d) The population of tendons from which a random sample is drawn for examination in accordance with Table IWL-2521-1 need not include tendons subject to augmented examination in accordance with Table IWL-2521-2.

IWL-2521.1 Exemptions. The following requirements shall apply to tendon anchorages that are not accessible for examination because of safety or radiological hazards or because of structural obstructions.

(a) After the process of randomly selecting tendons to be examined, any inaccessible tendons shall be designated as exempt and removed from the sample.

(b) Substitute tendons shall be selected for all tendons designated as exempt. Each substitute tendon shall be selected so that it is located as close as possible to the exempted tendon, and shall be examined in accordance with IWL-2520.

(c) Each exempted tendon shall be examined in accordance with IWL-2524 and IWL-2525 to the extent that the end anchorages of the exempt tendon are accessible either during operation or at an outage.

IWL-2521.2 Tendons Affected by Repair/Replacement Activities.

(a) Tendons requiring augmented examination in accordance with Table IWL-2521-2 shall be randomly selected from the population of tendons affected by a repair/replacement activity.

(b) The requirements of IWL-2521.1 apply, except that substitute tendons shall be selected from the population of tendons affected by a repair/replacement activity.

IWL-2522 Tendon Force and Elongation Measurements

(a) The prestressing force in all inspection sample tendons shall be measured by lift-off or an equivalent test.

(b) Equipment used to measure tendon force shall be calibrated in accordance with a calibration procedure prior to the first tendon force measurement and following the final tendon force measurement of the inspection period. Accuracy of the calibration shall be within 1.5% of the specified minimum ultimate strength of the tendon. If the post-test calibration differs from the pretest calibration by more than the specified accuracy tolerance, the results of the examination shall be evaluated.

During retensioning of a tendon, the tendon elongation shall be measured.

IWL-2523 Tendon Wire and Strand Sample Examination and Testing

IWL-2523.1 Tendon Detensioning and Sample Removal. One sample tendon of each type shall be completely detensioned. A single wire or strand shall be removed from each detensioned tendon.

Table IWL-2521-1
Number of Tendons for Examination

Inspection Period	Percentage [Note (1)], [Note (2)] of all Tendons of Each Type [Note (3)]	Required Minimum [Note (1)] Number of Each Type	Maximum Required Number of Each Type
1st year	4	4	10
3rd year	4	4	10
5th year	4	4	10
10th year [Note (4)]	2	3	5

NOTES:

(1) Fractional tendon numbers shall be rounded to the next higher integer. Actual number examined shall not be less than the minimum required number and need not be more than the maximum required number.

(2) The reduced sample size listed for the 10th year and subsequent inspections is applicable only if the acceptance criteria of IWL-3221.1 have been met for the last three inspections.

(3) A tendon type is defined by its geometry and position in the containment: e.g., hoop, vertical, dome, helical, and inverted U.

(4) The number and percentage of tendons to be examined every fifth year thereafter shall remain the same.

Table IWL-2521-2
Augmented Examination Requirements Following Post-Tensioning System Repair/Replacement Activities

Examination Frequency	Number (N) of Tendons of Each Type [Note (1)] Affected by Repair/Replacement Activity	Required Minimum Percentage of Tendons of Each Type [Note (1)] Affected by Repair/Replacement Activity To Be Examined	Augmented Examination Requirement [Note (2)], [Note (3)]
Initial Inspection: 1 yr (±3 months) following completion of the Repair/Replacement Activity [Note (4)]	$3 < N < 5\%$	4% [Note (5)]	L2.10, L2.30, L2.40, & L2.50
	$N \geq 5\%$	Lesser of 4% or 10 tendons	L2.10, L2.20, L2.30, L2.40, & L2.50
Subsequent Inservice Inspections scheduled to coincide with IWL-2420 [Note (6)] following completion of the Repair/Replacement Activity	$3 < N < 5\%$	4%	L2.10, L2.30, L2.40, & L2.50
	$N \geq 5\%$	Lesser of 4% or 10 tendons	L2.10, L2.20, L2.30, L2.40, & L2.50

NOTES:
(1) The tendon type is defined by its geometry and position in the containment: e.g., hoop, vertical, dome, helical, and inverted U. If more than one type of repair/replacement activity (e.g., tendon replacement, detensioning, retensioning) is performed on a group of tendons, each type of repair/replacement activity need not be considered separately when calculating the number (N) of tendons affected.
(2) A common tendon need not be selected for examination as specified in IWL-2521(b).
(3) Examination requirements are identified in Table IWL-2500-1 (L-B).
(4) If plant operating conditions are such that examination of portions of the post-tensioning system cannot be completed within this stated time interval, examination of those portions may be deferred until the next regularly scheduled plant outage.
(5) Where the minimum number of tendons is given as a percentage, fractional tendon numbers shall be rounded to the next highest integer and shall be considered the minimum number of tendons to be examined. The percentage is to be applied separately to each type of tendon affected.
(6) The required minimum number of affected tendons of each type to be examined may be reduced to the lesser of 2% or five tendons, if the acceptance criteria of IWL-3221.1 have been met for the last two inspections.

IWL-2523.2 Sample Examination and Testing.

(a) Each removed wire or strand shall be examined over its entire length for corrosion and mechanical damage. The examination shall determine the location of the most severe corrosion, if any. Strand wires shall be examined for wedge slippage marks.

(b) Tension tests shall be performed on each removed wire or strand: one at each end, one at midlength, and one in the location of the most corroded area, if any. The following information shall be obtained from each test:

(1) yield strength

(2) ultimate tensile strength

(3) elongation

IWL-2523.3 Retensioning.

(a) Tendons that have been detensioned shall be retensioned to at least the force predicted for the tendon at the time of the test. However, the tendon force after retensioning shall not exceed 70% of the specified minimum ultimate tensile strength of the tendon based on the number of effective wires or strands in the tendon at the time of retensioning.

(b) During retensioning, the tendon stresses shall not exceed the limits of the Construction Code and the Owner's Requirements.

IWL-2524 Examination of Tendon Anchorage Areas

IWL-2524.1 Visual Examination. A detailed visual examination in accordance with IWL-2310(b) shall be performed on the tendon anchorage hardware, including bearing plates, anchorheads, wedges, buttonheads, shims, and the concrete extending outward a distance of 2 ft from the edge of the bearing plate. The following shall be documented:

(a) concrete cracks having widths greater than 0.01 in.

(b) corrosion, broken or protruding wires, missing buttonheads, broken strands, and cracks in tendon anchorage hardware

(c) broken wires or strands, protruding wires and detached buttonheads following retensioning of tendons which have been detensioned

IWL-2524.2 Free Water Documentation. The quantity of free water contained in the anchorage end cap as well as any which drains from the tendon during the examination process shall be documented.

IWL-2525 Examination of Corrosion Protection Medium and Free Water

IWL-2525.1 Samples.

(a) Samples of the corrosion protection medium shall be taken from each end of each tendon examined. Free water shall not be included in the samples.

(b) Samples of free water shall be taken where water is present in quantities sufficient for laboratory analysis.

IWL-2525.2 Sample Analysis.

(a) Each corrosion protection medium sample shall be thoroughly mixed and analyzed for reserve alkalinity, water content, and concentrations of water soluble chlorides, nitrates, and sulfides. Analyses shall be performed in accordance with the procedures specified in Table IWL-2525-1.

(b) Free water samples shall be analyzed to determine pH.

IWL-2526 Removal and Replacement of Corrosion Protection Medium

(a) The amount of corrosion protection medium removed at each anchorage shall be measured and the total amount removed from each tendon sheath and end cap shall be recorded.

(b) Following completion of tests and examinations required by Examination Category L-B, Items L2.10, L2.20, and L2.30, corrosion protection medium shall be replaced to ensure sufficient coverage of anchorage hardware, wires, and strands. The total amount replaced in each tendon sheath shall be recorded and differences between amount removed and amount replaced shall be documented.

(c) Corrosion protection medium may be replaced using a pressurized system or cold pack, by pouring, or by nonpressurized pumping on each end. The Responsible Engineer shall specify the maximum pressure to be used in a pressurized system.

(d) The Responsible Engineer shall specify the installation method for corrosion protection medium.

Table IWL-2525-1
Corrosion Protection Medium Analysis

Characteristic	Test Method	Acceptance Limit
Water content	ASTM D95	10% maximum
Water soluble chlorides	ASTM D512 [Note (1)] or ASTM D4327 [Note (1)]	10 ppm maximum
Water soluble nitrates	ASTM D992 [Note (1)] or ASTM D3867 [Note (1)] or ASTM D4327 [Note (1)] or 4110 [Note (1)], [Note (2)] or 4500-NO_3^- [Note (1)], [Note (2)]	10 ppm maximum
Water soluble sulfides	APHA 427 [Note (1)] or APHA 4500-S^{2-} [Note (1)] or 4500-S^{2-} [Note (1)], [Note (2)]	10 ppm maximum
Reserve alkalinity (Base number)	ASTM D974 Modified [Note (3)]	[Note (4)]

NOTES:

(1) *Water Soluble Ion Tests*. The inside (bottom and sides) of a one (1) liter beaker, approx. OD 105 mm, height 145 mm, is thoroughly coated with 100 ± 10 grams of the sample. The coated beaker is filled with approximately 900 ml of distilled water and heated in an oven at a controlled temperature of 100°F (38°C) ±2°F (1°C) for 4 hr. The water extraction is tested by the noted test procedures for the appropriate water soluble ions. Results are reported as PPM (parts/million) in the extracted water.

(2) These referenced test methods are published in "Standard Methods for the Examination of Water and Wastewater," published jointly by APHA, AWWA, and WEF. The following specific test methods are approved for use:
   - *(a)* 4110 B. — Ion Chromatography With Chemical Suppression of Eluent Conductivity
   - *(b)* 4110 C. — Single-Column Ion Chromatography With Direct Conductivity Detection
   - *(c)* 4500-NO_3^- E. — Cadmium Reduction Method
   - *(d)* 4500-NO_3^- F. — Automated Cadmium Reduction Method
   - *(e)* 4500-NO_3^- H. — Automated Hydrazine Reduction Method
   - *(f)* 4500-NO_3^- I. — Cadmium Reduction Flow Injection Method
   - *(g)* 4500-S^{2-} D. — Methylene Blue Method
   - *(h)* 4500-S^{2-} I. — Distillation, Methylene Blue Flow Injection Method

(3) *ASTM D974 Modified*. Place 10 g of sample in a 500 ml Erlenmeyer flask. Add 10 cc isopropyl alcohol and 5 cc toluene. Heat until sample goes into solution. Add 90 cc distilled water and 20 cc 1 Normal (1N) H_2SO_4. Place solution on a steam bath for $1/2$ hr. Stir well. Add a few drops of indicator (1% phenolphthalein) and titrate with 1 Normal (1N) NaOH until the lower layer just turns pink. If acid or base solutions are not exactly 1N, the exact normalities should be used when calculating the base number. The Total Base Number (TBN), expressed as milligrams of KOH per gram of sample, is calculated as follows:

$$\text{TBN} = \frac{\left[20\left(N_A\right) - \left(B\right)\left(N_B\right)\right]56.1}{W}$$

where

B = milliliters NaOH
N_A = normality of H_2SO_4 solution
N_B = normality of NaOH solution
W = weight of sample in grams

(4) The base number shall be at least 50% of the as-installed value, unless the as-installed value is 5 or less, in which case the base number shall be no less than zero. If the tendon duct is filled with a mixture of materials having various as-installed base numbers, the lowest number shall govern acceptance.

ARTICLE IWL-3000
ACCEPTANCE STANDARDS

IWL-3100 PRESERVICE EXAMINATION

IWL-3110 CONCRETE SURFACE CONDITION

IWL-3111 Acceptance by Examination

The condition of the surface is acceptable if the Responsible Engineer determines that there is no evidence of damage or degradation requiring further evaluation or performance of repair/replacement activities.

IWL-3112 Acceptance by Evaluation

Items with examination results that do not meet the acceptance standards of IWL-3111 shall be evaluated as required by IWL-3300.

IWL-3113 Acceptance by Repair/Replacement Activity

Repair/replacement activities required to reestablish acceptability of an item shall be completed as required by IWL-3300.

IWL-3120 UNBONDED POST-TENSIONING SYSTEM

The condition of the unbonded post-tensioning system is acceptable if it met the requirements of the construction specification at the time of installation.

IWL-3200 INSERVICE EXAMINATION

IWL-3210 SURFACE CONDITION

IWL-3211 Acceptance by Examination

The condition of the concrete surface and tendon end anchorage areas is acceptable if the Responsible Engineer determines that there is no evidence of damage or degradation, corrosion protection medium leakage, or end-cap deformation requiring further evaluation or performance of repair/replacement activities.

IWL-3212 Acceptance by Evaluation

Items with examination results that do not meet the acceptance standards of IWL-3211 shall be evaluated as required by IWL-3300.

IWL-3213 Acceptance by Repair/Replacement Activity

Repair/replacement activities to reestablish the acceptability of an item shall be completed as required by IWL-3300.

IWL-3220 UNBONDED POST-TENSIONING SYSTEMS

IWL-3221 Acceptance by Examination

IWL-3221.1 Tendon Force and Elongation. Tendon (**15**) forces and elongation are acceptable if the following conditions are met:

(a) The average of all measured tendon forces, including those measured in (b)(2), for each type of tendon is equal to or greater than the minimum required prestress specified at the anchorage for that type of tendon.

(b) The measured force in each individual tendon is not less than the lower limit force, which is the greater of 95% of the force predicted for that tendon at the time of measurement or the minimum design prestress force for that tendon group, unless the following conditions are satisfied:

(1) The measured force in not more than one tendon is between 95% and 100% of the lower limit force.

(2) The measured forces in two tendons located adjacent to the tendon described in (1) are not less than the lower limit force.

(3) For tendons requiring augmented examination in accordance with Table IWL-2521-2, Item L2.10, the measured forces in two like tendons located nearest to but on opposite sides of the tendon described in (1) are not less than the lower limit force.

(4) The measured forces in all the remaining sample tendons are not less than the lower limit force.

(c) The prestressing forces for each type of tendon measured in (a) and (b), and the measurement from the previous examination, indicate a prestress loss such that predicted tendon forces meet the minimum design prestress forces at the next scheduled examination.

(d) The measured tendon elongation varies from the last measurement, adjusted for effective wires or strands, by less than 10%.

IWL-3221.2 Tendon Wire or Strand Samples. The condition of wire or strand samples is acceptable if:

(a) samples are free of physical damage;

(b) sample ultimate tensile strength and elongation are not less than minimum specified values.

IWL-3221.3 Tendon Anchorage Areas. The condition of tendon anchorage areas is acceptable if:

(a) there is no evidence of cracking in anchor heads, shims, or bearing plates;

(b) there is no evidence of active corrosion;

(c) broken or unseated wires, broken strands, and detached buttonheads were documented and accepted during a preservice examination or during a previous inservice examination;

(d) cracks in the concrete adjacent to the bearing plates do not exceed 0.01 in. (0.3 mm) in width;

(e) there is no evidence of free water.

IWL-3221.4 Corrosion Protection Medium. Corrosion protection medium is acceptable when the reserve alkalinity, water content, and soluble ion concentrations of all samples are within the limits specified in Table IWL-2525-1. The absolute difference between the amount removed and the amount replaced shall not exceed 10% of the tendon net duct volume.

IWL-3222 Acceptance by Evaluation

Items with examination results that do not meet the acceptance standards of IWL-3221 shall be evaluated as required by IWL-3300.

IWL-3223 Acceptance by Repair/Replacement Activity

Repair/replacement activities to reestablish acceptability of the condition of an item shall be completed as required by IWL-3300. Acceptable completion of the repair/replacement activity shall constitute acceptability of the item.

IWL-3300 EVALUATION

IWL-3310 EVALUATION REPORT

Items with examination results that do not meet the acceptance standards of IWL-3100 or IWL-3200 shall be evaluated by the Owner. The Owner shall be responsible for preparation of an Engineering Evaluation Report stating the following:

(a) the cause of the condition that does not meet the acceptance standards;

(b) the applicability of the condition to any other plants at the same site;

(c) the acceptability of the concrete containment without repair of the item;

(d) whether or not repair/replacement activity is required and, if required, the extent, method, and completion date for the repair/replacement activity;

(e) extent, nature, and frequency of additional examinations.

ARTICLE IWL-4000
REPAIR/REPLACEMENT ACTIVITIES

IWL-4100 GENERAL

The requirements of Article IWA-4000 are applicable except as follows.

(a) The requirements of IWA-4320, IWA-4340, and IWA-4700 are not applicable.

(b) The requirements of IWA-4224, IWA-4225, and IWA-4226 are applicable only to reinforcing steel, metallic load bearing items of the post-tensioning system, and welding materials.

(c) The requirements of IWA-4400 are applicable only to bearing plates.

IWL-4110 SCOPE

(a) This Article provides requirements for repair/replacement activities on concrete containments.

(b) The following are exempt from the requirements of the Article:

(1) anchorage end caps, including installation fasteners and seals or gaskets;

(2) sealants or coatings;

(3) removal, replacement, or addition of corrosion protection medium;[43]

(4) activities affecting concrete, provided

(-a) the affected concrete is external to the outermost layer of reinforcing steel and does not provide anchorage-bearing plate support;

(-b) the activities are not required to correct a condition unacceptable for continued service; and

(-c) the activities have been approved by the Responsible Engineer.

IWL-4120 REPAIR/REPLACEMENT PROGRAM

Repair/replacement activities shall be performed in accordance with the Repair/Replacement Program and Plan required by IWA-4150. For concrete repair/replacement activities, the Repair/Replacement Program shall specify requirements for material control.

IWL-4180 DOCUMENTATION

In addition to the requirements of Article IWA-6000, concrete test reports for quality control of materials for concrete repair/replacement activities shall be retained by the Owner.

IWL-4200 REPAIR/REPLACEMENT PLAN

IWL-4210 RESPONSIBLE ENGINEER

The Repair/Replacement Plan shall be developed under the direction of a Responsible Engineer (IWL-2300).

IWL-4220 CONCRETE

(a) The Repair/Replacement Plan shall document conditions indicative of damage or degradation, such as described in ACI 201.1R and ACI 349.3R, on surfaces requiring a repair/replacement activity and shall specify requirements for removal of defective material.

(b) The affected area shall be visually examined to assure specified surface preparation of concrete and reinforcing steel prior to placement of concrete.

(c) When removal of defective material exposes reinforcing steel, the reinforcing steel shall receive a detailed visual examination as defined in IWL-2310(b). Reinforcing steel is acceptable when the Responsible Engineer determines that there is no evidence of damage or degradation requiring further evaluation or repair. When required, reinforcing steel shall be repaired in accordance with IWL-4230. Repair/replacement activities on exposed-end anchors of the post-tensioning system shall be in accordance with IWL-4240.

(d) New material shall be chemically, mechanically, and physically compatible with existing concrete.

(e) When detensioning of prestressing tendons is required for the repair/replacement activity on the concrete surface adjacent to the tendon, the Repair/Replacement Plan shall require the following:

(1) selection of new material to minimize stress and strain incompatibilities between new material and existing concrete;

(2) procedures for application of new material;

(3) procedures for detensioning and retensioning of prestressing tendons.

(f) The Repair/Replacement Plan shall specify requirements for in-process sampling and testing of new material.

IWL-4230 REINFORCING STEEL

Damaged reinforcing steel shall be corrected by any method permitted in the original Construction Code or in Section III, Division 2, with or without removal of the damaged reinforcing steel.

IWL-4240 POST-TENSIONING SYSTEM

(a) Welding of the post-tensioning system shall be limited to bearing plates and shall be performed such that other post-tensioning system items are protected from the welding process.

(b) The following items, as applicable, shall be contained in the Repair/Replacement Plan:

(1) requirements for removal of items;

(2) surface preparation required prior to installation of items;

(3) examinations required prior to installation of items;

(4) detensioning and retensioning requirements for tendons affected by installation of items;

(5) requirements and procedures applicable to installation of items;

(6) in-process sampling and testing requirements to be performed during installation of items.

IWL-4300 EXAMINATION

Areas of repair/replacement activities shall be examined in accordance with Article IWL-2000 and shall meet the acceptance standards of Article IWL-3000.

ARTICLE IWL-5000
SYSTEM PRESSURE TESTS

IWL-5100 SCOPE

This Article provides requirements for pressure testing concrete containments following repair/replacement activities.

IWL-5200 SYSTEM TEST REQUIREMENTS

IWL-5210 GENERAL

A containment pressure test shall be performed following repair/replacement activities unless

(a) the repair/replacement activity consists of only the exchange of post-tensioning tendons, tendon anchorage hardware, shims or

(b) an evaluation is performed demonstrating that the containment satisfies the requirements of the Construction Code and the Owner's Requirements prior to and during the performance of the repair/replacement activity. This evaluation shall be reviewed by the Responsible Engineer.

IWL-5220 TEST PRESSURE

The pressure test shall be conducted at the design basis accident pressure, P_a.

IWL-5230 LEAKAGE TEST

A leakage test shall be conducted as required by Article IWE-5000.

IWL-5250 TEST PROCEDURE AND EXAMINATIONS

The Responsible Engineer shall review the pressure test procedure and shall authorize performance of the pressure test. The surface of all containment concrete placed during repair/replacement activities shall be examined in accordance with IWL-2310(b) prior to start of pressurization, at test pressure, and following completion of depressurization. Extended surface examinations, additional examinations during pressurization, other examinations, and measurements of structural response to pressure shall be conducted as specified by the Responsible Engineer.

IWL-5260 CORRECTIVE ACTION

If the surface examinations of IWL-5250 cannot satisfy the requirements specified by the Responsible Engineer, the area shall be examined to establish requirements for corrective action. Repair/replacement activities shall be performed in accordance with Article IWL-4000, and pressure testing shall be repeated in accordance with IWL-5200, prior to returning the containment to service.

IWL-5300 REPORT

A pressure test report shall be prepared under the direction of the Responsible Engineer. The report shall describe pressure test procedures, summarize examination results, and state whether or not the repair/replacement activity is acceptable. If the repair/replacement activity is not acceptable, the report shall specify corrective measures.

MANDATORY APPENDIX I ULTRASONIC EXAMINATIONS

ARTICLE I-1000 INTRODUCTION

I-1100 SCOPE

This Appendix provides rules for the ultrasonic examination required by IWA-2232.

ARTICLE I-2000
EXAMINATION REQUIREMENTS

I-2100 VESSELS GREATER THAN 2 in. (50 mm) IN THICKNESS

I-2110 REACTOR VESSELS

(a) Ultrasonic examination procedures, equipment, and personnel used to detect and size flaws in reactor vessels greater than 2 in. (50 mm) in thickness shall be qualified by performance demonstration in accordance with Mandatory Appendix VIII for the following specific examinations and no other Article I-2000 requirements apply.

(1) Shell and Head Welds Excluding Flange Welds

(2) Nozzle-to-Vessel Welds

(3) Nozzle Inside Radius Section

(4) Clad/Base Metal Interface Region

(b) Ultrasonic examination of reactor vessel-to-flange welds, closure head-to-flange welds, and attachment welds shall be conducted in accordance with Section V, Article 4, except that alternative examination beam angles may be used. These examinations shall be further supplemented by Table I-2000-1.

(c) Ultrasonic examination of reactor vessel CRD housing welds (if applicable) shall be conducted in accordance with Mandatory Appendix III, as supplemented by Table I-2000-1.

(d) Nonmandatory Appendix M provides guidance that may be used for validation of mathematical models used with procedure qualification in accordance with Mandatory Appendix VIII.

I-2120 OTHER VESSELS

Ultrasonic examination of all other vessels greater than 2 in. (50 mm) in thickness shall be conducted in accordance with Section V, Article 4, as supplemented by Table I-2000-1.

I-2200 VESSELS NOT GREATER THAN 2 in. (50 mm) IN THICKNESS AND ALL PIPING WELDS

I-2210 VESSELS

Ultrasonic examination of vessels not greater than 2 in. (50 mm) in thickness shall be conducted in accordance with Mandatory Appendix III, as supplemented by Table I-2000-1.

Table I-2000-1
Required Supplements

Supplement	Reactor Vessel Flange and Attachment Welds (b)	Reactor Vessel CRD Housing Welds (c)	Other Vessels > 2 in. (50 mm) Thick I-2120	Other Vessels ≤ 2 in. (50 mm) Thick I-2210	Other I-2400
1 — Calibration Block Material and Thickness	X	...	X	...	X
2 — Calibration Blocks for Clad Welds/ Components	X	...	X	X	X
3 — Calibration Blocks for Curved Surfaces	...	...	X	X	X
4 — Alternative Calibration Block Design	X	...	X	X	X
5 — Electronic Simulators	X	...	X	X	X
6 — Pulse Repetition Rate	X	...	X	X	X
7 — Instrument Calibration	X	...	X	...	X
8 — Scan Overlap and Search Unit Oscillation	...	...	X	...	X
9 — Scan Angles	...	...	X	...	...
10 — Recording Criteria	X	X	X	X	X
11 — Geometric Reflectors	X	...	X	X	X

I-2220 WELDS IN PIPING

Ultrasonic examination procedures, equipment, and personnel used to detect and size flaws in piping welds shall be qualified by performance demonstration in accordance with Mandatory Appendix VIII and no other Article I-2000 requirements apply.

I-2300 BOLTING

Ultrasonic examination procedures, equipment, and personnel used to detect flaws in bolts and studs shall be qualified by performance demonstration in accordance with Mandatory Appendix VIII and no other Article I-2000 requirements apply.

Ultrasonic examination to detect flaws in the threads of the reactor pressure vessel flange shall be conducted in accordance with either Section V, Article 5, or procedures qualified in accordance with Mandatory Appendix VIII, Supplement 8 for examination of the reactor vessel closure studs. No other Article I-2000 requirements apply.

I-2400 ALL OTHER EXAMINATIONS

When the requirements of I-2100, I-2200, or I-2300 do not apply, the ultrasonic examination of welds or materials shall be conducted in accordance with the applicable requirements of Section V, Article 4 or Article 5, respectively, as supplemented by Table I-2000-1.

I-2500 THICKNESS MEASUREMENTS

Ultrasonic thickness measurements shall be conducted in accordance with Section V, Article 23, SE-797, Standard Practice for Thickness Measurement by Manual Contact Ultrasonic Method, and as modified by a referencing Subsection.

I-2600 MANDATORY APPENDIX VIII EXAMINATION

(a) For components to which Mandatory Appendix VIII is not applicable, examination procedures, personnel, and equipment qualified in accordance with Mandatory Appendix VIII may be applied, provided such components, materials, sizes, and shapes are within the scope of the qualified examination procedure.

(b) Examination coverage shall be in accordance with I-3000.

(c) No other Article I-1000 or Article I-2000 requirements apply.

ARTICLE I-3000 EXAMINATION COVERAGE

I-3100 EXAMINATION

Components identified in I-2110(a), I-2220, and I-2300 shall be examined as follows.

(15) I-3200 PIPING

(a) The required piping examination volume shall be examined in two axial directions. When examination in the circumferential direction is required, the circumferential examination shall be performed in two directions.

(b) When examination of ferritic welds from both sides is not possible, procedures and personnel qualified for single-side examination in accordance with Mandatory Appendix VIII, Supplement 3 shall be used to examine the required volume. When examination of austenitic welds from both sides is not possible, procedures and personnel qualified for single-side examination in accordance with Mandatory Appendix VIII, Supplement 2, with all flaws on the opposite side of the weld, shall be used to examine the required volume.

(c) Dissimilar metal welds shall be examined in two axial and two circumferential directions. If examination from both sides of the weld is not possible, procedures and personnel qualified for single-side examination in accordance with Mandatory Appendix VIII, Supplement 10, shall be used to examine the required volume.

(d) Near side (same side) and far side (opposite side) of the weld are in relationship to the weld centerline and search unit location as depicted in Figure I-3200-1.

(e) When using angle beam examination, overlaid welds shall be examined in two axial and two circumferential directions. When using straight beam examination, overlaid welds shall be examined from the accessible surface.

I-3300 VESSEL SHELL AND NOZZLE-TO-SHELL WELDS

(a) The clad-to-base-metal interface and the adjacent volume to a depth of at least 15% of the vessel thickness, t, shall be examined from four orthogonal directions, using procedures and personnel qualified in accordance with Mandatory Appendix VIII, Supplement 4. The vessel thickness, t, shall be measured from the clad-to-base-metal interface. The examination shall include scans parallel and perpendicular to the weld.

(b) If the requirements of (a) cannot be met because of access restrictions, the required examination volume shall be scanned in accordance with the preceding (a) to the extent and in the directions allowed by the physical restrictions. The limitations shall be documented in the record of examination. Examination coverage of the inner 15% t shall meet the following requirements:

(1) The required volume shall be examined in one direction parallel and one direction perpendicular to the weld.

(2) The procedure and personnel shall be qualified for single-side access in accordance with the requirements of Mandatory Appendix VIII, Supplement 4.

(3) The initial examination shall be performed using a procedure qualified to detect flaws with a tilt angle of 45 deg relative to the weld centerline. Subsequent examinations shall be performed using procedures qualified for a tilt angle of at least 10 deg.

(c) The remaining 85% of the vessel thickness shall be examined in four orthogonal directions using procedures and personnel qualified in accordance with Mandatory Appendix VIII, Supplement 6.

(d) As an alternative to (c), the outer 85% of the vessel thickness shall be examined in one direction parallel and one direction perpendicular to the weld, using procedures and personnel qualified for single-side access in accordance with the requirements of Mandatory Appendix VIII, Supplement 6.

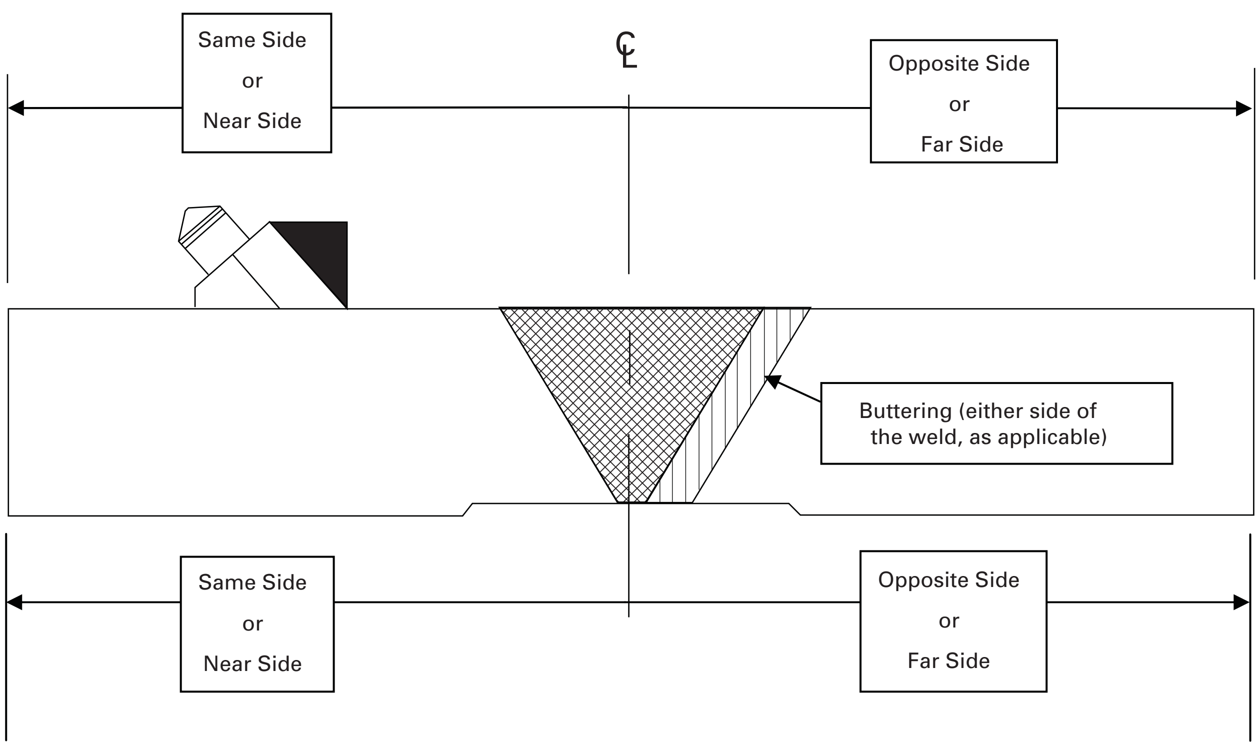
I-3310 NOZZLE-TO-SHELL WELD EXAMINATIONS CONDUCTED FROM THE INSIDE

(a) If the provisions of I-3300(b) cannot be met because of access restrictions, and the nozzle-to-shell weld is examined from the inside, the required examination volume shall be scanned in accordance with I-3300(a) and I-3300(b) to the extent and in the directions allowed by the physical restrictions.

(b) The inner 15% t shall be examined

(1) in one radial direction from the vessel shell using procedures and personnel qualified in accordance with the requirements of Mandatory Appendix VIII, Supplement 4 for single-side access or from the nozzle bore using procedures and personnel qualified in accordance with Mandatory Appendix VIII, Supplement 7; and

Figure I-3200-1
Ferritic, Austenitic, or Dissimilar Metal Weld



(2) in one circumferential direction using procedures and personnel qualified in accordance with the requirements of Mandatory Appendix VIII, Supplement 4 for single-side access.

(c) The remaining 85% of the required examination volume shall be examined in at least one radial direction from

(1) the nozzle bore, using procedures and personnel qualified in accordance with Mandatory Appendix VIII, Supplement 7, or

(2) the vessel shell, using procedures and personnel qualified for single-side examination in accordance with Mandatory Appendix VIII, Supplement 6.

I-3320 NOZZLE-TO-SHELL WELD EXAMINATIONS CONDUCTED FROM THE OUTSIDE

(a) If the provisions of I-3300(b) cannot be met because of access restrictions, and the nozzle-to-vessel weld is examined from the outside, the required examination volume shall be scanned in accordance with I-3300(a) and I-3300(b) to the extent and in the directions allowed by the physical restrictions.

(b) The inner 15% t shall be examined

(1) in two opposing radial directions using procedures and personnel qualified in accordance with Mandatory Appendix VIII, Supplement 4; or one radial direction using procedures and personnel qualified in accordance with Mandatory Appendix VIII, Supplement 4, for single-side access; and

(2) two opposing circumferential directions using procedures and personnel qualified in accordance with Mandatory Appendix VIII, Supplement 5.

(c) The remaining 85% of the required examination volume shall be examined in at least one radial direction using procedures and personnel qualified for a single-side examination in accordance with Mandatory Appendix VIII, Supplement 6.

I-3400 NOZZLE INSIDE-CORNER REGION

The nozzle inside-corner region shall be examined in two opposing circumferential directions using procedures and personnel qualified in accordance with Mandatory Appendix VIII, Supplement 5 for examinations conducted from the outside or Mandatory Appendix VIII, Supplement 7 for examinations conducted from the inside.

I-3500 BOLTING

Bolts and studs shall be examined using procedures and personnel qualified in accordance with Mandatory Appendix VIII, Supplement 8. The volume specified in IWB-2500 or IWC-2500 shall be examined.

Threads of the reactor pressure vessel flange shall be examined in accordance with either Section V, Article 5, or procedures qualified in accordance with Mandatory Appendix VIII, Supplement 8 for examination of the reactor vessel closure studs. The volume specified in accordance with IWB-2500 shall be examined.

MANDATORY APPENDIX I
SUPPLEMENTS

SUPPLEMENT 1 CALIBRATION BLOCK MATERIAL AND THICKNESS

(a) The material from which the blocks are fabricated shall be one of the following:

(1) a nozzle dropout from the component;

(2) a component prolongation; or

(3) material of the same material specification, product form, and heat treatment condition as one of the materials being joined.

(b) Where two or more base material thicknesses are involved, the calibration block thickness shall be of a size sufficient to contain the entire examination path.

SUPPLEMENT 2 CALIBRATION BLOCKS FOR CLAD WELDS OR COMPONENTS

Calibration blocks shall be clad using the same method (i.e., rollbonded, manual weld deposited, automatic wire deposited, or automatic strip deposited) as used to clad the base material of the component to be examined. In the event the cladding method is not known, the calibration shall be performed using a calibration block clad by a manual weld deposited method. When the base material on opposite sides of a weld are clad by different methods, the cladding on the calibration block shall be applied by the method used on the side of the weld from which the examination will be conducted. If the examination will be conducted from both sides of the weld, the calibration block shall provide for calibration for both methods of cladding.

SUPPLEMENT 3 CALIBRATION BLOCKS FOR EXAMINATION OF PARTS WITH CURVED SURFACES

(a) The rules of the referenced Article or Appendix shall be applied for selecting calibration blocks for examination surfaces in materials with diameters 20 in. (500 mm) and less.

(b) For calibration blocks for examination surfaces with diameters greater than 20 in. (500 mm), one of the following shall be applied.

(1) A calibration block of essentially the same curvature as the examination surface; or

(2) A single curved calibration block to calibrate the examination for surfaces in the range of curvature from 0.9 to 1.5 times the calibration block diameter; or

(3) A flat calibration block may be used. When the contact technique is used with a search unit having a flat contact surface (i.e., does not conform to the examination surface), the following additional requirements apply:

(-a) The minimum radius to be examined shall be determined and the search unit contact area and frequency shall be selected so that the minimum radius is greater than the critical radius as determined by Section V, Article 4, Nonmandatory Appendix G.

(-b) For determining the maximum allowable search unit contact area for the frequency and couplant selected, Nonmandatory Appendix G shall be applied for both straight beam and angle beam examinations and for convex, concave, or compound curvatures.

(-c) When rectangular search units are used, the width of the search unit face tangent to the minimum radius shall be used instead of the transducer diameter in Section V, Article 4, Nonmandatory Appendix G, Table G-461.

SUPPLEMENT 4 ALTERNATIVE WELD CALIBRATION BLOCK DESIGN

The alternative calibration block design of Figure I-S4 may be used in lieu of a separate block for each weld thickness as required by Section V, Article 4, provided that the following requirements are met.

(a) The calibration block thickness shall equal or exceed the maximum weld thickness to be examined.

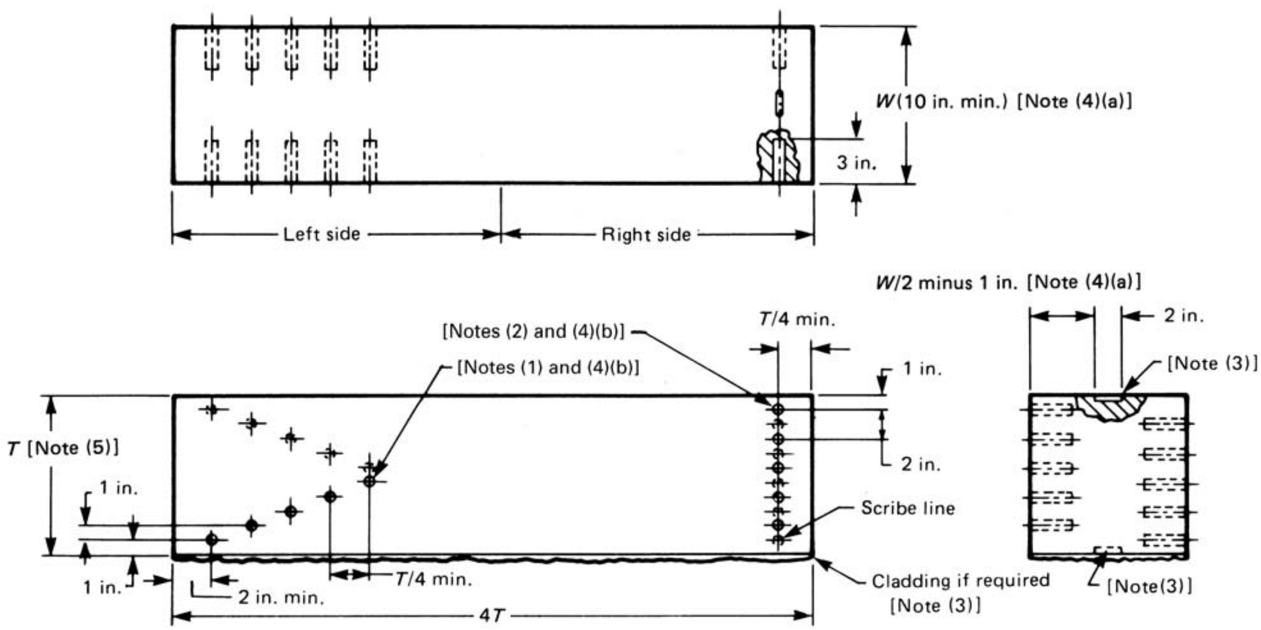
(b) The calibration block material requirements shall be as specified by Supplement 1 and Section V, Article 4.

(c) Calibration for examinations that include the clad–base metal interface shall employ additional reflectors as required by Figure I-S4. The instrument gain setting required to establish reference levels shall be based upon maximum allowable planar flaws located at the clad–base metal interface.

SUPPLEMENT 5 ELECTRONIC SIMULATORS

(a) Simulator use does not preclude the requirement for a written record of all calibration data.

Figure I-S4
Alternative Calibration Block
(10 in. = 250 mm, 3 in. = 75 mm, 2 in. = 50 mm, 1 in. = 25 mm)



GENERAL NOTES:

(a) The tolerance for hole diameters shall be ±$^1/_{32}$ in. (1 mm). Notch depth tolerance shall be +10 and −20%. The tolerance on hole location through the thickness and on depth shall be ±$^1/_8$ in. (3 mm).

(b) Calibration at DAC curves obtained using the block shall include all side-drilled holes representing the weld thickness to be examined.

(c) The surface notches and surface notch response calibration are optional.

(d) Inner near surface (clad–base metal interface) reflectors shall be installed as follows:

(1) a $^1/_8$ in. (3 mm) (max.) diameter side-drilled hole (SDH) shall be placed at the clad base metal interface to establish the reference level;

(2) at least two additional $^1/_8$ in. (3 mm) (max.) SDH shall be installed at $^1/_2$ in. (13 mm) increments (max.) to establish metal path calibration, and;

(3) alternatively, for examinations conducted from the clad surface, a separate clad block may be used containing the reflectors in this Note, (a) and (b). Block thickness shall be 2 in. (50 mm) (min.).

NOTES:

(1) Holes shall be drilled and reamed to $^5/_{16}$ in. (8 mm) diameter and positioned at 1 in. (25 mm) intervals through the calibration block thickness as shown on the left side of Figure I-S4. The five side-drilled holes positioned below center thickness are located on the near side; the five holes positioned above center thickness are located on the far side.

(2) Holes shall be drilled and reamed as shown in the right side of drawing but located on a scribe line at 1 in. (25 mm) intervals positioned through the thickness. The holes shall be alternated side to side as shown so that the distance between any two holes is 2 in. (50 mm) [top and bottom holes are 1 in. (25 mm) from the surface].

(3) One notch on top and one on the bottom as shown, each 2 in. (50 mm) long by $^1/_4$ in. (6 mm) wide by 2% T deep. If the block is cladded, the through clad notch shall be 2% deep into the base metal. Notches shall be installed using flat end mills or other suitable means achieving the same notch profile.

(4) For calibration blocks 4 in. (100 mm) and less in thickness, the dimensions shown are changed to:

(a) width W shall be 2 T or 6 in. (150 mm), whichever is less;

(b) three side-drilled holes (min.) shall be installed at $T/4$ (max.) locations with hole diameter at $^3/_{16}$ in. (5 mm), 1$^1/_2$ in. (38 mm) deep.

(5) Calibration block thickness shall equal or exceed the maximum weld thickness to be examined.

(b) Simulator use shall be described in the written examination procedure.

(c) Simulators shall be calibrated at least every 6 months to verify compliance with the manufacturer's specification.

(d) A minimum of three pulses shall be used to represent a DAC curve at three different delay times over the DAC range within the ranges of 15% to 30%, 40% to 60%, and 70% to 110% of the maximum transit time to cover the thickness to be examined.

(e) The final calibration check after the finish of each examination shall include a calibration check on at least three of the basic reflectors in the basic calibration block.

(f) As an alternative to (e) above, the final calibration check may be made without the basic calibration block provided calibration checks include measuring the response from at least three reflectors (or multiples from a single reflector) that are located in a test medium at distances providing transit times in the ranges of 15% to 30%, 40% to 60%, and 70% to 110% of the maximum transit time to cover the thickness to be examined.

SUPPLEMENT 6 PULSE REPETITION RATE

The ultrasonic instrument pulse repetition rate shall be sufficient to pulse the search unit at least six times within the time necessary to move one-half the transducer (piezoelectric element) dimension parallel to the direction of scan at maximum scanning speed. Alternatively, a dynamic calibration on multiple reflectors that is within ±2 dB of a static calibration may be used to verify an acceptable pulse repetition rate.

SUPPLEMENT 7 INSTRUMENT CALIBRATION

The requirements for screen height linearity and amplitude control linearity of Section V, Article 4, T-461, shall be met at the beginning and end of the weld examinations performed during one outage.

SUPPLEMENT 8 SCAN OVERLAP AND SEARCH UNIT OSCILLATION

(a) Each pass of the search unit shall overlap 50% of the transducer (piezoelectric element) dimension parallel to the direction of scan indexing. As an alternative, if the sound beam dimension parallel to the direction of scan indexing is measured in accordance with the Section V, Article 4 beam spread measurement rules, each pass of the search unit shall provide overlap of the minimum beam dimension determined from the Section V, Article 4 beam spread measurements.

(b) Oscillation of the search unit is permitted if it can be demonstrated that overlapping coverage is provided.

SUPPLEMENT 9 SCAN ANGLES

Two angle beams having nominal angles of 45 deg and 60 deg shall be used. An additional longitudinal wave beam having a nominal angle of 70 deg shall be used for vessel examination conducted from the inside diameter clad surface. The examination using the 70 deg beam shall cover the near surface to a depth of 1 in. (25 mm) in the required volume. For calibration of the 70 deg beam, a $1\frac{1}{2}$ in. (38 mm) deep minimum, $\frac{1}{8}$ in. (3 mm) diameter maximum, side-drilled hole, drilled parallel to the clad interface shall be located with the center at $\frac{1}{4}$ in. (6 mm) from the inside diameter clad surface or at the clad–base metal interface in the basic vessel calibration block. At least two additional $\frac{1}{8}$ in. (3 mm) diameter maximum side-drilled holes shall be installed at $\frac{1}{2}$ in. (13 mm) maximum increments to establish metal path calibration.

SUPPLEMENT 10 RECORDING CRITERIA

Angle beam reflectors that produce a response greater than 20% of the reference level shall be investigated. The maximum amplitude, location, and extent of these reflectors shall be recorded. The operator shall determine whether the indication originates from a flaw or is a geometric indication in accordance with Supplement 11. When the reflector is determined to be a flaw, the acceptance standards of Article IWA-3000 apply.

SUPPLEMENT 11 GEOMETRIC INDICATIONS (15)

Ultrasonic indications of geometric and metallurgical origin shall be classified as follows.

(a) Indications that are determined to originate from surface configurations (such as weld root geometry) or variations in metallurgical structure of materials (such as weld-to-base metal interface) may be classified as geometric indications. Such indications need not be characterized as originating from flaws, and flaw sizing and comparison of the reflector causing the indication with the allowable flaw standards of Article IWA-3000 are not required. The maximum indication amplitude and the location and extent of the reflector causing a geometric indication shall be recorded. (For example: internal attachment, 200% DAC maximum amplitude, 1 in. (25 mm) above the weld center line, on the inside surface, from 90 deg to 95 deg)

(b) The following steps shall be taken to classify an indication as geometric.

(1) Interpret the area containing the reflector in accordance with the applicable examination procedure;

(2) Plot and verify the reflector coordinates. Prepare a cross-sectional sketch showing the reflector position and surface discontinuities such as root and counterbore; and

(3) Review fabrication or weld prep drawings.

(c) Alternatively, other NDE methods or techniques may be applied to classify an indication as geometric (e.g., alternative UT beam angles, radiography, or I.D. and/or O.D. profiling).

(15)

MANDATORY APPENDIX II
OWNER'S RECORD AND REPORT

FORM NIS-2 OWNER'S REPAIR/REPLACEMENT CERTIFICATION RECORD
As Required by the Provisions of the ASME Code Section XI

OWNER'S CERTIFICATE OF CONFORMANCE

I certify that the Repair/Replacement activity represented by Repair/Replacement Plan number ______ (1) ______ conforms to the requirements of the ASME Code, Section XI necessary to place the item in service.

Edition and Addenda of Section XI used: ______ (2) ______

Code Cases used for repair/replacement activity: ______ (3) ______
(if applicable)

Signed ______ (4) ______ Date ______ (5) ______
(Owner or Owner's Designee, Title)

CERTIFICATE OF INSERVICE INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and employed by ______ (6) ______ of ______ (7) ______ have inspected the items described in Repair/Replacement Plan number ______ (8) ______ and state that, to the best of my knowledge and belief, the Owner has performed all the activities described in the Repair/Replacement Plan in accordance with the requirements of the ASME Code, Section XI necessary to place the item in service.

By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the activities described in the Repair/Replacement Plan. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or loss of any kind arising from or connected with this inspection.

______ (9) ______ Commission ______ (10) ______
(Inspector's Signature) (National Board Number and Endorsement)

Date ______ (11) ______

(07/15)

Table II-1
Guide for Completing Form NIS-2

Reference to Circled Numbers in the Form	Description
(1)	A unique identification number assigned to the Repair/Replacement Plan.
(2)	The Edition and Addenda of Section XI used for the Repair/Replacement activity.
(3)	Applicable Section XI Code Cases used for the Repair/Replacement activity during the current reporting period.
(4)	The signature of the individual and title representing the Owner who certified the accuracy of the contents of the Form NIS-2 and its attachments.
(5)	The date (month, day, year) the individual representing the Owner signed the Form NIS-2.
(6)	The name of the Inspector's employer, the Authorized Inspection Agency.
(7)	The address of the Authorized Inspection Agency (city or town and state or province).
(8)	The unique identification number assigned to the Repair/Replacement Plan.
(9)	The Authorized Nuclear Inservice Inspector's signature.
(10)	The Authorized Nuclear Inservice Inspector's National Board Commission Number and Endorsement.
(11)	The date (month, day, year) the Authorized Nuclear Inservice Inspector signed the Form NIS-2.

FORM OAR-1 OWNER'S ACTIVITY REPORT

Report Number ______ ① ______

Plant ______ ② ______

Unit No. ______ ③ ______ (if applicable) Commercial service date ______ ④ ______ Refueling outage no. ______ ⑤ ______

Applicable inspection interval ______ ⑥ ______ (1st, 2nd, 3rd, 4th, other)

Applicable inspection period ______ ⑦ ______ (1st, 2nd, 3rd)

Edition and Addenda of Section XI applicable to the inspection plans ______ ⑧ ______

Date and revision of inspection plans ______ ⑨ ______

Edition and Addenda of Section XI applicable to repair/replacement activities, if different than the inspection plans ______ ⑩ ______

Code Cases used for inspection and evaluation: ______ ⑪ ______ (if applicable)

CERTIFICATE OF CONFORMANCE

I certify that (a) the statements made in this report are correct; (b) the examinations and tests meet the Inspection Plan as required by the ASME Code, Section XI; and (c) the repair/replacement activities and evaluations supporting the completion of ______ ⑫ ______ (refueling outage number) conform to the requirements of the ASME Code, Section XI.

Signed ______ ⑬ ______ (Owner or Owner's Designee, Title) Date ______ ⑭ ______

CERTIFICATE OF INSERVICE INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and employed by ______ ⑮ ______ of ______ ⑯ ______ have inspected the items described in this Owner's Activity Report and state that, to the best of my knowledge and belief, the Owner has performed all activities represented by this report in accordance with the requirements of the ASME Code, Section XI.

By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the repair/replacement activities and evaluations described in this report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or loss of any kind arising from or connected with this inspection.

______ ⑰ ______ (Inspector's Signature) Commission ______ ⑱ ______ (National Board Number and Endorsement)

Date ______ ⑲ ______

(07/15)

FORM OAR-1 OWNER'S ACTIVITY REPORT (Cont'd)

Table 1
Items With Flaws or Relevant Conditions That Required Evaluation for Continued Service

Examination Category and Item Number (20)	Item and Flaw or Relevant Condition Description (21)	Evaluation Description (22)

Table 2
Abstract of Repair/Replacement Activities Required for Continued Service

Code Class (23)	Item Description (24)	Description of Work (25)	Date Completed (26)	Repair/Replacement Plan Number (27)

(07/15)

Table II-2
Guide for Completing Form OAR-1

Reference to Circled Numbers in the Form	Description
(1)	A unique number designation to identify the report, as assigned by the Owner for tracking purposes.
(2)	The name and address of the nuclear power plant where the inservice examinations and tests were performed.
(3)	The Owner's designated unit identification number.
(4)	The date (month, day, year) determined by the Owner that the nuclear power plant was originally available for regular production of electricity.
(5)	The number of the completed refueling outage during the current reporting period.
(6)	The applicable inspection interval (e.g., 1st, 2nd, 3rd, 4th, other) and the dates the interval commenced and is expected to conclude. When reporting multiple/overlapping intervals, clearly annotate the dates and interval number that will be associated with the applicable inspection period and Edition and Addenda of Section XI in lines 7 and 8 below. See IWA-2430.
(7)	The applicable inspection period (i.e., 1st, 2nd, 3rd) represented by this form as determined from Tables IWB-2411-1, IWC-2411-1, IWD-2411-1, IWE-2411-1, and IWF-2410-1. When reporting multiple/overlapping periods, clearly annotate the period associated with the applicable interval in line 6 and Edition and Addenda of Section XI in line 8.
(8)	The Edition and Addenda of Section XI applicable to the examinations and tests represented by this Form. When reporting multiple Editions and Addenda of Section XI, clearly annotate the Edition and Addenda associated with the applicable inspection interval and inspection period specified in lines 6 and 7, respectively.
(9)	The date and revision level of the inspection plan followed during the examinations and tests represented by this Form.
(10)	The Edition and Addenda of Section XI applicable to repair/replacement activities, if different than the inspection plans.
(11)	The number of any Section XI Case used for inspection and evaluation during the current reporting period, if applicable to the activities reported in Table 1 or Table 2.
(12)	The number of the completed refueling outage during the current reporting period.
(13)	The signature of the individual and title representing the Owner who certified the accuracy of the contents of the Form OAR-1 and its attachments.
(14)	The date (month, day, year) the individual representing the Owner signed the Form.
(15)	The name of the Inspector's employer, the Authorized Inspection Agency.
(16)	The address of the Authorized Inspection Agency (city or town and state or province).
(17)	The Authorized Nuclear Inservice Inspector's signature.
(18)	The Authorized Nuclear Inservice Inspector's National Board Commission Number and Endorsement.
(19)	The date (month, day, year) the Authorized Nuclear Inservice Inspector signed the Form.
(20)	Examination Category and Item Number from Section XI.
(21)	Brief description of the item and flaw or relevant condition. If no conditions required evaluation, then record the word "None."
(22)	Evaluation description of flaw or relevant condition.
(23)	Section XI Code Class.
(24)	A description of the item subject to the repair/replacement activity. If no repair/replacement activity was required for continued service, then record the word "None."
(25)	Brief description of repair/replacement activity required for continued service.
(26)	Date Repair/Replacement Plan completed.
(27)	Unique Repair/Replacement Plan Number.

MANDATORY APPENDIX III
ULTRASONIC EXAMINATION OF VESSEL AND PIPING WELDS

ARTICLE III-1000
INTRODUCTION

(15) ## III-1100 GENERAL

(a) This Appendix describes ultrasonic (UT) examination methods, equipment, and requirements applicable to vessel and piping welds when referenced by Mandatory Appendix I or Mandatory Appendix VIII.

(b) The requirements of Supplement 1 apply to examination of welds in wrought austenitic materials and dissimilar metal welds from the outside surface. The requirements of Supplement 2 apply to welds in centrifugally and statically cast austenitic materials examined from the outside surface.

(c) Alternative examination techniques and calibration block designs and materials may be used as provided by IWA-2240 except when the requirements of III-3430 apply.

ARTICLE III-2000 GENERAL REQUIREMENTS

III-2100 EQUIPMENT REQUIREMENTS

III-2110 INSTRUMENT

A pulse-echo ultrasonic flaw detection instrument shall be used. The instrument shall be equipped with a stepped gain control calibrated in units of 2 dB or less.

III-2120 SEARCH UNIT

(a) Search units may contain either single or dual transducer elements.

(b) Search units with contoured contact wedges may be used to aid ultrasonic coupling. Calibration shall be done with the contact wedges used during the examination.

(c) The maximum nominal search unit sizes for circular, square, or rectangular active elements shall not exceed those listed in Table III-2120-1. Larger search unit sizes may be used, provided equivalent sensitivity and examination coverage (III-2410) are demonstrated for a semicircular notch (0.5 aspect ratio) of the maximum size allowed by IWB-3500. Equivalence is established by comparing the responses from the semicircular notch of the larger search unit and the maximum size search unit allowed by Table III-2120-1. Equivalence may be obtained by adjusting examination coverage (III-2410), scanning sensitivity (III-2430), and recording levels in accordance with III-4510.

Table III-2120-1
Maximum Nominal Search Unit Sizes

Vessel Wall Thickness (Nominal), in. (mm)	Maximum Nominal Size, in. (mm) [Note (1)]
Less than 0.5 (13)	0.25 (6)
0.5 (13) to 2.0 (50)	0.5 (13)

NOTE:
(1) For dual element search units used in the pulse receiver mode, the dimension applies to each individual element.

III-2200 PERSONNEL REQUIREMENTS

(a) Nondestructive examination personnel shall be qualified in accordance with IWA-2300.

(b) Personnel who perform recording or determine which indications are to be recorded in accordance with III-4510 shall have successfully completed the qualification requirements of (a), for the procedure to be used for the examination. The qualification shall include demonstrated proficiency in discriminating between flaw indications and indications of geometric or metallurgical origin.

III-2300 WRITTEN PROCEDURE REQUIREMENTS

Ultrasonic examination shall be performed in accordance with a written procedure. Each procedure shall include, as a minimum, the following information:

(a) weld types and configurations to be examined, including thickness dimensions, materials, and product form (e.g., casting, forging, or plate);

(b) scanning surface and surface condition requirements;

(c) equipment list, including each of the following applicable items:

(1) make and model of pulse-echo ultrasonic flaw detection instrument;

(2) transducer size and search unit type, angle, and frequency;

(3) size and configuration of wedges and shoes;

(4) automatic alarm and recording equipment;

(5) rotating, revolving, or scanning mechanisms;

(6) couplant; and

(7) search unit cable type, length, and number of connectors.

(d) examination technique including angles and modes of wave propagation in the material, directions, maximum speed, and extent of scanning;

(e) calibration techniques including the establishment of scanning sensitivity levels, instrument controls to be used, and acceptance standards for the calibrated condition;

(f) calibration block design;

(g) data to be recorded and method of recording including interpretation of indications as required by III-4510;

(h) techniques for data interpretation and plotting;

(i) personnel qualification requirements.

III-2400 GENERAL EXAMINATION REQUIREMENTS

III-2410 EXAMINATION COVERAGE

(a) When a manual scan technique is used, the required examination volume shall be scanned with beam overlap. While scanning, the search unit shall be oscillated approximately ±20 deg. If oscillation is not possible, the search path shall be overlapped at least 50%.

(b) Automatic scanners shall provide demonstrated beam overlap or at least 50% search path overlap. Overlap may be demonstrated using the simulated maximum allowable flaw size (IWB-3500 or IWC-3500), as applicable for a 0.5 aspect ratio. The simulated maximum allowable flaw size shall exhibit a recordable indication on two consecutive scans separated by one increment.

III-2420 RATE OF SEARCH UNIT MOVEMENT

The rate of search unit movement shall not exceed 3 in./sec (75 mm/sec) unless calibration has been verified at the higher scanning speed.

III-2430 SCANNING SENSITIVITY

Manual scanning shall be done at a minimum of twice (+6 dB) the primary reference level.

ARTICLE III-3000
CALIBRATION

III-3100 INSTRUMENT CALIBRATION

III-3110 SCREEN HEIGHT LINEARITY

The ultrasonic instrument shall provide screen height linearity within 5% of full range for at least 80% of the full screen height (FSH) (base line to maximum calibrated screen points). Reject or clipping controls shall be set in the off or minimum position for calibration and examination.

III-3120 AMPLITUDE CONTROL LINEARITY

The ultrasonic instrument shall utilize an amplitude control, accurate over its useful range to ±20% of the nominal amplitude ratio, to allow measurement of indications beyond the linear range of the vertical display on the screen.

III-3200 SYSTEM CALIBRATION

III-3210 GENERAL REQUIREMENTS

(a) Calibration shall include the complete ultrasonic examination system. Any change in search units, shoes, couplants, cables, ultrasonic instruments, recording devices, or any other parts of the examination system shall be cause for calibration check. The original calibration shall be performed on the basic calibration block. Calibration checks may be performed on either a basic calibration block simulator or the basic calibration block, but must include a check of the entire examination system.

(b) The maximum calibration indications shall be obtained with the sound beam oriented essentially perpendicular to the axis of the calibration reflector. The center line of the search unit shall be at least $^3/_4$ in. (19 mm) from the nearest side of the block. (Rotation of the beam into a corner formed by the reflector and the side of the block may produce a higher amplitude signal at a longer beam path; this beam path shall not be used for calibration.)

(c) For contact examination, the temperature difference between the examination and basic calibration block surfaces shall not exceed 25°F (15°C).

(d) For immersion examination, the temperature difference between the examination and calibration couplants shall not exceed 25°F (15°C), or appropriate compensation for angle changes shall be made.

(e) Calibration shall be performed from the surface (clad or unclad) of the calibration block which corresponds to the component surface to be examined.

III-3230 ANGLE BEAM CALIBRATION

(a) Obtain the angle beam paths required in III-4420 and III-4430 on the sweep display. Variables such as weld preparation, weld crown width, or physical interference may preclude obtaining two-beam path direction coverage of the complete examination volume with half-V examination from two sides. If this interference with examination coverage occurs, the beam path shall be increased as required to obtain full coverage of the examination volume from two directions. Alternatively, the interference may be eliminated by one or more of the following:

(1) reducing the dimension of the wedge edge-to-beam entry point;

(2) reducing search unit size;

(3) increasing the beam angle;

(4) conditioning the weld surface.

(b) Position the search unit for maximum response from the notch on the opposite side of the calibration standard; then position the search unit to obtain the metal path determined in (a). Adjust the sweep control to display the indications from the notch at convenient intervals on the sweep range. Mark the indication locations on the screen and record them on the calibration data sheet.

(c) Sensitivity levels shall be established using the notch and shall be applicable to that region of the calibrated sweep length providing complete examination of the weld and heat-affected zone (HAZ). To establish calibration, maximize the signal amplitude from the calibration position and notch that give the greatest reflection. The response shall be set to 80% of FSH. Without changing the gain control, determine the peak indication amplitudes from the remaining points in the examination region and construct a distance–amplitude correction (DAC) curve. This curve shall be the primary reference level.

(d) When the calibration is limited to the half-V path due to material attenuation or examination technique selection, sensitivity shall be established by setting the back surface notch at 80% of FSH; no DAC curve is required.

III-3300 CALIBRATION CONFIRMATION

III-3310 INSTRUMENT

Instrument calibration for screen height and amplitude control linearity shall be verified at the beginning and end of the weld examinations performed during one outage.

III-3320 SYSTEM CALIBRATION CONFIRMATION

Complete ultrasonic examination system calibration, establishing the DAC curve, shall be performed within one day prior to use of the system for examination of those welds for which the calibration is applicable, and at least once each week during the examination.

III-3330 SYSTEM CHECK

A system calibration check, which is the verification of the instrument sensitivity and sweep range calibration, shall be performed:

(a) at the start and finish of each examination;

(b) at intervals not to exceed 12 hr;

(c) with any change in examination personnel, except when using mechanized equipment.

III-3331 Corrective Actions

(a) If the calibration point has decreased 20% or 2 dB of its amplitude, all data sheets since the last calibration check shall be marked void. A new calibration shall be made and recorded and the voided examination areas shall be reexamined.

(b) If the calibration point has increased more than 20% or 2 dB of its amplitude, recorded indications taken since the last valid calibration or calibration check may be reexamined with the correct calibration and their values changed on the data sheets.

(c) If the calibration point has moved on the sweep line more than 10% of the sweep division reading, correct the sweep range calibration and note the correction in the examination record. If recordable reflectors are noted on the data sheets, those data sheets shall be voided, a new calibration shall be recorded, and the examination areas shall be reexamined.

III-3400 BASIC CALIBRATION BLOCKS

III-3410 MATERIAL

The basic calibration blocks shall be made from material of the same wall thickness within 25% as the component to be examined.

The basic calibration block shall be curved for surface curvatures less than 20 in. (500 mm) diameter. A single curved basic calibration block may be used to calibrate the examination surfaces in the range of curvature from 0.9 to 1.5 times the basic block diameter. For examination of welds with surface curvatures greater than 20 in. (500 mm) diameter, a block of essentially the same curvature, or a flat basic calibration block shall be used.

III-3411 Material Specification

(a) The calibration blocks for similar metal welds shall be fabricated from one of the materials being joined by the weld.

(b) Calibration blocks for dissimilar welds shall be fabricated from the material specified for the side of the weld from which the examination will be conducted. If the examination will be conducted from both sides, calibration reflectors shall be provided in both materials.

(c) Where the examination is to be performed from only one side of the joint, the calibration block material shall be of the same specification as the material on that side of the joint.

(d) If material of the same specification is not available, material of similar chemical analysis, tensile properties, and metallurgical structure may be used.

(e) When the component material is clad, and the cladding is determined to be important to the examination, the block shall be clad by the same welding procedure as the production part. When the automatic method is impractical, a manual method shall be used.

III-3420 SURFACE FINISH

The finish on the surfaces of the block shall be representative of the surface finish of the vessel.

III-3430 CALIBRATION REFLECTORS

Basic calibration blocks shall contain circumferential and longitudinal notches whose sides are perpendicular to the surface, at least 1.0 in. (25 mm) long, on the O.D. and I.D. surfaces. Allowable notch configurations are shown in Figure III-3430-1. Notch width W shall be no greater than $^1/_4$ in. (6 mm). Notch depth d shall be as specified in Table III-3430-1. The reflecting surface of the notch shall be 90 deg ± 2 deg to the block surface. The blocks shall generally conform to the design shown in Figure III-3430-2. Alternate block layout may be used, provided similar beam paths are utilized. Additional reflectors may be installed; however, they shall not interfere with establishing the primary reference.

III-3440 RETENTION AND CONTROL

Basic calibration blocks shall be retained by the Owner.

III-3500 CALIBRATION DATA RECORD

The following data shall be recorded on a calibration data sheet:

(a) calibration sheet identification and date of calibration;

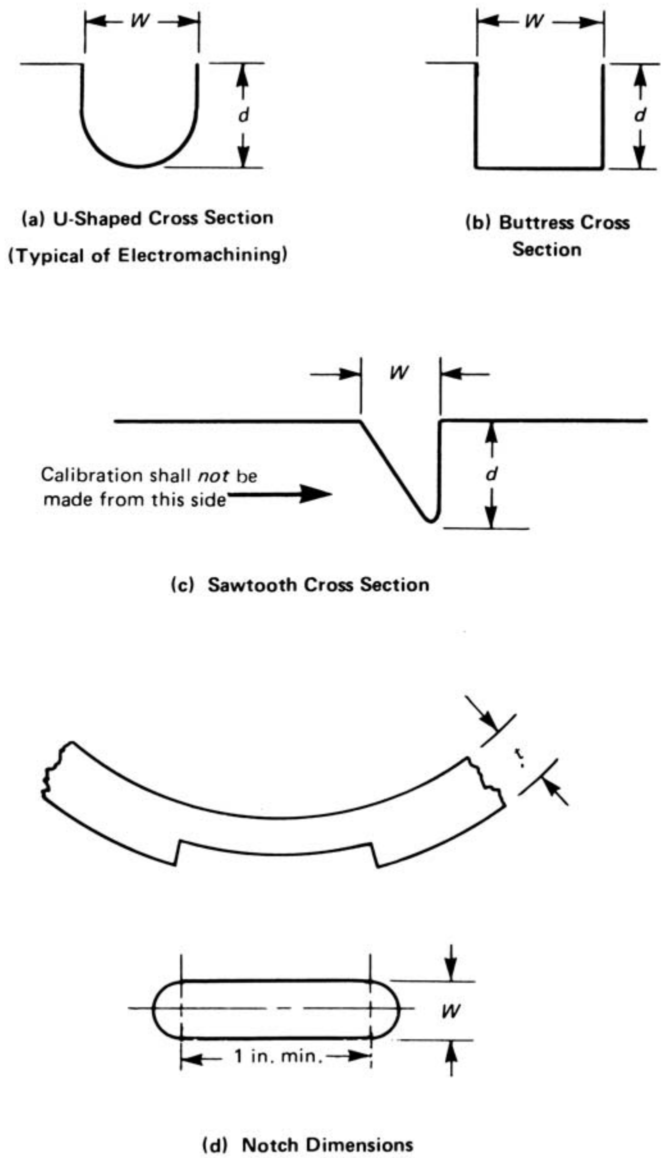
(b) names of examination personnel;

(c) examination procedure number and revision;

(d) basic calibration block identification;

(e) ultrasonic instrument identification and serial number;

Figure III-3430-1
Allowable Notch Configurations



GENERAL NOTES:
(a) Allowable cross sections are in sketches (a), (b), and (c).
(b) 1 in. = 25 mm

Table III-3430-1
Surface Notch Depths for Ultrasonic Calibration

Nominal Pipe Wall Thickness, t, in. (mm)	Notch Depth, d, in.	Tolerance
Less than 0.312 (8)	$0.10t$	+0.005 in. (+0.13 mm) −0.010 in. (−0.25 mm)
0.312 to 6.0 (8 to 150)	$0.104t - 0.009t^2$	+ 10% −20%

(f) beam angle, couplant, and mode of wave propagation in the material;

(g) orientation of search unit with respect to the weld (parallel or perpendicular);

(h) search unit identification — frequency, size, and manufacturer's serial number;

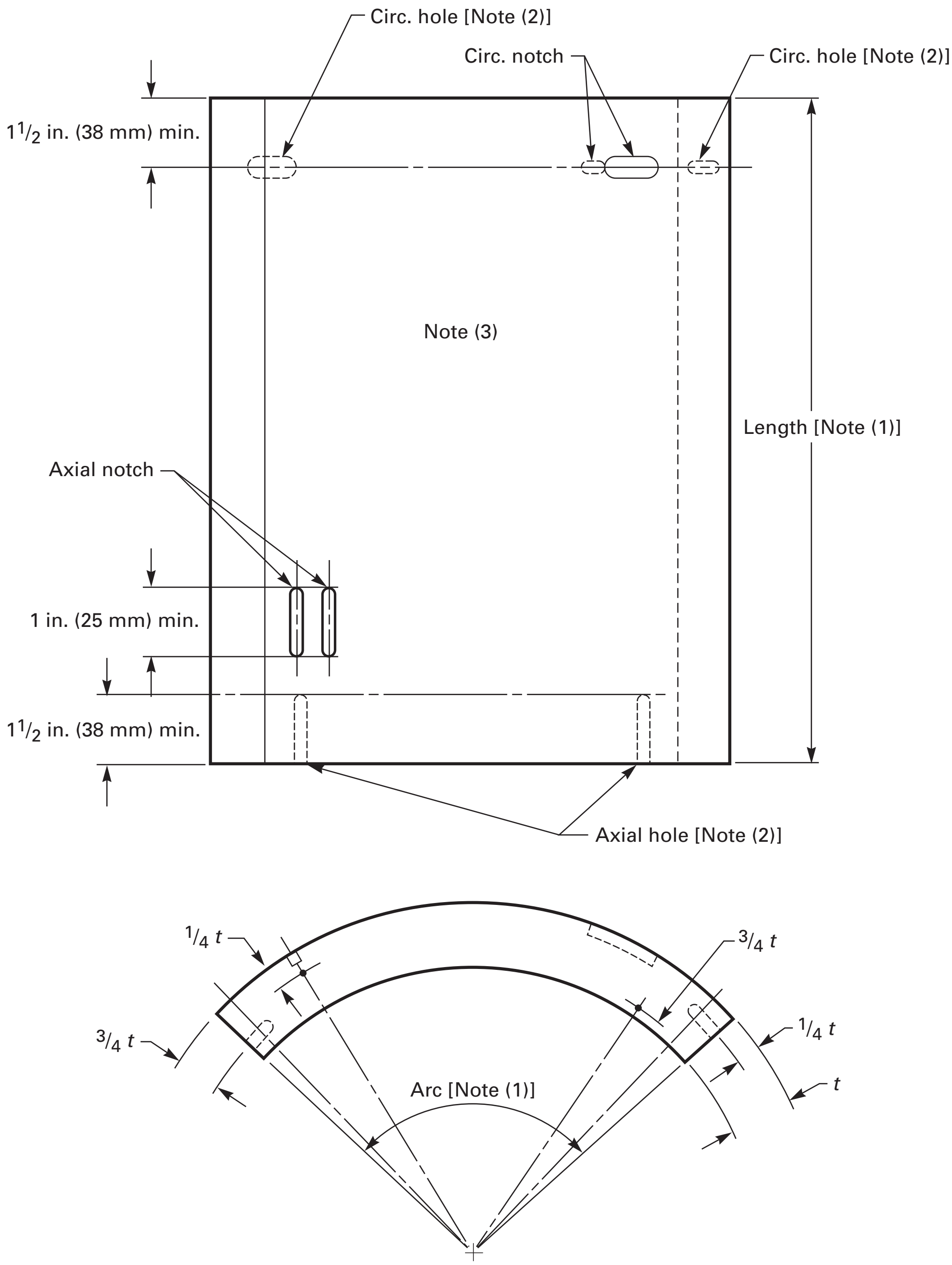
(i) special search units, wedges, shoe type, or saddle's identification, if used;

(j) search unit cable type and length;

(k) times of initial calibration and subsequent calibration checks;

(l) amplitudes and sweep readings obtained from the calibration reflectors.

Figure III-3430-2
Recommended Design for Basic Calibration Blocks



GENERAL NOTES:
(a) 1 in. = 25 mm
(b) 1½ in. = 38 mm

NOTES:
(1) Length and arc shall be adequate to provide required angle beam calibration.
(2) All side drilled holes are optional in accordance with III-3230(d).
(3) For vessels less than 1 in. (25 mm) nominal wall thickness
(a) stagger notch I.D./O.D. locations
(b) a ½t hole may be used in lieu of ¼t and ¾t side drilled holes

ARTICLE III-4000 EXAMINATION

III-4100 GENERAL

This Article describes the angle beam ultrasonic examination requirements for similar and dissimilar metal welds. The examination is applicable to welds accessible from at least one surface adjacent to the weld seam. This examination is intended to detect, locate, and dimension planar flaws.

III-4200 SURFACE PREPARATION

The examination surface shall be free of irregularities, loose material, or coatings which interfere with ultrasonic wave transmission.

III-4300 IDENTIFICATION OF EXAMINATION AREAS

III-4310 WELD LOCATION

Weld identification and location shall be shown on a weld identification plan.

III-4320 MARKING

Low stress stamps or vibratooling, or both, may be used to permanently identify each weld. Marking applied shall not be any deeper than $^3/_{64}$ in. (1.2 mm).

III-4330 REFERENCE SYSTEM

A reference system shall be established to locate the weld centerline. Circumferential and longitudinal welds requiring volumetric examination shall be marked once before or during the preservice examination to establish a reference point.

III-4400 ANGLE BEAM TECHNIQUE

III-4410 BEAM ANGLE

The search unit and beam angle selected shall be capable of detecting flaws within the required examination volume.

III-4420 REFLECTORS PARALLEL TO THE WELD SEAM

The examination shall be performed using a sufficiently long examination beam path to provide coverage of the required examination volume in two-beam path directions. The examination shall be performed from two sides of the weld, where practicable, or from one side of the weld, as a minimum.

III-4430 REFLECTORS TRANSVERSE TO THE WELD SEAM

The angle beam examination for reflectors transverse to the weld shall be performed on the weld crown on a single scan path to examine the weld root by one-half V path in two directions along the weld.

III-4450 INACCESSIBLE WELDS

Welds that cannot be examined from at least one side (edge) using the angle beam technique shall be examined by another volumetric method.

III-4500 RECORDING REQUIREMENTS

III-4510 INDICATIONS TO BE RECORDED

III-4511 Flaw Indications

(a) Any indication of a suspected flaw shall be recorded regardless of amplitude.

(b) Any other indications which are not determined to be of geometrical or metallurgical origin shall be recorded if they are 20% of DAC or greater.

III-4512 Indications Determined to Be of Geometric or Metallurgical Origin

(a) The following steps shall be taken in order to classify an indication to be of geometric or metallurgical origin:

(1) interpret the area containing the reflector in accordance with the applicable examination procedure;

(2) plot and verify the indication coordinates in accordance with III-4520(g)(2); and

(3) review fabrication or weld prep drawings.

(4) Alternatively, other NDE methods or techniques may be applied (e.g., alternate UT beam angles, radiography, I.D. and/or O.D. profiling).

(b) Indications 20% of DAC or greater shall be recorded for preservice examinations of new or replaced welds.

(c) Indications 50% of DAC or greater shall be recorded for inservice examinations. For indications classified and recorded in accordance with (a) and (b), the classification and recording do not have to be repeated for subsequent examinations.

III-4520 RECORDED DATA

The following data shall be recorded on the examination data sheet:

(a) data sheet identification and date and time period of examination;

(b) names and certification levels of examination personnel;

(c) examination procedure and revision;

(d) calibration sheet identification;

(e) identification and location of the weld or volume scanned (for example, marked up drawings or sketches);

(f) surfaces from which the examination is conducted; and

(g) examination results.

(1) Search unit location, orientation, and the following information shall be recorded for each indication (III-4511):

(-a) peak amplitude as dB from the reference level, sweep readings to reflector, search unit positions, search unit locations, and sound beam directions;

(-b) search unit positions parallel to the reflector at the end points where the reflector amplitude equals 50% of the peak amplitude (estimated length); and

(-c) the true position of the indication, plotted on a cross-sectional sketch showing O.D. profile and I.D. geometry (such as root and counterbore). For austenitic material, the beam angle as measured in accordance with Supplement 1 shall be used to plot the position of indications.

(2) The following shall be recorded for each indication that equals or exceeds the recording level and is not considered to be a flaw:

(-a) peak amplitude and amplitude range as dB from the reference level, sweep readings to reflector, search unit locations, and sound beam direction over the extent of the reflector;

(-b) reflector location (at a representative position), plotted on a cross-sectional sketch showing surface discontinuities (such as root and counterbore); and

(-c) basis for disposition.

(3) Welds and required examination volumes found free of indications shall be identified and recorded.

III-4530 FLAW SIZING

In the course of preparation.

(15)

MANDATORY APPENDIX III SUPPLEMENTS

SUPPLEMENT 1 AUSTENITIC AND DISSIMILAR METAL WELDS

(a) The following welds, because of their inherent coarse grained structure, may be subject to marked variations in attenuation, velocity, reflection, and refraction at grain boundaries:

(1) high alloy steels;

(2) high nickel alloys;

(3) dissimilar metal welds between combinations of (1) and (2) above and wrought carbon or low alloy steels

(b) For examination of the welds and materials in (a) above, the requirements of Mandatory Appendix III shall be modified as follows:

(1) III-4410 Beam Angle — The actual beam angle in the examination part shall be 40 deg or greater for shear wave at the inside surface. The shear wave beam angle in the examination part shall be determined for each weld to be examined. The refracted longitudinal wave beam angle shall be measured using the basic calibration block. The beam angle at the opposite surface of the basic calibration block shall be at least 35 deg. The beam angle measurements shall be used to assure coverage of the required examination volume by extending the calibration and examination distance, as required.

(2) III-4430 Reflectors Transverse to the Weld Seam — Substitute: The angle beam examination for reflectors transverse to the weld shall be performed in two directions covering the minimum area from $^1/_2$ in. (13 mm) from one side of the weld crown to $^1/_2$ in. (13 mm) from the other side of the weld crown including the crown.

(3) Table III-3430-1 Calibration Notches — Substitute: depth 10% of t.

(4) Scanning from both sides of the weld is required where practical. Single side access limitations shall be noted in the examination data record.

SUPPLEMENT 2 WELDS IN CAST AUSTENITIC MATERIALS

(a) In addition to variations in attenuation, velocity, reflection, and refraction at grain boundaries, the following welds are associated with beam splitting, distortion, and skewing due to the coarse-grained and anisotropic nature of the cast austenitic base materials:

(1) centrifugally cast or statically cast austenitic steel to wrought carbon or low alloy steel

(2) statically cast austenitic steel to centrifugally cast austenitic steel

(3) centrifugally cast austenitic steel to centrifugally cast austenitic steel

(4) statically cast austenitic steel to statically cast austenitic steel

(5) statically cast austenitic steel to wrought austenitic steel

(b) Examination of the welds for which the ultrasonic beam must pass through the wrought carbon, low alloy steel, or wrought austenitic steel materials of the welds in (a) are to be addressed using the requirements of Mandatory Appendix I, I-2220.

(c) For examination of the welds for which the ultrasonic beam must pass through the cast austenitic base materials listed in (a) above, the requirements of this Mandatory Appendix, as supplemented by Table I-2000-1, shall be met, with the following modifications. These requirements cover the examinations performed from the outside surface only.

(1) In lieu of the requirements of III-2120, the following requirements shall be met:

(-a) All search units shall be dual-element, transmit-receive, refracted-longitudinal-wave probes consisting of monolithic elements (conventional search unit) or multi-element phased arrays (phased-array search unit).

(-b) Wedges, whether integral or replaceable, shall allow for no more than a $^1/_{32}$-in. (0.8-mm) gap between the search unit and component surface along the scan length.

(-c) Two ranges of inspection frequencies are required.

(-1) For piping no thicker than 1.6 in. (41 mm), up to 1.5-MHz probes shall be used; however, higher frequency probes (up to and including 2 MHz) may be useful for flaw characterization.

(-2) For piping thicker than 1.6 in. (41 mm), 0.5-MHz to 1.0-MHz probes shall be used.

(-d) At least one inside-surface-impingement beam angle (calculated) shall be within the range of 30 deg to 50 deg for examination volume coverage. At least one beam angle greater than or equal to 55 deg is required for the detection of deeper flaws.

(-e) Search unit size is dependent on frequency and focal length or sound path. For detection of inner-surface-initiated flaws, the search unit shall have a sufficiently large active aperture to enable appropriate beam

focusing within 80% to 110% of the nominal wall thickness of the piping material. The following relationship can be used to determine if the appropriate aperture has been chosen:

$$D = \sqrt{N4c/f}$$

where

c = longitudinal wave velocity in material
D = minimum probe diameter or aperture
f = nominal probe frequency
N = required focal length

For phased-array search units, the focal sound path shall be verified using sound-beam modeling, to ensure that focal laws producing a beam focusing within 80% to 110% of the nominal wall thickness of the piping material are selected for the examination.

(2) In addition to III-2200(a) and III-2200(b), personnel shall receive 4 hr of training and 4 hr of hands-on laboratory examination of cast austenitic steel welds related to discriminating between flaw indications and indications of geometric or metallurgical origin. This training shall include descriptions of coarse grain structures, their effect on the ultrasonic beam, and the expected ultrasonic response characteristics of metallurgical and flaw reflectors.

(3) In lieu of the requirements of III-2430, scanning shall be conducted such that an average material noise level of 5% to 20% full screen height is observed.

(4) In lieu of the requirements of Table III-3430-1, a notch depth, d, of $0.1t$ shall be used, with the corresponding tolerances in the table for all material thicknesses.

(5) In addition to the requirements of III-4200, to allow adequate ultrasonic coupling with the examination surface and to accommodate the relatively large search units required, the scanning surface condition shall be flush. Flush is defined as no more than a $^1/_{32}$-in. (0.8-mm) gap between the search unit and the examination surface for the entire length of the scan.

(6) In lieu of the requirements of III-4430, the angle beam examination for reflectors transverse to the weld shall be performed in two directions covering at least $^1/_2$ in. (13 mm) of the cast austenitic steel base materials and the entire weld crown.

(7) In lieu of III-4520(g)(1)(-b), the search unit positions parallel to the reflector at the end points where the reflector response is reduced to the noise level shall be recorded (estimated length).

(8) In lieu of the requirements of III-4530, tip-diffraction methods shall be used for flaw depth sizing when a tip-diffracted signal can be resolved. Flaw length sizing should be performed using the full-amplitude drop technique.

(9) In addition to the requirements of Mandatory Appendix III, ultrasonic coupling between the contoured search units and examination surface must be over the entire contact face of the search unit. Continuous noise level on the ultrasonic display should not be used as the sole indicator of sufficient coupling. The examination procedure shall address adequate coupling, by requiring use of liberal amounts of couplant material, recognition of material reflectors at or near the inside surface, couplant monitoring beam angles, or a combination thereof.

(10) Encoded scans with off-line analysis shall be used. If encoded scanning and off-line analysis are not feasible, manual scans are allowed.

MANDATORY APPENDIX IV
EDDY CURRENT EXAMINATION

ARTICLE IV-1000
SCOPE

IV-1100 METHODS ADDRESSED

When eddy current examination is used as a surface examination method in accordance with IWA-2223, this Appendix provides requirements for performance demonstration of eddy current systems.

IV-1200 GENERAL

(a) This Appendix specifies performance demonstration requirements for eddy current examination procedures, equipment, and personnel used to detect and size flaws in piping and components. This Appendix does not include performance demonstration requirements for steam generator heat exchanger tubing examination.

(b) Each organization (i.e., Owner or vendor) shall have a written program that complies with this Appendix. Each organization that performs eddy current examination shall use procedures, equipment, and personnel qualified in accordance with this Appendix. The organization may contract implementation of the program.

(c) Performance demonstration requirements apply to procedures and equipment for acquisition and analysis and to personnel who are responsible for detecting, sizing, and reporting of flaws.

(d) The performance demonstration requirements specified in this Appendix apply to the acquisition process but do not apply to personnel involved in the acquisition process. Such personnel shall be trained and qualified by their employer for the specific tasks they perform. The requirements for training and qualification of such personnel shall be described in the employer's written practice (IWA-2300).

(e) This performance demonstration is applicable only to materials whose acceptance standard is $^1/_8$ in. (3 mm) or more in length.

(f) Equipment characterization described in Supplement 1 is optional. When Supplement 1 is selected, both the original and substitute equipment shall be characterized.

(g) Equipment and techniques qualified in accordance with this Appendix may be used in procedures without regard to the organization that qualified the procedure.

ARTICLE IV-2000
GENERAL SYSTEM AND PERSONNEL REQUIREMENTS

IV-2100 PROCEDURE REQUIREMENTS

The procedure shall contain a statement of scope that specifically defines the limits of procedure applicability (e.g., material specification, grade, type, or class). The procedure shall reference a technique specification, delineating the essential variables, qualified in accordance with the appropriate supplement referenced in Article IV-3000.

IV-2200 PROCEDURE SPECIFICATIONS

(a) The data acquisition procedure shall specify the following:

(1) instrument or system, including manufacturer's name and model

(2) size and type of probe, including manufacturer's name and part number

(3) analog cable type and length including

(-a) probe cable type and length

(-b) extension cable type and length

(4) examination frequencies, or minimum and maximum range, as applicable

(5) coil excitation mode, e.g., absolute or differential

(6) minimum data to be recorded

(7) method of data recording

(8) minimum digitizing rate (samples per in.) or maximum scanning speed (for analog systems) as applicable

(9) scan pattern, when applicable (e.g., helical pitch and direction, rectilinear rotation, length, scan index, or overlap)

(10) magnetic bias technique, when applicable

(11) material type

(12) coating type and thickness, when applicable

(b) The data analysis procedure shall define the following:

(1) method of calibration, e.g., phase angle or amplitude adjustments

(2) channel and frequencies used for analysis

(3) extent or area of the component evaluated

(4) data review requirements, e.g., secondary data review, computer data screening

(5) reporting requirements, i.e., signal-to-noise threshold, voltage threshold, flaw depth threshold

(6) methods of identifying flaw indications and distinguishing them from nonrelevant indications, such as indications from probe lift-off or conductivity and permeability changes in weld material

(7) manufacturer and model of eddy current data analysis equipment

(8) manufacturer, title and version of data analysis software, as applicable

(c) The acquisition procedure or the analysis procedure, or both, as applicable, shall address requirements for system calibration. Calibration requirements include those actions required to ensure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system, whether displayed, recorded, or automatically processed, are repeatable and correct. Any process of calibrating the system is acceptable; a description of the calibration process shall be included in the procedure.

IV-2300 PERSONNEL REQUIREMENTS

IV-2310 GENERAL

(a) Personnel shall be qualified to the applicable level in accordance with IWA-2300

(b) Personnel performing data acquisition shall have received specific training, and shall be qualified by examination, in accordance with the employer's procedures, in the operation of the equipment, applicable techniques, and recording of examination results.

IV-2320 PERSONNEL REQUIREMENTS FOR SURFACE EXAMINATION

(a) Personnel performing analysis of data shall have received additional specific training in the data analysis techniques used in the performance demonstration and shall successfully complete the performance demonstration described in IV-3100.

(b) Personnel involved in qualifying procedures, but who are not seeking qualification to perform examinations, e.g., laboratory personnel, need not meet the requirements of IV-2310 or (a).

ARTICLE IV-3000 QUALIFICATION REQUIREMENTS

IV-3100 QUALIFICATION TEST REQUIREMENTS

IV-3110 GENERAL

(a) Data sets for detection and sizing shall meet the requirements of the appropriate supplement listed in Table IV-3110-1.

(b) The acquisition procedure, analysis procedure, equipment and analysis personnel shall be considered qualified upon successful completion of the performance demonstration specified in the appropriate supplement listed in Table IV-3110-1.

(c) Once a procedure has been qualified, subsequent analyst qualifications may be performed using prerecorded data acquired using the qualified procedure.

IV-3120 ESSENTIAL VARIABLES

(a) An essential variable is a procedure, software, or hardware item that, if changed, could result in erroneous examination results. Further, any item that could decrease the signal to noise ratio to less than 2:1 shall be considered an essential variable. (Nonmandatory sample Data Acquisition Procedure Specification and Data Analysis Procedure Specification Forms are provided in supplements A and B for the purpose of documenting the essential variables.)

(b) Any two procedures with the same essential variables (IV-2100 and IV-2200) are considered equivalent. Equipment with essential variables that vary within the demonstrated ranges identified in the Data Acquisition Procedure Specification shall be considered equivalent. When the procedure allows more than one value or range for an essential variable, the qualification test shall be repeated at the minimum and maximum value for each essential variable with all other variables remaining at their nominal values. Changing essential variables may be accomplished during successive procedure qualifications involving different personnel. Each data analyst need not demonstrate qualification over the entire range of every essential variable.

(c) When the procedure does not specify a range for essential variables and establishes criteria for selecting values, the criteria must be demonstrated.

IV-3130 REQUALIFICATION

When a change in an acquisition technique or analysis technique causes an essential variable to exceed a qualified range, the acquisition or analysis technique shall be requalified for the revised range.

Table IV-3110-1

Component Type	Applicable Supplement
Piping and Vessels (Surface)	2
Bolting – Center Bore Hole (Surface)	3

ARTICLE IV-4000
ESSENTIAL VARIABLE TOLERANCES

IV-4100 INSTRUMENTS AND PROBES

The qualified acquisition procedure may be modified to replace instruments or probes of similar make, model, and manufacturer without requalification. Other equipment may be substituted, provided the performance constraints for essential variables are met (e.g., 2:1 signal-to-noise ratio is maintained). The qualified acquisition procedure may also be modified to replace instruments or probes without requalification, when the range of essential variables defined in the Data Acquisition Procedure Specification are met, provided the equipment is evaluated using Supplement 1.

IV-4200 COMPUTERIZED SYSTEM ALGORITHMS

Computerized system algorithms that are altered may be used when the altered algorithms are demonstrated equivalent to those qualified. When the performance demonstration results meet the acceptance requirements of Article IV-3000, the algorithm shall be considered qualified.

IV-4300 CALIBRATION METHODS

Alternative calibration methods may be demonstrated equivalent to those described in the qualified acquisition procedure or analysis procedure without requalification. This demonstration of equivalence shall be conducted as follows.

(a) Calibrate the system in accordance with the alternative methods.

(b) The alternative calibration method is acceptable when the system complies with the essential variables defined in the Data Acquisition or Data Analysis Procedure Specification.

ARTICLE IV-5000
RECORD OF QUALIFICATION

The organization's performance demonstration program shall specify the documentation that shall be maintained as qualification records. The qualification record shall include the following information:

(a) Identification of the procedure (acquisition or analysis) qualified and a summary of its essential variables (A copy of the procedure is sufficient.)

(b) Personnel performing and witnessing the qualification demonstrations

(c) Description and drawings of the qualification specimens and the calibration blocks, as applicable

(d) Qualification results

MANDATORY APPENDIX IV SUPPLEMENTS

SUPPLEMENT 1 EQUIPMENT CHARACTERIZATION

1.0 SCOPE

(a) This Supplement specifies essential variables associated with eddy current data acquisition instrumentation and establishes a methodology for essential variable measurement.

(b) Essential variables are divided into two categories:

(1) Those associated with an individual instrument, probe, or cable

(2) Those associated with specific on-site equipment configurations

(c) When the essential variables of both original and substitute equipment have been characterized in accordance with this Mandatory Appendix, and the essential variables of the substitute equipment are equivalent to those of the original equipment, the substitute equipment may be used without any supplemental performance demonstration.

2.0 EDDY CURRENT INSTRUMENT

2.1 The essential variables for the eddy current instrument are related to the three basic modules of the instrument:

(a) The transmitter (signal generation and injection)

(b) The receiver (probe signal detection, amplification, demodulation, and filtering)

(c) Analog-to-digital conversion

2.2 Transmitter.

2.2.1 Total Harmonic Distortion.

(a) Harmonic distortion is due to nonlinearities in the amplitude transfer characteristics of the instrument. The output contains not only the fundamental frequency, but integral multiples of the fundamental frequency. For eddy current instruments, harmonic distortion is a measure of the quality of the sinusoidal signal injected into the coil(s). The total harmonic distortion is expressed in either percent distortion compared to the fundamental sinusoidal frequency, or the ratio in dB of the amplitude of the fundamental frequency to the amplitude of the largest side lobe as displayed on a frequency spectrum plot. It shall be measured for each frequency specified.

(b) When used as an essential variable, the maximum harmonic distortion shall be specified.

2.2.2 Output Impedance. The output impedance is measured for each test frequency at the output connector of the instrument. Both the magnitude and phase shall be measured for each specified frequency. When used as an essential variable, the tolerance of the ratio of the output (transmitter) to input (receiver) impedance shall be specified.

2.3 Receiver.

2.3.1 Input Impedance.

(a) The input impedance is to be measured independently of the output impedance if the transmitter and receiver are not wired to the same coils as in the case for reflection (driver/pickup) arrangements. Both the magnitude and phase shall be measured at each specified frequency.

(b) When used as an essential variable, the tolerance of the ratio of the output (transmitter) to input (receiver) impedance shall be specified.

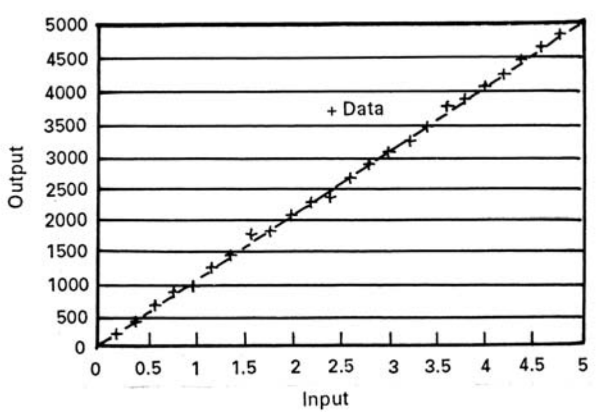
2.3.2 Amplifier Linearity and Stability.

(a) Amplifier linearity and stability of each channel used for inspection is measured as the ratio of the signal injected at the instrument input to the magnitude of the signal measured at the data analysis screen. It is a measurement of the similarity between the eddy current signal sensed at the coil side and the signal observed on the analysis screen after signal amplification and filtering. The measurement is performed for five different gain settings equally spaced between the smallest and largest gain values available on the instrument, and for five different signals injected at the instrument input at each gain setting, equally spaced between the smallest detectable signal and the largest signal that can be obtained without saturation.

(b) Linearity is expressed in terms of percentage deviation from a best-fit linear relationship between corresponding input and output values when plotted ona graph. The percentage is determined by dividing the maximum deviation from the line by the full scale value.

(c) When used as essential variables, linearity and stability shall be expressed as minimum requirements. The output/input graph shown in Figure 2.3.2-1 illustrates the curve fitting method used to determine amplifier linearity.

Figure 2.3.2-1
Instrument Linearity



2.4 A/D Converter.

2.4.1 A/D Resolution.

(a) The resolution of the analog-to-digital converter is the value of the input voltage that corresponds to a change of one bit. It is a measurement of the smallest change in the eddy current signal that can be observed after digitization. If applicable, it is measured for five equally spaced gain settings between the smallest and largest gain values available on the instrument.

(b) When used as an essential variable, the resolution of the analog-to-digital converter shall be expressed as a minimum value.

2.4.2 Dynamic Range.

(a) The number of bits for full-scale input determines the dynamic range of the A/D converter. It is a measure of the maximum eddy current signal that can be recorded without distortion after digitization.

(b) When used as an essential variable, the number of bits for full scale input shall be expressed as a minimum value.

2.4.3 Sample Rate.

(a) The sample rate is the frequency in Hz at which the analog to digital conversions are made. The sample rate in combination with the probe traverse speed determines the digitization rate.

$$\text{Digitization Rate}_{(\text{samples /in.})} = \frac{\text{Sample Rate}_{(\text{samples/second})}}{\text{Probe Speed}_{(\text{in./second})}}$$

(b) When used as an essential variable, the minimum digitization rate shall be specified. The minimum sample rate of the A/D converter must be capable of providing the specified digitization rate at the probe speeds to be used.

$$\text{Sample Rate}_{\text{Min}} = \text{Digitization Rate}_{\text{Min}} \times \text{Probe Speed}$$

(c) Conversely, the maximum probe speed is determined by the maximum sample rate of the instrument divided by the minimum digitization rate specified.

$$\text{Probe Speed}_{\text{Max}} = \frac{\text{Sample Rate}_{\text{Max}}}{\text{Digitization Rate}_{\text{Min}}}$$

3.0 PROBE CHARACTERIZATION

3.1 Impedance. The impedance (magnitude and phase) shall be measured for each test coil at the test frequencies selected for the examination. This is considered to be the input impedance of the instrument, as defined in 2.3.1.

3.2 Resonant Frequency.

(a) The resonant frequency is measured with the full cable length between the coil and the instrument input connector.

(b) When used as an essential variable, the allowable range of the resonant frequency shall be specified.

3.3 Magnetic Field. Measurements are performed with the eddy current instrument wired according to the on-site conditions (including the cable length) between the eddy current instrument and the coils. Essential variables are defined for pancake coils.

3.3.1 Bobbin Coil.

3.3.1.1 Effective Scan Field Width.

(a) The Effective Scan Field Width is a measure of the extent of the effective magnetic field in the preferred direction. It is also a measure of the spatial resolution. This resolution determines minimum spacing between three successive notches compared to a single notch of equal depth.

(b) The measurement is performed for each eddy current examination frequency and mode of coil operation, e.g., absolute or differential. A 0.050 in. (1.3 mm) deep notch of 0.008 in. (0.2 mm) width, and minimum length equal to the coil width 1.0 in. (+25 mm) is scanned perpendicular to the preferred direction.

(c) A curve is plotted for the signal amplitude as a function of the probe displacement. The effective scan field width in inches (millimeters) is determined by subtracting the crack length from the measured distance between corresponding signal amplitude points for a given attenuation below the maximum amplitude. The effective scan field width can be a negative value for one or all of the four points measured on the curve.

(d) When used as an essential variable, the effective scan field width shall be specified, for absolute and differential modes, as the maximum distance to a point on the curve used to determine the minimum value of four points, equally spaced, selected to define the curve on either side of the minimum and maximum signal amplitudes.

$$\text{Example: } \text{ESFW}_{-12\text{db}} = -0.08 \text{ in.} \left(2 \text{ mm}\right)$$

3.3.1.2 Fill Factor Coefficient. The Fill Factor Coefficient (FFC) is a measure of the drop in the effective magnetic field perpendicular to a tube. The measurement is performed for each eddy current examination frequency and absolute/differential coil configuration. A 0.050 in. (1.3 mm) notch of 0.008 in. (0.2 mm) width, and of a minimum length equal to the coil width 1 in. (+25 mm) is scanned perpendicular to the coil preferred direction.

(a) The gain setting is adjusted for an 80% full scale peak signal for the signal having the largest amplitude. The measurements are performed for three or more fill factors (ratio of square of O.D. probe diameter to I.D. hole diameter) between the largest and smallest to be encountered in bore holes.

(b) When used as an essential variable, the fill factor shall be specified, for absolute and differential modes, as the amplitude attenuation from the largest fill factor to the smallest fill factor.

$$\text{Example: FCC } 0.85 \text{ to } 0.70 = -5 \text{ dB}$$

3.3.1.3 Axial Length Coefficient.

(a) The Axial Length Coefficient (ALC) is a measure of the influence of the axial crack length on the amplitude of the eddy current signal. The measurement is performed for each of the examination frequencies, absolute/differential coil modes, and nominal fill factors expected in the bore hole. A 0.050 in. (1.3 mm) deep notch of 0.008 in. (2 mm) width, and of varying length from a minimum length equal to the coil width and up to the coil width 0.5 in. (+13 mm), at increments of 0.1 in. (2.5 mm) is scanned perpendicular to the coil preferred direction. The gain setting is adjusted for an 80% scale peak signal from the signal having the largest amplitude.

(b) When used as an essential variable, the axial length coefficient shall be specified, for absolute and differential modes, as a maximum amplitude attenuation for each length relative to the longest one.

$$\text{Example: } \quad \text{ALC}_{-2.5 \text{ mm}} = 0 \text{ dB}$$

$$\text{ALC}_{-5.0 \text{ mm}} = -2 \text{ dB}$$

3.3.1.4 Transverse Width Coefficient.

(a) The Transverse Width Coefficient (TWC) is a measure of the dependency of transverse crack width on the amplitude of the eddy current signal. The measurement is performed for each of the examination frequencies, absolute/differential coil mode and nominal fill factors expected in the bore hole. A 0.050 in. (1.3 mm) deep notch of the same length as the total coil width, and 0.008 in. (0.2 mm) to (0.02 in. (0.6 mm) wide, at increments of 0.004 in. (0.1 mm), is scanned parallel to the coil preferred direction. The gain setting is adjusted for an 80% full scale peak signal from the signal having the largest amplitude.

(b) When used as an essential variable, the transverse width coefficient shall be specified, for absolute and differential modes, as a maximum amplitude attenuation for each defect width relative to the largest one.

$$\text{Example: } \quad \text{TWC}_{-0.5 \text{ mm}} = 0.5 \text{ dB}$$

$$\text{TWC}_{-0.2 \text{ mm}} = -1.0 \text{ dB}$$

3.3.1.5 Direct Current Saturation Strength.

(a) The Direct Current Saturation Strength (DCSS) concerns only probes delivered with a supplemental coil or magnet designed to suppress the influence of possible magnetic variations. The direct current saturation strength is measured in air with a gauss meter located at the center of the coil at a nominal distance from the bore hole inner surface. It is expressed in millitesla.

(b) When used as an essential variable, the direct current saturation strength coefficient and direction shall be specified as a minimum requirement.

3.3.2 Pancake Coil.

3.3.2.1 Effective Scan Field Width. See 3.3.1.1.

3.3.2.2 Effective Track Field Width.

(a) The Effective Track Field Width (ETFW) takes into account the combined influence of the coil magnetic field and the coil scanning pitch. It measures the drop in signal amplitude when the coil scans the defect at increasing scanning distances. A 0.125 in. (3 mm) minimum depth notch of 0.008 in. (0.2 mm) maximum width, and of a minimum length equal to the coil width +1 in. (25 mm) is scanned perpendicular to the coil preferred direction for defect detection.

(b) The gain setting is adjusted for an 80% full scale peak signal for the signal having the largest amplitude.

(c) A curve is plotted for the signal amplitude as a function of the distance between the center of the coil and the center of the notch.

(d) When used as an essential variable, the effective track field width coefficient shall be specified, for absolute and differential modes, as the maximum distance from the notch, where a given signal attenuation is the minimum of four points, equally spaced, selected to define the curve on either side of the minimum and maximum signal amplitudes.

$$\text{Example: ETFW}_{-3 \text{ db}} = 0.125 \text{ in.} (3 \text{ mm})$$

3.3.2.3 Lift-Off Value (LOV).

(a) The Lift-Off Value (LOV) is a measure of the drop in the effective magnetic field in a direction perpendicular to the examination surface. The measurement is performed for each eddy current examination frequency and absolute/differential coil configuration. A 0.125 in. (3 mm) minimum depth notch of 0.008 in. (0.2 mm) maximum

width, and of a minimum length equal to the coil width +1 in. (25 mm) is scanned perpendicular to the coil preferred direction.

(b) The gain setting is adjusted for an 80% full scale peak signal for the signal having the largest amplitude. The measurements are performed for three or more lift-off values between the largest and smallest to be encountered for the configurations to be examined. When used as an essential variable, the lift-off value shall be specified, for absolute and differential modes, as the amplitude attenuation from the smallest lift-off to the largest lift-off value.

$$\text{Example: LOV } 0.85 \text{ to } 0.70 = -5\text{dB}$$

3.3.2.4 Axial Width Coefficient. See 3.3.1.3.

3.3.2.5 Transverse Width Coefficient. See 3.3.1.4.

SUPPLEMENT 2 QUALIFICATION REQUIREMENTS FOR SURFACE EXAMINATION OF PIPING AND VESSELS

(15) ### 1.0 SPECIMEN REQUIREMENTS

Specimens to be used in the qualification test shall meet the requirements listed herein unless a set of test specimens is designed to accommodate specific limitations stated in the scope of the examination procedure, e.g., surface roughness or contour limitations. The same specimens may be used to demonstrate both detection and sizing qualification. For examination of coated surfaces, Section V, Article 8 shall apply. Specimens shall conform to the following requirements:

(a) Specimens shall be fabricated from the same base material nominal composition (UNS Number) and heat treatment (e.g., solution annealed, precipitation hardened, solution heat treated and aged) as those to be examined.

(b) Welding shall be performed with the same filler metal AWS classification, and postweld heat treatment (e.g., as welded, solution annealed, stress relieved) as the welds to be examined.

(c) Specimen surface roughness and contour shall be generally representative of the surface roughness and contour of the component surface to be examined. The examination surface curvature need not be simulated if the ratio of the component diameter to the coil diameter exceeds 20:1.

(d) Defect conditions:

(1) The flawed grading units shall be cracks or notches.

(2) The length of cracks or notches open to the surface shall be either

(-a) $^1/_{16}$ in. (1.5 mm) or less, or

(-b) less than or equal to the allowable length specified in IWB-3514 and IWC-3514 for inservice surface flaws for piping or Tables IWB-3510-3 and IWC-3510-3 for vessels

(3) The maximum depth of a crack or compressed notch shall be 0.040 in. (1 mm)

(4) Machined notches shall have a maximum width of 0.010 in. (0.25 mm) and a maximum depth of 0.020 in. (0.5 mm)

(e) Demonstration Specimens:

(1) The demonstration specimen shall include one crack or notch at each of the following locations:

(a) on the weld

(b) in the heat-affected zone

(c) at the fusion line of the weld

(d) in the base material

(2) The demonstration shall include the effects of coating thickness, when applicable.

3.0 ACCEPTANCE CRITERIA

All flaws in each of the four identified areas must be detected with a minimum 2:1 signal-to-noise ratio at the minimum digitization rate (for digital systems) or maximum scanning speed (for analog systems) permitted by the procedure.

SUPPLEMENT 3 QUALIFICATION REQUIREMENTS FOR SURFACE EXAMINATION OF BOLTING — CENTER BORE HOLES

1.0 SPECIMEN REQUIREMENTS

This Supplement applies only to surface examination of the center bore hole of studs or bolts with eddy current examination. Specimens to be used in the qualification test for examination of the center bore hole surface shall meet the following requirements unless a set of test specimens is designed to accommodate specific limitations stated in the scope of the examination procedure. Specimens shall conform to the following requirements:

(a) Specimens shall be fabricated from materials of the same base material nominal composition (UNS Number) and heat treatment (e.g., solution annealed, precipitation hardened, solution heat treated and aged) as those to be examined.

(b) The effect of the presence of corrosion products must be evaluated if the bore hole of the bolt or stud is not thoroughly cleaned prior to examination [IV-3120(b)].

(c) Defect Conditions

(1) The crack shall be located in the bore hole and oriented circumferentially.

(2) The length of the crack open to the surface shall not exceed $^1/_4$ in. (6 mm).

(3) The crack used for qualification may be located in a block with different geometry if the qualification demonstrates that cracks can be detected in the bore hole. The alternative block shall be demonstrated by showing equivalent response in both geometries (bore hole and block) using calibration discontinuities specified by the qualified procedure.

2.0 CONDUCT OF PERFORMANCE DEMONSTRATION

Specimen identification and crack locations shall be obscured so as to maintain a "blind test."

3.0 ACCEPTANCE CRITERIA

Examination procedures, equipment, and personnel shall be considered qualified when the qualification crack has been detected with a minimum 2:1 signal-to-noise ratio. The notch axial location shall be correctly identified to within $\pm^{1}/_{2}$ in. (13 mm) or 5% of the bolt or stud length, whichever is greater.

Appendix IV
Supplement a Data Acquisition Procedure Specification

1. SCOPE:

2. INSTRUMENT:
Manufacturer:
Model:
Software/Mfg./Version:

3. PROBE:

Size:
Manufacturer:
Part No.:

4. CABLES

Probe Cable	Extension Cable
Type:	Type:
Length:	Length:

5. FREQUENCIES/MODES

Mode:		Mode:	
Frequencies/Channels:		Frequencies/Channels:	
1.	5.	1.	5.
2.	6.	2.	6.
3.	7.	3.	7.
4.	8.	4.	8.

6. CALIBRATION METHOD:

7. DATA RECORDING

Equipment Manufacturer:	Model:
Media:	Format:

8. DIGITIZING RATE
Samples Per Inch:

9. SCAN PATTERN

Pitch:	Direction:

Appendix IV
Supplement B Data Analysis Procedure Specification

1. CALIBRATION METHOD

Phase Angle to Depth:
(a) Frequency/Mix/Channel:
(b) Frequency/Mix/Channel:

Amplitude to Depth:
(a) Frequency/Mix/Channel:
(b) Frequency/Mix/Channel:

Other:

Tables (List & Attach):

2. DATA REVIEW REQUIREMENTS
Extent:
Two Party:
Computer Screen:
Software/Mfg./Version:
Other:

3. REPORTING REQUIREMENTS
Flaw Depth Threshold:
Voltage Threshold:
Signal to Noise Threshold:
Other:

4. INSTRUMENT
Manufacturer:
Software/Mfg./Version:

MANDATORY APPENDIX VI
QUALIFICATION OF PERSONNEL FOR VISUAL EXAMINATION

ARTICLE VI-1000
INTRODUCTION AND SCOPE

This Appendix specifies the training requirements and experience for visual examination personnel in preparation for employer certification to perform VT-1, VT-2, and VT-3 visual examinations. Personnel shall be qualified in accordance with IWA-2300 as modified by this Appendix.

ARTICLE VI-2000
QUALIFICATION LEVELS

VI-2100 GENERAL REQUIREMENTS

There are five qualification levels: Trainee, Level I, Level II, Level III, and NDE Instructor. The skills and responsibilities associated with each level shall be as defined in ANSI/ASNT CP-189, as modified by IWA-2300.

ARTICLE VI-3000
WRITTEN PRACTICE

VI-3100 GENERAL REQUIREMENTS

Organizations performing training, examination, or qualification activities shall prepare a written practice in accordance with ANSI/ASNT CP-189, as modified by this Division, for their control and administration.

VI-3110 EXPERIENCE

The written practice shall specify the experience requirements for each qualification level in accordance with ANSI/ASNT CP-189 and the additional experience that may be required for special visual examination applications, such as in-vessel visual examination.

VI-3120 TRAINING

The written practice shall specify the training requirements for each qualification level in accordance with ANSI/ASNT CP-189 and the additional training that may be required for special visual examination applications, such as in-vessel visual examination.

VI-3130 EXAMINATIONS

The written practice shall specify the examination requirements for each qualification level in accordance with ANSI/ASNT CP-189.

VI-3200 RESPONSIBILITIES

The written practice shall specify the responsibilities, duties, and qualifications required for personnel who perform examinations or implement the personnel qualification program.

VI-3300 USE OF AN OUTSIDE AGENCY

(a) An outside agency is an organization or individual that provides NDE Level III or Instructor services. The organization that engages the outside agency qualifies that agency. The written practice of the organization that engages the outside agency shall specify requirements for ensuring the outside agency meets the applicable requirements of ANSI/ASNT CP-189 and this Appendix.

(b) The outside agency shall maintain a written practice that specifies the documentation to be maintained in the agency's qualification records. This documentation shall include such information as stated in Mandatory Appendix VII, VII-3300(b).

(c) An outside agency administering the examinations required by this Appendix may be an independent company or a functionally independent organization within the same company.

VI-3400 CONFIDENTIALITY

The written practice shall specify the provisions to ensure the confidentiality of qualification materials, e.g., test questions, answer sheets, and test specimens.

ARTICLE VI-4000 QUALIFICATION REQUIREMENTS

VI-4100 EXPERIENCE

VI-4110 INITIAL CERTIFICATION FOR VISUAL EXAMINATION

(a) Experience in each discipline is required for unlimited certification. The term "experience" refers to visual examination defined in IWA-2211, IWA-2212, and IWA-2213, or related experience in the applicable method such as the following:

(1) for VT-1, experience as a weld examiner, AWS CWI or AWS CAWI;

(2) for VT-1, experience in performing surface examinations;

(3) for VT-2, experience in pressure tests;

(4) for VT-2, plant walkdown experience, such as that gained by licensed and nonlicensed operators, local leak rate personnel, system engineers, quality control personnel, and nondestructive examination personnel;

(5) for VT-3, installation, maintenance, or examination of pumps, valves, or supports;

(6) for VT-1 and VT-3, experience in installation, maintenance, or examination of RPV internals, or other remote visual examination;

(7) for Level III, documented visual training or examination activities; administration or development of VT-1, VT-2, or VT-3 visual examination training or examination programs; or experience as defined in (1) through (6) above.

(b) Experience shall be documented by specific tasks and disciplines, e.g., 10 hr VT-3 visual examination of supports.

(c) No more than 50% of the required experience for VT-1 visual examination shall be in surface examination.

VI-4200 TRAINING

Visual examination personnel shall successfully complete the training program outlined in Supplement 1. Training received in other NDE disciplines or academic training courses covering the topics in Supplement 1 may be credited toward certification. The hours of training shall be in accordance with ANSI/ASNT CP-189.

VI-4300 EXAMINATIONS

To be considered for examination, the Levels I, II, and III candidates shall successfully complete the training required by VI-4200. Levels I and II qualification examinations shall be in accordance with ANSI/ASNT CP-189. Level III qualification examinations shall be in accordance with IWA-2300.

MANDATORY APPENDIX VI SUPPLEMENTS

SUPPLEMENT 1 CONTENT OF INITIAL TRAINING COURSES

1.0 FUNDAMENTALS OF VISUAL EXAMINATION

1.1 Definition of visual examination

1.2 Overview of visual examination

1.3 Standard terms and definitions

1.4 Vision requirements

1.5 Lighting requirements

1.6 Direct and remote methods

2.0 VISUAL EXAMINATION METHODS

2.1 VT-1

2.2 VT-2

2.3 VT-3

3.0 VISUAL EXAMINATION EQUIPMENT

3.1 Optical aids
(a) Mirrors and magnifiers
(b) Borescopes and fiberscopes
(c) Closed-circuit television
(d) Lighting and light measurement

3.2 Mechanical measuring devices
(a) Scales and calipers
(b) Gages

4.0 MATERIALS AND PROCESSES

4.1 Manufacturing discontinuities
(a) Castings and forgings
(b) Rolled and wrought products
(c) Extruding, drawing, and piercing

4.2 Welding discontinuities

4.3 Service-related discontinuities

5.0 VISUAL EXAMINATION OF COMPONENTS

5.1 Valves

5.2 Pumps

5.3 Bolting

5.4 Welds

6.0 VISUAL EXAMINATION OF COMPONENT SUPPORTS

6.1 Support categories
(a) Plate and shell type supports
(b) Linear type supports
(c) Component standard supports

6.2 Types of supports
(a) Buried supports
(b) Constant load supports
(c) Hangers
(d) Variable spring type supports
(e) Restraints
(f) Mechanical and hydraulic snubbers
(g) Guides and stops
(h) Vibration control and sway braces

6.3 Examination boundaries

7.0 VISUAL EXAMINATION FOR LEAKAGE

7.1 System pressure testing
(a) System leakage test
(b) System hydrostatic test
(c) System pneumatic test
(d) Buried components

7.2 Plant systems and components

8.0 RECORDS AND REPORTS

8.1 Data sheets

8.2 Identification stamps and certification

9.0 PROCEDURES

9.1 Requirements

9.2 Format

9.3 Acceptance criteria

9.4 Documentation

10.0 ADDITIONAL TRAINING FOR REACTOR VESSEL INTERNALS EXAMINATION

10.1 BWR internal design (as applicable)

10.2 PWR internal design (as applicable)

10.3 Remote examination equipment
(a) Camera, monitor, and recording equipment design
(b) Operation, of specific equipment

10.4 Examination requirements for internals

11.0 ADDITIONAL TRAINING FOR LEVEL III CANDIDATES

11.1 Nuclear power plant design, function, and system operation

11.2 Materials, metal processing, fabrication technology, failure mechanisms, and fracture mechanics techniques

11.3 Review of NDE methods commonly used during ISI

11.4 Administration of NDE personnel qualification and certification practices and instructional techniques

11.5 Codes, standards, and regulatory requirements

11.6 Procedure preparation

Notes:
(1) The training shall cover the applicable topics for the visual technique and level.
(2) The hours of instruction devoted to each subject shall be determined by the Level III.

MANDATORY APPENDIX VII
QUALIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL FOR ULTRASONIC EXAMINATION

ARTICLE VII-1000
INTRODUCTION AND SCOPE

This Appendix specifies requirements for the training and qualification of ultrasonic nondestructive examination (NDE) personnel in preparation for Employer certification to perform NDE. Personnel shall be qualified in accordance with IWA-2300 as modified by this Appendix.

ARTICLE VII-2000
QUALIFICATION LEVELS

VII-2100 GENERAL REQUIREMENTS

There shall be five qualification levels: Trainee, Level I, Level II, Level III, and NDE Instructor. The skills and responsibilities associated with each level shall be as defined in ANSI/ASNT CP-189.

ARTICLE VII-3000
WRITTEN PRACTICE

VII-3100 GENERAL REQUIREMENTS

Organizations performing training, examination, or qualification activities shall prepare a written practice for their control and administration.

VII-3110 EXPERIENCE

The written practice shall specify the experience requirements for each qualification level in accordance with VII-4100 and the additional experience that may be required for special NDE applications.

VII-3120 TRAINING

The written practice shall specify the following:

(a) classroom and laboratory training requirements for each qualification level in accordance with VII-4200;

(b) additional training that may be required for special NDE applications; and

(c) course outlines for each qualification level including the number of instruction contact hours.

VII-3130 ANNUAL TRAINING

The written practice shall specify the requirements for annual training for each qualification level. Annual training shall be in accordance with VII-4240.

VII-3140 EXAMINATIONS

The written practice shall specify the examination requirements for each qualification level. Examination requirements shall be in accordance with VII-4300.

VII-3200 RESPONSIBILITIES

The written practice shall specify the responsibilities, duties, and qualifications required for personnel who perform examinations or implement the personnel qualification program. The written practice shall specify the responsibilities of NDE Instructors, Level III personnel, or other individuals providing classroom or laboratory training.

VII-3300 USE OF AN OUTSIDE AGENCY

(a) An outside agency is an organization or individual that provides NDE Level III or NDE Instructor services and whose qualifications have been accepted by the organization that engages the outside agency. The written practice of the organization that engages the outside agency shall specify requirements for assuring the outside agency meets the applicable requirements of this Appendix.

(b) Each outside agency shall maintain a written practice that specifies the documentation to be maintained in the agency's qualification records. This documentation shall include such information as the qualification examinations, candidate's name and certification level, date of examination, overall course grade, and formal qualification examination grade.

(c) An outside agency administering the examinations of VII-4342 may be an independent company or a functionally independent organization within the same company.

VII-3400 CONFIDENTIALITY

Provisions to assure the confidentiality of qualification materials (e.g., test questions, answer sheets, and test specimens) shall be included in the written practice. Access to such qualification materials shall be limited, and the qualification examinations shall be maintained in secure files.

VII-3500 AVAILABILITY OF TRAINING COURSE MATERIALS

Training course materials shall be available for review or audit by user organizations and cognizant authorities. Training course materials shall not be subject to any confidentiality requirements other than the normally applicable copyright laws.

ARTICLE VII-4000 QUALIFICATION REQUIREMENTS

VII-4100 EXPERIENCE

VII-4110 INITIAL CERTIFICATION FOR ULTRASONIC EXAMINATION

Table VII-4110-1 lists the required experience for initial certification for ultrasonic examination. As used in this Appendix, experience means performance of the skill activities described or referenced in Article VII-2000 for the applicable NDE Level.

VII-4120 EXPERIENCE OPTIONS FOR LEVEL III PERSONNEL

The three experience options identified in Table VII-4110-1 for qualification as a Level III are as follows.

Table VII-4110-1 Required Experience for Initial Certification for Ultrasonic Examination (Hours)

Trainee	Level I	Level II	Level III
None	250	800	4200 (Option 1) 6300 (Option 2) 8400 (Option 3)

GENERAL NOTES:
(a) For Level II certification, the experience shall consist of time at Level I. To certify a candidate directly to Level II with no time at Level I, the total experience hours required for Level I plus Level II shall apply.
(b) Prior certification as a Level I or Level II is not required.
(c) All or part of the Level I experience hours may be satisfied by laboratory practice hours beyond those required for training in accordance with VII-4220, provided those practice hours are dedicated to the Level I or Level II skill areas as described in CP-189.
(d) The 800 hr of Level II experience time may be reduced to 400 hr, which shall include a minimum of 80 hr of field experience and a minimum of 320 hr of laboratory practice, provided that the practice is dedicated to scanning specimens containing flaws in materials representative of those in actual power plant components and the candidate passes a Mandatory Appendix VIII, Supplement 2 performance demonstration for detection and length sizing.

VII-4121 Option 1

Graduate of a 4 yr accredited engineering or science college or university with a degree in engineering or science, plus 2 yr experience in NDE in an assignment comparable to that of an NDE Level II in the ultrasonic examination method.

VII-4122 Option 2

Completion with a passing grade of at least the equivalent of 2 full years of engineering or science study at a university, college, or technical school, plus 3 yr experience in an assignment comparable to that of a Level II in the ultrasonic examination method.

VII-4123 Option 3

High school graduate, or equivalent, plus 4 yr experience in an assignment comparable to that of a Level II in the ultrasonic examination method.

VII-4130 EXPERIENCE RECORDS

(a) The records maintained by the Employer to substantiate experience for initial certification to each level shall include the activity performed, the number of hours performing the method, and the level of certification.

(b) Documented experience with the current Employer may be used for certification in accordance with this Appendix, subject to acceptance by a Level III.

(c) Experience during previous employment may be accepted where such experience is supported by documentation. The documentation may be a copy of an experience record form obtained from the previous Employer or a written statement signed by a cognizant, responsible member of the previous Employer's staff attesting to the type and extent of ultrasonic examination experience to be credited. A Level III shall be responsible for reviewing the documentation and judging previous experience for acceptability under the current Employer's written practice.

VII-4200 TRAINING

VII-4210 PROGRAM, FACILITIES, AND MATERIALS

(a) Personnel shall successfully complete the training program outlined in Supplement 1.

(b) Training shall be conducted by an NDE Instructor except that portions of the training may be conducted by individuals designated by the NDE Instructor.

(c) Classroom and laboratory facilities shall be provided.

(d) Training course materials shall be prepared and made available to the candidate.

VII-4220 TRAINING COURSE CONTENT AND DURATION

VII-4221 Training Course Content

Training course content shall be in accordance with Supplement 1.

VII-4222 Initial Training Hours

The initial training hours shall be as specified in Table VII-4220-1.

VII-4223 Training Requirements for Previously Qualified Individuals

(a) For individuals who have been previously qualified to Level I or Level II under a written practice that did not include the additional requirements of this Appendix, additional training shall be required prior to requalification if the individual has not completed the cumulative hours of training in the ultrasonic method required by Table VII-4220-1 for the applicable Level of qualification.

(b) The individual's training, including the additional training of (a), shall cover the topics listed in Supplement 1 for the applicable Level of qualification.

(c) Prior documented training that addressed the topics covered in Supplement 1 may be credited for each individual. The credited training shall be subtracted from the requirements of Table VII-4220-1 and Supplement 1 to determine the hours and topics, respectively, to be covered in the additional training. The additional training shall be conducted by an NDE Instructor.

Table VII-4220-1
Initial Training Hours (Classroom/Laboratory)

Level I	Level II	Level III
40/40	40/40	40/0

GENERAL NOTES:

(a) To certify a candidate directly to Level II with no time at Level I, the total hours of training required for Level I plus Level II shall apply.

(b) To certify a candidate directly to Level III with no time at Level I or Level II, the total hours of training required for Level I plus Level II plus Level III shall apply.

(c) Industrial or academic training courses covering the topics listed in 9.0 of Supplement 1 may be credited toward the training required for Level III personnel.

(d) The hours of instruction devoted to each subject in Supplement 1 shall be determined by the NDE Instructor.

VII-4230 EVALUATION OF INITIAL TRAINING EFFECTIVENESS

(a) If the qualification examination for certification (VII-4300) is not given at the conclusion of training, a final course examination shall be given. A grade of 70% is necessary to receive credit for the training hours.

(b) When an individual fails a final course examination, additional training shall be required prior to reexamination. The additional training shall address the areas of weakness exhibited by the individual and shall be documented by the NDE Instructor.

VII-4240 ANNUAL PRACTICE

Supplemental practice shall be used to maintain UT Level II and Level III personnel examination skills. Personnel shall practice UT techniques by examining or by analyzing prerecorded data from material or welds containing flaws similar to those that may be encountered during inservice examinations. This practice shall be at least 8 hr per year and shall be administered by an NDE Instructor or Level III. No examination is required.

VII-4300 EXAMINATIONS

To be considered for examination, the Level I, II, and III candidates shall have successfully completed the training required in VII-4200.

VII-4310 EXAMINATION QUESTIONS AND TEST SPECIMENS

(a) For each written examination administered as part of the qualification examination, a "question bank" containing at least twice the minimum number of questions required per examination shall be available. Qualification examinations shall be assembled from the question bank using a random selection process. The random selection process shall be controlled by the employer's written practice, such that no individual takes the same examination more than once.

(b) For each Practical Examination that does not use specimens prepared for UT performance demonstrations (i.e., Mandatory Appendix VIII) and is administered as part of the qualification examination, a "specimen bank" containing at least five flaws shall be available. Grading units, as defined in Mandatory Appendix VIII, may be used to produce the specimen bank. The flaws in the specimen bank shall be simulated flaws not exceeding the standards of IWB-3500, actual flaws, or a mixture of both. The specimen or grading unit set for each Practical Examination shall be assembled from the specimen bank using a random selection process. Blank (sound) test specimens or grading units shall be included in the specimen set so that

no more than one-third of the specimens or grading units in the set contain flaws required to be detected. The specimens or grading units shall be masked such that flawed and blank specimens or grading units cannot be identified and the flaw locations are not visible.

VII-4320 LEVELS I AND II QUALIFICATION EXAMINATIONS

VII-4321 Levels I and II General Examinations

The General Examination shall be a written, closed book examination containing a minimum of 40 questions. The examination shall cover the technical principles relative to the ultrasonic (UT) method.

VII-4322 Levels I and II Specific Examinations

(a) The Specific Examination shall be a written examination containing a minimum of 40 questions. Necessary data, such as graphs, tables, specifications, procedures, and Codes shall be furnished.

(b) Forty to 60% of the specific examination questions shall cover Section XI NDE requirements. The remaining questions shall cover procedures and specifications applicable to the UT method.

VII-4323 Levels I and II Practical Examinations

(a) Candidates shall demonstrate to the satisfaction of a Level III that they are familiar with and can perform the applicable UT examinations using suitable calibration blocks and written UT procedures prepared for examination of plant components.

(b) The Practical Examination shall include examination of a specimen set that complies with VII-4310(b). Alternately, successful completion of a UT performance demonstration in accordance with Mandatory Appendix VIII may serve as this Practical Examination.

(c) An assessment report containing at least ten check points shall be used to evaluate the candidate's performance using longitudinal and shear wave techniques. The following check points shall be included:

(1) scanning technique;
(2) equipment set-up and calibration;
(3) selection of search unit;
(4) data recording (Levels I and II);
(5) NDE report (Level II); and
(6) evaluation in terms of the recording criteria.

(d) A description of the specimens and the calibration blocks, the procedures used, the assessment report, and the examination report prepared by the candidate shall be retained as part of the certification records.

VII-4330 LEVEL III QUALIFICATION EXAMINATIONS

(a) Level III Examinations shall be in accordance with IWA-2300, except that the Demonstration Examination shall meet VII-4323 Level II Practical Examination rules. In addition, the Specific Examination shall be a written examination containing at least 30 questions. Forty to 60% of the questions shall cover Section XI UT examination, evaluation, and acceptance criteria. Necessary data such as graphs, tables, specifications, procedures, and Codes shall be furnished.

(b) Level III personnel shall be recertified using the written Method, Specific, and Practical Examinations and the Demonstration Examination. Alternatively, Level III personnel may be recertified using only the written Method and Specific Examinations provided the following conditions are met:

(1) The Level III candidate was previously certified or recertified using all the written examinations and the Demonstration Examination.

(2) The Level III candidate is not being recertified due to interrupted service as defined in the Employer's written practice.

(3) The Level III candidate is not being recertified by a new Employer.

VII-4340 ADMINISTRATION OF EXAMINATIONS

VII-4341 Levels I and II General, Specific, and Practical Examinations

The General, Specific, and Practical Examinations shall be approved, administered, and graded by a Level III. The candidate shall perform the Practical Examinations using procedures, techniques, and equipment complying with Section XI requirements on specimens not used for training.

VII-4342 Level III Basic, Method, Specific, Practical, and Demonstration Examinations

(a) Level III Basic and Method Examinations shall be administered and graded by an outside agency.

(b) The Specific, Practical, and Demonstration Examinations shall be approved, administered, and graded by a Level III employed by an outside agency or the Employer.

VII-4343 Written Examination Administration

The administration of multiple-choice written examinations may be delegated by the Level III, with valid Level III certifications in the applicable test methods, to a noncertified proctor, if so documented.

VII-4350 GRADING OF EXAMINATIONS

(a) A minimum score of 80% is required for the composite score on a certification examination and a minimum score of 70% for each of the applicable general, basic, specific, method, demonstration, and practical examinations. When the examinations are graded by an outside agency, a grade of 80% shall be assigned for those examinations the candidate passed unless actual numerical grades are provided, in which case the numerical grades shall be recorded.

(b) The Levels I and II Practical Examinations and the Level III Demonstration Examinations shall be graded such that failure to accurately detect, locate, interpret, evaluate, or record, as applicable for the examination, 80% of the known conditions in the test specimen set shall cause the candidate to fail the examination. In addition, a maximum false call rate of 10% shall be imposed (i.e., no more than 10% of the blank test specimens shall be reported as flawed).

VII-4360 REEXAMINATION

(a) Those individuals failing to pass a qualification examination must receive additional training as determined by a Level III. This determination shall be based on the topics or subjects on which the individual failed to attain a passing grade.

(b) The reexamination questions shall be assembled by a random selection process or the examination shall contain at least 30% different or reworded questions. The Practical or Demonstration Examination test specimen set shall contain at least 50% different flaws from those used during the most recent Practical or Demonstration Examination that was not passed by the candidate.

(c) No individual shall be reexamined more than twice within any consecutive 12-month period.

VII-4400 INTERRUPTED SERVICE

Personnel who have not performed the duties associated with their certification level during any consecutive 12-month period shall be considered to have interrupted service and shall be required to successfully complete a Practical Examination (Levels I and II personnel), or a Specific Examination (Level III personnel), to assure continued proficiency prior to further assignment to perform NDE. The results of this examination shall be documented and maintained as part of the individual's certification records.

ARTICLE VII-5000 QUALIFICATION RECORDS

VII-5100 PRE-CERTIFICATION RECORDS

Prior to certification or recertification, the records of the individual shall include the following:

(a) name of the individual;

(b) qualification level;

(c) educational background and experience;

(d) statement indicating satisfactory completion of training, including training hours, dates attended, and training institution;

(e) record of annual supplemental training;

(f) results of vision examinations;

(g) current qualification examination results, with traceability to the actual examination; and

(h) grade assigned to each qualification examination.

VII-5200 CERTIFICATION RECORDS

In addition to the records required in VII-5100, the records of certified individuals shall include the following:

(a) date of current certification and expiration date;

(b) name and signature of certifying Employer representative; and

(c) evidence of continued proficiency (VII-4400).

VII-5300 MAINTENANCE OF RECORDS

The qualification records shall be maintained by the Employer. In addition, outside agencies that perform training and qualification activities shall maintain the qualification records specified in VII-3300.

MANDATORY APPENDIX VII SUPPLEMENTS

SUPPLEMENT 1 MINIMUM CONTENT OF INITIAL TRAINING COURSES FOR THE ULTRASONIC EXAMINATION METHOD

1.0 FUNDAMENTAL PROPERTIES OF SOUND

1.1 Frequency, velocity, and wavelength

1.2 Definition of ultrasonic vibrations

1.3 General application of ultrasonic vibrations

2.0 PRINCIPLES OF WAVE PROPAGATION

2.1 Modes of vibration

2.2 Acoustic impedance

2.3 Reflection

2.4 Refraction and mode conversion

2.5 Diffraction, dispersion, and attenuation

2.6 Fresnel and Fraunhofer effects

3.0 GENERATION OF ULTRASONIC WAVES

3.1 Piezoelectricity and types of crystals

3.2 Construction of ultrasonic search units

3.3 Characteristics of search units
(a) Frequency-crystal thickness relationships
(b) Conversion efficiencies of various crystals
(c) Damping and resolution
(d) Beam intensity characteristics
(e) Divergence

3.4 Care of search units

4.0 ULTRASONIC TESTING TECHNIQUES

4.1 Contact testing
(a) Straight beam
(b) Angle beam
(c) Surface wave
(d) Lamb wave
(e) Through transmission

4.2 Immersion testing
(a) Straight beam
(b) Angle beam
(c) Through transmission

4.3 Modified immersion testing
(a) Tests employing special devices

4.4 Resonance testing

4.5 Geometric indications, flaw indications, and methods of discrimination

4.6 Flaw sizing

5.0 ULTRASONIC TESTING EQUIPMENT

5.1 Description of basic pulse-echo instrument
(a) Time-base (synchronizer) circuit
(b) Pulser circuit
(c) A-scan display circuit

5.2 Special instruments
(a) B-scan display
(b) C-scan display
(c) Monitors and recording devices

5.3 Scanning equipment
(a) Manipulators
(b) Bridges
(c) Special scanning devices

6.0 OPERATION OF SPECIFIC EQUIPMENT

6.1 General operating characteristics

6.2 Functional block diagram of circuits

6.3 Purpose and adjustment of external controls

6.4 Care of equipment and calibration blocks

7.0 SPECIFIC TESTING PROCEDURES

7.1 Selection of test parameters
(a) Frequency
(b) Search unit size and type
(c) Water distance (immersed test)
(d) Scanning speed and index

7.2 Test standardization
(a) Ultrasonic reference blocks
(b) Adjustment of test sensitivity

7.3 Interpretation of results
(a) Acceptance standards
(b) Comparison between responses from discontinuities to those from ultrasonic reference standards
(c) Estimated length of discontinuities
(d) Location of discontinuities
(e) Zoning

7.4 Test records
(a) Data sheets
(b) Maps
(c) Identification stamps and certification

7.5 Equipment performance variations

8.0 VARIABLES AFFECTING TEST RESULTS

8.1 Instrument performance variations

8.2 Search unit performance variations

8.3 Inspected parts variations
(a) Entry surface condition
(b) Part size and geometry
(c) Metallurgical structure

8.4 Discontinuity variations
(a) Size and geometry
(b) Distance from entry point
(c) Orientation to entry surface
(d) Discontinuity types and reflecting characteristics

9.0 ADDITIONAL TRAINING FOR LEVEL III CANDIDATES

9.1 Nuclear power plant design, function, and system operation

9.2 Materials, metal processing, fabrication technology, failure mechanisms, and fracture mechanics techniques

9.3 Review of NDE methods commonly used during ISI

9.4 Administration of NDE personnel qualification and certification practices and instructional techniques

9.5 Code, standard, and regulatory requirements

9.6 Procedure preparation

MANDATORY APPENDIX VIII PERFORMANCE DEMONSTRATION FOR ULTRASONIC EXAMINATION SYSTEMS

ARTICLE VIII-1000 SCOPE

VIII-1100 GENERAL

(a) This Appendix provides requirements for performance demonstration for ultrasonic examination procedures, equipment, and personnel used to detect and size flaws.

(b) Each organization (e.g., Owner or vendor) shall have a written program that insures compliance with this Appendix. Each organization that performs ultrasonic examinations shall qualify its procedures, equipment, and personnel in accordance with this Appendix. The organization may contract implementation of the program.

(c) Performance demonstration requirements apply to personnel who detect, record, or interpret indications or size flaws in welds or components.

(d) The performance demonstration requirements specified in this Appendix do not apply to personnel whose involvement is limited to mounting a scanner device, marking pipe, or other situations where knowledge of ultrasonics is not important.

(e) Any procedure qualified in accordance with this Appendix is acceptable.

(f) Instrument characterization described in Supplement 1 is optional. When Supplement 1 is selected, both the original and substituted equipment shall be characterized.

ARTICLE VIII-2000
GENERAL EXAMINATION SYSTEM REQUIREMENTS

(15) VIII-2100 PROCEDURE REQUIREMENTS

(a) The examination procedure shall contain a statement of scope that specifically defines the limits of procedure applicability (e.g., materials, thickness, diameter, product form).

(b) The examination procedure shall specify a single value or a range of values for the variables listed in (d).

(c) Any calibration method may be used provided it is described and complies with (d)(5).

(d) The examination procedure shall specify the following essential variables:

(1) instrument or system, including manufacturer, and model or series, of pulser, receiver, and amplifier;

(2) search units, including manufacturer, and model or series, and the following:

(-a) nominal frequency or, if Supplement 1 is used, the center frequency and either bandwidth or waveform duration as defined in Article VIII-4000;

(-b) mode of propagation and nominal inspection angles;

(-c) number, size, shape, and configuration of active elements and wedges or shoes;

(3) search unit cable, including the following:

(-a) type;

(-b) maximum length, +1 ft (300 mm) to allow for manufacturing tolerances;

(-c) maximum number of connectors;

(4) detection and sizing techniques, including the following:

(-a) scan pattern and beam directions;

(-b) maximum scan speed;

(-c) minimum and maximum pulse repetition rate;

(-d) minimum sampling rate (automatic recording systems);

(-e) extent of scanning and action to be taken for access restrictions;

(5) methods of calibration for detection and sizing (e.g., actions required to insure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system, whether displayed, recorded, or automatically processed, are repeated from examination to examination);

(6) inspection and calibration data to be recorded;

(7) method of data recording;

(8) recording equipment (e.g., strip chart, analog tape, digitizing) when used;

(9) method and criteria for the discrimination of indications (e.g., geometric versus flaw indications and for length and depth sizing of flaws);

(10) surface preparation requirements.

VIII-2200 PERSONNEL REQUIREMENTS

Personnel shall meet the requirements of Article VIII-3000.

ARTICLE VIII-3000
QUALIFICATION REQUIREMENTS

VIII-3100 QUALIFICATION TEST REQUIREMENTS

(15) VIII-3110 DETECTION

(a) Qualification test specimens shall meet the requirements of the appropriate Supplement listed in Table VIII-3110-1.

(b) Qualification test specimens may be segments of full-scale mock-ups or separate specimens cut from full-scale segments. Additional specimens can be generated by altering the flow direction or by changing reference points. Divulgence of full-scale mock-up identification to the candidate is acceptable, provided the flaw locations and specimen identifications are not provided.

(c) The examination procedure, equipment, and personnel are qualified for detecting flaws upon successful completion of the performance demonstration specified in the appropriate Supplement listed in Table VIII-3110-1.

(d) For piping welds whose requirements are in course of preparation, the requirements of Mandatory Appendix III, as supplemented by Table I-2000-1, shall be met.

VIII-3120 SIZING (15)

(a) Qualification test specimens shall meet the requirements of the appropriate Supplement listed in Table VIII-3110-1.

(b) Qualification test specimens may be segments of full-scale mock-ups or separate specimens cut from full-scale segments. Additional specimens can be generated by altering the flow direction or by changing reference points. Divulgence of full-scale mock-up identification to the candidate is acceptable, provided the flaw locations (unless allowed by the specific supplement) and specimen identifications are not provided.

(c) The examination procedure, equipment, and personnel are qualified for sizing flaws upon successful completion of the performance demonstration specified in the appropriate Supplement listed in Table VIII-3110-1. When the applicable piping supplement contains no provisions for a performance demonstration using axially oriented flaws, examination personnel, equipment, procedures, and the associated techniques qualified for

Table VIII-3110-1
Component Qualification Supplements

Component Type	Applicable Supplement
Piping Welds	
Wrought austenitic	2
Ferritic	3
Cast austenitic	[Note (1)]
Structural weld inlay (corrosion- resistant clad) austenitic	[Note (1)]
Dissimilar metal	10
Overlay	11
Coordinated implementation	12
Vessels	
Clad/base metal interface region	4
Nozzle examinations from the outside surface	5
Reactor vessel welds other than clad/base metal interface	6
Nozzle examinations from the inside surface	7
Bolts and Studs	8

NOTE:
(1) In the course of preparation.

sizing on circumferentially oriented flaws shall be used, with any modifications to essential variables being limited to those that compensate for component geometry.

(d) For piping welds whose requirements are in course of preparation, the requirements of Mandatory Appendix III, as supplemented by Table I-2000-1, shall be met.

(e) RMS error shall be calculated as follows:

$$\mathrm{RMS} = \left[\frac{\sum_{i=1}^{n} \left(m_i - t_i \right)^2}{n} \right]^{1/2}$$

where

m_i = measured flaw size
n = number of flaws measured
t_i = true flaw size

VIII-3130 ESSENTIAL VARIABLE RANGES

(a) Any two procedures with the same essential variables [VIII-2100(d)] are considered equivalent. Pulsers, search units, and receivers that vary within the tolerances specified in VIII-4100 are considered equivalent. When the pulsers, search units, and receivers vary beyond the tolerances of VIII-4100, or when the examination procedure allows more than one value or range for an essential variable, the qualification test shall be repeated at the minimum and maximum value for each essential variable with all other variables remaining at nominal values. Changing the essential variable may be accomplished during successive personnel performance demonstrations. Each examiner need not demonstrate qualification over the entire range of every essential variable.

(b) When the procedure does not specify a range for essential variables and establishes criteria for selecting values, the criteria shall be demonstrated.

VIII-3140 REQUALIFICATION

When a change in an examination procedure causes an essential variable to exceed a qualified range, the examination procedure shall be requalified for the revised range.

ARTICLE VIII-4000
ESSENTIAL VARIABLE TOLERANCES

VIII-4100 PROCEDURE MODIFICATIONS

VIII-4110 EXAMINATION SYSTEM COMPONENTS

Components of the same manufacturer, and model or series, are substitutable without further consideration. The qualified procedure may be modified to replace examination system components without requalification when the following conditions are met.

(a) Instruments with reject, damping, or pulse tuning controls, have discrete settings specified in the procedure.

(b) Pulsers and receivers shall be evaluated using ASTM E1324, Guide for Measuring Some Electronic Characteristics of Ultrasonic Instruments, with the following exceptions:

(1) The lower (F_L) and upper (F_U) limits for receivers shall be determined between frequencies that are 6 dB below the peak frequency.

(2) The receiver center frequency (F_C) shall be determined by:

$$F_C = \frac{F_L + F_U}{2}$$

(3) The receiver band width (BW) shall be determined by:

$$BW = \frac{F_U - F_L}{F_C} \times 100$$

(c) Search units shall be evaluated using ASTM E1065, Evaluation of the Characteristics of Ultrasonic Search Units.

(d) Examination systems shall be evaluated using Supplement 1.

(e) Replacements of the instrument or the pulser section of the instrument system shall be within the following tolerances of the original equipment as measured into a 50 ohm, noninductive, noncapacitive, resistive load:

(1) pulse amplitude, ±10%;

(2) pulse rise time, ±10%;

(3) pulse duration, ±10%;

(f) Replacements of the instrument or the receiver section of the instrument system shall be within the following tolerances of the original equipment:

(1) lower and upper frequency limits at the −6 dB point, ±0.2 MHz;

(2) center frequency for instrument receivers with bandwidths less than 30%, ±5%;

(3) center frequency for instrument receivers with bandwidths equal to or greater than 30%, ±10%.

(g) Replacement search units of the same manufacturer's model, size, and nominal frequency may be used without requalification.

(h) Replacement search units not of the same manufacturer's model, size, and nominal frequency shall be within the following tolerances of the original search units:

(1) propagation mode is the same

(2) measured angle, ±3 deg

(3) center frequency for search units with bandwidths less than 30%, ±5%

(4) center frequency for search units with bandwidths equal to or greater than 30%, ±10%

(5) waveform duration, ±$\frac{1}{2}$ cycle or 20%, whichever is greater (measured at −20 dB), or bandwidth, ±10%

(i) As an alternative to (e) through (g) above, or for substitution of other components of the examination system identified as essential variables, equipment replacement is acceptable if the examination system is within the following tolerances of the original system when evaluated in accordance with Supplement 1:

(1) system center frequency for examination systems with bandwidths less than 30%, ±5%

(2) system center frequency for examination systems with bandwidths equal to or greater than 30%, ±10%

(3) system bandwidth, ±10%

VIII-4120 SEARCH UNIT CHARACTERIZATION

Characterization measurements of the search unit shall be made using either a sinusoidal tone burst technique or shock excitation. When using shock excitation, the characterization pulser and UT instrument pulser shall be the same within the limits of VIII-4110(e).

VIII-4200 COMPUTERIZED SYSTEM ALGORITHMS

When the performance demonstration uses prerecorded data, algorithms for automated decisions may be altered when the altered algorithms are demonstrated to be equivalent to those qualified. When the performance demonstration results meet the acceptance requirements of Article VIII-3000, the algorithm shall be considered qualified.

VIII-4300 CALIBRATION METHODS

Alternative calibration methods may be demonstrated equivalent to those described in the qualified procedure without requalification. This demonstration of equivalence shall be conducted for each beam angle and mode of propagation to which it applies, as follows.

(a) Calibrate the examination system in accordance with the alternative methods.

(b) Compare the sensitivity of the alternative calibration method to that of the qualified calibration method.

(c) The alternative calibration method is acceptable when the system sensitivity is no more than 2 dB below that obtained by the qualified method.

ARTICLE VIII-5000
RECORD OF QUALIFICATION

VIII-5100 GENERAL

The organization's performance demonstration program shall specify the documentation that shall be maintained as qualification records. Documentation shall include identification of personnel, NDE procedures, and equipment and specimens used during qualification, and results of the performance demonstration.

MANDATORY APPENDIX VIII SUPPLEMENTS

SUPPLEMENT 1 EVALUATING ELECTRONIC CHARACTERISTICS OF ULTRASONIC SYSTEMS

1.0 SYSTEM FREQUENCY CHARACTERISTICS

1.1 The frequency response, also known as the frequency spectrum, shall be determined by measuring of the amplitude of the pulse echo response from a target as a function of frequency. This response shall be used as a basis for establishing the center frequency and bandwidth of the ultrasonic system.

CAUTION: The required output signal test point from the ultrasonic instrument may require access to ultrasonic circuitry inside the instrument chassis. The use of high impedance test probes may also be required if the signal of interest is not buffered.

1.2 Connect the ultrasonic instrument including the search unit and, if applicable, the wedge, as shown in Figure VIII-S1-1A. The output signal from the ultrasonic instrument that is used in data analysis for flaw detection or flaw sizing (i.e., the output signal after amplification, filtering, and video detection) shall be input to a device that is capable of measuring the frequency spectrum (e.g., a spectrum analyzer or a digitizing circuit with a software package that determines the frequency response of waveforms). If a digitizing circuit is used, the rate of digitizing shall be at least five times the nominal (labeled) frequency of the search unit.

(a) If the receiver or transmitter provides variable signal filtering or frequency control, the signal controls shall be set as specified in the examination procedure. Check all connections in the test setup to ensure that it is safe to turn on the ultrasonic system.

(1) Flat or nonfocused search units shall be adjusted so that the distance (Z_o) from the face of the search unit to the target is 2 in. (50 mm)(see Figure VIII-S1-1B). A smooth glass block with dimensions 2 in. × 2 in. × 1 in. (50 mm × 50 mm × 25 mm) thick is recommended as the target. Using a manipulator, adjust the search unit angle with respect to the block until the return echo is maximized indicating that the sound field is perpendicular to the block. Adjust the receiver section gain controls until the ultrasonic signal amplitude from the block is 80% of full scale without saturating the ultrasonic signal. Plot the frequency spectrum of the ultrasonic signal as shown in Figure VIII-S1-2A.

(2) Determination of the frequency response for focused search units shall follow the same procedure for flat search units, except that the distance Z_o shall be adjusted to maximize echo from the glass target.

1.3 System Frequency Response Results

(a) Lower Frequency Limit (F_L) — The lower frequency limit (MHz) at a specific frequency control setting is the lowest frequency on the frequency response curve that is 6 dB below the maximum amplitude as shown in Figure VIII-S1-2A.

(b) Upper Frequency Limit (F_U) — The upper frequency limit (MHz) at a specific frequency control setting is the highest frequency on the frequency response curve that is 6 dB below the maximum amplitude as shown in Figure VIII-S1-2A.

(c) Center Frequency (F_C) — The center frequency (MHz) at a specific frequency control setting shall be calculated as follows:

$$F_C = \frac{F_L + F_U}{2}$$

(d) Bandwidth (BW) — The bandwidth (%) at a specific frequency control setting shall be calculated as follows:

$$BW = \frac{F_U - F_L}{F_C} \times 100$$

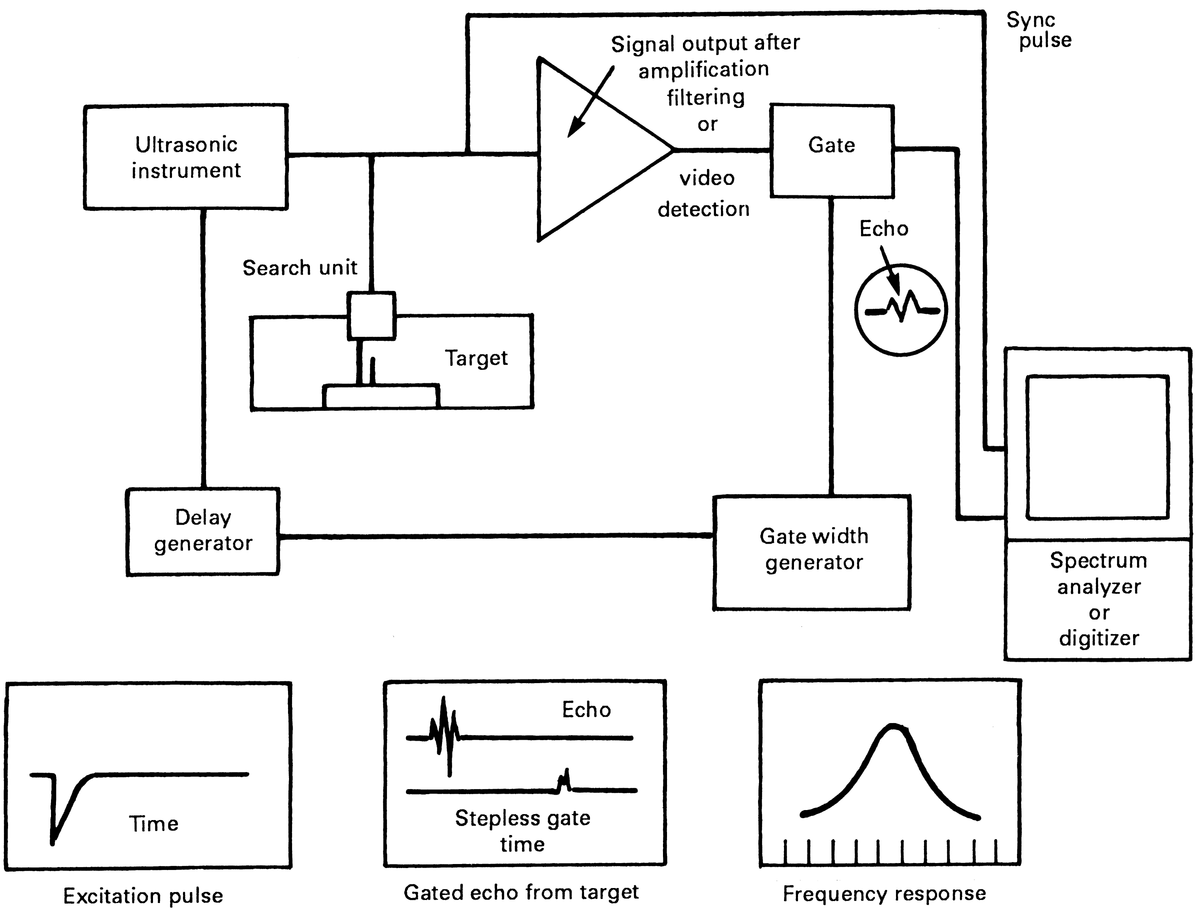
(e) The system frequency response results, (a) through (d) above, shall be obtained for the remaining receiver and transmitter control module setting combinations used in the performance demonstration. These values shall be recorded.

SUPPLEMENT 2 QUALIFICATION REQUIREMENTS FOR WROUGHT AUSTENITIC PIPING WELDS

1.0 SPECIMEN REQUIREMENTS

Qualification test specimens shall meet the requirements listed herein, unless a set of specimens is designed to accommodate specific limitations stated in the scope of the examination procedure (e.g., pipe size, access limitations). The same specimens may be used to demonstrate both detection and sizing qualification.

Figure VIII-S1-1A
System Configuration



1.1 General. This Supplement is applicable to austenitic piping welds examined from either the inside (I.D.) or outside (O.D.) surface. The applicable qualification criteria shall be satisfied separately. This Supplement is not applicable to piping welds containing supplemental corrosion-resistant cladding applied to mitigate IGSCC. The specimen set shall conform to the following requirements.

(a) Specimens shall have sufficient volume to minimize spurious reflections that may interfere with the interpretation process.

(b) The specimen set shall consist of at least four specimens having different nominal pipe diameters and thicknesses. The set shall include pipe specimens not thicker than 0.1 in. (2.5 mm) more than the minimum thickness, nor thinner than 0.5 in. (13 mm) less than the maximum thickness for which the examination procedure is applicable. It shall include the minimum, within NPS $^1/_2$, and maximum pipe diameters for which the examination procedure is applicable. If the procedure is applicable to pipe O.D. of 24 in. (600 mm) or larger, the specimen set must include at least one specimen 24 in. O.D. (600 mm) or larger but need not include the maximum diameter.

(c) Taking into consideration the accessible scanning surface, the O.D. or I.D. specimen set shall include applicable examples of the following fabrication conditions:

(1) unground weld reinforcement (crowns);

(2) wide crowns, such that the total crown width is $1^1/_2$ to 2 times the nominal pipe wall thickness;

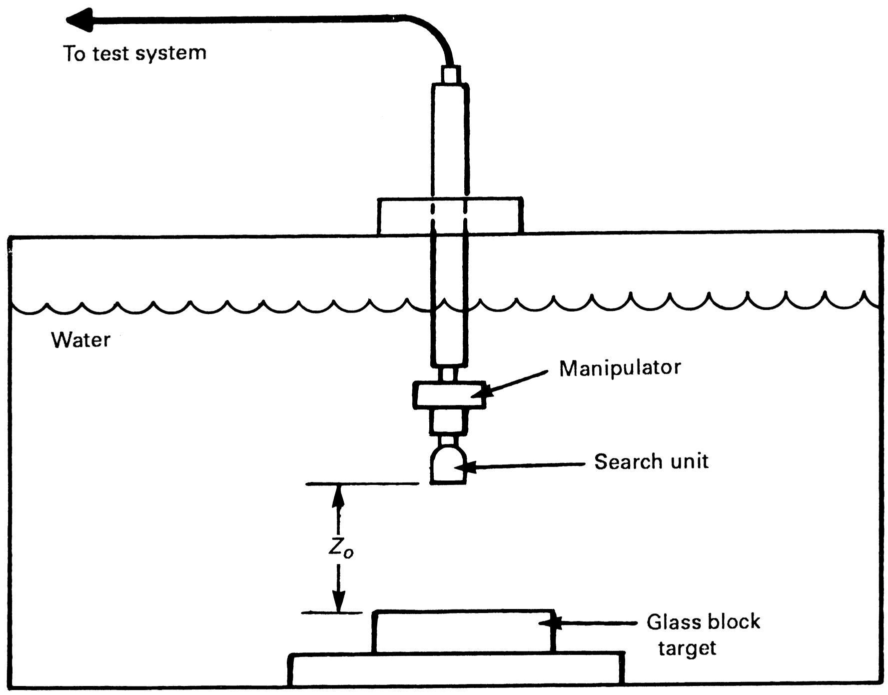
(3) geometric conditions that normally require discrimination from flaws (e.g., counterbore, weld root conditions such as excessive I.D. reinforcement for O.D. scans, or O.D. reinforcement for I.D. scans, as applicable);

(4) typical limited scanning surface conditions (e.g., diametrical shrink, single-side access due to safe ends or fittings, clad surfaces, or counterbore within the scanning area, as applicable).

(d) All flaws in the specimen set shall be cracks.

(1) Mechanical fatigue cracks and either IGSCC or thermal fatigue cracks shall be used. At least 75% of the cracks shall be either IGSCC or thermal fatigue cracks.

Figure VIII-S1-1B
Test Configuration



(2) At least 50% of the cracks shall be coincident with fabricated conditions described in (c) above.

1.2 Detection Specimens. The specimen set shall include detection specimens that meet the following requirements.

(a) Specimens shall be divided into grading units. Each grading unit shall include at least 3 in. (75 mm) of weld length. If a grading unit is designed to be unflawed, at least 1 in. (25 mm) of unflawed material shall exist on either side of the grading unit. The segment of weld length used in one grading unit shall not be used in another grading unit. Grading units need not be uniformly spaced around the pipe specimen.

(b) Detection sets for personnel qualification shall be selected from Table VIII-S2-1. The number of unflawed grading units shall be at least twice the number of flawed grading units. For initial procedure qualification, detection sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables, at least one personnel qualification set is required.

(c) Flawed grading units shall meet the following criteria for flaw depth, orientation, and type.

(1) A minimum of one-third of the flaws, rounded to the next higher whole number, shall have depths between 5% and 30% of the nominal pipe wall thickness. At least one-third of the flaws, rounded to the next higher whole number, shall have depths greater than 30% of the nominal pipe wall thickness.

(2) At least one and a maximum of 10% of the flaws, rounded to the next higher whole number, shall be oriented axially. The remainder of the flaws shall be oriented circumferentially.

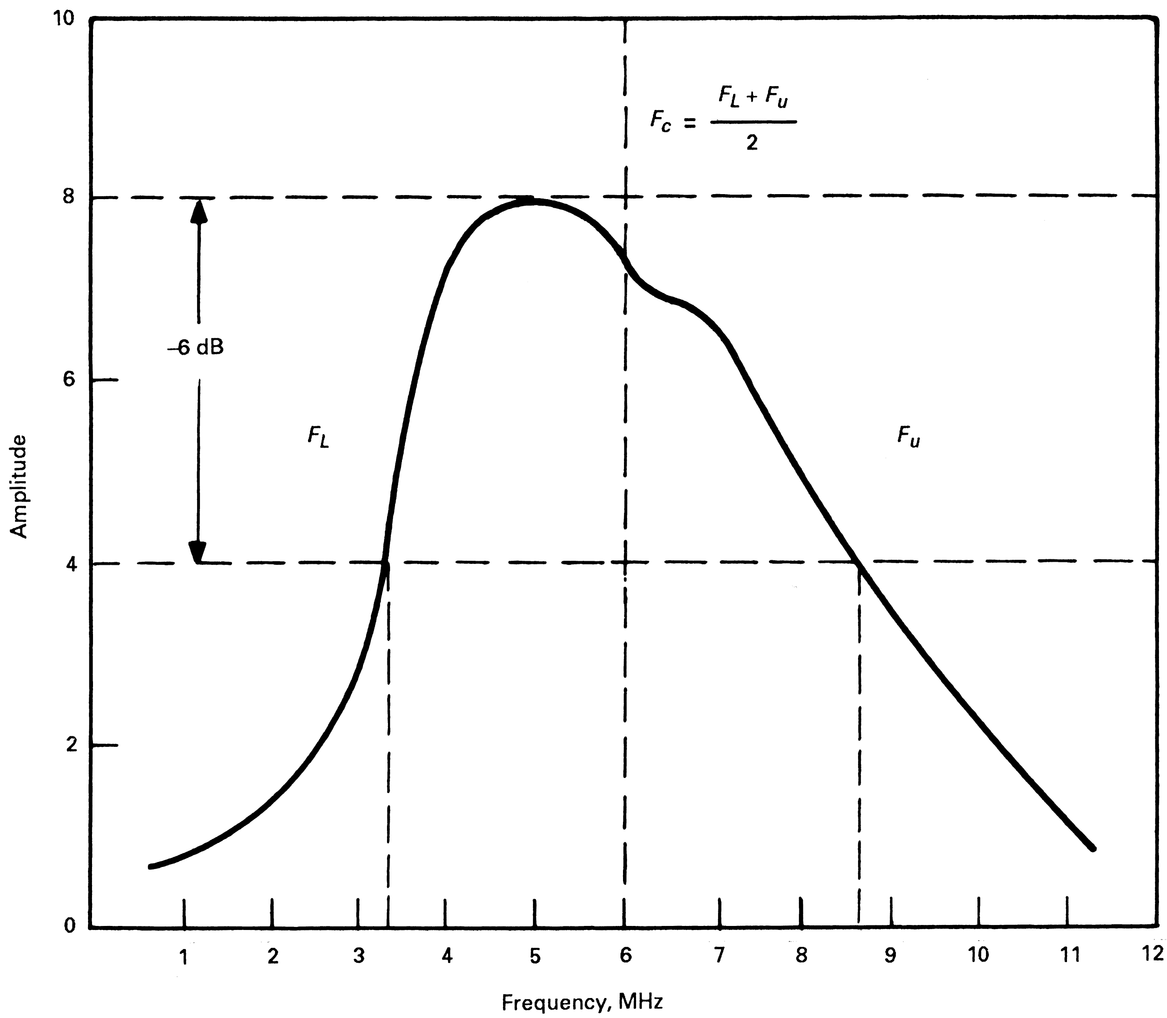
(3) Service-induced flaws shall be included when available. When the procedure is intended to detect IGSCC, at least four field-removed, IGSCC-flawed grading units shall be included in the detection test set.

1.3 Sizing Specimens. The specimen set shall contain sizing specimens that meet the following requirements.

(a) The minimum number of flaws shall be ten. For initial procedure qualification, sizing sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables at least one personnel qualification set is required.

(b) Flaws in length sizing sample sets shall meet the requirements of 1.2(c)(1), when given in conjunction with a detection test. When the length sizing test is administered independently, the flaw depth requirements do not apply.

Figure VIII-S1-2A
Frequency Response Curve



(c) Flaws in the depth sizing sample set shall be distributed as follows:

Flaw Depth (% Wall Thickness)	Minimum Percentage of Flaws
5–30%	20%
31–60%	20%
61–100%	20%

The remaining flaws shall be in any of the above categories.

2.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS

When scanning from the O.D., the specimen inside surface and identification shall be concealed from the candidate. When scanning from the I.D., flaw location and specimen identification shall be obscured to maintain a "blind test." All examinations shall be completed prior to grading the results and presenting the results to the candidate. Divulgence of particular specimen results or candidate viewing of unmasked specimens after the performance demonstration is prohibited.

2.1 Detection Test. Flawed and unflawed grading units shall be randomly mixed.

2.2 Length and Depth Sizing Test.

(a) Each reported flaw in the detection test shall be length sized. When only length sizing is being tested, the regions of each specimen containing a flaw to be sized may be identified to the candidate. The candidate shall determine the length of the flaw in each region.

Table VIII-S2-1
Performance Demonstration Detection Test Acceptance Criteria

Detection Test Acceptance Critera		False Call Test Acceptance Criteria	
No. of Flawed Grading Units	Minimum Detection Criteria	No. of Unflawed Grading Units	Maximum Number of False Calls
5	5	10	0
6	6	12	1
7	6	14	1
8	7	16	2
9	7	18	2
10	8	20	3
11	9	22	3
12	9	24	3
13	10	26	4
14	10	28	5
15	11	30	5
16	12	32	6
17	12	34	6
18	13	36	7
19	13	38	7
20	14	40	8

(b) The depth sizing test may be performed in conjunction with or separate from the detection test. When only depth sizing is being tested, the regions of each specimen containing a flaw to be sized may be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.

3.0 ACCEPTANCE CRITERIA

3.1 Detection Acceptance Criteria.

(a) Personnel demonstration shall meet the requirements of Table VIII-S2-1 for both detection and false calls. If the procedure is intended to detect IGSCC, failure to detect more than one of the IGSCC flaws is unacceptable for personnel qualification.

(b) Procedure qualification shall demonstrate detectability of each flaw within the scope of the procedure. Successful personnel demonstrations may be combined to satisfy the requirements for procedure qualification.

3.2 Sizing Acceptance Criteria. Examination procedures, equipment, and personnel are qualified for sizing if the results of the performance demonstration satisfy the following criteria:

(a) The RMS error of the flaw lengths estimated by ultrasonics, as compared with the true lengths, shall not exceed 0.75 in. (19 mm);

(b) The RMS error of the flaw depths estimated by ultrasonics, as compared with the true depths, shall not exceed 0.125 in. (3 mm).

SUPPLEMENT 3 QUALIFICATION REQUIREMENTS FOR FERRITIC PIPING WELDS

Qualification of examination procedures, equipment, and personnel for ferritic pipe examination shall be accomplished by satisfying the requirements of Supplement 2, except that the sample material shall be ferritic and 75% of the sample set defects shall be mechanically or thermally induced fatigue cracks. In addition, the set shall include pipe specimens not thicker than 0.1 in. (2.5 mm) more than the minimum thickness, nor thinner than 1.0 in. (25 mm) less than the maximum thickness for which the examination procedure is applicable.

SUPPLEMENT 4 QUALIFICATION REQUIREMENTS FOR THE CLAD/BASE METAL INTERFACE OF REACTOR VESSEL

1.0 SCOPE

This Supplement applies to the inner 15% of the clad ferritic reactor vessel. It may also be applied to the inner 15% of the unclad ferritic reactor vessel in accordance with Table VIII-S6-1, Note 1.

2.0 SPECIMEN REQUIREMENTS

The qualification test specimens shall provide full and unrestricted access to the examination volume to permit scanning in two directions parallel and two directions perpendicular to the weld. The same specimens may be used to demonstrate single-side access conditions.

2.1 Detection Specimens. Detection specimens, which may be full-scale mock-ups, shall conform to the following requirements.

(a) Specimens shall have sufficient volume to minimize spurious reflections. Specimen length and width shall be at least 12 in. (300 mm). There shall be at least 10 ft^2 (1 m^2) of clad surface in the specimen set.

(b) Specimen Thickness

(1) When the examination procedure requires the examination to be performed from the vessel I.D. (clad surface), the specimen minimum thickness shall be 3 in. (75 mm) or the maximum thickness of the vessel (whichever is less).

(2) When the examination procedure requires the examination to be performed from the vessel O.D. surface, the specimen shall be at least 90% of the maximum thickness to be examined.

(c) The performance demonstration shall be on the same type cladding as that to be examined, with the following exceptions:

(1) demonstration on shielded metal arc weld (SMAW) single-wire cladding is transferable to multiple-wire or strip-clad processes;

(2) demonstration of multiple-wire or strip-clad is considered equivalent but is not transferable to SMAW-type clad.

(d) The surface condition of the test specimens shall be representative of the general condition of the vessel scanning surface.

(e) The detection test matrix shall include flaws with the following description.

(1) Flaw Type. At least 70% of the flaws shall be cracks. The balance shall be cracks, fabrication flaws (e.g., slag, lack of fusion), or machined notches. Notches may be used only if the examination is performed from the clad surface. Machined notches shall meet the following requirements:

(-a) Notches shall have a maximum width of 0.010 in. (0.25 mm) at the tip. The width at the clad-to-base-metal interface shall not exceed 0.020 in. (0.5 mm)

(-b) Notches shall conform to the following:

(-1) Notch depth shall not exceed 0.25 in. (6 mm)

(-2) Notches shall be semi-elliptical.

(2) Flaws shall be oriented either parallel or perpendicular to the clad direction ±10 deg. For procedure qualification, at least 40% of the flaws shall be included in each orientation. For personnel tests, at least 20% of the flaws shall be included in each orientation.

(3) The flaw sizes shall be a representative distribution of through-wall depths among the ranges:

(-a) 0.075 in. to 0.200 in. (1.9 mm to 5.1 mm)

(-b) 0.201 in. to 0.350 in. (5.11 mm to 8.9 mm)

(-c) 0.351 in. to 0.550 in. (8.91 mm to 14 mm)

(-d) 0.551 in. to 0.750 in. (14 mm to 19 mm)

(4) No flaw shall have an aspect ratio (depth/length) less than 0.1. Flaws smaller than 50% of the allowable flaw size, as defined in IWB-3500, need not be included as detection flaws.

(5) The material thickness used to determine flaw acceptability shall be as follows:

(-a) The minimum thickness specified in the scope of the procedure, for procedures applied from the inside surface.

(-b) The thickness of the test specimen, for procedures applied from the outside surface.

(f) The number of flaws in a personnel detection demonstration shall be selected from Table VIII-S4-1.

(g) For initial procedure qualification, the detection set shall include the equivalent of three personnel qualification sets. To qualify new value of essential variables, at least one personnel qualification set is required.

(h) The requirements of Article IWA-3000 shall be used to determine if closely spaced flaws are to be treated as separate flaws.

(i) Flaw location and specimen identification shall be obscured to maintain a "blind test."

Table VIII-S4-1
Personnel Detection Test Acceptance Criteria

Detection Test Acceptance Criteria	
No. of Flaws	Minimum Detection Criteria
7	7
8	8
9	9
10	10
11	11
12	11
13	12
14	13
15	14
16	14
17	15
18	16
19	17
20	18

2.2 Sizing Specimens.

(a) The sizing test matrix shall contain a minimum of ten flaws, at least 70% of which shall be cracks.

(b) Procedure qualifications shall include the equivalent of three personnel qualification sets.

(c) Sizing specimens shall conform with the requirements of 2.1(b), 2.1(c), 2.1(d), and 2.1(e).

2.3 Supplemental Single-Side Access Test Specimens. Supplemental test specimens required to demonstrate the effectiveness of single-side examination procedures for detecting or sizing of reflectors with non-optimum sound-reflecting properties shall comply with the following:

(a) All flaws shall be cracks.

(b) Two or more cracks shall be included.

(c) The cracks shall exhibit nonoptimum sound reflecting properties.

(1) The nominal orientation shall be 45 deg ± 10 deg relative to the local surface normal.

(2) The reflecting surface shall exhibit the characteristics of a crack that could occur during fabrication or repair.

(d) The inner tip of the cracks shall be located no more than 2.5 in. (65 mm) and no less than 0.1 in. (2 mm) from the clad-to-base-metal interface.

(e) The flaws shall be oriented parallel or perpendicular to the clad direction.

3.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS

3.1 Detection Test.

(a) Flaw locations shall be obscured so as to maintain a "blind test." Divulging particular specimen results or candidate viewing of unmasked specimens is prohibited.

(b) If a flaw is reported within the greater of 1 in. (25 mm) or 10% of the metal path length to the flaw from its true location (x, y, and z) it shall be considered detected. All other reported flaws shall be considered false calls.

3.2 Length and Depth Sizing Test.

(a) Each reported flaw in the detection test shall be length sized.

(b) When only length sizing is being tested, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the length of the flaw in each region.

(c) For the depth sizing test, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.

3.3 Single-Side Access.

(a) Qualification of personnel and procedures for single-side access shall be performed as in 3.1, except that access shall be restricted to one direction parallel and one direction perpendicular to the weld.

(b) The procedure shall demonstrate that it is capable of detecting flaws described in 2.3. This need not be a blind demonstration.

(c) The procedure shall define specific evaluation criteria for detection, such that an independent evaluator can make an unbiased decision.

4.0 ACCEPTANCE CRITERIA

4.1 Detection Acceptance Criteria.

(a) Procedure qualification shall demonstrate detectability of each flaw within the scope of the procedure.

(b) Personnel are qualified if the results of the performance demonstration satisfy the acceptance criteria of Table VIII-S4-1 and no flaw greater than 0.25 in. (6 mm) depth is missed.

(c) For procedure and personnel demonstrations, the number of false calls shall not exceed $A/10$, rounded to the next whole number, where A is the total scan area of specimens in the test measured in square feet. The total scan area is defined as the area that would be scanned when scanning from all four directions.

4.2 Sizing Acceptance Criteria. Examination procedures, equipment, and personnel are qualified for sizing if the results of the performance demonstration satisfy the following criteria:

(a) The RMS error of the flaw lengths estimated by ultrasonics, as compared to the true lengths, shall not exceed 0.75 in. (19 mm)

(b) The RMS error of the flaw depths estimated by the ultrasonics, as compared to the true depths, shall not exceed 0.15 in. (4 mm)

4.3 Single-Side Acceptance Criteria.

(a) Demonstrations performed according to 3.3(a) shall meet the applicable requirements of 4.1 for flaws located within the inner 10% of the vessel thickness.

(b) The supplemental procedure demonstration of 3.3 is acceptable when all flaws described in 2.3 are detected in accordance with the evaluation criteria qualified in 3.3(c).

SUPPLEMENT 5 QUALIFICATION REQUIREMENTS FOR NOZZLE EXAMINATION FROM THE OUTSIDE SURFACE

1.0 SCOPE

This Supplement is applicable to examination of ferritic nozzle inside-corner regions and the inner 15% of ferritic nozzle-to-shell welds when scanning for flaws oriented perpendicular to the weld. Demonstration on clad nozzle mockups may be used for examination of unclad nozzles. Demonstrations performed on unclad nozzle mockups shall not be used for examination of clad nozzles. Supplement 4 qualification is required when scanning for flaws oriented parallel to ferritic nozzle-to-shell welds. Supplement 6 qualification is required for the outer 85% of ferritic nozzle-to-shell welds.

2.0 MODELING REQUIREMENTS

The examination procedure shall include or provide for the following.

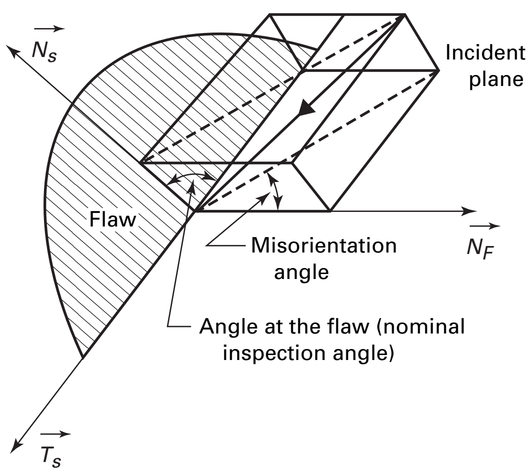
2.1 A computational model that calculates misorientation angles, the maximum metal path distance to the required examination volume, and the angle at the flaw (nominal inspection angle). Misorientation angle and the angle at the flaw is shown in Figure VIII-S5-1. These calculations apply to the central ray of the ultrasonic beam. The modeling process and associated essential variables shall be identified and defined.

2.2 A statement that specifies the examination surface and the associated maximum acceptable misorientation angle and metal path, and the range of angles at the flaw for the examinations.

2.3 Division of the surface of the required examination volume into grids of 1.0 in. (25 mm) or less in the nozzle axis direction and 10 deg or less of azimuth.

2.4 The misorientation angle, metal path distance, and angle at the flaw in each grid cell location for each search unit or scan shall be documented. Alternatively, when multiple search units with different skew or incident angles are used, the search unit or scan that produces the minimum misorientation angle and the associated metal path and angle at the flaw in each grid cell location shall be documented.

Figure VIII-S5-1
Misorientation Angle



3.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS

3.1 Specimen Requirements. Demonstration specimens shall meet the following requirements.

(a) Two or more full-size or sections of full-size nozzle mockups shall be used. Specimens shall have sufficient volume to minimize spurious reflections.

(b) Nozzle mockup material and configurations shall be representative of nozzles installed in operating reactor vessels, but may be any thickness, diameter, or radius suitable for demonstration in accordance with 3.2 or 3.5.

(c) The performance demonstration shall be on the same type of cladding as that to be examined, with the following exceptions.

(1) Demonstration on shielded metal arc welding (SMAW) single-wire cladding is transferable to multiple-wire or strip-clad process.

(2) Demonstrations on multiple-wire or strip-clad are considered equivalent but are not transferable to SMAW-type clad.

(d) The surface condition of the test specimens shall be representative of the general condition of the vessel scanning surface.

(e) The detection test matrix shall include flaws with the following description.

(1) Flaw type. At least 50% of the flaws shall be cracks. The balance shall be cracks, fabrication flaws (e.g., slag, lack of fusion), or machined notches. Notches shall have a maximum width of 0.010 in. (0.25 mm) at the tip. The width at the clad-to-base-metal interface shall not exceed 0.020 in. (0.50 mm).

(2) The flaw sizes shall be distributed in through-wall depths among the ranges:

(-a) 0.075 in. to 0.200 in. (1.90 mm to 5.08 mm)

(-b) 0.201 in. to 0.350 in. (5.09 mm to 8.89 mm)

(-c) 0.351 in. to 0.550 in. (8.90 mm to 13.97 mm)

(-d) 0.551 in. to 0.750 in. (13.98 mm to 19.05 mm)

(f) Flaws in the nozzle inside radius section shall be uniformly distributed in examination zones A and B of Figure VIII-S5-2. At least 50% of the flaws shall be located within ±45 deg of nozzle azimuth angles 90 deg or 270 deg.

(g) All flaws shall be located in the required examination volume and shall be oriented in the radial axial plane as shown in Figures IWB-2500-7(a) through IWB-2500-7(d).

(h) Flaw location and specimen identification shall be obscured to maintain a "blind test."

3.2 Procedure Qualification Demonstrations.

(a) The qualification shall demonstrate the following:

(1) examination surfaces to be used, for example, vessel plate, outer blend radius, nozzle boss, nozzle extension, and taper

(2) maximum metal path length

(3) maximum misorientation angles

(4) range of angles at the flaw

(b) The demonstration shall include at least 10 flaws for detection and sizing, in one or more mockups. At least one but no more than two flaws shall be located in the nozzle-to-vessel weld. At least 50% of the flaws in the demonstration test set must be cracks, and the maximum misorientation shall be demonstrated with cracks. Flaws in nozzles with bore diameters not exceeding 4 in. (100 mm) may be notches. The demonstration test set shall contain a representative distribution (e.g., depths, examination zones, and flaw azimuth locations) of flaws.

(c) The initial demonstration shall be a blind test.

3.3 Procedures Using Multiple Search Units.

(a) After a successful initial demonstration, the procedure may be extended by nonblind demonstrations on at least one flaw using scan parameters calculated to provide the desired maximum path length, misorientation angle, or angle at the flaw. Detection shall be demonstrated to specific criteria listed in the examination procedure for any expansion of procedure scope.

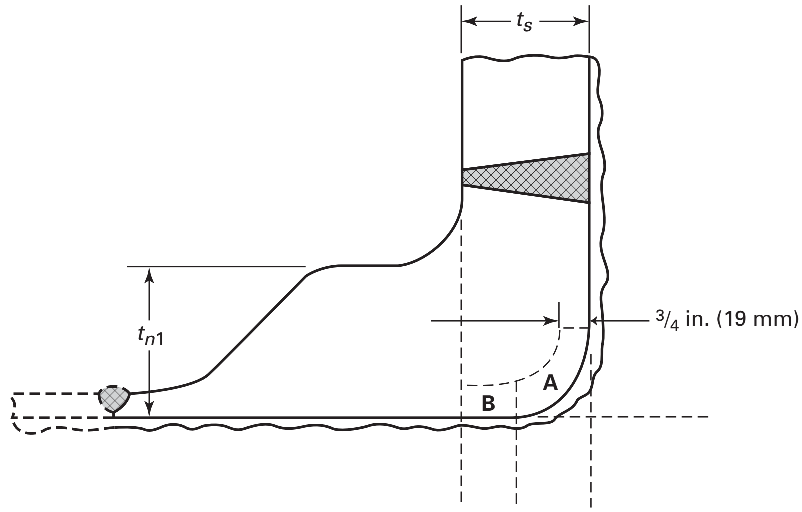
(b) This demonstration shall not be performed successively or increase the misorientation angle or angle at the flaw by more than 9 deg or the maximum metal path by more than 30%.

(c) Qualification of other essential variables requires at least one acceptable personnel qualification test.

3.4 Procedure Qualification Documentation.

(a) The examination procedure, modeling program and methods, and qualification results shall be documented to the extent necessary to determine that inservice examinations produce equivalent or smaller misorientation angles than the procedure demonstrated.

Figure VIII-S5-2
Flaw Distribution Zones



GENERAL NOTE: The extremities of Zone A are defined by the tangent points of the nozzle bore and the vessel inside diameter.

(b) The qualified essential variables associated with the maximum metal path, misorientation angles, and range of angles at the flaw shall be defined by the model documentation. Individual flaw validation is not required except for nonblind expansions of scope.

3.5 Personnel Qualification.

(a) Personnel shall be qualified in accordance with the requirements of Supplement 4, for the same type of procedure (manual or automated), from the outside surface, using the same type of instruments and data recording and analysis equipment, and the following additional requirements.

(1) Successful demonstration shall include at least three additional flaws.

(2) Examinations shall be demonstrated from a selection of scan surfaces covered by the procedure.

(3) The candidate shall demonstrate a selection of essential variables covered by the procedure, but need not demonstrate the full range.

(b) The demonstration test set shall contain a representative distribution (e.g., depths, examination zones, and flaw azimuth locations) of flaws. Flaws in the nozzle-to-vessel weld are not required for personnel demonstration.

3.6 Acceptance Criteria.

(a) Examination procedures and equipment are qualified for detection if each flaw is detected and identified at the proper azimuth within the greater of ±1 in. (25 mm) or 10% of the metal path. The number of false calls shall not exceed $D/10$ ($D/254$) rounded up to the next whole number, with a maximum of 3, where D is the nominal nozzle inside diameter, in. (mm). If only a portion of a nozzle is examined, proportional credit for false calls shall be allowed. Personnel are qualified if each of the flaws presented are detected at the proper azimuth within the greater of ±1 in. (25 mm) or 10% of the metal path and identified with no false calls.

(b) Examination procedures and equipment are qualified for depth sizing if the results of the sizing demonstration meet the requirements of Supplement 4. Personnel are qualified if the results from the depth sizing test, when added to the results from Supplement 4 met the acceptance criteria of Supplement 4.

(c) Examination procedures and equipment are qualified for length sizing if the deviation between measured length and true length does not exceed 0.75 in. (19 mm). Length sizing is required only for flaws in the nozzle-to-shell weld. No additional personnel qualifications are required.

4.0 FIELD EXAMINATIONS

4.1 To demonstrate that the proposed examination variables are within the bounds of the qualified demonstration, the computational model requirements defined in 2.0 shall be applied in conjunction with each field examination. Documentation shall be provided for each nozzle examination application.

4.2 Modeling need not be applied for repeated examination of the same or identical nozzles.

4.3 As an alternative to Supplement 5, if the qualified model indicates that the maximum misorientation angle is 10 deg or less, examination of the nozzle-to-vessel weld may be performed using personnel, procedures, and equipment qualified in accordance with Supplement 4. The examinations shall be conducted from the vessel shell, and the component materials and sizes shall be within the scope of the qualified procedure. The Supplement 4 procedure essential variables shall be demonstrated on a specimen meeting the requirements of 3.1(b) that contains at least one nonblind flaw, oriented perpendicular to the weld, in the inner 15% of the volume. The demonstration shall meet the applicable requirements of 3.6(a) for detection and 3.6(b) and 3.6(c) for sizing. No additional personnel qualifications are required.

4.4 If an area can be examined by the addition of new search unit angles, orientations, or scan surfaces that produce misorientation angles and path lengths within or equal to the qualified values, the originally qualified procedure and personnel are qualified to examine the field component. These new search unit angles, orientations, or scan areas may be used to obtain examination volume coverage.

SUPPLEMENT 6 QUALIFICATION REQUIREMENTS FOR REACTOR VESSEL WELDS OTHER THAN CLAD/BASE METAL INTERFACE

1.0 SCOPE

This Supplement applies to unclad ferritic components and the outer 85% of clad ferritic components.

2.0 SPECIMEN REQUIREMENTS

Qualification test specimens shall meet the requirements listed herein unless a set of specimens is designed to accommodate specific limitations stated in the scope of the examination procedure. The same specimens may be used to demonstrate both detection and sizing qualification.

2.1 Detection Specimens. Detection specimens, which may be full-scale mock-ups, shall conform to the following requirements.

(a) Specimens shall have sufficient volume to minimize spurious reflections. Specimen length and width shall be at least 12 in. (300 mm). There shall be at least 10 ft^2 (1 m^2) of scan surface in the specimen set.

(b) The specimen set shall contain at least one sample that is at least 90% of the maximum thickness to be examined. The specimen set shall contain one or more flaws in each of the locations and size ranges shown in Table VIII-S6-1.

(c) When the examination procedure requires the examination to be performed from the vessel I.D. (clad surface), the cladding on the mockup shall be of the same type as the cladding on the component to be examined, with the following exceptions:

(1) demonstration on shielded metal arc weld (SMAW) single-wire cladding is transferable to multiple-wire or strip-clad processes;

(2) demonstration on multiple-wire or strip-clad is considered equivalent but is not transferable to SMAW-type clad.

(d) The surface condition of the test specimens shall be representative of the general condition of the vessel scanning surface.

(e) The detection test matrix shall include flaws with the following description.

(1) Flaw Type. At least 55% of the flaws shall be cracks. The balance shall be cracks or fabrication flaws (e.g., slag, lack of fusion).

(2) Detection and sizing examinations shall include surface-connected flaws or flaws with unflawed ligaments of more than 0.2 in. (5 mm) Procedure demonstrations shall include examples of both.

(3) Flaws shall be oriented either parallel or perpendicular to the clad direction ±10 deg. For procedure qualification, at least 40% of the flaws shall be included in each orientation. For personnel qualification, at least 20% of the flaws shall be included in each orientation.

(4) Flaws for the detection test matrix shall be selected from Table VIII-S6-1. The flaws selected shall provide a demonstration of the minimum and maximum metal path ranges to be demonstrated as well as a representative distribution of flaw sizes and locations.

(5) For initial procedure qualification, the detection set shall include the equivalent of three personnel qualification sets. Qualification of new values of essential variables requires at least one personnel qualification set. Procedure qualification flaws shall be uniformly distributed over the ranges defined in Table VIII-S6-1. The number of flaws in a personnel detection demonstration shall be selected from Table VIII-S4-1.

(6) The requirements of Article IWA-3000 shall be used to determine if closely spaced flaws are to be treated as separate flaws.

2.2 Sizing Specimens.

(a) Personnel qualification test sets shall include at least ten flaws. Procedure qualification demonstrations shall include the equivalent of three personnel qualification sets. At least 55% of the flaws shall be cracks and the balance shall be fabrication flaws (slag, lack of fusion).

(b) Sizing specimens shall conform with the requirements of 2.1(b), 2.1(c), 2.1(d), and 2.1(e), except that the test matrix shall be selected from the sizing and detection test flaws included in Table VIII-S6-1.

3.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS

3.1 Detection Test.

(a) Flaw locations shall be obscured so as to maintain a "blind test." Divulging particular specimen results or candidate viewing of unmasked specimens is prohibited.

Table VIII-S6-1
Detection and Sizing Test Flaws and Locations

Flaw Location	Flaw Through-Wall Dimension, in. (mm) [Note (2)] 0.075–0.200 (1.9–5.1)	0.201–0.350 (5.11–8.9)	0.351–0.550 (8.91–14)	0.551–0.750 (14.01–19)	0.751–2.00 (19.01–50)
Inner 10% [Note (1)]	X	X	S	S	...
Outer 10%	X	X	S	S	...
11%–30% *T*	...	...	X	X	S
31%–60% *T*	...	...	X	X	S
61%–89% *T*	...	...	X	X	S

GENERAL NOTES:
(a) *X* applies to detection and sizing flaws.
(b) *S* applies only to sizing flaws.
(c) *T* is the thickness of the thickest specimen in the specimen set.

NOTES:
(1) Demonstrations conducted on clad vessel specimens in accordance with Supplement 4 may be used in lieu of these requirements. Demonstrations performed on unclad vessel specimens shall not be used for examination of clad vessels.
(2) Flaws smaller than 50% of the allowable flaw size specified in IWB-3500 need not be included as detection flaws.

(b) If a flaw is reported within the greater of 1.0 in. (25 mm) or 10% of the metal path length to the flaw from its true location (x, y, and z), it shall be considered detected. All other reported flaws shall be considered false calls.

3.2 Length and Depth Sizing Test.

(a) Each reported flaw shall be length sized.

(b) For the length sizing test, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the length of the flaw in each region.

(c) When only depth sizing is being tested, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.

3.3 Single-Side Access. Qualification of personnel and procedures for single-side access shall be performed as in 3.1, except that access shall be restricted to one direction parallel and one direction perpendicular to the weld.

4.0 ACCEPTANCE CRITERIA

4.1 Detection Acceptance Criteria.

(a) Procedure qualification shall demonstrate detectability of each flaw within the scope of the procedure.

(b) Personnel are qualified if the results of the performance demonstration satisfy the acceptance criteria of Table VIII-S4-1 and no surface-connected flaw greater than 0.25 in. (6 mm) depth or embedded flaw (distance from nearest surface exceeds 10%t) greater than 0.5 in. (13 mm) was missed.

(c) For procedures and personnel demonstrations, the number of false calls shall not exceed $A/10$, rounded to the next whole number, where A is the total scan area of specimens in the test measured in square feet. The total scan area is defined as the area that would be scanned when scanning from all four directions.

4.2 Sizing Acceptance Criteria.

(a) The RMS error of the flaw lengths estimated by ultrasonics, as compared to the true lengths, shall not exceed 0.75 in. (19 mm).

(b) The RMS error of the flaw depths estimated by ultrasonics, as compared to the true depths, shall not exceed 0.25 in. (6 mm).

(c) The slope of the linear regression line, calculated as shown in Figure VIII-S6-1, shall be at least 0.7.

SUPPLEMENT 7 QUALIFICATION REQUIREMENTS FOR NOZZLE EXAMINATION FROM THE INSIDE SURFACE

1.0 SCOPE

This Supplement is applicable to examination of radial flaws in ferritic nozzle inside-radius sections. It is also applicable to examination of parallel flaws in ferritic nozzle-to-shell welds for examinations from the nozzle bore. Demonstrations on clad nozzle mockups may be used for examination of unclad nozzles. Demonstrations performed on unclad nozzle mockups shall not be used for examination of clad nozzles. Supplement 4 and Supplement 6 qualifications are required when scanning the nozzle-to-vessel weld from the vessel wall.

Figure VIII-S6-1
Definition of Statistical Parameters

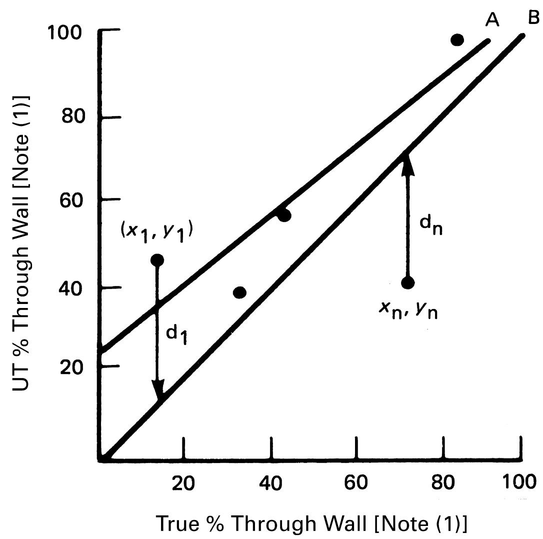
LINE A: Linear regression line, $y = a + bx$, giving the best fit of n data points $(x_1, y_1), \ldots (x_n, y_n)$ obtained by the least-square method where,

$$a = y \text{ intercept} = \frac{\Sigma y_i}{N} - b\,\frac{\Sigma x_i}{N}$$

$$b = \text{slope of the regression line}$$

$$= \frac{N\Sigma x_i y_i - (\Sigma x_i)(\Sigma y_i)}{N\Sigma x_i^2 - (\Sigma x_i)^2}$$

n = number of data points



LINE B: Ideal line, $y = x$ (perfect UT measurements).

GENERAL NOTE: *Standard Mathematical Tables*, 25th ed., William H. Beyer, Ph. D., Ed., CRC Press, Inc., Boca Raton, FL, 1979.

NOTE:
(1) Percent through-wall units apply to Supplements 2 and 3. Flaw depth units apply to Supplements 4 through 7.

2.0 CONDUCT OF PERFORMANCE DEMONSTRATION FOR NOZZLE INSIDE-RADIUS SECTION

Demonstration on clad/base metal interface of reactor vessel plate specimens (Supplement 4) qualifies examination personnel for nozzle inside-radius section examination when the following requirements are met.

2.1 For detection and sizing, at least three additional flaws at the inside radius section in one or more full-scale nozzle mockups shall be added to the test set.

(a) Specimens shall have sufficient volume to minimize spurious reflections.

(b) Flaws shall be located in the radial-axial plane of the nozzle inside radius section as shown in Figures IWB-2500-7(a) through IWB-2500-7(d). At least one mock-up shall have the minimum nozzle inside-corner radius covered by the procedure.

(c) The performance demonstration shall be on the same type of cladding as that to be examined, with the following exceptions.

(1) Demonstration on shielded metal arc welding (SMAW) single-wire cladding is transferable to multiple-wire or strip-clad process.

(2) Demonstrations on multiple-wire or strip-clad are considered equivalent but are not transferable to SMAW-type clad.

(d) The surface condition of the test specimens shall be representative of the general condition of the vessel scanning surface.

(e) The detection test matrix shall include flaws with the following description.

(1) Flaw Type. At least 50% of the flaws shall be cracks. The balance shall be machined notches. Notches shall have a maximum width of 0.010 in. (0.25 mm) at the tip. The width at the clad-to-base-metal interface shall not exceed 0.020 in. (0.5 mm).

(2) Distribution of Flaw Sizes. The flaw sizes shall be distributed in through-wall depths among the ranges

(-a) 0.075 in. to 0.200 in. (1.90 mm to 5.08 mm)

(-b) 0.201 in. to 0.350 in. (5.09 mm to 8.89 mm)

(-c) 0.351 in. to 0.550 in. (8.90 mm to 13.97 mm)

(-d) 0.551 in. to 0.750 in. (13.98 mm to 19.05 mm)

2.2 Each of the flaws presented for demonstration shall be correctly identified at the proper azimuth within the greater of ±1 in. (25 mm) or 10% of the metal path with no false calls.

2.3 For depth sizing, the sizing results shall be combined with the sizing results from Supplement 4. The combined results shall meet the depth sizing acceptance criteria contained in Supplement 4.

2.4 Personnel shall be qualified in accordance with the requirements of Supplement 4 using the same type of instruments and data recording and analysis equipment. For initial procedure and equipment qualification, test sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables, at least one personnel qualification set is required.

3.0 CONDUCT OF PERFORMANCE DEMONSTRATION FOR EXAMINATION OF THE NOZZLE-TO-SHELL WELD FROM THE BORE

Single-side access demonstration to Supplement 6 qualifies examination personnel for nozzle-to-vessel weld examination when the following requirements are met.

3.1 For detection and sizing, a minimum of three additional flaws in one or more full-scale nozzle mock-ups shall be added to the test set.

(a) Flaws shall be oriented parallel to the weld and at either the inside or outside surface, or subsurface. At least one subsurface flaw shall be included, and there shall be no more than two flaws from each category.

(b) Specimens shall have sufficient volume to minimize spurious reflections.

(c) The performance demonstration shall be on the same type of cladding as that to be examined, with the following exceptions.

(1) Demonstrations on shielded metal arc welding (SMAW) single-wire cladding are transferable to multiple-wire or strip-clad process.

(2) Demonstrations on multiple-wire or strip- clad are considered equivalent but are not transferable to SMAW-type clad.

(d) The surface condition of the test specimens shall be representative of the general condition of the vessel scanning surface.

(e) The detection test matrix shall include flaws with the following description.

(1) Flaw Type. At least 75% of the flaws shall be cracks. The balance shall be cracks, fabrication flaws (e.g., slag, lack of fusion), or machined notches.

(-a) Notches shall have a maximum width of 0.010 in. (0.25 mm) at the tip. The width at the clad-to-base-metal interface shall not exceed 0.020 in. (0.50 mm).

(-b) Notches shall conform to the following:

(-1) Notch depth shall not exceed $^1/_4$ in. (6 mm).

(-2) Notches shall be semielliptical.

(2) At least one flaw parallel to the weld shall provide a metal path distance within 10% of the equivalent path length to the weld centerline of the thickest component to be examined.

(f) There shall be a representative distribution of flaw depths from Table VIII-S6-1.

3.2 Each of the flaws presented for demonstration shall be correctly identified at the proper azimuth within the greater of ±1 in. (25 mm) or 10% of the metal path, with no false calls.

3.3 For length sizing, the results shall be added to the combined results of Supplement 4 and Supplement 6. The combined results shall meet the length sizing acceptance standards of Supplement 4.

3.4 For depth sizing, the inside surface and inner 15% results shall be combined with the sizing results from Supplement 4. The combined results shall meet the depth sizing acceptance criteria of Supplement 4. The remaining results shall be combined with the sizing results from Supplement 6. The combined results shall meet the depth sizing acceptance criteria of Supplement 6.

3.5 Personnel shall be qualified in accordance with the requirements of Supplement 6 for single-side access, using the same type of instruments and data recording and analysis equipment. For initial procedure and equipment qualification, test sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables, at least one personnel qualification set is required.

SUPPLEMENT 8 QUALIFICATION REQUIREMENTS FOR BOLTS AND STUDS

1.0 SPECIMEN REQUIREMENTS

Qualification test specimens shall meet the requirements listed herein, unless a set of specimens is designed to accommodate specific limitations stated in the scope of the examination procedure.

1.1 Specimens shall conform to the following requirements:

(a) The qualification process shall be performed with a full-scale section bolt or stud that is sufficient to contain the beam path and demonstrate the scanning technique.

(b) The qualification specimen shall be of similar chemical composition, tensile properties, and metallurgical structure as the bolt or stud to be examined. The scan surface of the qualification specimen shall have a configuration similar to the bolt or stud to be examined.

(c) Circumferentially oriented notches shall be located in the qualification specimen at the minimum and maximum qualified metal paths. Notches located within one diameter of the end of the bolt or stud are suitable for demonstrating the metal path distance. These notches are required on the outside threaded surface, with maximum depths and reflective areas as specified in Table VIII-S8-1.

(d) Additional notches may be located within the range specified in (c) above, provided they do not interfere with the detection of other notches.

Table VIII-S8-1
Maximum Notch Dimensions

Bolt or Stud Size	Depth, in. (mm) [Note (1)]	Reflective Area, in.^{2} (mm^2)
Greater than 4 in. (100 mm) diameter	0.157 (4)	0.059 (38)
2 in. (50 mm) diameter and greater, but not over 4 in. (100 mm) diameter	0.107 (2.7)	0.027 (17)

NOTE:
(1) For threaded surfaces, depth is measured from the bottom of the thread root to bottom of notch.

2.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS

Specimen identification and notch locations shall be obscured so as to maintain a "blind test." A flaw shall be considered detected when the notch, as defined in 1.1, is found. The notch axial location correlation shall be ±$^1/_2$ in. (±13 mm) or ±5% of the bolt or stud length, whichever is greater.

3.0 ACCEPTANCE CRITERIA

3.1 Examination procedures, equipment, and personnel are qualified for detection when each qualification notch (as described in 1.1) has been detected and its response equals or exceeds the reporting criteria specified in the procedure. The notch response shall have a minimum peak signal to peak noise ratio of 2:1.

SUPPLEMENT 9 QUALIFICATION REQUIREMENTS FOR CAST AUSTENITIC PIPING WELDS

(In the course of preparation)

(15) SUPPLEMENT 10 QUALIFICATION REQUIREMENTS FOR DISSIMILAR METAL PIPING WELDS

1.0 SCOPE

Supplement 10 is applicable to dissimilar metal piping welds examined from either the inside or outside surface. Supplement 10 is not applicable to piping welds containing supplemental corrosion-resistant clad (CRC) applied to mitigate intergranular stress corrosion cracking (IGSCC).

2.0 SPECIMEN REQUIREMENTS

Qualification test specimens shall meet the requirements listed herein, unless a set of specimens is designed to accommodate specific limitations stated in the scope of the examination procedure (e.g., pipe size, weld joint configuration, access limitations). The same specimens may be used to demonstrate both detection and sizing qualification.

2.1 General. The specimen set shall conform to the following requirements.

(a) The minimum number of flaws in a specimen set shall be ten.

(b) Specimens shall have sufficient volume to minimize spurious reflections that may interfere with the interpretation process.

(c) The specimen set shall include the minimum and maximum pipe diameters and thicknesses for which the examination procedure is applicable. Pipe diameters within a range of $^1/_2$ in. (13 mm) of the nominal diameter shall be considered equivalent. Pipe diameters larger than 24 in. (600 mm) shall be considered to be flat. When a range of thicknesses is to be examined, a thickness tolerance of ±25% is acceptable.

(d) The specimen set shall include examples of the following fabrication conditions:

(1) geometric and material conditions that normally require discrimination from flaws (e.g., counterbore or weld root conditions, cladding, weld buttering, remnants of previous welds, adjacent welds in close proximity, weld repair areas)

(2) typical limited scanning surface conditions shall be included as follows

(-a) for outside surface examinations, weld crowns, diametrical shrink, single-side access due to nozzle, and safe end external tapers

(-b) for inside surface examinations, internal tapers, exposed weld roots, and cladding conditions

(e) Qualification requirements shall be satisfied separately for outside surface and inside surface examinations.

2.2 Flaw Location.

(a) At least 80% of the flaws shall be contained wholly in the weld or buttering material.

(b) If the specimens in the test set have both austenitic and ferritic sides, at least one flaw and no more than 10% of the total flaws shall be located in ferritic material, and at least one flaw and no more than 10% of the total flaws shall be in austenitic base material.

(c) For single-side qualifications, flaws located on the far side of the weld shall be included in the test set.

2.3 Flaw Type.

(a) At least 60% of the flaws shall be cracks, and the remainder shall be alternative flaws. Specimens with IGSCC shall be used when available. Alternative flaws shall meet the following requirements:

(1) Alternative flaws, if used, shall provide crack-like reflective characteristics and shall only be used when implantation of cracks would produce spurious reflectors that are uncharacteristic of service-induced flaws.

(2) Alternative flaws shall have a tip width of no more than 0.002 in. (0.05 mm).

(b) At least 50% of the flaws shall be coincident with areas described in 2.1(d).

2.4 Flaw Depth. All flaw depths shall be greater than 10% of the nominal pipe wall thickness. Flaw depths shall exceed the nominal clad thickness when placed in cladding. Flaws in the specimen set shall be distributed as follows.

Flaw Depth (% Wall Thickness)	Minimum Number of Flaws
10–30%	20%
31–60%	20%
61–100%	20%

At least 75% of the flaws shall be in the range of 10% to 60% of wall thickness.

2.5 Flaw Orientation.

(a) For other than sizing specimens, at least 30% and no more than 70% of the flaws, rounded to the next higher whole number, shall be oriented axially. The remainder of the flaws shall be oriented circumferentially.

(b) Sizing specimen sets shall meet the following requirements.

(1) Length-sizing flaws shall be oriented circumferentially.

(2) Depth-sizing flaws shall be oriented as in (a).

3.0 PERFORMANCE DEMONSTRATION

Personnel and procedure performance demonstration tests shall be conducted according to the following requirements.

(a) For qualifications from the outside surface, the specimen inside surface and specimen identification shall be concealed from the candidate. When qualifications are performed from the inside surface, the flaw location and specimen identification shall be obscured to maintain a "blind test." All examinations shall be completed prior to grading the results and presenting the results to the candidate. Divulgence of particular specimen results or candidate viewing of unmasked specimens after the performance demonstration is prohibited.

(b) For single-side qualifications, the specimen set shall contain a range of access restrictions.

(1) For components that have scan access from both the ferritic and austenitic sides, qualification shall be performed from the austenitic side of the weld only.

(2) For components with no austenitic side, or for which scan access is limited to the ferritic side only, qualification may be performed from the ferritic side.

3.1 Detection Test.

(a) The specimen set shall include detection specimens that meet the following requirements.

(1) Specimens shall be divided into grading units.

(-a) Each grading unit shall include at least 3 in. (75 mm) of weld length.

(-b) The end of each flaw shall be separated from an unflawed grading unit by at least 1 in. (25 mm) of unflawed material. A flaw may be less than 3 in. (76 mm) in length.

(-c) The segment of weld length used in one grading unit shall not be used in another grading unit.

(-d) Grading units need not be uniformly spaced around the pipe specimen.

(2) Personnel performance demonstration detection test sets shall be selected from Table VIII-S10-1. The number of unflawed grading units shall be at least $1^1/_2$ times the number of flawed grading units.

(3) Flawed and unflawed grading units shall be randomly mixed.

(b) Examination equipment and personnel are qualified for detection when personnel performance demonstrations satisfy the acceptance criteria of Table VIII-S10-1 for both detection and false calls.

3.2 Length-Sizing Test.

(a) Each reported circumferential flaw in the detection test shall be length sized.

(b) When the length-sizing test is conducted in conjunction with the detection test, and less than ten circumferential flaws are detected, additional specimens shall be provided to the candidate such that at least ten flaws are sized. The regions of each specimen containing a flaw to be sized shall be identified to the candidate, provided it does not compromise the sample or data set confidentiality. The candidate shall determine the length of the flaw in each region.

(c) For a separate length-sizing test, the regions of each specimen containing a flaw to be sized shall be identified to the candidate, provided it does not compromise the sample or data set confidentiality. The candidate shall determine the length of the flaw in each region.

(d) Examination procedures, equipment, and personnel are qualified for length-sizing when the RMS error of the flaw length measurements, compared to the true flaw lengths, do not exceed 0.75 in. (19 mm).

3.3 Depth-Sizing Test.

(a) The depth-sizing test may be conducted separately or in conjunction with the detection test. For a separate depth-sizing test, the regions of each specimen containing a flaw to be sized shall be identified to the candidate,

Table VIII-S10-1
Personnel Performance Demonstration Detection Test Acceptance Criteria

Detection Test Acceptance Criteria		False Call Acceptance Criteria	
No. of Flawed Grading Units	Minimum Detection Criteria	No. of Unflawed Grading Units	Maximum No. of False Calls
10	8	15	2
11	9	17	3
12	9	18	3
13	10	20	3
14	10	21	3
15	11	23	3
16	12	24	4
17	12	26	4
18	13	27	4
19	13	29	4
20	14	30	5

provided it does not compromise the sample or data set confidentiality. The candidate shall determine the maximum depth of the flaw in each region.

(b) When the depth-sizing test is conducted in conjunction with the detection test, and less than ten flaws are detected, additional specimens shall be provided to the candidate such that at least ten flaws are sized. The regions of each specimen containing a flaw to be sized shall be identified to the candidate, provided it does not compromise the sample or data set confidentiality. The candidate shall determine the maximum depth of the flaw in each region.

(c) Examination procedures, equipment, and personnel are qualified for depth-sizing when the RMS error of the flaw depth measurements, as compared to the true flaw depths, do not exceed 0.125 in. (3 mm).

4.0 PROCEDURE QUALIFICATION

Procedure qualification shall include the following additional requirements.

(a) The specimen set shall include the equivalent of at least three personnel performance demonstration test sets.

Successful personnel performance demonstrations may be combined to satisfy these requirements.

(b) Detectability of all flaws in the procedure qualification test set that are within the scope of the procedure shall be demonstrated. Length and depth sizing shall meet the requirements of 3.2 and 3.3.

(c) At least one successful personnel performance demonstration shall be performed.

(d) To qualify new values of essential variables, at least one personnel performance demonstration set is required. The acceptance test criteria of (b) shall be met.

SUPPLEMENT 11 QUALIFICATION REQUIREMENTS FOR FULL STRUCTURAL OVERLAID WROUGHT AUSTENITIC PIPING WELDS

1.0 SPECIMEN REQUIREMENTS

Qualification test specimens shall meet the requirements listed herein, unless a set of specimens is designed to accommodate specific limitations stated in the scope of the examination procedure (e.g., pipe size, weld joint configuration, access limitations). The same specimens may be used to demonstrate both detection and sizing qualification.

1.1 General. The specimen set shall conform to the following requirements.

(a) Specimens shall have sufficient volume to minimize spurious reflections that may interfere with the interpretation process.

(b) The specimen set shall consist of at least three specimens having different nominal pipe diameters and overlay thicknesses. They shall include the minimum and maximum nominal pipe diameters for which the examination procedure is applicable. Pipe diameters within a range of 0.9 to 1.5 times a nominal diameter shall be considered equivalent. If the procedure is applicable to pipe diameters of 24 in. (600 mm) or larger, the specimen set must include at least one specimen 24 in. (600 mm) or larger but need not include the maximum diameter. The specimen set shall include at least one specimen with overlay not thicker than 0.1 in. (2.5 mm) more than the minimum thickness, and at least one specimen with overlay not thinner than 0.25 in. (6 mm) less than the maximum for which the examination procedure is applicable.

(c) The surface condition of at least two specimens shall approximate the roughest surface condition for which the examination procedure is applicable.

(d) Flaw Conditions

(1) Base Metal Flaws. All flaws must be in or near the butt weld heat-affected zone, open to the inside surface, and extending at least 75% through the base metal wall. Intentional overlay fabrication flaws shall not interfere with ultrasonic detection or characterization of the base metal flaws. At least 70% of the flaws in the detection and sizing tests shall be actual cracks. Specimens containing IGSCC shall be used if they are available. If implantation of actual cracks produces spurious reflectors that are not characteristic of actual flaws, alternative flaws may be used but shall comprise not more than 30% of the total of base material flaws. Alternative flaws, if used, shall provide crack-like reflective charactistics and shall be semielliptical. The tip width of the alternative flaws shall not exceed 0.002 in.

(2) Overlay Fabrication Flaws. At least 40% of the flaws shall be noncrack fabrication flaws (e.g., sidewall lack of fusion or laminar lack of bond) in the overlay or the pipe-to-overlay interface. At least 20% of the flaws shall be cracks. The balance of the flaws shall be of either type.

(e) Detection Specimens

(1) At least 20% but less than 40% of the base metal flaws shall be oriented within ±20 deg of the pipe axial direction. The remainder shall be oriented circumferentially. Flaws shall not be open to any surface to which the candidate has physical or visual access.

(2) Specimens shall be divided into base metal and overlay fabrication grading units. Each specimen shall contain one or both types of grading units. Flaws shall not interfere with ultrasonic detection or characterization of other flaws.

(-a)

(-1) A base metal grading unit includes the overlay material and the outer 25% of the original overlaid weld. The base metal grading unit shall extend circumferentially for at least 1 in. (25 mm) and shall start at the weld centerline and be wide enough in the axial direction to encompass one half of the original weld crown and at least $^{1}/_{2}$ in. (13 mm) of the adjacent base material. For axially oriented discontinuities, the axial dimension of the base metal grading unit may encompass the original weld crown and at least $^{1}/_{2}$ in. (13 mm) of the adjacent base materials.

(-2) When base metal flaws penetrate into the overlay material, the base metal grading unit shall not be used as part of any overlay grading unit.

(-3) Sufficient unflawed overlaid weld and base metal shall exist on all sides of the grading unit to preclude interfering reflections from adjacent flaws.

(-b) See below.

(-1) An overlay fabrication grading unit shall include the overlay material and the base metal-to-overlay interface for a length of at least 1 in. (25 mm).

(-2) Overlay fabrication grading units designed to be unflawed shall be separated by unflawed overlay material and unflawed base metal-to-overlay interface for at least 1 in. (25 mm) at both ends. Sufficient unflawed overlaid weld and base metal shall exist on both sides of the overlay fabrication grading unit to preclude interfering reflections from adjacent flaws. The specific area used in one overlay fabrication grading unit shall not be used in another overlay fabrication grading unit. Overlay fabrication grading units need not be spaced uniformly about the specimen.

(3) Detection sets shall be selected from Table VIII-S2-1. The minimum detection sample set is five flawed base metal grading units, ten unflawed base metal grading units, five flawed overlay fabrication grading units, and ten unflawed overlay fabrication grading units. For each type of grading unit, the set shall contain at least twice as many unflawed as flawed grading units. For initial procedure qualification, detection sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables, at least one personnel qualification set is required.

(f) Sizing Specimen

(1) The minimum number of flaws shall be ten. At least 30% of the flaws shall be overlay fabrication flaws. At least 40% of the flaws shall be open to the inside surface. To assess sizing capabilities, sizing sets shall contain a representative distribution of flaw dimensions. For initial procedure qualification, sizing sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables, at least one personnel qualification set is required.

(2) At least 20% but less than 40% of the flaws shall be oriented axially. The remainder shall be oriented circumferentially. Flaws shall not be open to any surface to which the candidate has physical or visual access.

(3) Base metal flaws used for length sizing demonstrations shall be oriented circumferentially.

(4) Depth sizing specimen sets shall include at least two distinct locations where a base metal flaw extends into the overlay material by at least 0.1 in. (2.5 mm) in the through-wall direction.

2.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS

The specimen inside surface and identification shall be concealed from the candidate. All examinations shall be completed prior to grading the results and presenting the results to the candidate. Divulgence of particular specimen results or candidate viewing of unmasked specimens after the performance demonstration is prohibited. The overlay fabrication flaw test and the base metal flaw test may be performed separately.

2.1 Detection Test. Flawed and unflawed grading units shall be randomly mixed. Although the boundaries of specific grading units shall not be revealed to the candidate, the candidate shall be made aware of the type or types of grading units (base metal or overlay fabrication) that are present for each specimen.

2.2 Length Sizing Test.

(a) The length sizing test may be conducted separately or in conjunction with the detection test.

(b) If the length sizing test is conducted in conjunction with the detection test and the detected flaws do not satisfy the requirements of 1.1(f), additional specimens shall be provided to the candidate. The regions containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the length of the flaw in each region.

(c) For a separate length sizing test, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the length of the flaw in each region.

(d) For flaws in base metal grading units, the candidate shall estimate the length of that part of the flaw that is in the outer 25% of the base wall thickness.

2.3 Depth Sizing Test.

(a) Depth sizing consists of measuring the metal thickness above the flaw (i.e., remaining ligament), and may be conducted separately or in conjunction with the detection test.

(b) If the depth sizing test is conducted in conjunction with the detection test and the detected flaws do not satisfy the requirements of 1.1(f), additional specimens shall be provided to the candidate. The regions containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.

(c) For a separate depth sizing test, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.

3.0 ACCEPTANCE CRITERIA

3.1 Detection Acceptance Criteria.

(a) Examination procedures shall be qualified as follows:

(1) All flaws within the scope of the procedure shall be detected, and the results of the performance demonstration shall satisfy the acceptance criteria of Table VIII-S2-1 for false calls.

(2) At least one successful personnel demonstration shall be performed meeting the acceptance criteria defined in (b).

(b) Examination equipment and personnel shall be considered qualified for detection if the results of the performance demonstration satisfy the acceptance criteria of Table VIII-S2-1 for both detection and false calls.

(c) The criteria in (a) and (b) shall be satisfied separately by the demonstration results for base metal grading units and by those for overlay fabrication grading units.

3.2 Sizing Acceptance Criteria. Examination procedures, equipment, and personnel are qualified for sizing when the results of the performance demonstration satisfy the following criteria.

(a) The RMS error of the flaw length measurements, as compared to the true flaw lengths, is less than or equal to 0.75 in. (19 mm). The length of a base metal flaw is measured at the 75% through-base-metal position.

(b) The RMS error of the flaw depth measurements, as compared to the true flaw depths, is less than or equal to 0.125 in. (3.2 mm).

SUPPLEMENT 12 REQUIREMENTS FOR COORDINATED IMPLEMENTATION OF SELECTED ASPECTS OF SUPPLEMENTS 2 AND 3 (15)

1.0 SCOPE

This Supplement provides for expansion of Supplement 2 qualifications to permit coordinated qualification for Supplement 3.

2.0 DETECTION AND LENGTH SIZING

2.1 Ferritic Piping. Examination personnel, equipment, and procedure qualification requirements for detection and length sizing for Supplements 2 and 3 are satisfied when the following requirements are met.

(a) For detection qualification, at least three additional flawed grading units and six additional unflawed units in ferritic piping shall be added to the test set. A grading unit shall include at least 3 in. (75 mm) continuous weld length. All nine ferritic grading units shall be correctly identified.

(b) The demonstration shall meet the requirements of Supplement 2, except that for length sizing qualification, the minimum number of flaws shall be ten, and the specimen set shall include at least three, but not more than four, flaws in ferritic material.

(c) The ferritic grading units added to expand the qualification are not required to span the full thickness and diameter ranges of the Supplement 2 test set.

3.0 DEPTH SIZING

Examination personnel, equipment, and procedure qualification requirements for depth sizing for Supplements 2 and 3 are met by the following demonstration.

(a) Specimens

(1) The minimum number of flaws shall be ten.

(2) The specimen set shall include at least four but no more than five Supplement 3 flaws.

(3) The overall flaw depth distribution shall meet the requirements of Supplement 2, 1.3(c).

(b) The demonstration shall be conducted in accordance with the requirements of Supplement 2, 2.2(b).

(c) The examination procedure, equipment, and personnel are qualified for depth sizing when the RMS error of the flaw depth measurements, as compared to the true flaw depths, does not exceed 0.125 in. (3.2 mm).

(15)
SUPPLEMENT 14 QUALIFICATION REQUIREMENTS FOR COORDINATED IMPLEMENTATION OF SUPPLEMENTS 10, 2, AND 3 FOR PIPING EXAMINATIONS PERFORMED FROM THE INSIDE SURFACE

1.0 SCOPE

This supplement is applicable to wrought austenitic, ferritic, and dissimilar metal piping welds examined from the inside surface. This supplement provides for expansion of Supplement 10 qualifications to permit coordinated qualification for Supplements 2 and 3.

2.0 SPECIMEN REQUIREMENTS

Qualification test specimens shall meet the requirements listed herein, unless a set of specimens is designed to accomodate specific limitations stated in the scope of the examination procedure (e.g., pipe size, access limitations). The same specimens may be used to demonstrate both detection and sizing qualification.

2.1 General. The specimen set shall conform to the following requirements.

(a) Specimens shall have sufficient volume to minimize spurious reflections that may interfere with the interpretation process.

(b) The specimen set shall include the minimum and maximum pipe diameters and thicknesses for which the examination procedure is applicable. Applicable tolerances are provided in Supplements 2, 3, and 10.

(c) The specimen set shall include examples of the following fabrication conditions:

(1) geometric and material conditions that normally require discrimination from flaws (e.g., counterbore or weld root conditions, cladding, weld buttering, remnants of previous welds, adjacent welds in close proximity, and weld repair areas)

(2) typical limited scanning surface conditions (e.g., internal tapers, exposed weld roots, and cladding conditions)

2.2 Supplement 2 Flaws.

(a) At least 70% of the flaws shall be cracks, the remainder shall be alternative flaws.

(b) Specimens with IGSCC shall be used when available.

(c) Alternative flaws, if used, shall provide crack-like reflective characteristics and shall comply with the following.

(1) Alternative flaws shall be used only when implantation of cracks produces spurious reflectors that are uncharacteristic of service-induced flaws.

(2) Alternative flaws shall have a tip width of no more than 0.002 in. (0.05 mm).

2.3 Supplement 3 Flaws. Supplement 3 flaws shall be mechanical or thermal fatigue cracks.

2.4 Distribution. The specimen set shall contain a representative distribution of flaws. Flawed and unflawed grading units shall be randomly mixed.

3.0 PERFORMANCE DEMONSTRATION

Personnel and procedure performance demonstration tests shall be conducted according to the following requirements.

(a) The same essential variable values, or, when appropriate, the same criteria for selecting values as demonstrated in Supplement 10 shall be used.

(b) The flaw location and specimen identification shall be obscured to maintain a "blind test."

(c) All examinations shall be completed prior to grading the results and presenting the results to the candidate. Divulgence of particular specimen results or candidate viewing of unmasked specimens after the performance demonstration is prohibited.

3.1 Detection Test.

(a) The specimen set for Supplement 2 qualification shall include at least five flawed grading units and ten unflawed grading units in austenitic piping. A maximum of one flaw shall be oriented axially.

(b) The specimen set for Supplement 3 qualification shall include at least three flawed grading units and six unflawed grading units in ferritic piping. A maximum of one flaw shall be oriented axially.

(c) Specimens shall be divided into grading units.

(1) Each grading unit shall include at least 3 in. (76 mm) of weld length.

(2) The end of each flaw shall be separated from an unflawed grading unit by at least 1 in. (25 mm) of unflawed material. A flaw may be less than 3 in. (76 mm) in length.

(3) The segment of weld length used in one grading unit shall not be used in another grading unit.

(4) Grading units need not be uniformly spaced around the pipe specimen.

(d) All grading units shall be correctly identified as being either flawed or unflawed.

3.2 Length-Sizing Test.

(a) The coordinated implementation shall include the following requirements for personnel length-sizing qualification.

(b) The specimen set for Supplement 2 qualification shall include at least four flaws in austenitic material.

(c) The specimen set for Supplement 3 qualification shall include at least three flaws in ferritic material.

(d) Each reported circumferential flaw in the detection test shall be length sized. When only length-sizing is being tested, the regions of each specimen containing a flaw to be sized may be identified to the candidate. The candidate shall determine the length of the flaw in each region.

(e) Supplement 2 or Supplement 3 examination procedures, equipment, and personnel are qualified for length-sizing when the flaw lengths estimated by ultrasonics, as compared with the true length, do not exceed 0.75 in. (19 mm) RMS, when they are combined with a successful Supplement 10 qualification.

3.3 Depth-Sizing Test. The coordinated implementation shall include the following requirements for personnel depth-sizing qualification.

(a) The specimen set for Supplement 2 qualification shall include at least four circumferentially-oriented flaws in austenitic material.

(b) The specimen set for Supplement 3 qualification shall include at least three circumferentially oriented flaws in ferritic material.

(c) For a separate depth-sizing test, the regions of each specimen containing a flaw to be sized may be identified to the candidate. The candidate shall determine the depth of the flaw in each region.

(d) Supplement 2 or Supplement 3 examination procedures, equipment, and personnel are qualified for depth-sizing when the flaw depths estimated by ultrasonics, as compared with the true depths, do not exceed 0.125 in. (3 mm) RMS, when they are combined with a successful Supplement 10 qualification.

4.0 PROCEDURE QUALIFICATION

Procedure qualification shall include the following additional requirements.

(a) The specimen set shall include the equivalent of at least three personnel performance demonstration test sets. Successful personnel performance demonstrations may be combined to satisfy these requirements.

(b) Detectability of all flaws in the procedure qualification test set that are within the scope of the procedure shall be demonstrated. Detection, length sizing, and depth sizing shall meet the requirements of 3.1, 3.2, and 3.3.

(c) At least one successful personnel demonstration shall be performed.

(d) To qualify new values of essential variables, at least one personnel performance demonstration is required. The acceptance criteria of (b) shall be met.

MANDATORY APPENDIX IX

Redesignated as Nonmandatory Appendix W and moved.

MANDATORY APPENDIX X
STANDARD UNITS FOR USE IN EQUATIONS

Table X-1
Standard Units for Use in Equations

Quantity	U.S. Customary Units	SI Units
Linear dimensions (e.g., length, height, thickness, radius, diameter)	inches (in.)	millimeters (mm)
Area	square inches ($in.^2$)	square millimeters (mm^2)
Volume	cubic inches ($in.^3$)	cubic millimeters (mm^3)
Section modulus	cubic inches ($in.^3$)	cubic millimeters (mm^3)
Moment of inertia of section	inches^4 ($in.^4$)	millimeters^4 (mm^4)
Mass (weight)	pounds mass (lbm)	kilograms (kg)
Force (load)	pounds force (lbf)	newtons (N)
Bending moment	inch-pounds (in.-lb)	newton-millimeters (N·mm)
Pressure, stress, stress intensity, and modulus of elasticity	pounds per square inch (psi)	megapascals (MPa)
Energy (e.g., Charpy impact values)	foot-pounds (ft-lb)	joules (J)
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)
Absolute temperature	Rankine (°R)	kelvin (K)
Fracture toughness	ksi square root inches $\left(\text{ksi}\sqrt{\text{in.}}\right)$	MPa square root meters $\left(\text{MPa}\sqrt{\text{m}}\right)$
Angle	degrees or radians	degrees or radians
Boiler capacity	Btu/hr	watts (W)

NONMANDATORY APPENDIX A
ANALYSIS OF FLAWS

ARTICLE A-1000
INTRODUCTION

(15) A-1100 SCOPE

This Nonmandatory Appendix provides analytical procedures[44] that may be used for determining acceptability of flaws that have been detected during inspection (including preservice inspection) that exceed the allowable flaw standards of IWB-3500. Analytical evaluations performed using this Nonmandatory Appendix shall meet all the requirements of the Appendix. The procedure is based upon the principles of linear elastic fracture mechanics and can be used to support acceptability for continued service for a specified evaluation time period. This procedure applies to ferritic materials 4 in. (100 mm) and greater in thickness with specified minimum yield strengths of 50.0 ksi (350 MPa) or less in components having simple geometries and stress distributions. The basic concepts of the procedure may be extended to other ferritic materials (including clad ferritic materials) and more complex geometries; however, they are not intended to apply to austenitic or high nickel alloys. For purposes of analysis, indications that exceed the standards of IWB-3500 are considered flaws. The following is a summary of the analytical procedure.

(a) Determine the actual flaw configuration from the measured flaw in accordance with Article IWA-3000.

(b) Characterize the flaw in accordance with IWB-3610.

(c) Using Article A-2000, resolve the actual flaw into a simple shape that can be analyzed.

(d) Determine the stresses at the location of the observed flaw for normal (including upset), emergency, and faulted conditions.

(e) Calculate stress intensity factors for each condition using the methods outlined in Article A-3000.

(f) Using the methods outlined in Article A-4000, determine the necessary material properties, including the effects of irradiation if applicable.

(g) Using the analytical procedures described in Article A-5000, determine the following critical flaw parameters:

a_c = minimum critical flaw size for normal conditions
a_f = expected end-of-life flaw size
a_i = minimum critical initiation flaw size for emergency and faulted conditions

(h) Using the critical flaw parameters a_f, a_c, and a_i, apply the analytical evaluation criteria of IWB-3600 to determine whether the observed flaw is acceptable for continued service.

ARTICLE A-2000
FLAW MODEL FOR ANALYSIS

A-2100 SCOPE

This Article provides the rules for flaw shape, proximity to closest flaw, flaw orientation, and flaw location, which are used in the analytical model for linear elastic fracture mechanics.

A-2200 FLAW SHAPE

The flaw indication should be completely circumscribed by an elliptical or circular planar area according to the methods outlined in IWA-3300.

A-2300 PROXIMITY TO CLOSEST FLAW

In the case of multiple neighboring flaws, if the shortest distance between the boundaries of two neighboring flaws is within the proximity limits described in IWA-3300, the neighboring flaws should be circumscribed by a single ellipse as described in IWA-3300.

A-2400 FLAW ORIENTATION

Flaws that do not lie in a plane perpendicular to the maximum principal stress direction should be projected into that plane following the rules in IWA-3340.

A-2500 FLAW LOCATION

(a) For purposes of analysis, the flaw is to be considered in its actual location. The stresses due to system loading should be computed at this location. Surface flaw or subsurface flaw expressions should be used depending upon the type of flaw. Where the flaw is a subsurface flaw, but is within the proximity limit in IWA-3340 of the surface of the component, the flaw should be considered to be a surface flaw and should be circumscribed by a semiellipse, with its major axis on the surface.

(b) For clad components, flaw depth should be determined in accordance with IWB-3610.

(15)

ARTICLE A-3000 METHOD OF K_I DETERMINATION

A-3100 SCOPE

(a) This Article provides methods of calculating crack tip stress intensity factors, K_I, for subsurface and surface flaws using the representative stresses at the flaw location and acting normal to the plane of the flaw (Mode I). The solutions for K_I are based on either flat plate or cylindrical geometries, and can be used for subsurface flaws, and internal and external surface flaws in various types of components (e.g., vessels, pumps, valves, etc.), for which the flaw can be defined in terms of crack depth, a, for surface flaws (half crack depth for subsurface flaws), wall thickness, t, and component curvature, R_i/t (ratio of inside radius to wall thickness).

(b) The flaw shall be represented by an ellipse or semiellipse, as applicable, as shown in Figure A-3100-1. K_I for the appropriate flaw model shall be determined using the stress representation described in A-3200 and the equations provided in A-3300 for subsurface flaws or A-3400 for surface flaws.

A-3200 STRESSES

(a) When defining the stresses acting at the flaw location, applied stresses from all forms of loading, including internal pressure, thermal transients, cladding-induced stresses, and weld residual, shall be evaluated. When surface flaws are in contact with the pressure side of the component, the pressure acting on the crack faces shall be included in the determination of K_I.

(b) When stress distributions are determined using a numerical stress analysis method, stress values are obtained at discrete locations. Stress distribution may be represented by a polynomial equation as described in A-3210. Stress distribution may also be represented over discrete intervals as described in A-3220.

A-3210 POLYNOMIAL STRESS REPRESENTATION

The stress distribution may be represented by a polynomial. The selection of the order of the polynomial fit is established based on achieving the best fit to the actual stress variation. For nonlinear stress variations through the wall of the component, higher order regression fits up to fourth order might be required. Two acceptable fitting methods, as described in A-3211 and A-3212, may be used; namely, stress fit over the crack depth or stress fit over the wall thickness of the component.

A-3211 Stress Fit Over Crack Depth

For a surface or subsurface flaw, the stresses normal to the plane of the flaw at the flaw location may be represented by a polynomial relation fitted over the full crack depth by the following relationship:

$$\sigma = A_0 + A_1\left(\frac{x}{a}\right) + A_2\left(\frac{x}{a}\right)^2 + A_3\left(\frac{x}{a}\right)^3 + A_4\left(\frac{x}{a}\right)^4 \quad (1)$$

where

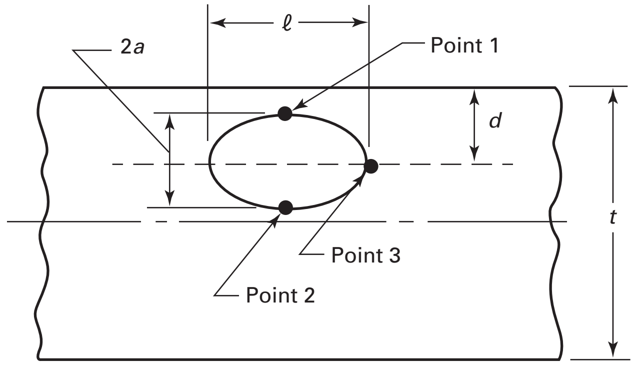
a = half crack depth for a subsurface flaw and total crack depth for a surface flaw

x = distance through the wall measured from the intersection point of the major and minor axes of the flaw as shown in Figure A-3210-1 for a surface flaw and Figure A-3210-2, illustration (a) for a subsurface flaw. The origin of the stress distribution is at the center of the flaw for a surface or subsurface flaw.

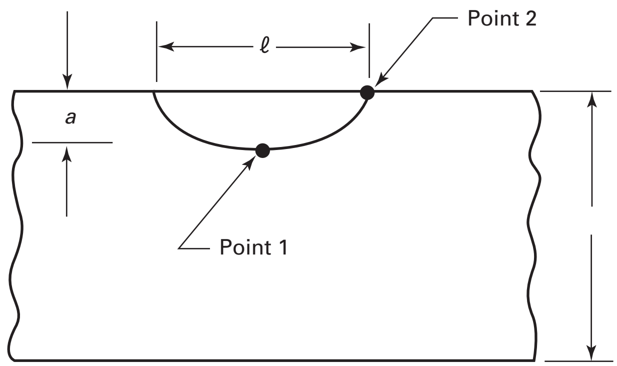
A_0, A_1, A_2, A_3, A_4 = fitting constants in units of stress derived from fitting the actual stress distribution at the flaw plane

Coefficients A_0 through A_4 shall provide an accurate representation of stress over the flaw plane for all values of flaw depths covered by the analysis (i.e., $-1 \le x/a \le 1$ for a subsurface flaw and $0 \le x/a \le 1$ for a surface flaw). Alternatively, the stress distribution that upper bounds the actual stress field over the flaw may be used. An example of a conservative linearization of a stress field is illustrated in Figure A-3210-3.

Figure A-3100-1
Elliptical Flaw Models



(a) Subsurface Flaw



(b) Surface Flaw

A-3212 Stress Fit Over the Wall Thickness

For a surface or subsurface flaw, the stresses normal to the plane of the flaw at the flaw location may be represented by a polynomial fit through the thickness by the following relationship:

$$\sigma = B_0 + B_1\left(\frac{x}{t}\right) + B_2\left(\frac{x}{t}\right)^2 + B_3\left(\frac{x}{t}\right)^3 + B_4\left(\frac{x}{t}\right)^4 \quad (2)$$

where

x = distance through the wall measured from the component surface nearest the flaw, as shown in Figure A-3210-1 for a surface flaw and Figure A-3210-2, illustration (b) for a subsurface flaw. For a surface flaw, the origin of the stress distribution is at the center of the flaw. For a subsurface flaw, the origin of the stress distribution is at the free surface closest to the flaw.

B_0, B_1, B_2, B_3, B_4 = fitting constants in units of stress derived from fitting the actual stress distribution at the flaw plane

Coefficients B_0 through B_4 shall provide an accurate representation of stress over the flaw plane for all values of flaw depth covered by the analysis [i.e., $(d - a)/t \le x/t \le (d + a)/t$ for subsurface flaws and $0 \le x/t \le a/t$ for surface flaws]. The dimension d is the distance from the surface boundary to the center of the subsurface flaw as illustrated in Figure A-3210-2, illustration (b).

Figure A-3210-1
Definition of *x* Distance Through the Wall for the Surface Flaws

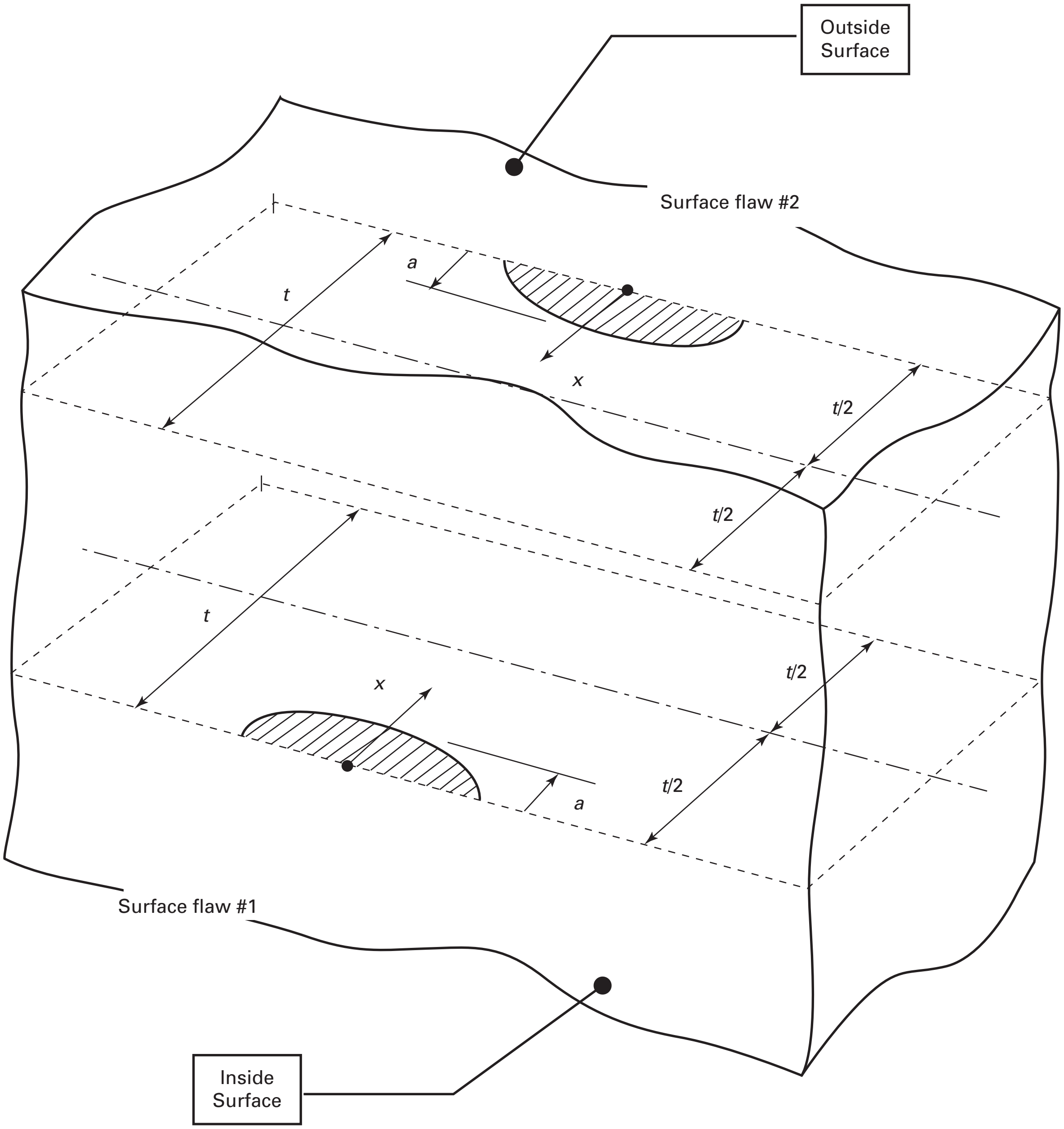
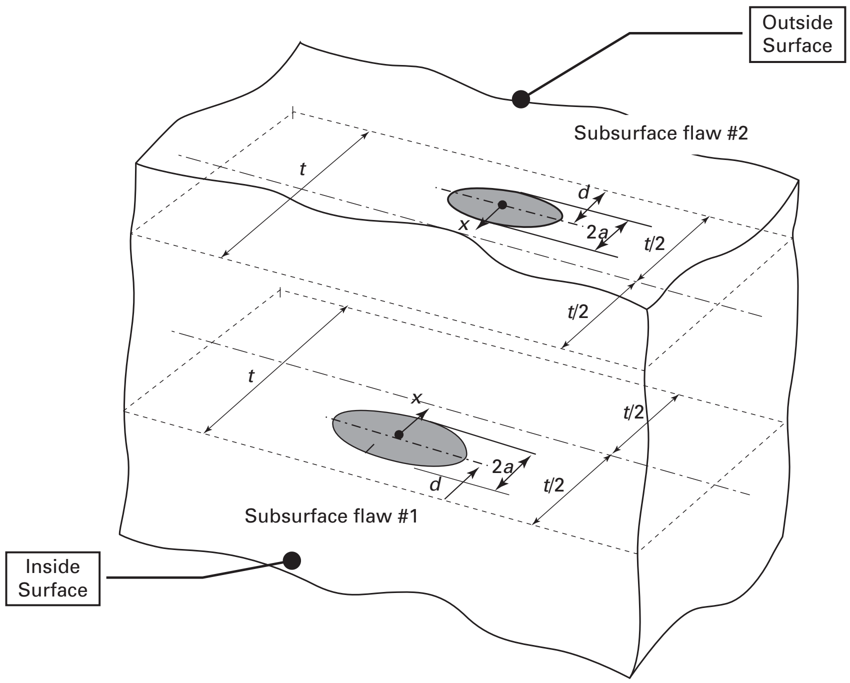
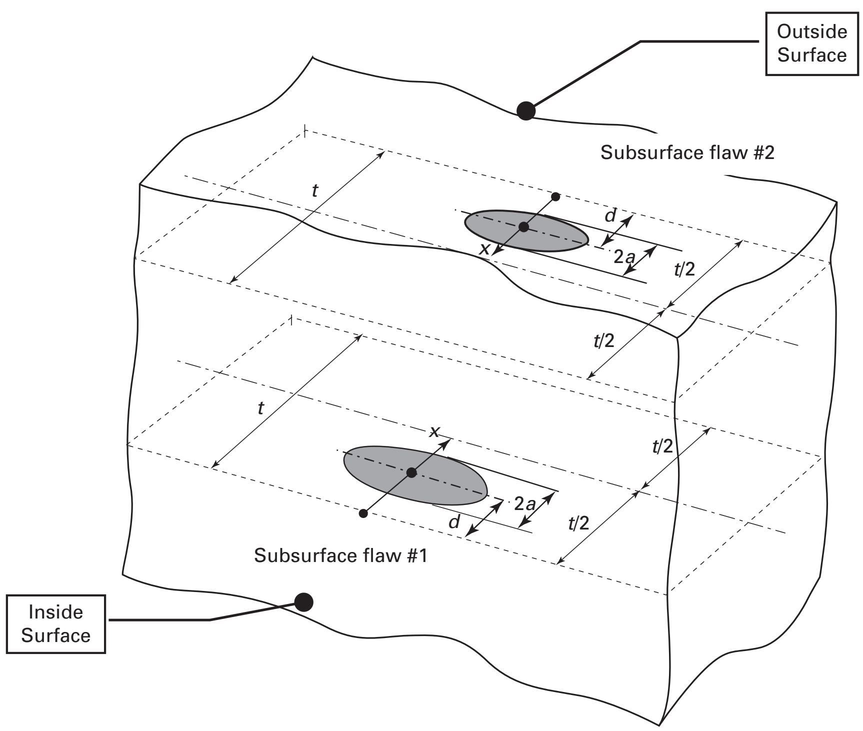


Figure A-3210-2
Definition of *x* Distance for the Subsurface Flaw Stress Definition

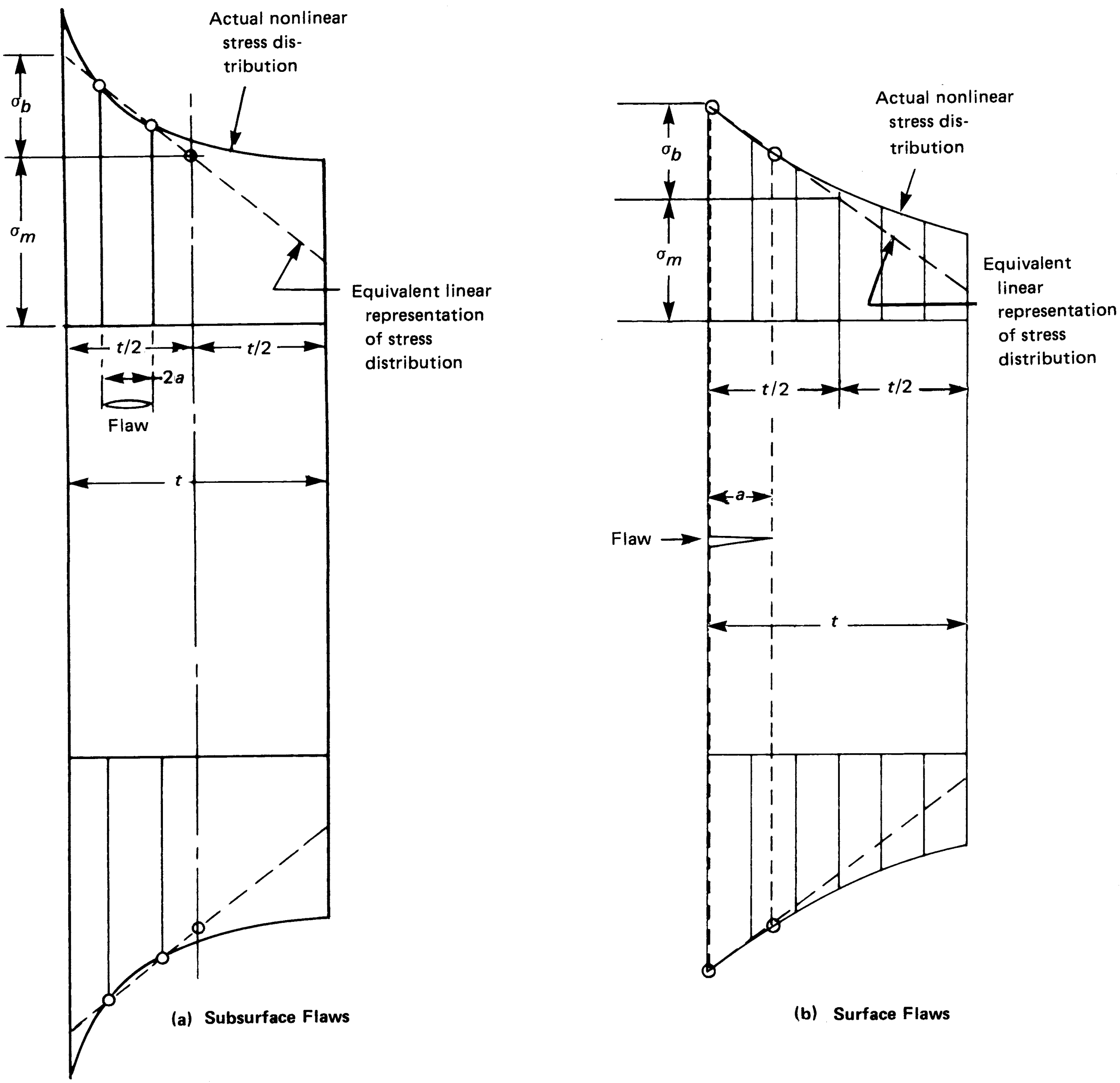


(a) Coordinate Relative to Center of Subsurface Flaw



(b) Coordinate Relative to Component Surface

Figure A-3210-3
Linearization of Stress Versus Distance Through the Wall



Legend:

t = wall thickness

A-3220 STRESS REPRESENTATION OVER DISCRETE INTERVALS

The variation of stress over the intervals between the discrete locations where stress is known may be approximated for the calculation of stress intensity factors using the weight function method described in A-3420. Piecewise linear variation is an acceptable approximation method, as described in A-3221.

A-3221 Linear Variation Over Interval

The stress normal to the plane of the flaw may be assumed to vary linearly between the discrete locations where stress is known. Piecewise linear format over a given interval is written as

$$\sigma_i(x) = k_i x + b_i (i = 1, \ldots , n) \tag{3}$$

where

b_i = constant of piecewise linear stress variation over the interval x_i and x_{i+1}

$= \sigma(x_i) - x_i\left(\frac{\sigma(x_{i+1}) - \sigma(x_i)}{x_{i+1} - x_i}\right)$

k_i = coefficient of piecewise linear stress variation over the interval x_i and x_{i+1}

$= \frac{\sigma(x_{i+1}) - \sigma(x_i)}{x_{i+1} - x_i}$

n = number of intervals of discrete locations at which stress is known

x_i = discrete locations

$\sigma(x_i)$ = value of known stress at locations x_i

$\sigma_i(x)$ = piecewise linear stress approximation over the i-interval

A-3300 STRESS INTENSITY FACTORS FOR SUBSURFACE FLAWS

The detected flaw shall be represented by an ellipse as illustrated in Figure A-3100-1, illustration (a). The stress intensity factors for the elliptical flaw model shall be determined using the representative stresses and flaw geometry described in A-3310.

A-3310 K_I BASED ON POLYNOMIAL STRESS REPRESENTATION

A-3311 K_I Equations

(a) The stress intensity factors for subsurface flaws shall be calculated using superposition of stress terms by the relationships given in (b) or (c).

(b) For stresses represented by A-3211 eq. (1) where the stress is defined over the crack depth, the stress intensity factor is given by

$$K_I = \left(C_0G_0 + C_1G_1 + C_2G_2 + C_3G_3 + C_4G_4\right)\sqrt{\pi a/Q} \tag{4}$$

where

$$C_0 = A_0 - A_1\left(\frac{d}{a}\right) + A_2\left(\frac{d}{a}\right)^2 - A_3\left(\frac{d}{a}\right)^3 + A_4\left(\frac{d}{a}\right)^4$$

$$C_1 = \left(\frac{t}{a}\right)\left[A_1 - 2A_2\left(\frac{d}{a}\right) + 3A_3\left(\frac{d}{a}\right)^2 - 4A_4\left(\frac{d}{a}\right)^3\right]$$

$$C_2 = \left(\frac{t}{a}\right)^2\left[A_2 - 3A_3\left(\frac{d}{a}\right) + 6A_4\left(\frac{d}{a}\right)^2\right]$$

$$C_3 = \left(\frac{t}{a}\right)^3\left[A_3 - 4A_4\left(\frac{d}{a}\right)\right]$$

$$C_4 = A_4\left(\frac{t}{a}\right)^4$$

d = distance from the intersection of the major and minor axes of the flaw to the nearest free boundary surface as shown in Figure A-3210-2

A_0, A_1, A_2, A_3, A_4 = coefficients from A-3211 eq. (1) that represent the stress distribution over the flaw depth, -1 ≤ x/a ≤ 1. When calculating K_I as a function of flaw depth, a new set of coefficients A_0 through A_4 shall be determined for each new value of flaw depth.

G_0, G_1, G_2, G_3, G_4 = K_I coefficients provided in tabular format in A-3312 or in equational format in A-3313

The flaw shape parameter Q is calculated using the following equation:

$$Q = \Phi - q_y \tag{5}$$

where

a/ℓ = the flaw aspect ratio $0 \le a/\ell \le 0.5$

q_y = the plastic zone correction factor calculated using the following equation:

$$q_y = \left[\left(C_0G_0 + C_1G_1 + C_2G_2 + C_3G_3 + C_4G_4\right)/\sigma_{ys}\right]^2/6$$

ℓ = the length of the major axis of the flaw

σ_{ys} = material yield strength

Φ = $1 + 4.593\,(a/\ell)^{1.65}$

(c) For stresses represented by A-3212 eq. (2) where the stress is defined over the component thickness, the stress intensity factor is given by

$$K_I = \left(B_0G_0 + B_1G_1 + B_2G_2 + B_3G_3 + B_4G_4\right)\sqrt{\pi a/Q} \tag{6}$$

where

d = distance from the intersection of the major and minor axes of the flaw to the nearest free boundary surface as shown in Figure A-3210-2

Q = flaw shape parameter given by (b) eq. (5)

q_y = the plastic zone correction factor calculated using the following equation:

$$q_y = \left[\left(B_0G_0 + B_1G_1 + B_2G_2 + B_3G_3 + B_4G_4\right)/\sigma_{ys}\right]^2/6$$

B_0, B_1, B_2, B_3, B_4 = coefficients from A-3212 eq. (2)

G_0, G_1, G_2, G_3, G_4 = K_I coefficients for subsurface flaw geometry as provided in tabular format in A-3312 or in equational format in A-3313

σ_{ys} = material yield strength

A-3312 Tabular G_i Coefficients

The G_i coefficients for subsurface flaws for ranges of flaw geometries are provided in Tables A-3610-1 through A-3610-6. Interpolation within the listed values is permitted.

A-3313 Equations for G_i Coefficients

In the course of preparation.

A-3400 STRESS INTENSITY FACTORS FOR SURFACE FLAWS

The detected flaw shall be represented by a semiellipse as illustrated in Figure A-3100-1, illustration (b). The stress intensity factors for the semielliptical flaw model shall be determined using the stresses and flaw geometry as described in A-3410 or A-3420.

A-3410 K_I BASED ON POLYNOMIAL STRESS REPRESENTATION

A-3411 K_I Equations

(a) The stress intensity factors for surface flaws shall be calculated using superposition of stress terms by the relationships given in (b) or (c).

(b) For stresses represented by A-3211 eq. (1) where the stress is defined over the crack depth, the stress intensity factor is given by

$$K_I = \left[\left(A_0 + A_p\right)G_0 + A_1G_1 + A_2G_2 + A_3G_3 + A_4G_4\right]\sqrt{\pi a/Q} \tag{7}$$

where

A_p = pressure for surface flaws exposed to pressure loading (A_p = 0 for flaws not exposed to pressure loading)
Q = flaw shape parameter given by A-3311(b) eq. (5)
q_y = the plastic zone correction factor calculated using the following equation:

$$q_y = \left[\left(A_0G_0 + A_pG_0 + A_1G_1 + A_2G_2 + A_3G_3 + A_4G_4\right)/\sigma_{ys}\right]^2/6$$

$A_0, A_1, A_2,$
A_3, A_4 = coefficients from A-3211 eq. (1). When calculating K_I as a function of flaw depth, a new set of coefficients A_0 through A_4 shall be determined for each new value of flaw depth.
$G_0, G_1, G_2,$
G_3, G_4 = K_I coefficients specified in A-3412 or A-3413
σ_{ys} = material yield strength

(c) For stresses represented by A-3212 eq. (2) where the stress is defined over the component thickness, the stress intensity factor is given by

$$K_I = \left[\left(B_0 + B_p\right)G_0 + B_1\left(a/t\right)G_1 + B_2\left(a/t\right)^2G_2 + B_3\left(a/t\right)^3G_3 + B_4\left(a/t\right)^4G_4\right]\sqrt{\pi a/Q} \tag{8}$$

where

B_p = pressure for surface flaws exposed to pressure loading (B_p = 0 for flaws not exposed to pressure loading)
Q = flaw shape parameter given by A-3311(b) eq. (5)
q_y = the plastic zone correction factor calculated using the following equation:

$$q_y = \left\{\left[B_0G_0 + B_pG_0 + B_1\left(a/t\right)G_1 + B_2\left(a/t\right)^2G_2 + B_3\left(a/t\right)^3G_3 + B_4\left(a/t\right)^4G_4\right]/\sigma_{ys}\right\}^2/6$$

$B_0, B_1, B_2,$
B_3, B_4 = coefficients from A-3212 eq. (2)
$G_0, G_1, G_2,$
G_3, G_4 = K_I coefficients specified in A-3412 or A-3413
σ_{ys} = material yield strength

A-3412 Tabular G_i Coefficients

The G_i coefficients for a surface flaw in a flat plate for a range of flaw geometries are provided in Tables A-3620-1 through A-3620-3. Tabular values for circumferential inside surface flaws in selected cylindrical geometries are provided in Tables A-3630-1 through A-3630-8.

A-3413 Equations for G_i Coefficients

(a) The equations for G_i for the deepest point (Point 1) of a surface flaw are given below:

$$G_0 = Y_0$$

$$G_1 = Y_1$$

$$G_2 = \frac{2}{35}\frac{\sqrt{2\Phi}}{\pi} - \frac{1}{6}Y_0 + Y_1$$

$$G_3 = \frac{52}{525}\frac{\sqrt{2\Phi}}{\pi} - \frac{1}{5}Y_0 + \frac{9}{10}Y_1$$

$$G_4 = \frac{316}{2,475}\frac{\sqrt{2\Phi}}{\pi} - \frac{1}{5}Y_0 + \frac{4}{5}Y_1$$

where Y_0 and Y_1 are the solution functions given in A-3500 for the appropriate flaw model and geometry for the component, and Φ is defined in A-3311.

(b) For the surface point (Point 2), G_i shall be determined from the following equations:

$$G_0 = F_0$$

$$G_1 = F_1$$

$$G_2 = \frac{4}{105}\frac{\sqrt{\Phi}}{\pi} - \frac{1}{14}F_0 + \frac{5}{7}F_1$$

$$G_3 = \frac{4}{105}\frac{\sqrt{\Phi}}{\pi} - \frac{1}{15}F_0 + \frac{1}{2}F_1$$

$$G_4 = \frac{16}{495}\frac{\sqrt{\Phi}}{\pi} - \frac{3}{55}F_0 + \frac{4}{11}F_1$$

where F_0 and F_1 are the solution functions given in A-3500 for the appropriate flaw model and geometry for the component, and Φ is defined in A-3311.

A-3420 K_I BASED ON WEIGHT FUNCTION METHOD

For an arbitrary stress distribution $\sigma(x)$ on crack face, the stress intensity factor is given by the following equation using the weight function method:

$$K_I = \int_0^a m(x,a)\sigma(x)dx \tag{9}$$

where

a = crack depth
K_I = stress intensity factor
$m(x,a)$ = Mode I weight function
x = distance from the surface and moving positive toward the tip of the surface crack, defined in Figure A-3210-1
$\sigma(x)$ = stress distribution normal to the plane of the flaw

A-3421 K_I Equations Based on Weight Functions

(a) For the deepest point (Point 1) of a semielliptical surface crack as shown in Figure A-3100-1, illustration (b), the weight function is given by

$$m(x,a) = \frac{2}{\left[2\pi(a-x)\right]^{1/2}}\left[1 + M_1\left(1-\frac{x}{a}\right)^{1/2} + M_2\left(1-\frac{x}{a}\right) + M_3\left(1-\frac{x}{a}\right)^{3/2}\right]$$

where the weight function coefficients M_j are dependent on geometry of the structure and crack dimensions. The stress intensity factor calculated using A-3420 eq. (9) and the piecewise linear stress distribution of A-3221 eq. (3) is given by

$$K_I = K_{IM0} + K_{IM1}M_1 + K_{IM2}M_2 + K_{IM3}M_3 \tag{10}$$

where

$$K_{IM0} = \frac{2\sqrt{2}}{3\sqrt{\pi}} \sum_{i=1}^{n} \left[\left(k_i x_i + 2k_i a + 3b_i\right)\sqrt{a - x_i} - \left(k_i x_{i+1} + 2k_i a + 3b_i\right)\sqrt{a - x_{i+1}} \right]$$

$$K_{IM1} = \sqrt{\frac{2}{\pi}} \frac{1}{\sqrt{a}} \sum_{i=1}^{n} \left[\frac{k_i}{2}\left(x_{i+1}^2 - x_i^2\right) + b_i\left(x_{i+1} - x_i\right) \right]$$

$$K_{IM2} = \frac{2}{15}\sqrt{\frac{2}{\pi}} \frac{1}{a} \sum_{i=1}^{n} \left[\left(3k_i x_i + 2k_i a + 5b_i\right)\left(a - x_i\right)^{3/2} - \left(3k_i x_{i+1} + 2k_i a + 5b_i\right)\left(a - x_{i+1}\right)^{3/2} \right]$$

$$K_{IM3} = \sqrt{\frac{2}{\pi}} \frac{1}{a\sqrt{a}} \sum_{i=1}^{n} \left[\frac{k_i}{3}\left(x_i^3 - x_{i+1}^3\right) + \frac{1}{2}\left(k_i a - b_i\right)x_{i+1}^2 - \frac{1}{2}\left(k_i a - b_i\right)x_i^2 + b_i a\left(x_{i+1} - x_i\right) \right]$$

In eq. (10) and (b) eq. (11), k_i and b_i are defined in A-3221 eq. (3).

(b) For the surface point (Point 2) of a semielliptical surface crack as shown in Figure A-3100-1, illustration (b), the weight function is given by

$$m(x,a) = \frac{2}{(\pi x)^{1/2}}\left[1 + N_1\left(\frac{x}{a}\right)^{1/2} + N_2\left(\frac{x}{a}\right) + N_3\left(\frac{x}{a}\right)^{3/2}\right]$$

where weight function coefficients, N_j, are dependent on geometry of the structure and crack dimensions. The stress intensity factor calculated using the weight function method of A-3420 eq. (9) and the piecewise linear stress of A-3221 eq. (3) is given by

$$K_I = K_{IN0} + K_{IN1}N_1 + K_{IN2}N_2 + K_{IN3}N_3 \qquad (11)$$

where

$$K_{IN0} = \frac{4}{3\sqrt{\pi}} \sum_{i=1}^{n} \left[\sqrt{x_{i+1}}\left(k_i x_{i+1} + 3b_i\right) - \sqrt{x_i}\left(k_i x_i + 3b_i\right) \right]$$

$$K_{IN1} = \frac{1}{\sqrt{\pi a}} \sum_{i=1}^{n} \left[x_{i+1}\left(k_i x_{i+1} + 2b_i\right) - x_i\left(k_i x_i + 2b_i\right) \right]$$

$$K_{IN2} = \frac{4}{15a\sqrt{\pi}} \sum_{i=1}^{n} \left[x_{i+1}^{3/2}\left(3k_i x_{i+1} + 5b_i\right) - x_i^{3/2}\left(3k_i x_i + 5b_i\right) \right]$$

$$K_{IN3} = \frac{1}{3a\sqrt{\pi a}} \sum_{i=1}^{n} \left[x_{i+1}^2\left(2k_i x_{i+1} + 3b_i\right) - x_i^2\left(2k_i x_i + 3b_i\right) \right]$$

In (a) eq. (10) and eq. (11), k_i and b_i are defined in A-3221 eq. (3).

A-3422 Equations for Weight Function Coefficients, M_j and N_j

(a) Coefficients M_j for j = 1, 2, and 3, to calculate K_I in A-3421(a), where G_i is evaluated at the deepest point (Point 1), are given by

$$M_1 = \frac{2\pi}{\sqrt{2\Phi}}\left(3G_i - G_0\right) - \frac{24}{5}$$

$$M_2 = 3$$

$$M_3 = \frac{6\pi}{\sqrt{2\Phi}}\left(G_0 - 2G_1\right) + \frac{8}{5}$$

Solutions for G_0 and G_1 are provided in A-3412 and A-3413 for various flaw geometries.

(b) Coefficients N_j for j = 1, 2, and 3, to calculate K_I in A-3421(b), where G_i is evaluated at the surface point (Point 2), are given by

$$N_1 = \frac{3\pi}{\sqrt{\Phi}}\left(2G_0 - 5G_1\right) - 8$$

$$N_2 = \frac{15\pi}{\sqrt{\Phi}}\left(3G_1 - G_0\right) + 15$$

$$N_3 = \frac{3\pi}{\sqrt{\Phi}}\left(3G_0 - 10G_1\right) - 8$$

Solutions for G_0 and G_1 are provided in A-3412 and A-3413 for various flaw geometries.

A-3500 FLAW MODEL SOLUTIONS

A-3510 SUBSURFACE FLAWS

In the course of preparation. The tabular G_i coefficients for subsurface flaws in Tables A-3610-1 through A-3610-6 may be used. Interpolation within the listed values is permitted.

A-3520 SURFACE FLAWS IN FLAT PLATE

For surface flaws in a flat plate of finite thickness, the following expressions define the solution functions for determining the G_i coefficients in A-3413. For the deepest point (Point 1)

$$Y_0 = f_0$$

$$Y_1 = f_0 - f_1$$

where

$f_0 = a_0 + a_1 (a/t)^2 + a_2 (a/t)^4$

$a_0 = 1.10190 - 0.019863(a/c) - 0.043588(a/c)^2$
$a_1 = 4.32489 - 14.9372(a/c) + 19.4389(a/c)^2 - 8.52318(a/c)^3$
$a_2 = -3.03329 + 9.96083(a/c) - 12.582(a/c)^2 + 5.3462(a/c)^3$

$f_1 = b_0 + b_1 (a/t)^2 + b_2 (a/t)^4$

$b_0 = 0.456128 - 0.114206(a/c) - 0.046523(a/c)^2$
$b_1 = 3.022 - 10.8679(a/c) + 14.94(a/c)^2 - 6.8537(a/c)^3$
$b_2 = -2.28655 + 7.88771(a/c) - 11.0675(a/c)^2 + 5.16354(a/c)^3$

over the ranges $0 < a/t \le 0.8$ and $0.2 \le a/c \le 1.0$, where $c = \ell/2$.

For the surface point (Point 2)

$$F_0 = g_0$$

$$F_1 = g_0 - g_1$$

where

$g_0 = c_0 (a/c)^{m_0}$

$c_0 = 1.143260 + 0.0175996(a/t) + 0.501001(a/t)^2$
$m_0 = 0.458320 - 0.102985(a/t) - 0.398185(a/t)^2$

$g_1 = c_1 (a/c)^{m_1}$

$c_1 = 0.976770 - 0.131975(a/t) + 0.484875(a/t)^2$
$m_1 = 0.448863 - 0.173295(a/t) - 0.267775(a/t)^2$

over the ranges $0 < a/t \le 0.8$ and $0.2 \le a/c \le 1.0$.

A-3530 CIRCUMFERENTIAL INSIDE SURFACE FLAWS IN CYLINDERS

(a) This section provides closed-form solutions to determine Y_0 and Y_1 for the deepest point, and F_0 and F_1 for the surface point, of circumferential flaws on the inside surface of cylinders. The deepest and surface points (Points 1 and 2) are shown in Figure A-3100-1, illustration (b). These coefficients are used in conjunction with equations in A-3413 to determine G_0 through G_4 for use in calculating stress intensity factors. The equations cover R_i/t range from 1 to 100.

(b) The range over which an inside surface flaw can be defined as an elliptical crack geometry depends on R_i/t, a/ℓ, and a/t. The governing equation for a valid elliptical crack shown in Figure A-3530-1 is

$$a/\ell_{360} = [1/(2\pi)](a/t)(t/R_i)$$

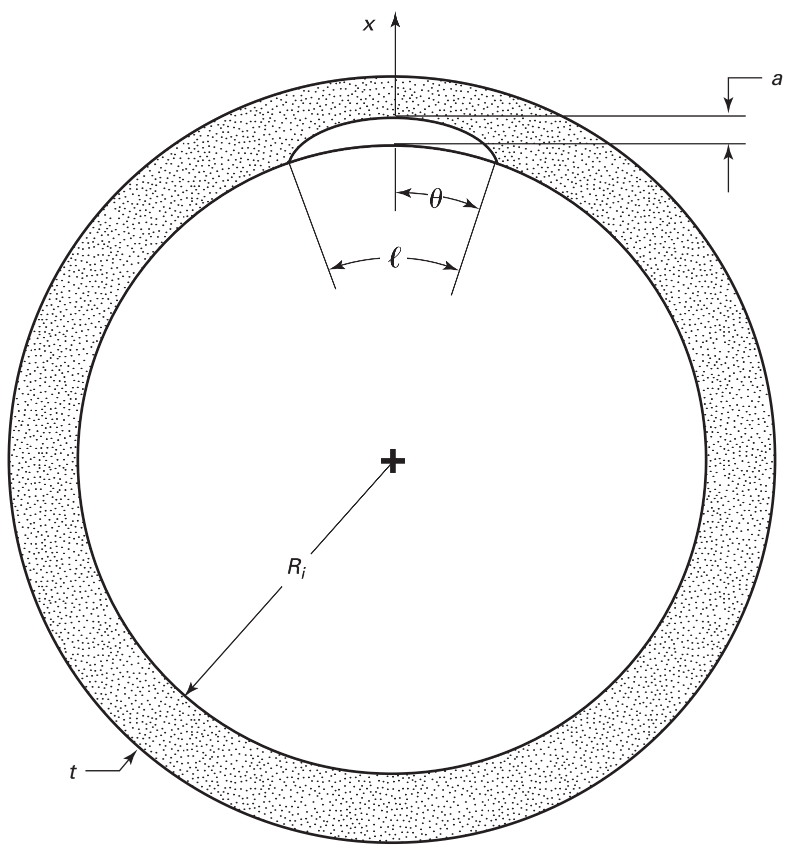
$$\ell = 2\theta R_i$$

where ℓ_{360} is that value of ℓ equal to the circumference of the inside surface ($\ell_{360} = 2\pi R_i$). A 360-deg circumferential flaw is achieved when $a/\ell = a/\ell_{360}$. Any flaw having a/ℓ ratio less than or equal to a/ℓ_{360} shall be treated as a 360-deg circumferential flaw (see A-3531).

(c) The equations for Y_0, Y_1, F_0, and F_1 are based on stress analysis data over a specific range of values for a/t and a/ℓ. The ranges over which the equations are valid are defined with each set of equations. Exceeding these bounds on a/t and a/ℓ results in extrapolation, and the calculated values shall be justified.

(d) Interpolation in Y_0, Y_1, F_0, and F_1 to obtain intermediate values for R_i/t is permitted, provided the interpolation is performed based on t/R_i ratio. The t/R_i ratios shall be checked to ensure that the flaw size and shape for the appropriate t/R_i remains a valid elliptical geometry. Otherwise, a 360-deg circumferential flaw geometry shall be used.

Figure A-3530-1
Cylindrical Flaw Geometry



A-3531 360-Deg Circumferential Inside Surface Flaw

For a 360-deg circumferential surface flaw on the inside surface of a cylinder (Figure A-3531-1), the following equation defines the solution for the G_i coefficients in A-3413 for the deepest point.

$$Y_i = m_1 + m_2\left(\frac{a}{t}\right) + m_3 \ln\left(\frac{R_i}{t}\right) + m_4\left(\frac{a}{t}\right)^2 + m_5\left[\ln\left(\frac{R_i}{t}\right)\right]^2 + m_6\left(\frac{a}{t}\right)\ln\left(\frac{R_i}{t}\right) + m_7\left(\frac{a}{t}\right)^3 + m_8\left[\ln\left(\frac{R_i}{t}\right)\right]^3 + m_9\left(\frac{a}{t}\right)\left[\ln\left(\frac{R_i}{t}\right)\right]^2 + m_{10}\left(\frac{a}{t}\right)^2 \ln\left(\frac{R_i}{t}\right)$$

where Y_i represents Y_0 or Y_1 for the flaw equations for the deepest point with coefficients given in Table A-3531-1. The range of applicability is $0 \le a/t \le 0.8$ and $1 \le R_i/t \le 100$. Use of the above equation outside these parameter ranges will result in extrapolation and shall be justified.

A-3532 Elliptical Inside Surface Flaw

(a) For a circumferential elliptical surface flaw on the inside surface of a cylinder, the following equations define the solution for the G_i coefficients in A-3413.

(b) For the case when R_i/t = 1, at the deepest point of the flaw (Point 1)

$$Y_0 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{t}\right)^2 + m_4\left(\frac{a}{\ell}\right) + m_5\left(\frac{a}{\ell}\right)^2}{1 + m_6\left(\frac{a}{t}\right) + m_7\left(\frac{a}{\ell}\right)}$$

Figure A-3531-1
360-deg Inside Surface Flaw Geometry

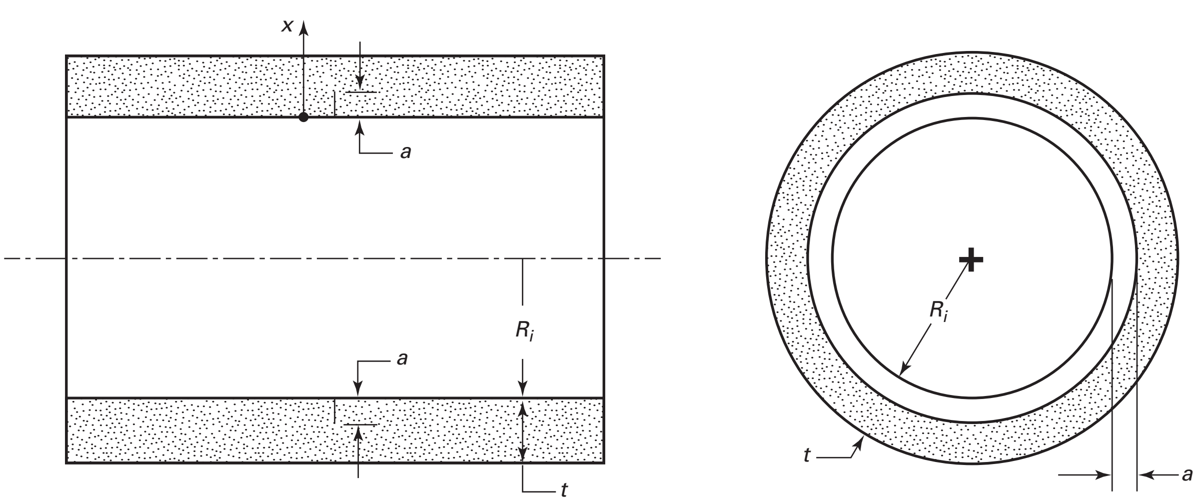


Table A-3531-1
Coefficients for 360-deg Circumferential Inside Surface Flaw Equation

Coefficients	Y_0	Y_1
m_1	1.07130 E+00	6.48814 E−01
m_2	1.52135 E−01	1.75457 E−01
m_3	9.77012 E−02	4.34760 E−02
m_4	−3.35553 E−01	−3.58231 E−01
m_5	−2.14289 E−02	−8.42949 E−03
m_6	−3.46308 E−01	−1.40864 E−01
m_7	9.51292 E−01	6.06585 E−01
m_8	−1.20085 E−05	−1.54100 E−04
m_9	8.99698 E−02	3.65687 E−02
m_{10}	1.00469 E+00	3.46561 E−01

$$Y_1 = m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right) + m_4\left(\frac{a}{t}\right)^2 + m_5\left(\frac{a}{\ell}\right)^2 + m_6\left(\frac{a}{t}\right)\left(\frac{a}{\ell}\right) + m_7\left(\frac{a}{t}\right)^3 + m_8\left(\frac{a}{\ell}\right)^3 + m_9\left(\frac{a}{t}\right)\left(\frac{a}{\ell}\right)^2 + m_{10}\left(\frac{a}{t}\right)^2\left(\frac{a}{\ell}\right)$$

where Y_0 and Y_1 are the flaw equations for the deepest point with coefficients, m_i, given in Table A-3532-1. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equations outside these parameter ranges will result in extrapolation and shall be justified. If $a/\ell \le a/\ell_{360}$, use a 360-deg circumferential flaw in A-3531.

For the surface point of the flaw (Point 2)

$$F_0 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right)}{1 + m_4\left(\frac{a}{t}\right) + m_5\left(\frac{a}{t}\right)^2 + m_6\left(\frac{a}{t}\right)^3 + m_7\left(\frac{a}{\ell}\right)}$$

$$F_1 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{t}\right)^2 + m_4\left(\frac{a}{\ell}\right) + m_5\left(\frac{a}{\ell}\right)^2}{1 + m_6\left(\frac{a}{t}\right) + m_7\left(\frac{a}{t}\right)^2 + m_8\left(\frac{a}{t}\right)^3 + m_9\left(\frac{a}{\ell}\right)}$$

where F_0 and F_1 are the surface flaw equations with coefficients, m_i, given in Table A-3532-2. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. If $a/\ell \le a/\ell_{360}$, the flaw is 360 deg, and values for F_0 and F_1 do not exist. Use of the above equations outside these parameters shall be justified. Tabulated values of G_0 through G_4 are shown in Tables A-3630-1 and A-3630-2.

(c) For the case when $R_i/t = 3$, at the deepest point of the flaw (Point 1)

$$Y_i = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{t}\right)^2 + m_4\left(\frac{a}{\ell}\right) + m_5\left(\frac{a}{\ell}\right)^2}{1 + m_6\left(\frac{a}{t}\right) + m_7\left(\frac{a}{\ell}\right)}$$

where Y_i represents Y_0 or Y_1 for the flaw equations for the deepest point with coefficients, m_i, given in Table A-3532-1. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equation outside these parameter ranges will result in extrapolation and shall be justified. If $a/\ell \le a/\ell_{360}$, use a 360-deg circumferential flaw in A-3531.

For the surface point of the flaw (Point 2)

$$F_0 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right)}{1 + m_4\left(\frac{a}{t}\right) + m_5\left(\frac{a}{t}\right)^2 + m_6\left(\frac{a}{t}\right)^3 + m_7\left(\frac{a}{\ell}\right)}$$

$$F_1 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right)}{1 + m_4\left(\frac{a}{t}\right) + m_5\left(\frac{a}{\ell}\right)}$$

where F_0 and F_1 are the surface flaw equations with coefficients, m_i, given in Table A-3532-2. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equations outside these parameter ranges shall be justified.

(d) For the case when $R_i/t = 5$, at the deepest point of the flaw (Point 1)

$$Y_0 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right) + m_4\left(\frac{a}{\ell}\right)^2 + m_5\left(\frac{a}{\ell}\right)^3}{1 + m_6\left(\frac{a}{t}\right) + m_7\left(\frac{a}{\ell}\right) + m_8\left(\frac{a}{\ell}\right)^2 + m_9\left(\frac{a}{\ell}\right)^3}$$

$$Y_1 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right) + m_4\left(\frac{a}{\ell}\right)^2}{1 + m_5\left(\frac{a}{t}\right) + m_6\left(\frac{a}{\ell}\right)}$$

where Y_0 and Y_1 are the flaw equations for the deepest point with coefficients, m_i, given in Table A-3532-1. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equations outside these parameter ranges will result in extrapolation and shall be justified. If $a/\ell \le a/\ell_{360}$, use a 360-deg circumferential flaw in A-3531.

For the surface point of the flaw (Point 2)

$$F_0 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{t}\right)^2 + m_4\left(\frac{a}{t}\right)^3 + m_5\left(\frac{a}{\ell}\right) + m_6\left(\frac{a}{\ell}\right)^2}{1 + m_7\left(\frac{a}{t}\right) + m_8\left(\frac{a}{t}\right)^2 + m_9\left(\frac{a}{t}\right)^3 + m_{10}\left(\frac{a}{\ell}\right)}$$

$$F_1 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right)}{1 + m_4\left(\frac{a}{t}\right) + m_5\left(\frac{a}{t}\right)^2 + m_6\left(\frac{a}{t}\right)^3 + m_7\left(\frac{a}{\ell}\right)}$$

where F_0 and F_1 are the surface flaw equations with coefficients, m_i, given in Table A-3532-2. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equations outside these parameter ranges shall be justified. Tabulated values of G_0 through G_4 are shown in Tables A-3630-3 and A-3630-4.

(e) For the case when $R_i/t = 10$, at the deepest point of the flaw (Point 1)

$$Y_0 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right) + m_4\left(\frac{a}{\ell}\right)^2 + m_5\left(\frac{a}{\ell}\right)^3}{1 + m_6\left(\frac{a}{t}\right) + m_7\left(\frac{a}{\ell}\right) + m_8\left(\frac{a}{\ell}\right)^2 + m_9\left(\frac{a}{\ell}\right)^3}$$

$$Y_1 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right) + m_4\left(\frac{a}{\ell}\right)^2}{1 + m_5\left(\frac{a}{t}\right) + m_6\left(\frac{a}{\ell}\right)}$$

where Y_0 and Y_1 are the flaw equations for the deepest point with coefficients, m_i, given in Table A-3532-1. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equations outside these parameter ranges will result in extrapolation and shall be justified. If $a/\ell \le a/\ell_{360}$, use a 360-deg circumferential flaw in A-3531.

For the surface point of the flaw (Point 2)

$$F_0 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{t}\right)^2 + m_4\left(\frac{a}{t}\right)^3 + m_5\left(\frac{a}{\ell}\right)}{1 + m_6\left(\frac{a}{t}\right) + m_7\left(\frac{a}{t}\right)^2 + m_8\left(\frac{a}{t}\right)^3 + m_9\left(\frac{a}{\ell}\right)}$$

$$F_1 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{t}\right)^2 + m_4\left(\frac{a}{\ell}\right) + m_5\left(\frac{a}{\ell}\right)^2}{1 + m_6\left(\frac{a}{t}\right) + m_7\left(\frac{a}{t}\right)^2 + m_8\left(\frac{a}{\ell}\right) + m_9\left(\frac{a}{\ell}\right)^2}$$

where F_0 and F_1 are the surface flaw equations with coefficients, m_i, given in Table A-3532-2. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equations outside these parameter ranges shall be justified. Tabulated values of G_0 through G_4 are shown in Tables A-3630-5 and A-3630-6.

(f) For the case when $R_i/t = 20$, at the deepest point of the flaw (Point 1)

$$Y_0 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right) + m_4\left(\frac{a}{\ell}\right)^2 + m_5\left(\frac{a}{\ell}\right)^3}{1 + m_6\left(\frac{a}{t}\right) + m_7\left(\frac{a}{\ell}\right) + m_8\left(\frac{a}{\ell}\right)^2}$$

$$Y_1 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right) + m_4\left(\frac{a}{\ell}\right)^2}{1 + m_5\left(\frac{a}{t}\right) + m_6\left(\frac{a}{\ell}\right)}$$

where Y_0 and Y_1 are the flaw equations for the deepest point with coefficients, m_i, given in Table A-3532-1. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equations outside these parameter ranges will result in extrapolation and shall be justified. If $a/\ell \le a/\ell_{360}$, use a 360-deg circumferential flaw in A-3531.

For the surface point of the flaw (Point 2)

$$F_0 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{t}\right)^2 + m_4\left(\frac{a}{t}\right)^3 + m_5\left(\frac{a}{\ell}\right) + m_6\left(\frac{a}{\ell}\right)^2}{1 + m_7\left(\frac{a}{t}\right) + m_8\left(\frac{a}{t}\right)^2 + m_9\left(\frac{a}{t}\right)^3 + m_{10}\left(\frac{a}{\ell}\right)}$$

$$F_1 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right)}{1 + m_4\left(\frac{a}{t}\right) + m_5\left(\frac{a}{\ell}\right)}$$

where F_0 and F_1 are the surface flaw equations with coefficients, m_i, given in Table A-3532-2. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equations outside these parameter ranges shall be justified. Tabulated values of G_0 through G_4 are shown in Tables A-3630-7 and A-3630-8.

(g) For the case when $R_i/t = 60$, at the deepest point of the flaw (Point 1)

$$Y_0 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right) + m_4\left(\frac{a}{\ell}\right)^2 + m_5\left(\frac{a}{\ell}\right)^3}{1 + m_6\left(\frac{a}{t}\right) + m_7\left(\frac{a}{\ell}\right) + m_8\left(\frac{a}{\ell}\right)^2}$$

$$Y_1 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right) + m_4\left(\frac{a}{\ell}\right)^2}{1 + m_5\left(\frac{a}{t}\right) + m_6\left(\frac{a}{\ell}\right)}$$

where Y_0 and Y_1 are the flaw equations for the deepest point with coefficients, m_i, given in Table A-3532-1. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equations outside these parameter ranges will result in extrapolation and shall be justified. If $a/\ell \le a/\ell_{360}$, use a 360-deg circumferential flaw in A-3531.

For the surface point of the flaw (Point 2)

$$F_0 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{t}\right)^2 + m_4\left(\frac{a}{t}\right)^3 + m_5\left(\frac{a}{\ell}\right) + m_6\left(\frac{a}{\ell}\right)^2}{1 + m_7\left(\frac{a}{t}\right) + m_8\left(\frac{a}{t}\right)^2 + m_9\left(\frac{a}{t}\right)^3 + m_{10}\left(\frac{a}{\ell}\right)}$$

$$F_1 = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{t}\right)^2 + m_4\left(\frac{a}{\ell}\right) + m_5\left(\frac{a}{\ell}\right)^2}{1 + m_6\left(\frac{a}{t}\right) + m_7\left(\frac{a}{\ell}\right) + m_8\left(\frac{a}{\ell}\right)^2}$$

where F_0 and F_1 are the surface flaw equations with coefficients, m_i, given in Table A-3532-2. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equations outside these parameter ranges shall be justified.

(h) For the case when $R_i/t = 100$, at the deepest point of the flaw (Point 1)

$$Y_i = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right) + m_4\left(\frac{a}{\ell}\right)^2}{1 + m_5\left(\frac{a}{t}\right) + m_6\left(\frac{a}{\ell}\right) + m_7\left(\frac{a}{\ell}\right)^2}$$

where Y_i represents Y_0 or Y_1 for the flaw equations for the deepest point with coefficients, m_i, given in Table A-3532-1. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equation outside these parameter ranges will result in extrapolation and shall be justified. If $a/\ell \le a/\ell_{360}$, use a 360-deg circumferential flaw in A-3531.

For the surface point of the flaw (Point 2)

$$F_i = \frac{m_1 + m_2\left(\frac{a}{t}\right) + m_3\left(\frac{a}{\ell}\right) + m_4\left(\frac{a}{\ell}\right)^2 + m_5\left(\frac{a}{\ell}\right)^3}{1 + m_6\left(\frac{a}{t}\right) + m_7\left(\frac{a}{t}\right)^2 + m_8\left(\frac{a}{\ell}\right) + m_9\left(\frac{a}{\ell}\right)^2}$$

where F_i represents F_0 or F_1 for the surface flaw equation with coefficients, m_i, given in Table A-3532-2. The range of applicability is $0 \le a/t \le 0.8$ and $a/\ell_{360} < a/\ell \le 0.5$. Use of the above equation outside these parameter ranges shall be justified.

A-3540 CIRCUMFERENTIAL O.D. SURFACE FLAWS IN CYLINDERS

In the course of preparation. The solution for the flat plate model for G_i in A-3520 may be used.

A-3550 AXIAL INSIDE SURFACE FLAWS IN CYLINDERS

In the course of preparation. The solution for the flat plate model for G_i in A-3520 may be used.

A-3560 AXIAL OUTSIDE SURFACE FLAWS IN CYLINDERS

In the course of preparation. The solution for the flat plate model for G_i in A-3520 may be used.

A-3600 G_i COEFFICIENTS IN TABULAR FORM

This subarticle contains tabulated values for G_0 through G_4 for various geometries. These tables are referenced by A-3312 and A-3412. Interpolation in a/ℓ, a/d, a/t, t/R_i, and d/t is permitted in the Tables of A-3610, A-3620, and A-3630.

A-3610 COEFFICENTS G_0 THROUGH G_4 FOR SUBSURFACE CRACK

See Tables A-3610-1 through A-3610-6.

Table A-3532-1
Coefficients for Semielliptical Circumferential Inside Surface Flaw Equations, Deepest Point (Point 1)

Coefficients	$R_i/t = 1$		$R_i/t = 3$		$R_i/t = 5$		$R_i/t = 10$	
	Y_0	Y_1	Y_0	Y_1	Y_0	Y_1	Y_0	Y_1
m_1	1.10889 E+00	6.85352 E−01	1.15125 E+00	6.98772 E−01	1.11343 E+00	7.09517 E−01	1.09199 E+00	6.91614 E−01
m_2	−1.25394 E+00	−1.50548 E−01	−8.82425 E−01	−6.58620 E−01	−4.57201 E−01	−5.50839 E−01	−6.34066 E−02	−3.74200 E−01
m_3	5.97485 E−01	−1.72245 E−01	1.93364 E−01	1.79846 E−01	6.41084 E−01	1.06038 E+00	3.93480 E+00	2.51851 E+00
m_4	4.86147 E−01	7.36887 E−02	2.03438 E+00	1.28738 E+00	3.30691 E+01	9.68824 E−01	4.07522 E+01	1.07367 E+00
m_5	2.89649 E−01	1.40103 E+00	5.18324 E−01	9.94781 E−01	−5.29889 E+01	−1.00092 E+00	−6.35645 E+01	−9.25019 E−01
m_6	−9.07933 E−01	−3.15954 E−01	−9.75983 E−01	−9.79754 E−01	−8.75031 E−01	2.16603 E+00	−8.17658 E−01	4.24183 E+00
m_7	6.68014 E−01	7.86514 E−01	2.46237 E+00	2.42710 E+00	8.80344 E−01	N/A	3.75120 E+00	N/A
m_8	N/A	−1.69966 E+00	N/A	N/A	3.08549 E+01	N/A	3.83982 E+01	N/A
m_9	N/A	1.63055 E+00	N/A	N/A	−4.89480 E+01	N/A	−5.79021 E+01	N/A
m_{10}	N/A	−1.23433 E+00	N/A	N/A	N/A	N/A	N/A	N/A

Coefficients	$R_i/t = 20$		$R_i/t = 60$		$R_i/t = 100$	
	Y_0	Y_1	Y_0	Y_1	Y_0	Y_1
m_1	1.09357 E+00	6.96626 E−01	1.08043 E+00	6.88471 E−01	1.06719 E+00	6.93887 E−01
m_2	1.84693 E−01	−2.54857 E−01	3.80354 E−01	−1.82010 E−01	5.05303 E−01	−1.76885 E−01
m_3	6.31565 E+00	3.73189 E+00	7.18740 E+00	5.48211 E+00	7.55482 E+00	4.35984 E+00
m_4	2.04554 E+01	1.59309 E+00	3.56638 E+01	1.19796 E+00	1.14005 E+01	2.93971 E+00
m_5	−2.07996 E−01	−8.84114 E−01	−6.37988 E+00	−9.14096 E−01	−8.73938 E−01	−9.21967 E−01
m_6	−8.22268 E−01	6.28557 E+00	−8.76588 E−01	8.48290 E+00	7.40188 E+00	7.23332 E+00
m_7	6.21895 E+00	N/A	7.07112 E+00	N/A	1.19984 E+01	1.88388 E+00
m_8	1.99526 E+01	N/A	3.15701 E+01	N/A	N/A	N/A
m_9	N/A	N/A	N/A	N/A	N/A	N/A
m_{10}	N/A	N/A	N/A	N/A	N/A	N/A

Table A-3532-2
Coefficients for Semielliptical Circumferential Inside Surface Flaw Equations, Surface Point (Point 2)

Coefficients	R_i/t = 1		R_i/t = 3		R_i/t = 5		R_i/t = 10	
	F_0	F_1	F_0	F_1	F_0	F_1	F_0	F_1
m_1	1.64496 E−01	4.88938 E−04	1.32440 E−01	−1.50149 E−02	1.13982 E−01	−1.39698 E−02	1.11374 E−01	−4.24930 E−03
m_2	−2.98905 E−01	−8.69283 E−02	−1.15242 E−01	−3.11917 E−03	8.21739 E−02	−7.19889 E−03	1.38732 E−01	−8.20587 E−03
m_3	4.90225 E+00	1.07598 E−01	5.69683 E+00	8.80608 E−01	−7.41220 E−01	8.78529 E−01	−7.06971 E−01	2.35630 E−02
m_4	9.04706 E−02	6.25873 E−01	6.40066 E−02	−7.74366 E−01	5.20565 E−01	−1.87063 E+00	4.92779 E−01	5.95009 E−01
m_5	−1.15432 E+00	−5.99429 E−01	−1.30963 E+00	2.42183 E+00	6.18421 E+00	2.80791 E+00	5.98338 E+00	6.98387 E−01
m_6	5.08381 E−01	−1.00626 E+00	6.70826 E−01	N/A	1.19860 E+00	−2.01685 E+00	3.32795 E−01	−1.18458 E+00
m_7	2.34511 E+00	1.68297 E+00	3.01176 E+00	N/A	1.87491 E−01	2.62123 E+00	−2.87288 E+00	4.79557 E−01
m_8	N/A	−1.06351 E+00	N/A	N/A	−2.50254 E+00	N/A	1.94042 E+00	8.56237 E−01
m_9	N/A	−2.44089 E−01	N/A	N/A	1.61212 E+00	N/A	3.22359 E+00	4.17703 E+00
m_{10}	N/A	N/A	N/A	N/A	3.88243 E+00	N/A	N/A	N/A

Coefficients	R_i/t = 20		R_i/t = 60		R_i/t = 100	
	F_0	F_1	F_0	F_1	F_0	F_1
m_1	9.88052 E−02	−8.82484 E−03	1.00475 E−01	−5.12509 E−03	1.20136 E−01	−5.79084 E−03
m_2	2.26670 E−01	9.45840 E−03	2.16208 E−01	1.08802 E−02	−8.53915 E−02	4.52833 E−03
m_3	−9.09763 E−01	8.47324 E−01	−9.31311 E−01	−4.30886 E−03	5.28063 E+00	6.63713 E−01
m_4	5.44771 E−01	−9.08933 E−01	6.12986 E−01	6.18669 E−01	−7.01427 E+00	−5.60214 E−01
m_5	6.68337 E+00	2.50035 E+00	6.61383 E+00	7.37669 E−01	1.74082 E+01	2.24920 E+00
m_6	1.80906 E+00	N/A	1.25411 E+00	−9.38562 E−01	−4.86581 E−01	−1.41017 E+00
m_7	5.36798 E−01	N/A	4.97886 E−01	9.50809 E−01	−4.09918 E−01	5.24646 E−01
m_8	−3.93476 E+00	N/A	−3.85173 E+00	4.50179 E+00	5.77134 E−01	−2.16250 E−01
m_9	2.61316 E+00	N/A	2.56365 E+00	N/A	5.57884 E+00	6.42538 E+00
m_{10}	4.53166 E+00	N/A	4.26498 E+00	N/A	N/A	N/A

Table A-3610-1
Coefficients G_0 Through G_4 for Subsurface Crack With Flaw Aspect Ratio, a/ℓ = 0.0

a/d	d/t	Point	G_0	G_1	G_2	G_3	G_4
0.0	0.2	1	0.9871	0.1974	0.0395	0.0079	0.0016
		2	0.9871	0.1974	0.0395	0.0079	0.0016
		3	...	...	...	...	...
	0.3	1	0.9871	0.2961	0.0888	0.0267	0.0080
		2	0.9871	0.2961	0.0888	0.0267	0.0080
		3	...	...	...	...	...
	0.4	1	0.9871	0.3948	0.1579	0.0632	0.0253
		2	0.9871	0.3948	0.1579	0.0632	0.0253
		3	...	...	...	...	...
	0.5	1	0.9871	0.4935	0.2468	0.1234	0.0617
		2	0.9871	0.4935	0.2468	0.1234	0.0617
		3	...	...	...	...	...
0.1	0.2	1	0.9886	0.1876	0.0357	0.0068	0.0013
		2	0.9884	0.2078	0.0438	0.0092	0.0020
		3	...	...	...	...	...
	0.3	1	0.9886	0.2814	0.0804	0.0230	0.0066
		2	0.9884	0.3117	0.0985	0.0312	0.0990
		3	...	...	...	...	...
	0.4	1	0.9662	0.3670	0.1398	0.0534	0.0205
		2	0.9659	0.4058	0.1709	0.0722	0.0305
		3	...	...	...	...	...
	0.5	1	0.9900	0.4697	0.2235	0.1067	0.0511
		2	0.9900	0.5202	0.2740	0.1447	0.0765
		3	...	...	...	...	...
0.2	0.2	1	1.0012	0.1800	0.0328	0.0061	0.0011
		2	0.9987	0.2199	0.0489	0.0109	0.0025
		3	...	...	...	...	...
	0.3	1	1.0031	0.2706	0.0740	0.0205	0.0058
		2	1.0006	0.3305	0.1101	0.0307	0.0125
		3	...	...	...	...	...
	0.4	1	1.0036	0.3610	0.1316	0.0486	0.0182
		2	1.0010	0.4408	0.1958	0.0877	0.0395
		3	...	...	...	...	...
	0.5	1	1.0067	0.4529	0.2064	0.0954	0.0448
		2	1.0067	0.5539	0.3074	0.1720	0.0969
		3	...	...	...	...	...
0.4	0.2	1	1.0674	0.1727	0.0298	0.0055	0.0011
		2	1.0412	0.2484	0.0611	0.0154	0.0040
		3	...	...	...	...	...
	0.3	1	1.0781	0.2621	0.0680	0.0189	0.0056
		2	1.0472	0.3745	0.1381	0.0522	0.0201
		3	...	...	...	...	...
	0.4	1	1.0812	0.3505	0.1214	0.0449	0.0177
		2	1.0522	0.5016	0.2466	0.1242	0.0636
		3	...	...	...	...	...
	0.5	1	1.0901	0.4428	0.1921	0.0891	0.0440
		2	1.0901	0.6473	0.3966	0.2489	0.1591
		3	...	...	...	...	...

Table A-3610-1
Coefficients G_0 Through G_4 for Subsurface Crack With Flaw Aspect Ratio, a/ℓ = 0.0 (Cont'd)

a/d	d/t	Point	G_0	G_1	G_2	G_3	G_4
0.6	0.2	1	1.2207	0.1809	0.0319	0.0065	0.0015
		2	1.1216	0.2841	0.0767	0.0216	0.0063
		3	...	...	...	...	...
	0.3	1	1.2259	0.2809	0.0747	0.0228	0.0077
		2	1.1309	0.4288	0.1735	0.0732	0.0318
		3	...	...	...	...	...
	0.4	1	1.2640	0.3767	0.1333	0.0542	0.0244
		2	1.1451	0.5792	0.3124	0.1757	0.1016
		3	...	...	...	...	...
	0.5	1	1.2766	0.4772	0.2117	0.1080	0.0609
		2	1.2766	0.7994	0.5339	0.3722	0.2670
		3	...	...	...	...	...
0.8	0.2	1	1.6155	0.2273	0.0441	0.0103	0.0027
		2	1.2606	0.3295	0.0965	0.0300	0.0097
		3	...	...	...	...	...
	0.3	1	1.7332	0.3710	0.1086	0.0379	0.0147
		2	1.2826	0.5006	0.2193	0.1022	0.0494
		3	...	...	...	...	...
	0.4	1	1.7643	0.5001	0.1933	0.0892	0.0456
		2	1.3132	0.6872	0.4016	0.2493	0.1604
		3	...	...	...	...	...
	0.5	1	1.7729	0.6260	0.3009	0.1727	0.1099
		2	1.7729	1.1469	0.8218	0.6249	0.4934
		3	...	...	...	...	...

A-3620 COEFFICIENTS G_0 THROUGH G_4 FOR FLAT PLATE SURFACE CRACK

See Tables A-3620-1 through A-3620-3.

A-3630 COEFFICIENTS G_i FOR CIRCUMFERENTIAL SEMIELLIPTICAL INSIDE SURFACE FLAW

See Tables A-3630-1 through A-3630-8.

Table A-3610-2
Coefficients G_0 Through G_4 for Subsurface Crack With Flaw Aspect Ratio, a/ℓ = 0.1

a/d	d/t	Point	G_0	G_1	G_2	G_3	G_4
0.0	0.2	1	0.9871	0.1974	0.0395	0.0079	0.0016
		2	0.9781	0.1974	0.0395	0.0079	0.0016
		3	0.4277	0.0855	0.0171	0.0034	0.0007
	0.3	1	0.9871	0.2961	0.0888	0.0267	0.0080
		2	0.9871	0.2961	0.0888	0.0267	0.0080
		3	0.4277	0.1283	0.0385	0.0115	0.0035
	0.4	1	0.9871	0.3948	0.1579	0.0632	0.0253
		2	0.9871	0.3948	0.1579	0.0632	0.0253
		3	0.4277	0.1711	0.0684	0.0274	0.0109
	0.5	1	0.9871	0.4936	0.2468	0.1234	0.0617
		2	0.9871	0.4936	0.2468	0.1234	0.0617
		3	0.4277	0.2139	0.1069	0.0535	0.0267
0.1	0.2	1	0.9820	0.1861	0.0354	0.0067	0.0013
		2	0.9781	0.2059	0.0435	0.0092	0.0019
		3	0.4399	0.0879	0.0176	0.0035	0.0035
	0.3	1	0.9821	0.2823	0.0824	0.0245	0.0074
		2	0.9811	0.3133	0.1016	0.0335	0.0112
		3	0.4401	0.1333	0.0409	0.0127	0.0127
	0.4	1	0.9823	0.3747	0.1443	0.0561	0.0220
		2	0.9820	0.4161	0.1779	0.0767	0.0333
		3	0.4404	0.1770	0.0717	0.0292	0.0292
	0.5	1	0.9826	0.4656	0.2212	0.1054	0.0504
		2	0.9826	0.5171	0.2728	0.1442	0.0764
		3	0.4412	0.2203	0.1101	0.0550	0.0550
0.2	0.2	1	0.9869	0.1768	0.0322	0.0060	0.0011
		2	0.9837	0.2174	0.0485	0.0109	0.0025
		3	0.4389	0.0876	0.0175	0.0035	0.0035
	0.3	1	0.9875	0.2683	0.0750	0.0216	0.0064
		2	0.9852	0.3302	0.1133	0.0398	0.0143
		3	0.4392	0.1329	0.0408	0.0127	0.0127
	0.4	1	0.9884	0.3565	0.1315	0.0496	0.0191
		2	0.9866	0.4387	0.1984	0.0912	0.0425
		3	0.4396	0.1765	0.0714	0.0291	0.0291
	0.5	1	0.9905	0.4438	0.2021	0.0935	0.0440
		2	0.9905	0.5469	0.3051	0.1719	0.0977
		3	0.4406	0.2197	0.1097	0.0549	0.0549
0.4	0.2	1	1.0206	0.1627	0.0277	0.0050	0.0010
		2	1.0052	0.2423	0.0601	0.0153	0.0039
		3	0.4441	0.0884	0.0177	0.0036	0.0036
	0.3	1	1.0247	0.2480	0.0650	0.0184	0.0057
		2	1.0082	0.3685	0.1405	0.0556	0.0227
		3	0.4452	0.1344	0.0413	0.0129	0.0129
	0.4	1	1.0289	0.3308	0.1144	0.0425	0.0169
		2	1.0146	0.4918	0.2470	0.1277	0.0676
		3	0.4463	0.1787	0.0725	0.0297	0.0297
	0.5	1	1.0373	0.4151	0.1775	0.0811	0.0395
		2	1.0372	0.6225	0.3849	0.2436	0.1570
		3	0.4489	0.2233	0.1118	0.0563	0.0563

Table A-3610-2
Coefficients G_0 Through G_4 for Subsurface Crack With Flaw Aspect Ratio, a/ℓ = 0.1 (Cont'd)

a/d	d/t	Point	G_0	G_1	G_2	G_3	G_4
0.6	0.2	1	1.1108	0.1585	0.0270	0.0053	0.0012
		2	1.0423	0.2701	0.0741	0.0211	0.0062
		3	0.4545	0.0902	0.0181	0.0037	0.0037
	0.3	1	1.1260	0.2448	0.0644	0.0199	0.0069
		2	1.0512	0.4126	0.1738	0.0771	0.0357
		3	0.4574	0.1376	0.0425	0.0135	0.0135
	0.4	1	1.1384	0.3294	0.1145	0.0463	0.0209
		2	1.0720	0.5571	0.3088	0.1790	0.1072
		3	0.4597	0.1835	0.0748	0.0311	0.0311
	0.5	1	1.1559	0.4177	0.1800	0.0896	0.0494
		2	1.1558	0.7389	0.5012	0.3539	0.2569
		3	0.4654	0.2310	0.1164	0.0595	0.0595
0.8	0.2	1	1.3438	0.1754	0.0323	0.0072	0.0018
		2	1.0989	0.3009	0.0904	0.0286	0.0093
		3	0.4694	0.0927	0.0188	0.0039	0.0039
	0.3	1	1.3905	0.2792	0.0796	0.0279	0.0110
		2	1.1223	0.4645	0.2139	0.1053	0.0543
		3	0.4754	0.1424	0.0444	0.0144	0.0144
	0.4	1	1.4237	0.3810	0.1431	0.0654	0.0334
		2	1.1709	0.6411	0.3879	0.2489	0.1659
		3	0.4792	0.1905	0.0785	0.0334	0.0334
	0.5	1	1.4502	0.4833	0.2238	0.1250	0.0776
		2	1.4502	0.9683	0.7089	0.5480	0.4385
		3	0.4906	0.2431	0.1242	0.0653	0.0653

Table A-3610-3
Coefficients G_0 Through G_4 for Subsurface Crack With Flaw Aspect Ratio, a/ℓ = 0.2

a/d	d/t	Point	G_0	G_1	G_2	G_3	G_4
0.0	0.2	1	0.9842	0.1968	0.0394	0.0079	0.0016
		2	0.9842	0.1968	0.0394	0.0079	0.0016
		3	0.6180	0.1236	0.0247	0.0049	0.0010
	0.3	1	0.9842	0.2953	0.0886	0.0266	0.0080
		2	0.9842	0.2953	0.0886	0.0266	0.0080
		3	0.6180	0.1854	0.0556	0.0167	0.0050
	0.4	1	0.9842	0.3937	0.1575	0.0630	0.0252
		2	0.9842	0.3937	0.1575	0.0630	0.0252
		3	0.6180	0.2472	0.0989	0.0396	0.0158
	0.5	1	0.9842	0.4921	0.2461	0.1230	0.0615
		2	0.9842	0.4921	0.2461	0.1230	0.0615
		3	0.6180	0.3090	0.1545	0.0773	0.0386
0.1	0.2	1	0.9881	0.1864	0.0353	0.0067	0.0013
		2	0.9850	0.2082	0.0441	0.0094	0.0020
		3	0.6293	0.1258	0.0252	0.0050	0.0010
	0.3	1	0.9881	0.2827	0.0822	0.0243	0.0073
		2	0.9842	0.3156	0.1027	0.0340	0.0114
		3	0.6293	0.1909	0.0587	0.0183	0.0058
	0.4	1	0.9883	0.3753	0.1438	0.0556	0.0217
		2	0.9877	0.4202	0.1803	0.0780	0.0340
		3	0.6294	0.2534	0.1027	0.0419	0.0172
	0.5	1	0.9885	0.4662	0.2205	0.1045	0.0497
		2	0.9885	0.5223	0.2765	0.1467	0.0780
		3	0.6300	0.3150	0.1576	0.0788	0.0395
0.2	0.2	1	0.9913	0.1759	0.0317	0.0058	0.0011
		2	0.9890	0.2202	0.0495	0.0112	0.0026
		3	0.6300	0.1260	0.0252	0.0051	0.0010
	0.3	1	0.9917	0.2669	0.0738	0.0210	0.0062
		2	0.9890	0.3340	0.1153	0.0408	0.0148
		3	0.6301	0.1911	0.0588	0.0184	0.0059
	0.4	1	0.9922	0.3544	0.1293	0.0482	0.0184
		2	0.9908	0.4440	0.2021	0.0934	0.0438
		3	0.6305	0.2538	0.1030	0.0422	0.0174
	0.5	1	0.9934	0.4407	0.1985	0.0908	0.0422
		2	0.9934	0.5527	0.3105	0.1760	0.1006
		3	0.6315	0.3157	0.1582	0.0794	0.0400
0.4	0.2	1	1.0139	0.1578	0.0261	0.0046	0.0009
		2	1.0022	0.2452	0.0616	0.0158	0.0041
		3	0.6366	0.1273	0.0256	0.0052	0.0011
	0.3	1	1.0161	0.2401	0.0611	0.0169	0.0050
		2	1.0039	0.3725	0.1436	0.0573	0.0236
		3	0.6376	0.1933	0.0599	0.0190	0.0061
	0.4	1	1.0186	0.3196	0.1074	0.0388	0.0150
		2	1.0081	0.4961	0.2522	0.1316	0.0702
		3	0.6391	0.2572	0.1050	0.0435	0.0183
	0.5	1	1.0239	0.3996	0.1660	0.0736	0.0348
		2	1.0239	0.6245	0.3909	0.2498	0.1621
		3	0.6432	0.3215	0.1621	0.0824	0.0422

Table A-3610-3
Coefficients G_0 Through G_4 for Subsurface Crack With Flaw Aspect Ratio, a/ℓ = 0.2 (Cont'd)

a/d	d/t	Point	G_0	G_1	G_2	G_3	G_4
0.6	0.2	1	1.0842	0.1480	0.0241	0.0046	0.0010
		2	1.0271	0.2724	0.0759	0.0219	0.0064
		3	0.6529	0.1304	0.0265	0.0055	0.0012
	0.3	1	1.0929	0.2270	0.0569	0.0168	0.0057
		2	1.0323	0.4149	0.1775	0.0797	0.0371
		3	0.6562	0.1987	0.0622	0.0201	0.0067
	0.4	1	1.1005	0.3040	0.1007	0.0390	0.0170
		2	1.0471	0.5575	0.3141	0.1841	0.1111
		3	0.6601	0.2653	0.1095	0.0464	0.0201
	0.5	1	1.1119	0.3831	0.1572	0.0750	0.0400
		2	1.1119	0.7290	0.5032	0.3597	0.2634
		3	0.6704	0.3351	0.1710	0.0890	0.0473
0.8	0.2	1	1.2626	0.1534	0.0267	0.0057	0.0014
		2	1.0671	0.3022	0.0926	0.0296	0.0098
		3	0.6757	0.1345	0.0278	0.0059	0.0013
	0.3	1	1.2883	0.2398	0.0645	0.0217	0.0084
		2	1.0784	0.4623	0.2173	0.1083	0.0564
		3	0.6831	0.2062	0.0655	0.0218	0.0077
	0.4	1	1.3079	0.3243	0.1150	0.0505	0.0251
		2	1.1167	0.6332	0.3910	0.2542	0.1710
		3	0.6911	0.2770	0.1162	0.0508	0.0231
	0.5	1	1.3246	0.4088	0.1787	0.0960	0.0580
		2	1.3246	0.9161	0.6860	0.5387	0.4361
		3	0.7129	0.3563	0.1856	0.1004	0.0563

Table A-3610-4
Coefficients G_0 Through G_4 for Subsurface Crack With Flaw Aspect Ratio, a/ℓ = 0.3

a/d	d/t	Point	G_0	G_1	G_2	G_3	G_4
0.0	0.2	1	0.9879	0.1976	0.0395	0.0079	0.0016
		2	0.9879	0.1976	0.0395	0.0079	0.0016
		3	0.7582	0.1516	0.0303	0.0061	0.0012
	0.3	1	0.9879	0.2964	0.0889	0.0267	0.0080
		2	0.9879	0.2964	0.0889	0.0267	0.0080
		3	0.7582	0.2275	0.0682	0.0205	0.0061
	0.4	1	0.9879	0.3952	0.1581	0.0632	0.0253
		2	0.9879	0.3952	0.1581	0.0632	0.0253
		3	0.7582	0.3033	0.1213	0.0485	0.0194
	0.5	1	0.9879	0.4940	0.2470	0.1235	0.0617
		2	0.9879	0.4940	0.2470	0.1235	0.0617
		3	0.7582	0.3791	0.1896	0.0095	0.0474
0.1	0.2	1	0.9923	0.1864	0.0351	0.0066	0.0013
		2	0.9911	0.2102	0.0447	0.0095	0.0020
		3	0.7664	0.1533	0.0307	0.0061	0.0012
	0.3	1	0.9924	0.2827	0.0818	0.0241	0.0072
		2	0.9905	0.3187	0.1041	0.0345	0.0117
		3	0.7667	0.2325	0.0715	0.0223	0.0071
	0.4	1	0.9924	0.3752	0.1431	0.0551	0.0214
		2	0.9917	0.4234	0.1823	0.0791	0.0346
		3	0.7665	0.3086	0.1251	0.0511	0.0210
	0.5	1	0.9926	0.4661	0.2194	0.1035	0.0490
		2	0.9926	0.5264	0.2796	0.1488	0.0793
		3	0.7669	0.3834	0.1918	0.0960	0.0481
0.2	0.2	1	0.9947	0.1748	0.0312	0.0056	0.0010
		2	0.9934	0.2227	0.0504	0.0115	0.0026
		3	0.7664	0.1533	0.0307	0.0062	0.0012
	0.3	1	0.9950	0.2652	0.0726	0.0205	0.0060
		2	0.9934	0.3378	0.1174	0.0417	0.0152
		3	0.7666	0.2325	0.0716	0.0224	0.0072
	0.4	1	0.9953	0.3520	0.1271	0.0469	0.0177
		2	0.9942	0.4487	0.2056	0.0956	0.0451
		3	0.7668	0.3087	0.1254	0.0514	0.0212
	0.5	1	0.9961	0.4376	0.1951	0.0883	0.0405
		2	0.9961	0.5582	0.3156	0.1799	0.1034
		3	0.7677	0.3838	0.1924	0.0967	0.0487
0.4	0.2	1	1.0109	0.1537	0.0248	0.0043	0.0008
		2	1.0017	0.2484	0.0630	0.0163	0.0043
		3	0.7735	0.1546	0.0312	0.0064	0.0013
	0.3	1	1.0124	0.2336	0.0580	0.0156	0.0045
		2	1.0028	0.3772	0.1470	0.0591	0.0245
		3	0.7743	0.2348	0.0728	0.0231	0.0075
	0.4	1	1.0140	0.3107	0.1017	0.0357	0.0135
		2	1.0057	0.5018	0.2578	0.1357	0.0728
		3	0.7757	0.3122	0.1277	0.0531	0.0224
	0.5	1	1.0176	0.3877	0.1569	0.0677	0.0311
		2	1.0176	0.6295	0.3985	0.2569	0.1679
		3	0.7798	0.3898	0.1968	0.1004	0.0517

Table A-3610-4
Coefficients G_0 Through G_4 for Subsurface Crack With Flaw Aspect Ratio, a/ℓ = 0.3 (Cont'd)

a/d	d/t	Point	G_0	G_1	G_2	G_3	G_4
0.6	0.2	1	1.0662	0.1393	0.0217	0.0040	0.0008
		2	1.0195	0.2759	0.0780	0.0227	0.0067
		3	0.7894	0.1576	0.0322	0.0067	0.0014
	0.3	1	1.0720	0.2131	0.0511	0.0146	0.0048
		2	1.0229	0.4197	0.1821	0.0825	0.0388
		3	0.7923	0.2400	0.0753	0.0245	0.0083
	0.4	1	1.0771	0.2846	0.0901	0.0336	0.0143
		2	1.0340	0.5622	0.3213	0.1902	0.1157
		3	0.7963	0.3201	0.1326	0.0565	0.0247
	0.5	1	1.0847	0.3570	0.1400	0.0642	0.0333
		2	1.0847	0.7271	0.5098	0.3685	0.2721
		3	0.8076	0.4037	0.2067	0.1082	0.0580
0.8	0.2	1	1.2119	0.1372	0.0227	0.0047	0.0011
		2	1.0478	0.3052	0.0951	0.0308	0.0102
		3	0.8147	0.1622	0.0337	0.0073	0.0016
	0.3	1	1.2290	0.2128	0.0543	0.0177	0.0067
		2	1.0554	0.4657	0.2227	0.1123	0.0589
		3	0.8214	0.2479	0.0792	0.0266	0.0094
	0.4	1	1.2419	0.2862	0.0962	0.0410	0.0200
		2	1.0847	0.6333	0.3982	0.2619	0.1776
		3	0.8300	0.3327	0.1404	0.0619	0.0286
	0.5	1	1.2515	0.3584	0.1483	0.0771	0.0456
		2	1.2515	0.8922	0.6815	0.5426	0.4438
		3	0.8547	0.4272	0.2237	0.1220	0.0693

Table A-3610-5
Coefficients G_0 Through G_4 for Subsurface Crack With Flaw Aspect Ratio, a/ℓ = 0.4

a/d	d/t	Point	G_0	G_1	G_2	G_3	G_4
0.0	0.2	1	0.9947	0.1989	0.0398	0.0080	0.0016
		2	0.9947	0.1989	0.0398	0.0080	0.0016
		3	0.8780	0.1756	0.0351	0.0070	0.0014
	0.3	1	0.9947	0.2984	0.0895	0.0269	0.0081
		2	0.9947	0.2984	0.0895	0.0269	0.0081
		3	0.8780	0.2634	0.0790	0.0237	0.0071
	0.4	1	0.9947	0.3979	0.1592	0.0637	0.0255
		2	0.9947	0.3979	0.1592	0.0637	0.0255
		3	0.8780	0.3512	0.1405	0.0562	0.0225
	0.5	1	0.9947	0.4974	0.2487	0.1243	0.0622
		2	0.9947	0.4974	0.2487	0.1243	0.0622
		3	0.8780	0.4390	0.2195	0.1098	0.0549
0.1	0.2	1	0.9964	0.1864	0.0349	0.0066	0.0012
		2	0.9949	0.2118	0.0452	0.0096	0.0021
		3	0.8835	0.1767	0.0354	0.0071	0.0014
	0.3	1	0.9965	0.2827	0.0814	0.0238	0.0071
		2	0.9951	0.3213	0.1053	0.0350	0.0119
		3	0.8837	0.2681	0.0824	0.0257	0.0082
	0.4	1	0.9965	0.3753	0.1425	0.0546	0.0211
		2	0.9960	0.4268	0.1844	0.0803	0.0352
		3	0.8837	0.3558	0.1442	0.0589	0.0242
	0.5	1	0.9966	0.4661	0.2185	0.1026	0.0483
		2	0.9966	0.5304	0.2828	0.1510	0.0807
		3	0.8840	0.4420	0.2211	0.1107	0.0555
0.2	0.2	1	0.9980	0.1738	0.0307	0.0055	0.0010
		2	0.9969	0.2251	0.0513	0.0118	0.0027
		3	0.8837	0.1767	0.0354	0.0071	0.0014
	0.3	1	0.9981	0.2637	0.0715	0.0200	0.0057
		2	0.9970	0.3415	0.1195	0.0427	0.0156
		3	0.8839	0.2681	0.0826	0.0259	0.0083
	0.4	1	0.9984	0.3501	0.1252	0.0457	0.0170
		2	0.9976	0.4535	0.2091	0.0978	0.0463
		3	0.8841	0.3559	0.1446	0.0593	0.0245
	0.5	1	0.9988	0.4350	0.1921	0.0860	0.0391
		2	0.9988	0.5638	0.3209	0.1840	0.1063
		3	0.8846	0.4423	0.2218	0.1115	0.0562
0.4	0.2	1	1.0102	0.1504	0.0237	0.0040	0.0007
		2	1.0026	0.2520	0.0646	0.0168	0.0044
		3	0.8893	0.1778	0.0359	0.0073	0.0015
	0.3	1	1.0112	0.2284	0.0553	0.0144	0.0041
		2	1.0033	0.3825	0.1507	0.0611	0.0255
		3	0.8899	0.2699	0.0838	0.0266	0.0087
	0.4	1	1.0123	0.3036	0.0969	0.0331	0.0122
		2	1.0054	0.5085	0.2641	0.1401	0.0757
		3	0.8910	0.3586	0.1468	0.0611	0.0258
	0.5	1	1.0148	0.3784	0.1493	0.0627	0.0280
		2	1.0148	0.6365	0.4074	0.2649	0.1744
		3	0.8948	0.4474	0.2261	0.1154	0.0595

Table A-3610-5
Coefficients G_0 Through G_4 for Subsurface Crack With Flaw Aspect Ratio, a/ℓ = 0.4 (Cont'd)

a/d	d/t	Point	G_0	G_1	G_2	G_3	G_4
0.6	0.2	1	1.0548	0.1325	0.0197	0.0035	0.0007
		2	1.0160	0.2803	0.0803	0.0236	0.0070
		3	0.9046	0.1807	0.0370	0.0077	0.0017
	0.3	1	1.0590	0.2021	0.0464	0.0127	0.0040
		2	1.0184	0.4260	0.1874	0.0858	0.0406
		3	0.9069	0.2747	0.0864	0.0282	0.0095
	0.4	1	1.0626	0.2695	0.0816	0.0293	0.0121
		2	1.0270	0.5695	0.3300	0.1974	0.1209
		3	0.9105	0.3662	0.1519	0.0649	0.0285
	0.5	1	1.0677	0.3370	0.1263	0.0557	0.0280
		2	1.0677	0.7307	0.5200	0.3800	0.2829
		3	0.9216	0.4608	0.2362	0.1240	0.0666
0.8	0.2	1	1.1754	0.1245	0.0195	0.0039	0.0009
		2	1.0369	0.3100	0.0981	0.0321	0.0107
		3	0.9296	0.1851	0.0385	0.0083	0.0019
	0.3	1	1.1880	0.1922	0.0464	0.0146	0.0054
		2	1.0424	0.4722	0.2295	0.1170	0.0618
		3	0.9353	0.2824	0.0904	0.0305	0.0109
	0.4	1	1.1970	0.2575	0.0819	0.0336	0.0160
		2	1.0653	0.6388	0.4085	0.2717	0.1856
		3	0.9434	0.3783	0.1599	0.0708	0.0328
	0.5	1	1.2023	0.3206	0.1252	0.0626	0.0361
		2	1.2023	0.8817	0.6863	0.5535	0.4569
		3	0.9678	0.4839	0.2538	0.1388	0.0790

Table A-3610-6
Coefficients G_0 Through G_4 for Subsurface Crack With Flaw Aspect Ratio, a/ℓ = 0.5

a/d	d/t	Point	G_0	G_1	G_2	G_3	G_4
0.0	0.2	1	1.0014	0.2003	0.0401	0.0080	0.0016
		2	1.0014	0.2003	0.0401	0.0080	0.0016
		3	0.9978	0.1996	0.0399	0.0080	0.0016
	0.3	1	1.0014	0.3004	0.0901	0.0270	0.0081
		2	1.0014	0.3004	0.0901	0.0270	0.0081
		3	0.9978	0.2993	0.0898	0.0269	0.0081
	0.4	1	1.0014	0.4006	0.1602	0.0641	0.0256
		2	1.0014	0.4006	0.1602	0.0641	0.0256
		3	0.9978	0.3991	0.1596	0.0639	0.0255
	0.5	1	1.0014	0.5007	0.2504	0.1252	0.0626
		2	1.0014	0.5007	0.2504	0.1252	0.0626
		3	0.9978	0.4989	0.2495	0.1247	0.0624
0.1	0.2	1	1.0005	0.1864	0.0348	0.0065	0.0012
		2	0.9986	0.2134	0.0457	0.0098	0.0021
		3	1.0005	0.2001	0.0400	0.0080	0.0016
	0.3	1	1.0006	0.2828	0.0811	0.0236	0.0070
		2	0.9996	0.3240	0.1065	0.0356	0.0121
		3	1.0008	0.3036	0.0933	0.0291	0.0092
	0.4	1	1.0006	0.3753	0.1419	0.0541	0.0208
		2	1.0002	0.4302	0.1865	0.0814	0.0358
		3	1.0010	0.4030	0.1634	0.0667	0.0274
	0.5	1	1.0006	0.4661	0.2175	0.1017	0.0477
		2	1.0006	0.5345	0.2859	0.1532	0.0821
		3	1.0011	0.5005	0.2504	0.1254	0.0628
0.2	0.2	1	1.0012	0.1729	0.0302	0.0054	0.0010
		2	1.0003	0.2275	0.0521	0.0120	0.0028
		3	1.0010	0.2002	0.0402	0.0081	0.0016
	0.3	1	1.0013	0.2622	0.0705	0.0195	0.0055
		2	1.0006	0.3452	0.1215	0.0437	0.0161
		3	1.0012	0.3037	0.0936	0.0293	0.0094
	0.4	1	1.0015	0.3481	0.1233	0.0446	0.0164
		2	1.0011	0.4582	0.2127	0.1000	0.0476
		3	1.0013	0.4031	0.1638	0.0672	0.0278
	0.5	1	1.0016	0.4324	0.1891	0.0838	0.0376
		2	1.0016	0.5694	0.3261	0.1881	0.1092
		3	1.0016	0.5008	0.2512	0.1263	0.0637
0.4	0.2	1	1.0095	0.1471	0.0226	0.0037	0.0006
		2	1.0035	0.2556	0.0662	0.0174	0.0046
		3	1.0051	0.2010	0.0406	0.0083	0.0017
	0.3	1	1.0099	0.2232	0.0526	0.0133	0.0037
		2	1.0039	0.3878	0.1543	0.0631	0.0265
		3	1.0055	0.3050	0.0947	0.0302	0.0099
	0.4	1	1.0106	0.2965	0.0922	0.0306	0.0108
		2	1.0052	0.5152	0.2703	0.1446	0.0787
		3	1.0064	0.4051	0.1659	0.0691	0.0293
	0.5	1	1.0120	0.3690	0.1417	0.0577	0.0250
		2	1.0120	0.6435	0.4163	0.2730	0.1809
		3	1.0097	0.5049	0.2553	0.1305	0.0674

Table A-3610-6
Coefficients G_0 Through G_4 for Subsurface Crack With Flaw Aspect Ratio, a/ℓ = 0.5 (Cont'd)

a/d	d/t	Point	G_0	G_1	G_2	G_3	G_4
0.6	0.2	1	1.0435	0.1256	0.0178	0.0030	0.0006
		2	1.0124	0.2847	0.0826	0.0245	0.0074
		3	1.0198	0.2037	0.0417	0.0088	0.0019
	0.3	1	1.0460	0.1912	0.0417	0.0109	0.0033
		2	1.0139	0.4324	0.1927	0.0890	0.0424
		3	1.0216	0.3095	0.0974	0.0318	0.0108
	0.4	1	1.0481	0.2544	0.0732	0.0249	0.0098
		2	1.0200	0.5768	0.3388	0.2045	0.1261
		3	1.0248	0.4122	0.1712	0.0732	0.0323
	0.5	1	1.0506	0.3171	0.1127	0.0471	0.0226
		2	1.0506	0.7343	0.5302	0.3914	0.2936
		3	1.0355	0.5178	0.2658	0.1397	0.0752
0.8	0.2	1	1.1389	0.1117	0.0163	0.0031	0.0007
		2	1.0261	0.3147	0.1012	0.0334	0.0112
		3	1.0446	0.2080	0.0434	0.0094	0.0021
	0.3	1	1.1470	0.1715	0.0385	0.0115	0.0041
		2	1.0294	0.4786	0.2363	0.1216	0.0647
		3	1.0493	0.3169	0.1016	0.0344	0.0123
	0.4	1	1.1521	0.2287	0.0675	0.0263	0.0121
		2	1.0460	0.6443	0.4187	0.2814	0.1937
		3	1.0567	0.4239	0.1794	0.0796	0.0370
	0.5	1	1.1531	0.2828	0.1021	0.0482	0.0267
		2	1.1531	0.8712	0.6911	0.5644	0.4700
		3	1.0809	0.5405	0.2839	0.1555	0.0888

Table A-3620-1
Coefficients G_0 Through G_4 for Flat Plate Surface Crack With Flaw Aspect Ratio, a/ℓ = 0.0
(In the course of preparation)

Table A-3620-2
Coefficients G_0 Through G_4 for Flat Plate Surface Crack at Point 1

Coefficients	Flaw Depth, a/t	Flaw Aspect Ratio, a/ℓ								
		0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Uniform G_0	0.00	1.0962	1.0920	1.0870	1.0811	1.0743	1.0666	1.0581	1.0487	1.0384
	0.05	1.1013	1.0954	1.0893	1.0827	1.0756	1.0678	1.0592	1.0497	1.0392
	0.10	1.1165	1.1055	1.0961	1.0875	1.0794	1.0713	1.0626	1.0528	1.0415
	0.15	1.1415	1.1222	1.1072	1.0954	1.0858	1.0770	1.0681	1.0578	1.0451
	0.20	1.1757	1.1449	1.1224	1.1062	1.0944	1.0848	1.0756	1.0647	1.0501
	0.25	1.2182	1.1732	1.1413	1.1197	1.1051	1.0945	1.0849	1.0731	1.0562
	0.30	1.2682	1.2063	1.1635	1.1353	1.1176	1.1058	1.0957	1.0830	1.0633
	0.35	1.3244	1.2435	1.1882	1.1528	1.1315	1.1184	1.1078	1.0939	1.0710
	0.40	1.3852	1.2837	1.2149	1.1716	1.1464	1.1319	1.1207	1.1056	1.0791
	0.45	1.4491	1.3257	1.2427	1.1911	1.1618	1.1458	1.1341	1.1176	1.0872
	0.50	1.5140	1.3682	1.2707	1.2106	1.1772	1.1597	1.1474	1.1294	1.0950
	0.55	1.5779	1.4098	1.2978	1.2294	1.1920	1.1731	1.1601	1.1406	1.1020
	0.60	1.6384	1.4488	1.3230	1.2466	1.2054	1.1852	1.1717	1.1506	1.1077
	0.65	1.6929	1.4835	1.3450	1.2613	1.2168	1.1954	1.1813	1.1587	1.1116
	0.70	1.7386	1.5119	1.3624	1.2726	1.2253	1.2030	1.1885	1.1643	1.1131
	0.75	1.7724	1.5319	1.3737	1.2793	1.2300	1.2072	1.1923	1.1666	1.1116
	0.80	1.7911	1.5413	1.3775	1.2803	1.2301	1.2071	1.1919	1.1649	1.1064
Linear G_1	0.00	0.6648	0.6743	0.6840	0.6937	0.7034	0.7133	0.7231	0.7331	0.7431
	0.05	0.6664	0.6754	0.6847	0.6941	0.7037	0.7135	0.7233	0.7332	0.7432
	0.10	0.6713	0.6787	0.6868	0.6955	0.7046	0.7141	0.7238	0.7337	0.7437
	0.15	0.6793	0.6842	0.6904	0.6978	0.7061	0.7152	0.7248	0.7346	0.7445
	0.20	0.6904	0.6916	0.6953	0.7009	0.7082	0.7167	0.7261	0.7358	0.7456
	0.25	0.7042	0.7010	0.7014	0.7049	0.7109	0.7187	0.7278	0.7374	0.7470
	0.30	0.7206	0.7120	0.7087	0.7097	0.7142	0.7212	0.7299	0.7393	0.7487
	0.35	0.7392	0.7246	0.7171	0.7153	0.7180	0.7242	0.7325	0.7417	0.7507
	0.40	0.7596	0.7385	0.7263	0.7215	0.7225	0.7277	0.7356	0.7445	0.7530
	0.45	0.7815	0.7533	0.7363	0.7283	0.7274	0.7317	0.7392	0.7478	0.7556
	0.50	0.8042	0.7688	0.7468	0.7356	0.7330	0.7364	0.7434	0.7515	0.7585
	0.55	0.8273	0.7846	0.7576	0.7434	0.7390	0.7416	0.7482	0.7558	0.7616
	0.60	0.8501	0.8002	0.7685	0.7515	0.7456	0.7475	0.7537	0.7607	0.7650
	0.65	0.8719	0.8153	0.7793	0.7598	0.7527	0.7541	0.7600	0.7662	0.7687
	0.70	0.8921	0.8294	0.7896	0.7681	0.7603	0.7615	0.7670	0.7723	0.7726
	0.75	0.9098	0.8419	0.7992	0.7765	0.7684	0.7697	0.7750	0.7791	0.7768
	0.80	0.9241	0.8522	0.8077	0.7846	0.7769	0.7787	0.7839	0.7867	0.7811
Quadratic G_2	0.00	0.5091	0.5205	0.5324	0.5446	0.5572	0.5701	0.5833	0.5967	0.6103
	0.05	0.5099	0.5211	0.5327	0.5448	0.5573	0.5701	0.5833	0.5967	0.6104
	0.10	0.5122	0.5227	0.5338	0.5454	0.5576	0.5702	0.5832	0.5967	0.6105
	0.15	0.5161	0.5253	0.5354	0.5464	0.5580	0.5703	0.5832	0.5967	0.6107
	0.20	0.5214	0.5290	0.5378	0.5477	0.5587	0.5706	0.5833	0.5968	0.6109
	0.25	0.5282	0.5336	0.5408	0.5495	0.5596	0.5709	0.5834	0.5969	0.6113
	0.30	0.5362	0.5392	0.5444	0.5517	0.5608	0.5715	0.5838	0.5973	0.6118
	0.35	0.5455	0.5456	0.5486	0.5543	0.5623	0.5724	0.5843	0.5978	0.6126
	0.40	0.5558	0.5527	0.5534	0.5574	0.5642	0.5737	0.5853	0.5987	0.6135
	0.45	0.5670	0.5606	0.5587	0.5609	0.5666	0.5754	0.5867	0.5999	0.6148
	0.50	0.5789	0.5690	0.5646	0.5650	0.5696	0.5777	0.5886	0.6017	0.6163
	0.55	0.5913	0.5778	0.5709	0.5696	0.5732	0.5807	0.5913	0.6041	0.6183
	0.60	0.6040	0.5869	0.5776	0.5749	0.5776	0.5846	0.5949	0.6073	0.6208
	0.65	0.6168	0.5963	0.5847	0.5807	0.5828	0.5895	0.5996	0.6115	0.6238
	0.70	0.6293	0.6056	0.5921	0.5872	0.5889	0.5956	0.6055	0.6167	0.6275
	0.75	0.6414	0.6147	0.5998	0.5944	0.5962	0.6031	0.6128	0.6231	0.6319
	0.80	0.6526	0.6236	0.6077	0.6024	0.6047	0.6121	0.6218	0.6310	0.6371

Table A-3620-2
Coefficients G_0 Through G_4 for Flat Plate Surface Crack at Point 1 (Cont'd)

Coefficients	Flaw Depth, a/t	Flaw Aspect Ratio, a/ℓ								
		0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Cubic G_3	0.00	0.4259	0.4374	0.4495	0.4621	0.4752	0.4886	0.5024	0.5166	0.5310
	0.05	0.4263	0.4377	0.4497	0.4622	0.4752	0.4886	0.5024	0.5165	0.5310
	0.10	0.4277	0.4386	0.4502	0.4624	0.4752	0.4885	0.5022	0.5164	0.5310
	0.15	0.4299	0.4402	0.4512	0.4629	0.4753	0.4883	0.5019	0.5161	0.5310
	0.20	0.4330	0.4423	0.4525	0.4636	0.4755	0.4881	0.5016	0.5159	0.5310
	0.25	0.4370	0.4451	0.4543	0.4645	0.4757	0.4880	0.5013	0.5156	0.5310
	0.30	0.4417	0.4484	0.4564	0.4657	0.4762	0.4880	0.5010	0.5154	0.5311
	0.35	0.4472	0.4523	0.4590	0.4672	0.4769	0.4881	0.5009	0.5153	0.5314
	0.40	0.4535	0.4568	0.4620	0.4690	0.4779	0.4886	0.5011	0.5155	0.5319
	0.45	0.4603	0.4617	0.4654	0.4712	0.4793	0.4894	0.5017	0.5161	0.5326
	0.50	0.4678	0.4671	0.4692	0.4739	0.4812	0.4908	0.5028	0.5171	0.5336
	0.55	0.4758	0.4730	0.4735	0.4772	0.4837	0.4929	0.5046	0.5187	0.5350
	0.60	0.4842	0.4793	0.4783	0.4810	0.4869	0.4958	0.5073	0.5211	0.5370
	0.65	0.4930	0.4859	0.4836	0.4855	0.4910	0.4997	0.5110	0.5244	0.5395
	0.70	0.5020	0.4929	0.4895	0.4908	0.4962	0.5048	0.5159	0.5288	0.5427
	0.75	0.5111	0.5002	0.4958	0.4969	0.5025	0.5113	0.5223	0.5345	0.5468
	0.80	0.5203	0.5076	0.5027	0.5041	0.5101	0.5194	0.5304	0.5417	0.5517
Fourth order G_4	0.00	0.3729	0.3840	0.3959	0.4083	0.4213	0.4346	0.4484	0.4625	0.4770
	0.05	0.3732	0.3842	0.3960	0.4084	0.4212	0.4346	0.4483	0.4625	0.4769
	0.10	0.3741	0.3849	0.3964	0.4085	0.4212	0.4344	0.4481	0.4623	0.4769
	0.15	0.3755	0.3859	0.3970	0.4087	0.4211	0.4341	0.4477	0.4619	0.4768
	0.20	0.3775	0.3873	0.3978	0.4091	0.4211	0.4338	0.4473	0.4615	0.4766
	0.25	0.3801	0.3891	0.3990	0.4096	0.4211	0.4335	0.4468	0.4611	0.4765
	0.30	0.3832	0.3913	0.4004	0.4103	0.4212	0.4332	0.4463	0.4607	0.4765
	0.35	0.3868	0.3940	0.4021	0.4112	0.4215	0.4330	0.4460	0.4604	0.4766
	0.40	0.3910	0.3970	0.4042	0.4125	0.4221	0.4331	0.4458	0.4603	0.4768
	0.45	0.3957	0.4005	0.4066	0.4140	0.4230	0.4336	0.4461	0.4605	0.4772
	0.50	0.4009	0.4044	0.4094	0.4160	0.4243	0.4345	0.4468	0.4612	0.4780
	0.55	0.4066	0.4087	0.4126	0.4184	0.4262	0.4361	0.4481	0.4624	0.4791
	0.60	0.4127	0.4134	0.4163	0.4215	0.4288	0.4384	0.4502	0.4643	0.4807
	0.65	0.4193	0.4185	0.4205	0.4251	0.4322	0.4416	0.4532	0.4670	0.4828
	0.70	0.4263	0.4241	0.4253	0.4296	0.4366	0.4460	0.4575	0.4708	0.4857
	0.75	0.4337	0.4301	0.4307	0.4349	0.4421	0.4517	0.4631	0.4758	0.4893
	0.80	0.4414	0.4365	0.4368	0.4412	0.4489	0.4589	0.4703	0.4823	0.4938

Table A-3620-3
Coefficients G_0 Through G_4 for Flat Plate Surface Crack at Point 2

Coefficients	Flaw Depth, a/t	Flaw Aspect Ratio, a/ℓ 0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Uniform G_0	0.00	0.5468	0.6584	0.7512	0.8321	0.9046	0.9708	1.0321	1.0894	1.1433
	0.05	0.5532	0.6645	0.7569	0.8372	0.9092	0.9748	1.0355	1.0921	1.1454
	0.10	0.5628	0.6738	0.7656	0.8454	0.9166	0.9816	1.0415	1.0975	1.1500
	0.15	0.5756	0.6863	0.7775	0.8566	0.9271	0.9913	1.0504	1.1055	1.1572
	0.20	0.5918	0.7022	0.7928	0.8710	0.9407	1.0038	1.0620	1.1161	1.1668
	0.25	0.6117	0.7217	0.8115	0.8887	0.9573	1.0194	1.0765	1.1294	1.1790
	0.30	0.6356	0.7449	0.8338	0.9099	0.9772	1.0380	1.0938	1.1454	1.1936
	0.35	0.6638	0.7723	0.8599	0.9346	1.0005	1.0598	1.1140	1.1641	1.2108
	0.40	0.6967	0.8040	0.8901	0.9631	1.0272	1.0847	1.1372	1.1855	1.2305
	0.45	0.7349	0.8406	0.9246	0.9956	1.0576	1.1130	1.1634	1.2097	1.2526
	0.50	0.7790	0.8823	0.9639	1.0323	1.0918	1.1447	1.1927	1.2366	1.2773
	0.55	0.8296	0.9298	1.0082	1.0735	1.1299	1.1800	1.2251	1.2664	1.3045
	0.60	0.8877	0.9836	1.0579	1.1194	1.1723	1.2190	1.2609	1.2991	1.3342
	0.65	0.9541	1.0445	1.1137	1.1706	1.2192	1.2618	1.3000	1.3346	1.3664
	0.70	1.0301	1.1131	1.1760	1.2272	1.2708	1.3087	1.3426	1.3731	1.4011
	0.75	1.1169	1.1904	1.2454	1.2899	1.3274	1.3599	1.3887	1.4147	1.4383
	0.80	1.2163	1.2775	1.3228	1.3590	1.3893	1.4155	1.4386	1.4592	1.4780
Linear G_1	0.00	0.0725	0.0894	0.1038	0.1165	0.1280	0.1386	0.1484	0.1577	0.1665
	0.05	0.0744	0.0923	0.1075	0.1209	0.1331	0.1444	0.1548	0.1647	0.1740
	0.10	0.0771	0.0959	0.1119	0.1260	0.1387	0.1505	0.1615	0.1718	0.1816
	0.15	0.0807	0.1003	0.1169	0.1316	0.1449	0.1571	0.1685	0.1792	0.1893
	0.20	0.0852	0.1056	0.1227	0.1379	0.1515	0.1641	0.1757	0.1867	0.1970
	0.25	0.0907	0.1117	0.1293	0.1448	0.1587	0.1715	0.1833	0.1944	0.2049
	0.30	0.0973	0.1188	0.1367	0.1524	0.1665	0.1793	0.1912	0.2023	0.2128
	0.35	0.1050	0.1269	0.1451	0.1608	0.1749	0.1877	0.1995	0.2105	0.2208
	0.40	0.1141	0.1363	0.1544	0.1700	0.1839	0.1965	0.2081	0.2188	0.2289
	0.45	0.1248	0.1469	0.1648	0.1802	0.1937	0.2059	0.2171	0.2274	0.2371
	0.50	0.1373	0.1591	0.1765	0.1913	0.2042	0.2159	0.2265	0.2362	0.2453
	0.55	0.1519	0.1729	0.1895	0.2035	0.2156	0.2265	0.2363	0.2453	0.2536
	0.60	0.1689	0.1887	0.2041	0.2169	0.2280	0.2378	0.2466	0.2546	0.2620
	0.65	0.1888	0.2067	0.2205	0.2317	0.2414	0.2498	0.2574	0.2642	0.2705
	0.70	0.2121	0.2273	0.2388	0.2480	0.2558	0.2627	0.2687	0.2741	0.2791
	0.75	0.2394	0.2509	0.2593	0.2660	0.2716	0.2764	0.2806	0.2843	0.2877
	0.80	0.2714	0.2779	0.2824	0.2859	0.2887	0.2911	0.2931	0.2949	0.2965
Quadratic G_2	0.00	0.0254	0.0301	0.0344	0.0385	0.0423	0.0460	0.0495	0.0529	0.0563
	0.05	0.0264	0.0318	0.0367	0.0413	0.0456	0.0498	0.0538	0.0577	0.0615
	0.10	0.0276	0.0337	0.0392	0.0443	0.0491	0.0537	0.0582	0.0625	0.0666
	0.15	0.0293	0.0359	0.0419	0.0475	0.0527	0.0577	0.0625	0.0671	0.0716
	0.20	0.0313	0.0385	0.0450	0.0509	0.0565	0.0618	0.0669	0.0717	0.0764
	0.25	0.0338	0.0415	0.0484	0.0546	0.0605	0.0660	0.0713	0.0763	0.0812
	0.30	0.0368	0.0449	0.0521	0.0586	0.0646	0.0703	0.0757	0.0808	0.0858
	0.35	0.0403	0.0488	0.0561	0.0628	0.0689	0.0747	0.0801	0.0853	0.0903
	0.40	0.0445	0.0532	0.0607	0.0673	0.0735	0.0792	0.0846	0.0897	0.0946
	0.45	0.0494	0.0582	0.0656	0.0723	0.0783	0.0839	0.0892	0.0941	0.0989
	0.50	0.0552	0.0639	0.0712	0.0776	0.0834	0.0888	0.0938	0.0985	0.1030
	0.55	0.0620	0.0704	0.0773	0.0834	0.0888	0.0938	0.0985	0.1029	0.1070
	0.60	0.0700	0.0778	0.0842	0.0897	0.0946	0.0991	0.1033	0.1072	0.1109
	0.65	0.0795	0.0863	0.0919	0.0966	0.1008	0.1046	0.1082	0.1115	0.1147
	0.70	0.0907	0.0962	0.1005	0.1042	0.1075	0.1105	0.1132	0.1158	0.1183
	0.75	0.1039	0.1075	0.1102	0.1126	0.1147	0.1166	0.1184	0.1202	0.1218
	0.80	0.1197	0.1205	0.1212	0.1218	0.1225	0.1231	0.1238	0.1245	0.1252

Table A-3620-3
Coefficients G_0 Through G_4 for Flat Plate Surface Crack at Point 2 (Cont'd)

Coefficients	Flaw Depth, a/t	Flaw Aspect Ratio, a/ℓ								
		0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Cubic G_3	0.00	0.0125	0.0141	0.0158	0.0175	0.0192	0.0209	0.0226	0.0243	0.0261
	0.05	0.0131	0.0151	0.0172	0.0193	0.0214	0.0235	0.0256	0.0276	0.0297
	0.10	0.0138	0.0163	0.0188	0.0213	0.0237	0.0261	0.0285	0.0309	0.0332
	0.15	0.0147	0.0177	0.0206	0.0234	0.0261	0.0288	0.0314	0.0340	0.0365
	0.20	0.0159	0.0193	0.0225	0.0255	0.0285	0.0314	0.0343	0.0370	0.0398
	0.25	0.0173	0.0210	0.0245	0.0278	0.0310	0.0341	0.0371	0.0400	0.0429
	0.30	0.0190	0.0230	0.0267	0.0302	0.0336	0.0368	0.0399	0.0429	0.0459
	0.35	0.0210	0.0253	0.0292	0.0328	0.0362	0.0395	0.0427	0.0457	0.0487
	0.40	0.0234	0.0278	0.0318	0.0355	0.0390	0.0423	0.0454	0.0485	0.0515
	0.45	0.0262	0.0307	0.0347	0.0384	0.0418	0.0451	0.0482	0.0512	0.0541
	0.50	0.0295	0.0340	0.0379	0.0415	0.0448	0.0479	0.0509	0.0538	0.0565
	0.55	0.0334	0.0378	0.0415	0.0449	0.0480	0.0509	0.0537	0.0563	0.0589
	0.60	0.0380	0.0421	0.0455	0.0485	0.0513	0.0539	0.0564	0.0588	0.0611
	0.65	0.0435	0.0470	0.0499	0.0525	0.0549	0.0571	0.0592	0.0613	0.0632
	0.70	0.0501	0.0527	0.0549	0.0569	0.0587	0.0604	0.0620	0.0636	0.0652
	0.75	0.0580	0.0594	0.0606	0.0617	0.0628	0.0639	0.0649	0.0660	0.0670
	0.80	0.0673	0.0670	0.0670	0.0670	0.0672	0.0675	0.0679	0.0683	0.0687
Fourth order G_4	0.00	0.0073	0.0079	0.0086	0.0094	0.0103	0.0113	0.0123	0.0133	0.0143
	0.05	0.0077	0.0086	0.0096	0.0108	0.0120	0.0132	0.0144	0.0157	0.0169
	0.10	0.0082	0.0094	0.0108	0.0122	0.0136	0.0150	0.0165	0.0180	0.0195
	0.15	0.0088	0.0103	0.0119	0.0136	0.0152	0.0169	0.0186	0.0202	0.0219
	0.20	0.0095	0.0114	0.0132	0.0151	0.0169	0.0188	0.0206	0.0224	0.0242
	0.25	0.0104	0.0125	0.0146	0.0166	0.0186	0.0206	0.0225	0.0245	0.0263
	0.30	0.0115	0.0138	0.0161	0.0183	0.0204	0.0224	0.0245	0.0265	0.0284
	0.35	0.0128	0.0153	0.0177	0.0200	0.0222	0.0243	0.0264	0.0284	0.0304
	0.40	0.0143	0.0170	0.0194	0.0218	0.0240	0.0261	0.0282	0.0303	0.0323
	0.45	0.0161	0.0189	0.0213	0.0237	0.0259	0.0280	0.0301	0.0321	0.0340
	0.50	0.0182	0.0210	0.0234	0.0257	0.0279	0.0299	0.0319	0.0338	0.0357
	0.55	0.0208	0.0234	0.0258	0.0279	0.0299	0.0318	0.0337	0.0355	0.0372
	0.60	0.0238	0.0262	0.0284	0.0303	0.0321	0.0338	0.0355	0.0371	0.0387
	0.65	0.0274	0.0295	0.0312	0.0329	0.0344	0.0359	0.0373	0.0387	0.0400
	0.70	0.0317	0.0332	0.0345	0.0357	0.0369	0.0380	0.0391	0.0402	0.0412
	0.75	0.0369	0.0376	0.0382	0.0388	0.0395	0.0402	0.0409	0.0416	0.0423
	0.80	0.0431	0.0426	0.0424	0.0423	0.0423	0.0425	0.0427	0.0430	0.0433

Table A-3630-1
Coefficients G_i for Circumferential Semielliptical Inside Surface Flaw (R_i/t = 1), Deepest Point (Point 1)

		Aspect Ratio, a/ℓ			
Coefficients	a/t	360-deg Circum. Flaw	0.125	0.25	0.50
G_0	0.0	1.071 E+00	1.084 E+00	1.070 E+00	1.068 E+00
	0.2	1.096 E+00	1.050 E+00	1.037 E+00	1.039 E+00
	0.4	1.139 E+00	1.066 E+00	1.048 E+00	1.049 E+00
	0.6	1.247 E+00	1.182 E+00	1.143 E+00	1.124 E+00
	0.8	1.465 E+00	[Note (1)]	1.425 E+00	1.322 E+00
G_1	0.0	6.488 E−01	6.824 E−01	7.033 E−01	7.370 E−01
	0.2	6.744 E−01	6.525 E−01	6.747 E−01	7.414 E−01
	0.4	7.005 E−01	6.540 E−01	6.650 E−01	7.401 E−01
	0.6	7.561 E−01	7.245 E−01	7.120 E−01	7.707 E−01
	0.8	8.705 E−01	[Note (1)]	8.536 E−01	8.712 E−01
G_2	0.0	4.960 E−01	5.293 E−01	5.561 E−01	5.994 E−01
	0.2	5.177 E−01	5.051 E−01	5.330 E−01	6.086 E−01
	0.4	5.370 E−01	5.038 E−01	5.215 E−01	6.056 E−01
	0.6	5.752 E−01	5.551E−01	5.527 E−01	6.238 E−01
	0.8	6.539 E−01	[Note (1)]	6.473 E−01	6.912 E−01
G_3	0.0	4.143 E−01	4.452 E−01	4.730 E−01	5.198 E−01
	0.2	4.327 E−01	4.250 E−01	4.538 E−01	5.294 E−01
	0.4	4.482 E−01	4.231 E−01	4.429 E−01	5.262 E−01
	0.6	4.777 E−01	4.634 E−01	4.662 E−01	5.388 E−01
	0.8	5.383 E−01	[Note (1)]	5.373 E−01	5.896 E−01
G_4	0.0	3.623 E−01	3.908 E−01	4.183 E−01	4.663 E−01
	0.2	3.783 E−01	3.736 E−01	4.020 E−01	4.755 E−01
	0.4	3.914 E−01	3.715 E−01	3.920 E−01	4.725 E−01
	0.6	4.156 E−01	4.048 E−01	4.106 E−01	4.820 E−01
	0.8	4.650 E−01	[Note (1)]	4.675 E−01	5.227 E−01

NOTE:
(1) Flaw geometry for a/t = 0.8 and a/ℓ = 0.125 exceeds 360 deg. Use 360-deg flaw for calculations.

Table A-3630-2
Coefficients G_i for Circumferential Semielliptical Inside Surface Flaw (R_i/t = 1), Surface Point (Point 2)

Coefficients	a/t	Aspect Ratio, a/ℓ 0.125	0.25	0.50
G_0	0.0	6.011 E−01	8.763 E−01	1.204 E+00
	0.2	5.653 E−01	8.515 E−01	1.190 E+00
	0.4	5.587 E−01	8.641 E−01	1.214 E+00
	0.6	5.740 E−01	9.070 E−01	1.268 E+00
	0.8	[Note (1)]	9.752 E−01	1.345 E+00
G_1	0.0	7.154 E−02	1.273 E−01	1.863 E−01
	0.2	6.804 E−02	1.336 E−01	2.046 E−01
	0.4	6.743 E−02	1.382 E−01	2.158 E−01
	0.6	7.540 E−02	1.491 E−01	2.309 E−01
	0.8	[Note (1)]	1.782 E−01	2.690 E−01
G_2	0.0	2.116 E−02	4.299 E−02	6.611 E−02
	0.2	2.122 E−02	4.929 E−02	8.021 E−02
	0.4	2.125 E−02	5.167 E−02	8.647 E−02
	0.6	2.585 E−02	5.640 E−02	9.336 E−02
	0.8	[Note (1)]	7.235 E−02	1.151 E−01
G_3	0.0	8.694 E−03	1.989 E−02	3.192 E−02
	0.2	9.328 E−03	2.471 E−02	4.203 E−02
	0.4	9.464 E−03	2.617 E−02	4.601 E−02
	0.6	1.243 E−02	2.877 E−02	4.992 E−02
	0.8	[Note (1)]	3.879 E−02	6.384 E−02
G_4	0.0	4.255 E−03	1.094 E−02	1.823 E−02
	0.2	4.933 E−03	1.459 E−02	2.566 E−02
	0.4	5.072 E−03	1.558 E−02	2.841 E−02
	0.6	7.134 E−03	1.721 E−02	3.093 E−02
	0.8	[Note (1)]	2.408 E−02	4.058 E−02

NOTE:
(1) Surface point does not exist. Flaw geometry for a/t = 0.8 and a/ℓ = 0.125 exceeds 360 deg.

Table A-3630-3 Coefficients G_i for Circumferential Semielliptical Inside Surface Flaw (R_i/t = 5), Deepest Point (Point 1)

Coefficients	a/t	Aspect Ratio, a/ℓ: 360-deg Circum. Flaw	0.03125	0.0625	0.125	0.25	0.50
G_0	0.0	1.173 E+00	1.102 E+00	1.091 E+00	1.074 E+00	1.054 E+00	1.014 E+00
	0.2	1.197 E+00	1.217 E+00	1.192 E+00	1.147 E+00	1.096 E+00	1.044 E+00
	0.4	1.370 E+00	1.390 E+00	1.336 E+00	1.242 E+00	1.146 E+00	1.078 E+00
	0.6	1.736 E+00	1.675 E+00	1.559 E+00	1.372 E+00	1.204 E+00	1.117 E+00
	0.8	2.342 E+00	2.242 E+00	1.950 E+00	1.558 E+00	1.275 E+00	1.161 E+00
G_1	0.0	6.963 E−01	6.965 E−01	6.866 E−01	6.746 E−01	6.715 E−01	7.114 E−01
	0.2	7.178 E−01	7.302 E−01	7.158 E−01	6.978 E−01	6.896 E−01	7.286 E−01
	0.4	7.844 E−01	7.841 E−01	7.609 E−01	7.317 E−01	7.140 E−01	7.498 E−01
	0.6	9.252 E−01	8.843 E−01	8.397 E−01	7.859 E−01	7.489 E−01	7.767 E−01
	0.8	1.169 E+00	1.135 E+00	1.013 E+00	8.862 E−01	8.025 E−01	8.120 E−01
G_2	0.0	5.265 E−01	5.387 E−01	5.311 E−01	5.232 E−01	5.270 E−01	5.828 E−01
	0.2	5.440 E−01	5.532 E−01	5.435 E−01	5.343 E−01	5.381 E−01	5.949 E−01
	0.4	5.819 E−01	5.784 E−01	5.645 E−01	5.523 E−01	5.543 E−01	6.105 E−01
	0.6	6.616 E−01	6.310 E−01	6.062 E−01	5.849 E−01	5.793 E−01	6.309 E−01
	0.8	8.048 E−01	7.870 E−01	7.141 E−01	6.541 E−01	6.212 E−01	6.589 E−01
G_3	0.0	4.367 E−01	4.513 E−01	4.453 E−01	4.402 E−01	4.476 E−01	5.075 E−01
	0.2	4.512 E−01	4.586 E−01	4.515 E−01	4.465 E−01	4.554 E−01	5.169 E−01
	0.4	4.767 E−01	4.727 E−01	4.632 E−01	4.579 E−01	4.675 E−01	5.292 E−01
	0.6	5.302 E−01	5.057 E−01	4.896 E−01	4.808 E−01	4.871 E−01	5.457 E−01
	0.8	6.288 E−01	6.178 E−01	5.671 E−01	5.338 E−01	5.213 E−01	5.686 E−01
G_4	0.0	3.799 E−01	3.946 E−01	3.899 E−01	3.865 E−01	3.960 E−01	4.566 E−01
	0.2	3.923 E−01	3.986 E−01	3.931 E−01	3.905 E−01	4.021 E−01	4.643 E−01
	0.4	4.111 E−01	4.073 E−01	4.003 E−01	3.986 E−01	4.117 E−01	4.744 E−01
	0.6	4.506 E−01	4.303 E−01	4.188 E−01	4.160 E−01	4.279 E−01	4.882 E−01
	0.8	5.248 E−01	5.173 E−01	4.790 E−01	4.589 E−01	4.566 E−01	5.076 E−01

Table A-3630-4
Coefficients G_i for Circumferential Semielliptical Inside Surface Flaw (R_i/t = 5), Surface Point (Point 2)

Coefficients	a/t	Aspect Ratio, a/ℓ 0.03125	0.0625	0.125	0.25	0.50
G_0	0.0	2.750 E−01	4.065 E−01	6.098 E−01	8.804 E−01	1.192 E+00
	0.2	2.794 E−01	4.159 E−01	6.246 E−01	8.985 E−01	1.209 E+00
	0.4	2.847 E−01	4.437 E−01	6.756 E−01	9.623 E−01	1.270 E+00
	0.6	2.985 E−01	4.986 E−01	7.661 E−01	1.065 E+00	1.360 E+00
	0.8	3.359 E−01	5.890 E−01	8.889 E−01	1.185 E+00	1.453 E+00
G_1	0.0	1.246 E−02	3.518 E−02	7.219 E−02	1.242 E−01	1.841 E−01
	0.2	1.498 E−02	4.459 E−02	8.994 E−02	1.483 E−01	2.085 E−01
	0.4	1.622 E−02	5.173 E−02	1.033 E−01	1.652 E−01	2.244 E−01
	0.6	1.714 E−02	5.938 E−02	1.173 E−01	1.817 E−01	2.387 E−01
	0.8	2.208 E−02	8.148 E−02	1.513 E−01	2.165 E−01	2.658 E−01
G_2	0.0	1.474 E−03	8.497 E−03	2.100 E−02	4.054 E−02	6.537 E−02
	0.2	2.964 E−03	1.455 E−02	3.262 E−02	5.641 E−02	8.160 E−02
	0.4	3.464 E−03	1.766 E−02	3.856 E−02	6.397 E−02	8.859 E−02
	0.6	3.138 E−03	1.921 E−02	4.204 E−02	6.840 E−02	9.243 E−02
	0.8	3.998 E−03	2.854 E−02	5.755 E−02	8.471 E−02	1.051 E−01
G_3	0.0	1.129 E−04	2.896 E−03	8.439 E−03	1.811 E−02	3.160 E−02
	0.2	1.084 E−03	6.977 E−03	1.632 E−02	2.892 E−02	4.267 E−02
	0.4	1.345 E−03	8.693 E−03	1.963 E−02	3.314 E−02	4.655 E−02
	0.6	8.866 E−04	8.863 E−03	2.056 E−02	3.453 E−02	4.775 E−02
	0.8	8.656 E−04	1.388 E−02	2.937 E−02	4.396 E−02	5.505 E−02
G_4	0.0	−1.039 E−04	1.146 E−03	4.017 E−03	9.616 E−03	1.807 E−02
	0.2	5.764 E−04	4.058 E−03	9.661 E−03	1.737 E−02	2.601 E−02
	0.4	7.331 E−04	5.137 E−03	1.176 E−02	2.005 E−02	2.847 E−02
	0.6	3.166 E−04	4.928 E−03	1.188 E−02	2.044 E−02	2.879 E−02
	0.8	7.473 E−05	8.032 E−03	1.754 E−02	2.657 E−02	3.354 E−02

Table A-3630-5
Coefficients G_i for Circumferential Semielliptical Inside Surface Flaw (R_i/t = 10), Deepest Point (Point 1)

		Aspect Ratio, a/ℓ						
Coefficients	a/t	360-deg Circum. Flaw	0.015625	0.03125	0.0625	0.125	0.25	0.50
G_0	0.0	1.183 E+00	1.089 E+00	1.087 E+00	1.081 E+00	1.072 E+00	1.057 E+00	1.012 E+00
	0.2	1.236 E+00	1.272 E+00	1.253 E+00	1.217 E+00	1.163 E+00	1.106 E+00	1.042 E+00
	0.4	1.493 E+00	1.536 E+00	1.486 E+00	1.396 E+00	1.272 E+00	1.160 E+00	1.075 E+00
	0.6	1.999 E+00	1.949 E+00	1.834 E+00	1.641 E+00	1.405 E+00	1.221 E+00	1.109 E+00
	0.8	2.801 E+00	2.689 E+00	2.410 E+00	1.998 E+00	1.572 E+00	1.288 E+00	1.146 E+00
G_1	0.0	7.023 E−01	6.858 E−01	6.811 E−01	6.744 E−01	6.687 E−01	6.738 E−01	7.111 E−01
	0.2	7.338 E−01	7.448 E−01	7.351 E−01	7.206 E−01	7.050 E−01	7.004 E−01	7.304 E−01
	0.4	8.295 E−01	8.352 E−01	8.153 E−01	7.860 E−01	7.529 E−01	7.327 E−01	7.523 E−01
	0.6	1.019 E+00	9.911 E−01	9.468 E−01	8.854 E−01	8.190 E−01	7.731 E−01	7.774 E−01
	0.8	1.330 E+00	1.324 E+00	1.202 E+00	1.055 E+00	9.160 E−01	8.247 E−01	8.064 E−01
G_2	0.0	5.310 E−01	5.300 E−01	5.259 E−01	5.205 E−01	5.176 E−01	5.287 E−01	5.828 E−01
	0.2	5.536 E−01	5.585 E−01	5.521 E−01	5.441 E−01	5.388 E−01	5.471 E−01	5.971 E−01
	0.4	6.065 E−01	6.050 E−01	5.935 E−01	5.797 E−01	5.685 E−01	5.705 E−01	6.136 E−01
	0.6	7.113 E−01	6.920 E−01	6.671 E−01	6.382 E−01	6.124 E−01	6.008 E−01	6.330 E−01
	0.8	8.893 E−01	9.012 E−01	8.267 E−01	7.481 E−01	6.816 E−01	6.412 E−01	6.558 E−01
G_3	0.0	4.402 E−01	4.440 E−01	4.406 E−01	4.364 E−01	4.352 E−01	4.490 E−01	5.075 E−01
	0.2	4.579 E−01	4.606 E−01	4.558 E−01	4.508 E−01	4.497 E−01	4.631 E−01	5.189 E−01
	0.4	4.927 E−01	4.892 E−01	4.814 E−01	4.738 E−01	4.711 E−01	4.814 E−01	5.322 E−01
	0.6	5.616 E−01	5.468 E−01	5.303 E−01	5.143 E−01	5.039 E−01	5.056 E−01	5.479 E−01
	0.8	6.818 E−01	6.981 E−01	6.452 E−01	5.953 E−01	5.579 E−01	5.387 E−01	5.666 E−01
G_4	0.0	3.829 E−01	3.884 E−01	3.855 E−01	3.821 E−01	3.821 E−01	3.972 E−01	4.566 E−01
	0.2	3.974 E−01	3.990 E−01	3.953 E−01	3.919 E−01	3.931 E−01	4.086 E−01	4.661 E−01
	0.4	4.226 E−01	4.186 E−01	4.129 E−01	4.084 E−01	4.096 E−01	4.237 E−01	4.772 E−01
	0.6	4.727 E−01	4.606 E−01	4.486 E−01	4.389 E−01	4.358 E−01	4.439 E−01	4.904 E−01
	0.8	5.617 E−01	5.787 E−01	5.379 E−01	5.030 E−01	4.801 E−01	4.718 E−01	5.062 E−01

Table A-3630-6
Coefficients G_i for Circumferential Semielliptical Inside Surface Flaw (R_i/t = 10), Surface Point (Point 2)

		Aspect Ratio, a/ℓ					
Coefficients	a/t	0.015625	0.03125	0.0625	0.125	0.25	0.50
G_0	0.0	1.950 E−01	2.710 E−01	4.039 E−01	6.125 E−01	8.900 E−01	1.188 E+00
	0.2	2.047 E−01	2.826 E−01	4.182 E−01	6.297 E−01	9.084 E−01	1.205 E+00
	0.4	2.108 E−01	3.031 E−01	4.597 E−01	6.940 E−01	9.860 E−01	1.277 E+00
	0.6	2.205 E−01	3.408 E−01	5.350 E−01	8.045 E−01	1.109 E+00	1.383 E+00
	0.8	2.454 E−01	4.009 E−01	6.363 E−01	9.346 E−01	1.237 E+00	1.483 E+00
G_1	0.0	5.144 E−03	1.458 E−02	3.334 E−02	6.913 E−02	1.276 E−01	1.892 E−01
	0.2	5.673 E−03	1.762 E−02	4.104 E−02	8.416 E−02	1.491 E−01	2.072 E−01
	0.4	9.243 E−03	2.448 E−02	5.374 E−02	1.052 E−01	1.750 E−01	2.257 E−01
	0.6	1.843 E−02	3.772 E−02	7.377 E−02	1.334 E−01	2.046 E−01	2.437 E−01
	0.8	3.676 E−02	6.035 E−02	1.030 E−01	1.685 E−01	2.357 E−01	2.601 E−01
G_2	0.0	1.898 E−03	3.269 E−03	7.370 E−03	1.862 E−02	4.222 E−02	6.933 E−02
	0.2	1.587 E−03	4.620 E−03	1.185 E−02	2.814 E−02	5.629 E−02	8.099 E−02
	0.4	3.699 E−03	8.056 E−03	1.797 E−02	3.855 E−02	6.924 E−02	8.901 E−02
	0.6	9.565 E−03	1.482 E−02	2.689 E−02	5.081 E−02	8.159 E−02	9.431 E−02
	0.8	2.088 E−02	2.669 E−02	4.051 E−02	6.658 E−02	9.467 E−02	9.891 E−02
G_3	0.0	1.725 E−03	1.436 E−03	2.149 E−03	6.727 E−03	1.913 E−02	3.444 E−02
	0.2	1.346 E−03	2.190 E−03	5.048 E−03	1.310 E−02	2.867 E−02	4.233 E−02
	0.4	2.722 E−03	4.253 E−03	8.638 E−03	1.931 E−02	3.644 E−02	4.673 E−02
	0.6	6.666 E−03	8.360 E−03	1.363 E−02	2.606 E−02	4.303 E−02	4.867 E−02
	0.8	1.417 E−02	1.567 E−02	2.147 E−02	3.493 E−02	5.006 E−02	5.023 E−02
G_4	0.0	1.546 E−03	8.824 E−04	6.191 E−04	2.756 E−03	1.030 E−02	2.016 E−02
	0.2	1.212 E−03	1.361 E−03	2.641 E−03	7.287 E−03	1.712 E−02	2.579 E−02
	0.4	2.175 E−03	2.737 E−03	5.000 E−03	1.142 E−02	2.231 E−02	2.856 E−02
	0.6	4.985 E−03	5.496 E−03	8.176 E−03	1.565 E−02	2.635 E−02	2.932 E−02
	0.8	1.029 E−02	1.045 E−02	1.326 E−02	2.132 E−02	3.069 E−02	2.986 E−02

Table A-3630-7
Coefficients G_i for Circumferential Semielliptical Inside Surface Flaw (R_i/t = 20), Deepest Point (Point 1)

		Aspect Ratio, a/ℓ						
Coefficients	a/t	360-deg Circum. Flaw	0.015625	0.03125	0.0625	0.125	0.25	0.50
G_0	0.0	1.171 E+00	1.086 E+00	1.080 E+00	1.069 E+00	1.054 E+00	1.038 E+00	1.027 E+00
	0.2	1.270 E+00	1.316 E+00	1.284 E+00	1.233 E+00	1.163 E+00	1.095 E+00	1.050 E+00
	0.4	1.629 E+00	1.644 E+00	1.565 E+00	1.443 E+00	1.293 E+00	1.158 E+00	1.073 E+00
	0.6	2.293 E+00	2.149 E+00	1.973 E+00	1.725 E+00	1.449 E+00	1.227 E+00	1.098 E+00
	0.8	3.308 E+00	3.028 E+00	2.623 E+00	2.122 E+00	1.642 E+00	1.303 E+00	1.124 E+00
G_1	0.0	6.993 E−01	6.878 E−01	6.810 E−01	6.721 E−01	6.653 E−01	6.725 E−01	7.147 E−01
	0.2	7.476 E−01	7.644 E−01	7.491 E−01	7.279 E−01	7.067 E−01	7.008 E−01	7.337 E−01
	0.4	8.795 E−01	8.775 E−01	8.458 E−01	8.027 E−01	7.584 E−01	7.337 E−01	7.545 E−01
	0.6	1.124 E+00	1.061 E+00	9.939 E−01	9.082 E−01	8.246 E−01	7.723 E−01	7.773 E−01
	0.8	1.510 E+00	1.411 E+00	1.249 E+00	1.068 E+00	9.126 E−01	8.182 E−01	8.025 E−01
G_2	0.0	5.298 E−01	5.325 E−01	5.270 E−01	5.202 E−01	5.172 E−01	5.305 E−01	5.840 E−01
	0.2	5.616 E−01	5.708 E−01	5.610 E−01	5.488 E−01	5.404 E−01	5.494 E−01	5.992 E−01
	0.4	6.338 E−01	6.293 E−01	6.110 E−01	5.885 E−01	5.705 E−01	5.719 E−01	6.160 E−01
	0.6	7.677 E−01	7.287 E−01	6.909 E−01	6.470 E−01	6.106 E−01	5.990 E−01	6.346 E−01
	0.8	9.848 E−01	9.318 E−01	8.377 E−01	7.408 E−01	6.665 E−01	6.323 E−01	6.555 E−01
G_3	0.0	4.397 E−01	4.464 E−01	4.419 E−01	4.366 E−01	4.357 E−01	4.515 E−01	5.079 E−01
	0.2	4.634 E−01	4.694 E−01	4.623 E−01	4.542 E−01	4.512 E−01	4.656 E−01	5.204 E−01
	0.4	5.104 E−01	5.057 E−01	4.932 E−01	4.794 E−01	4.717 E−01	4.827 E−01	5.343 E−01
	0.6	5.977 E−01	5.698 E−01	5.448 E−01	5.180 E−01	5.000 E−01	5.037 E−01	5.499 E−01
	0.8	7.424 E−01	7.087 E−01	6.443 E−01	5.826 E−01	5.407 E−01	5.299 E−01	5.674 E−01
G_4	0.0	3.826 E−01	3.906 E−01	3.867 E−01	3.826 E−01	3.830 E−01	3.999 E−01	4.567 E−01
	0.2	4.015 E−01	4.059 E−01	4.003 E−01	3.946 E−01	3.943 E−01	4.112 E−01	4.673 E−01
	0.4	4.353 E−01	4.308 E−01	4.216 E−01	4.123 E−01	4.097 E−01	4.250 E−01	4.791 E−01
	0.6	4.982 E−01	4.767 E−01	4.584 E−01	4.403 E−01	4.314 E−01	4.421 E−01	4.924 E−01
	0.8	6.043 E−01	5.806 E−01	5.324 E−01	4.890 E−01	4.633 E−01	4.637 E−01	5.074 E−01

Table A-3630-8
Coefficients G_i for Circumferential Semielliptical Inside Surface Flaw (R_i/t = 20), Surface Point (Point 2)

		Aspect Ratio, a/ℓ					
Coefficients	a/t	**0.015625**	**0.03125**	**0.0625**	**0.125**	**0.25**	**0.50**
G_0	0.0	1.902 E−01	2.710 E−01	4.080 E−01	6.144 E−01	8.827 E−01	1.192 E+00
	0.2	2.083 E−01	2.901 E−01	4.281 E−01	6.347 E−01	9.012 E−01	1.207 E+00
	0.4	2.231 E−01	3.237 E−01	4.862 E−01	7.146 E−01	9.880 E−01	1.283 E+00
	0.6	2.401 E−01	3.852 E−01	5.971 E−01	8.574 E−01	1.128 E+00	1.396 E+00
	0.8	2.553 E−01	4.797 E−01	7.544 E−01	1.031 E+00	1.274 E+00	1.499 E+00
G_1	0.0	4.249 E−03	1.637 E−02	3.817 E−02	7.397 E−02	1.249 E−01	1.844 E−01
	0.2	7.356 E−03	2.181 E−02	4.723 E−02	8.754 E−02	1.420 E−01	2.015 E−01
	0.4	1.214 E−02	3.000 E−02	6.045 E−02	1.063 E−01	1.639 E−01	2.219 E−01
	0.6	2.044 E−02	4.379 E−02	8.153 E−02	1.340 E−01	1.933 E−01	2.467 E−01
	0.8	3.841 E−02	7.186 E−02	1.205 E−01	1.788 E−01	2.345 E−01	2.773 E−01
G_2	0.0	1.604 E−03	4.553 E−03	1.053 E−02	2.194 E−02	4.086 E−02	6.558 E−02
	0.2	2.531 E−03	7.072 E−03	1.557 E−02	3.018 E−02	5.171 E−02	7.674 E−02
	0.4	4.889 E−03	1.052 E−02	2.086 E−02	3.788 E−02	6.120 E−02	8.588 E−02
	0.6	9.605 E−03	1.598 E−02	2.800 E−02	4.743 E−02	7.213 E−02	9.551 E−02
	0.8	2.136 E−02	2.928 E−02	4.458 E−02	6.709 E−02	9.119 E−02	1.100 E−01
G_3	0.0	1.599 E−03	2.335 E−03	4.293 E−03	9.019 E−03	1.830 E−02	3.175 E−02
	0.2	1.947 E−03	3.780 E−03	7.485 E−03	1.445 E−02	2.558 E−02	3.932 E−02
	0.4	3.351 E−03	5.637 E−03	1.022 E−02	1.850 E−02	3.078 E−02	4.444 E−02
	0.6	6.369 E−03	8.432 E−03	1.337 E−02	2.281 E−02	3.609 E−02	4.930 E−02
	0.8	1.434 E−02	1.617 E−02	2.236 E−02	3.368 E−02	4.700 E−02	5.775 E−02
G_4	0.0	1.484 E−03	1.536 E−03	2.153 E−03	4.411 E−03	9.737 E−03	1.817 E−02
	0.2	1.627 E−03	2.472 E−03	4.353 E−03	8.236 E−03	1.492 E−02	2.359 E−02
	0.4	2.558 E−03	3.619 E−03	5.989 E−03	1.070 E−02	1.818 E−02	2.685 E−02
	0.6	4.650 E−03	5.279 E−03	7.609 E−03	1.297 E−02	2.119 E−02	2.970 E−02
	0.8	1.035 E−02	1.033 E−02	1.319 E−02	1.983 E−02	2.824 E−02	3.522 E−02

ARTICLE A-4000 MATERIAL PROPERTIES

A-4100 SCOPE

This Article provides the rules and equations for determining the material properties that are utilized in the analyses.

A-4200 FRACTURE TOUGHNESS (15)

(a) The fracture toughness of the material is determined by two properties K_{Ia} and K_{Ic}, which represent critical values of the stress intensity factor K_I. K_{Ia} is based on the lower bound of crack arrest critical K_I values measured as a function of temperature. K_{Ic} is based on the lower bound of static initiation critical K_I values measured as a function of temperature. The K_{Ia} and K_{Ic} values used in the analysis should represent conservative values obtained preferably from the specific material and product form involved. The values so used should be justified on the basis of current technology and should take into account material variability, testing techniques, and any other variables which may lower these toughness values.

(b) Lower bound K_{Ia} and K_{Ic} versus temperature curves from tests of SA-533 Grade B Class 1, SA-508 Class 2, and SA-508 Class 3 steel are provided in Figure A-4200-1 (Figure A-4200-1M) for use if data from the actual product form are not available. The temperature scale of this data should be related to the reference nil-ductility temperature RT_{NDT}, as determined for the material prior to irradiation, according to the rules of NB-2331, or as irradiated according to A-4400. The curves in Figure A-4200-1 are intended to be very conservative since the recommended procedure is to determine the material fracture toughness from specimens of the actual material and product form in question. Analytical approximations for these curves are as follows:

(U.S. Customary Units)

$$K_{Ic} = 33.2 + 20.734 \exp\left[0.02\left(T - RT_{NDT}\right)\right]$$

$$K_{Ia} = 26.8 + 12.445 \exp\left[0.0145\left(T - RT_{NDT}\right)\right]$$

(SI Units)

$$K_{Ic} = 36.5 + 22.783 \exp\left[0.036\left(T - RT_{NDT}\right)\right]$$

$$K_{Ia} = 29.4 + 13.675 \exp\left[0.0261\left(T - RT_{NDT}\right)\right]$$

where K_{Ic} and K_{Ia} are in units of $\text{ksi}\sqrt{\text{in.}}\ \left(\text{MPa}\sqrt{\text{m}}\right)$ and T and RT_{NDT} are in units of °F (°C).

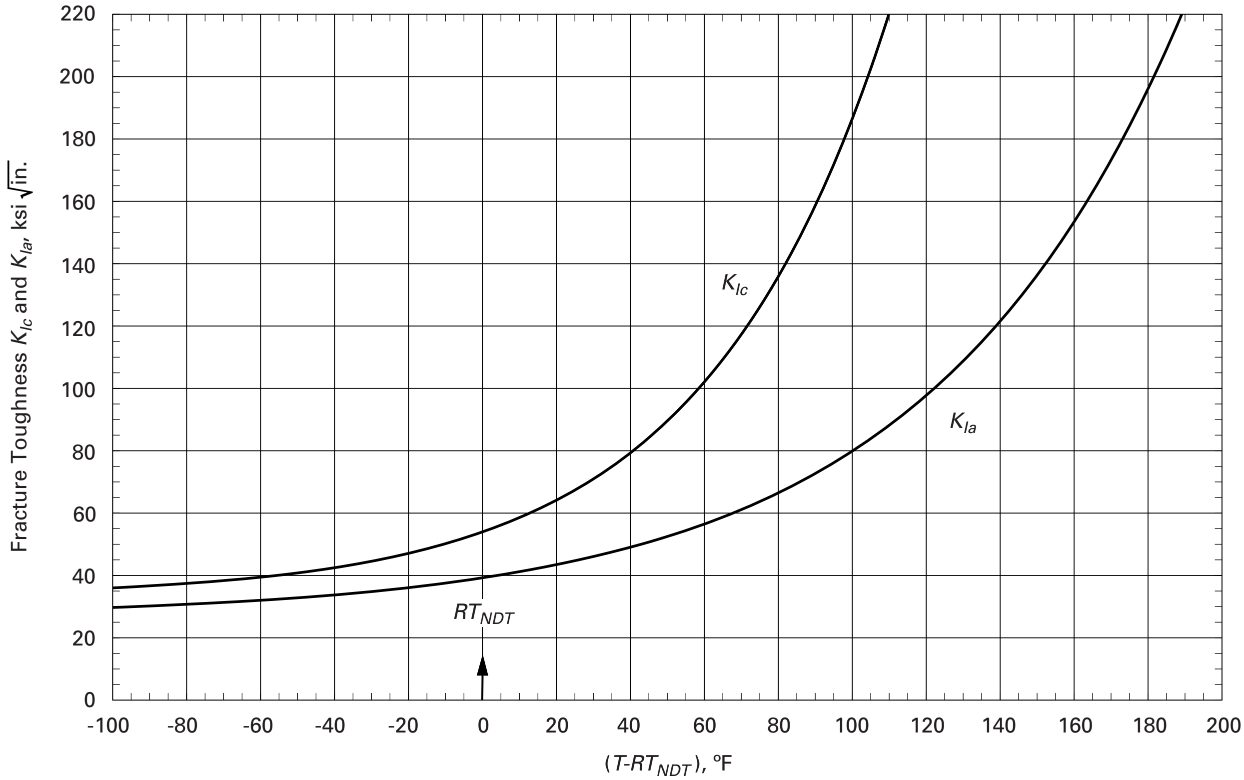
(c) If a material-specific temperature, T_0, value determined in accordance with ASTM E1921, Standard Test Method for the Determination of Reference Temperature, T_0, for Ferritic Steels in the Transition Range, is available, a reference temperature, RT_{T_0}, may be used in place of RT_{NDT} for the K_{Ic} curve. For the K_{Ia} curve, the reference temperature, $RT_{K_{Ia}}$, may be used in place of RT_{NDT}.

The reference temperatures, RT_{T_0} and $RT_{K_{Ia}}$, are defined as

(U.S. Customary Units)

$$RT_{T_0} = T_0 + 35°\text{F}$$

Figure A-4200-1
Lower Bound K_{Ia} and K_{Ic} Test Data for SA-533 Grade B Class 1, SA-508 Class 2, and SA-508 Class 3 Steels



$$RT_{K_{Ia}} = T_0 + 80.95 \exp(-0.00613T_0)$$

(SI Units)

$$RT_{T_0} = T_0 + 19.4°C$$

$$RT_{K_{Ia}} = T_0 + 44.97 \exp(-0.00613T_0)$$

Determination of RT_{T_0} and $RT_{K_{Ia}}$ shall be the responsibility of the Owner and subject to the approval of the regulatory authority having jurisdiction at the plant site.

A-4300 FATIGUE CRACK GROWTH RATE

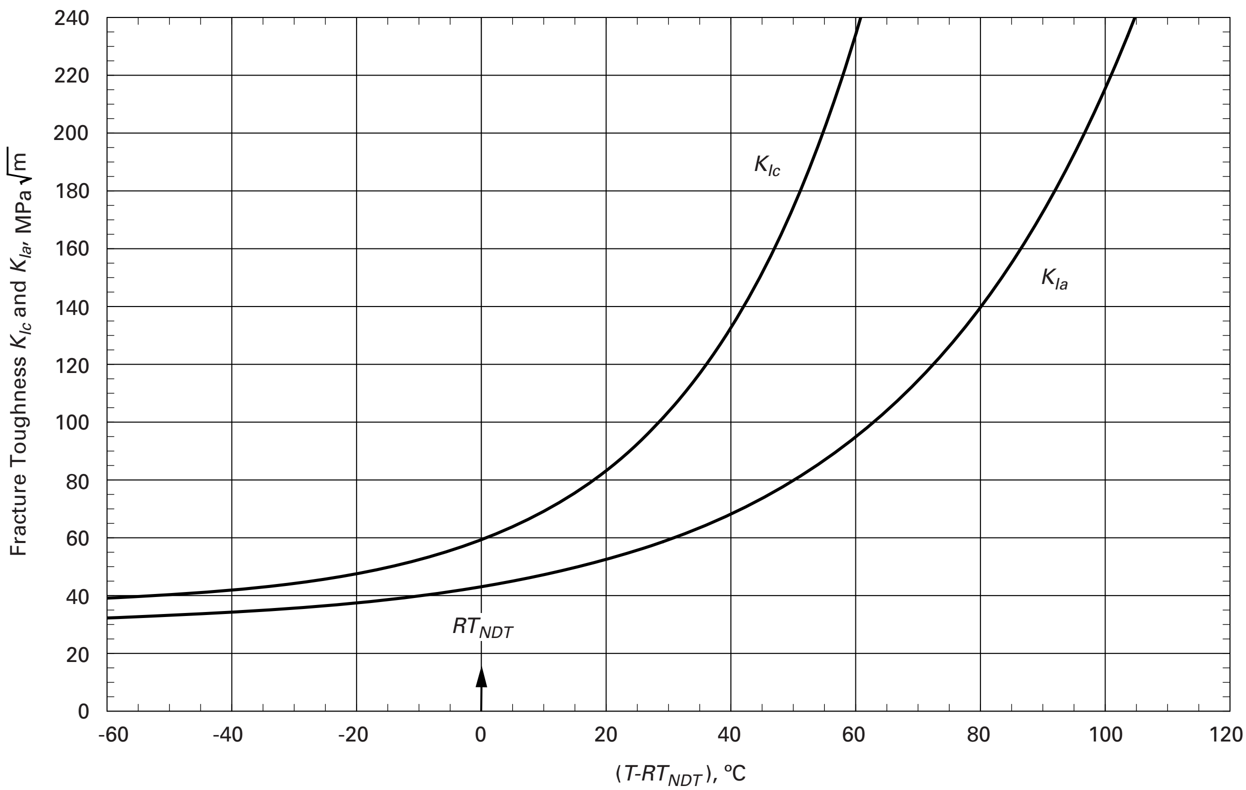
(a) The fatigue crack growth rate da/dN of the material is characterized in terms of the range of applied stress intensity factor ΔK_I. This characterization is generally of the form:

$$da/dN = C_o(\Delta K_I)^n \quad (1)$$

where

C_o = a scaling constant
n = the slope of the log (da/dN) versus log (ΔK_I)

Figure A-4200-1M
Lower Bound K_{Ia} and K_{Ic} Test Data for SA-533 Grade B Class 1, SA-508 Class 2, and SA-508 Class 3 Steels



Data should be obtained from specimens of the actual material and product form, considering material variability, environment, test frequency, and other variables that affect the data.

(b) The fatigue crack growth behavior of the material is affected by the R ratio (K_{min}/K_{max}) and the environment. For air or water environments

$$C_0 = 0 \text{ for } \Delta K_I < \Delta K_{th}$$

where ΔK_{th} is the threshold ΔK_I value below which the fatigue crack growth rate is negligible. ΔK_{th} in units of $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$ is given by

(U.S. Customary Units)

$$\Delta K_{th} = 5.0 \text{ for } R < 0$$

$$\Delta K_{th} = 5.0(1 - 0.8R) \text{ for } 0 \leq R < 1.0$$

(SI Units)

$$\Delta K_{th} = 5.5 \text{ for } R < 0$$

$$\Delta K_{th} = 5.5(1 - 0.8R) \text{ for } 0 \leq R < 1.0$$

Reference fatigue crack growth rates for carbon and low alloy ferritic steels for air and water environments at $\Delta K_I \geq \Delta K_{th}$ are given below.

(1) Reference fatigue crack growth behavior of the material exposed to air environments (subsurface flaws) is given by eq. (a)(1) with n = 3.07 and

(U.S. Customary Units)

$$C_o = 1.99 \times 10^{-10} S \tag{2}$$

(SI Units)

$$C_o = 3.78 \times 10^{-9} S \tag{2}$$

S is a scaling parameter to account for the R ratio and is given by $S = 25.72\ (2.88 - R)^{-3.07}$, where $0 \le R \le 1$ and $\Delta K_I = K_{max} - K_{min}$. For $R < 0$, ΔK_I depends on the crack depth, a, and the flow stress, σ_f. The flow stress is defined by $\sigma_f = \frac{1}{2}(\sigma_{ys} + \sigma_{ult})$, where σ_{ys} is the yield strength and σ_{ult} is the ultimate tensile strength in units ksi (MPa) and a is in units in. (m). For $-2 \le R \le 0$ and $K_{max} - K_{min} \le 1.12\,\sigma_f\sqrt{\pi a}, S = 1$ and $\Delta K_I = K_{max}$. For $R < -2$ and $K_{max} - K_{min} \le 1.12\,\sigma_f\sqrt{\pi a}, S = 1$ and $\Delta K_I = (1 - R)\ K_{max}/3$. For $R < 0$ and $K_{max} - K_{min} > 1.12\,\sigma_f\sqrt{\pi a}, S = 1$ and $\Delta K_I = K_{max} - K_{min}$.

The scaling constant C_o from eq. (2) produces fatigue crack growth rates in units of in./cycle (mm/cycle) where ΔK_I is in units of $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$ and is intended for use when data from the actual product form are not available. Reference fatigue crack growth rate curves given by eqs. (a)(1) and (2) are provided in Figure A-4300-1 (Figure A-4300-1M).

(2) Reference fatigue crack growth behavior of material exposed to light-water reactor environments is given by eq. (a)(1) using $\Delta K_I = K_{max} - K_{min}$. If K_{min} is equal to or less than zero, use R = 0. C_o and n are given by whichever of the following results in the higher fatigue crack growth rate, da/dN: (1) n and C_o in (1) for air environments, or (2) either of the following, as applicable.

(-a) For low ΔK_I values,[45] n = 5.95 and

(U.S. Customary Units)

$$C_o = 1.02 \times 10^{-12} S \tag{3}$$

(SI Units)

$$C_o = 1.48 \times 10^{-11} S \tag{3}$$

where S is given by

S = 1.0 for $0 \le R \le 0.25$
= $26.9\ R - 5.725$ for $0.25 < R < 0.65$
= 11.76 for $0.65 \le R \le 1.0$

(-b) For high ΔK_I values,[45] n = 1.95 and

(U.S. Customary Units)

$$C_o = 1.01 \times 10^{-7} S \tag{4}$$

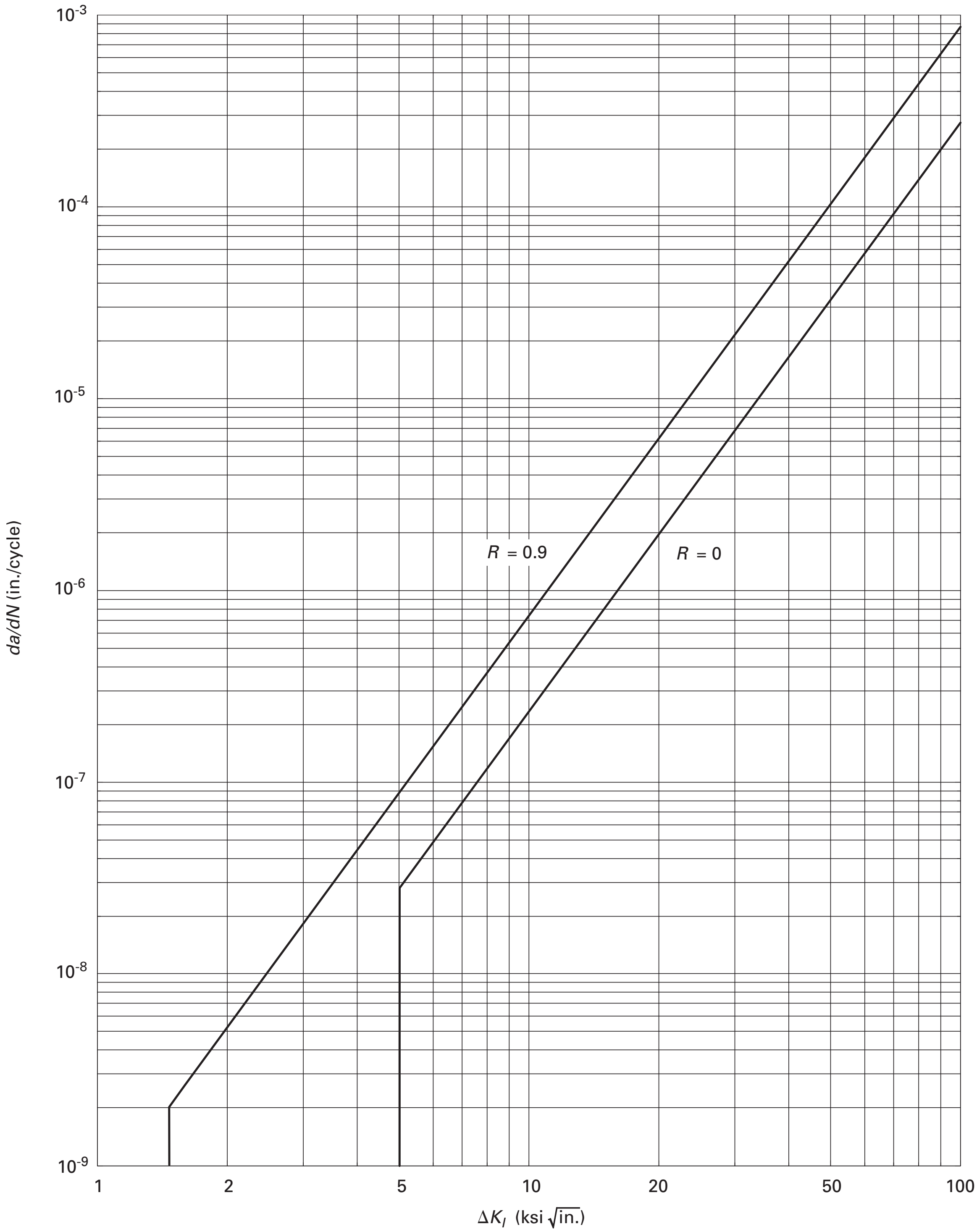
(SI Units)

$$C_o = 2.13 \times 10^{-6} S \tag{4}$$

where S is given by

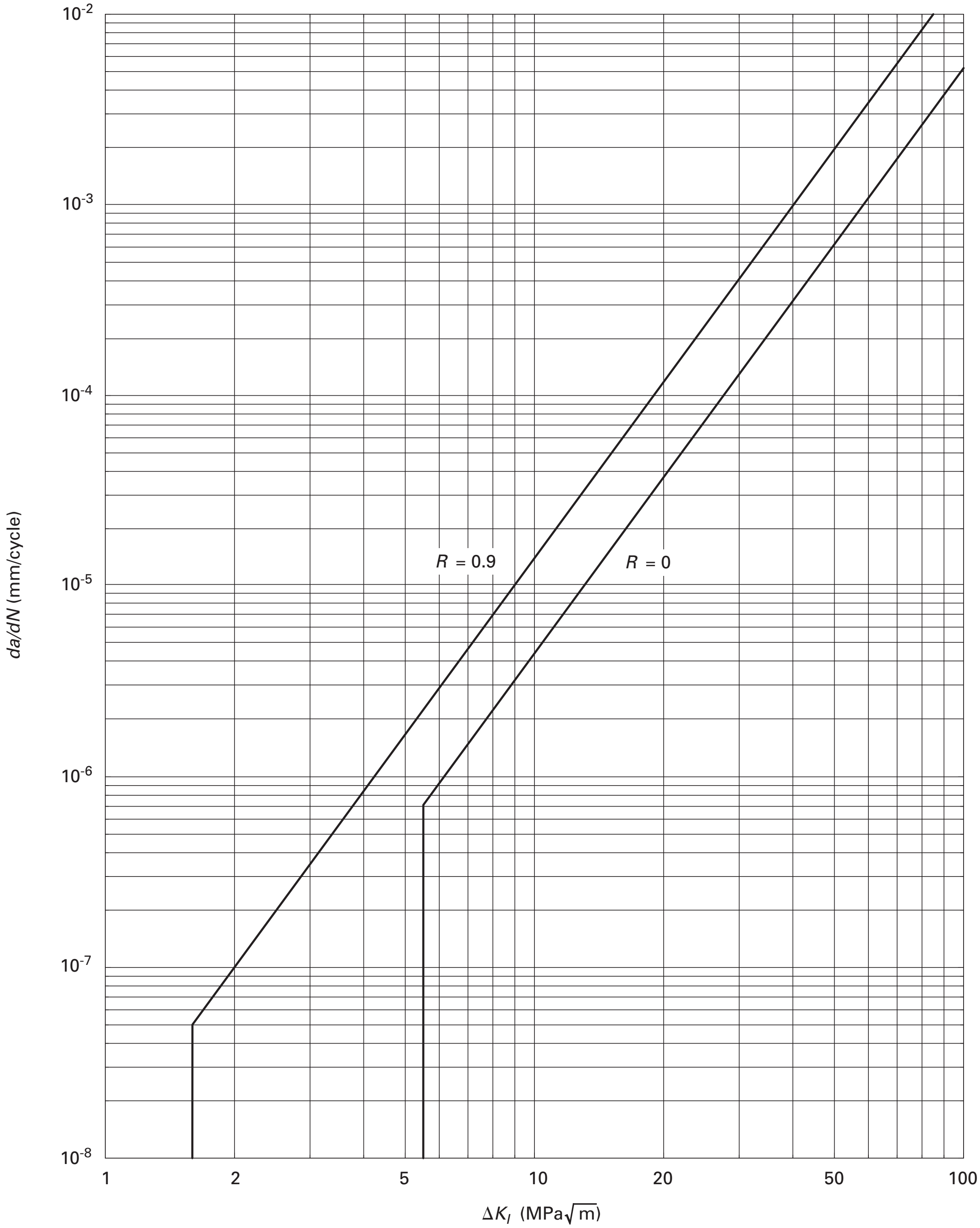
S = 1.0 for $0 \le R \le 0.25$
= $3.75\ R + 0.06$ for $0.25 < R < 0.65$
= 2.5 for $0.65 \le R \le 1.0$

Figure A-4300-1
Reference Fatigue Crack Growth Curves for Carbon and Low Alloy Ferritic Steels Exposed to Air Environments (Subsurface Flaws)



GENERAL NOTE: For other R ratios, see A-4300(b)(1).

Figure A-4300-1M
Reference Fatigue Crack Growth Curves for Carbon and Low Alloy Ferritic Steels Exposed to Air Environments (Subsurface Flaws)



GENERAL NOTE: For other R ratios, see A-4300(b)(1).

The applicable set of material parameters n and C_o is determined by calculating the ΔK_I at which the two curves intersect. This is given by

(U.S. Customary Units)

$$\Delta K_I = 17.74 \text{ for } 0 \le R \le 0.25$$

$$\Delta K_I = 17.74\left[(3.75R + 0.06)/(26.9R - 5.725)\right]^{0.25} \text{ for } 0.25 < R < 0.65$$

$$\Delta K_I = 12.04 \text{ for } 0.65 \le R \le 1.0$$

(SI Units)

$$\Delta K_I = 19.49 \text{ for } 0 \le R \le 0.25$$

$$\Delta K_I = 19.49\left[(3.75R + 0.06)/(26.9R - 5.725)\right]^{0.25} \text{ for } 0.25 < R < 0.65$$

$$\Delta K_I = 13.23 \text{ for } 0.65 \le R \le 1.0$$

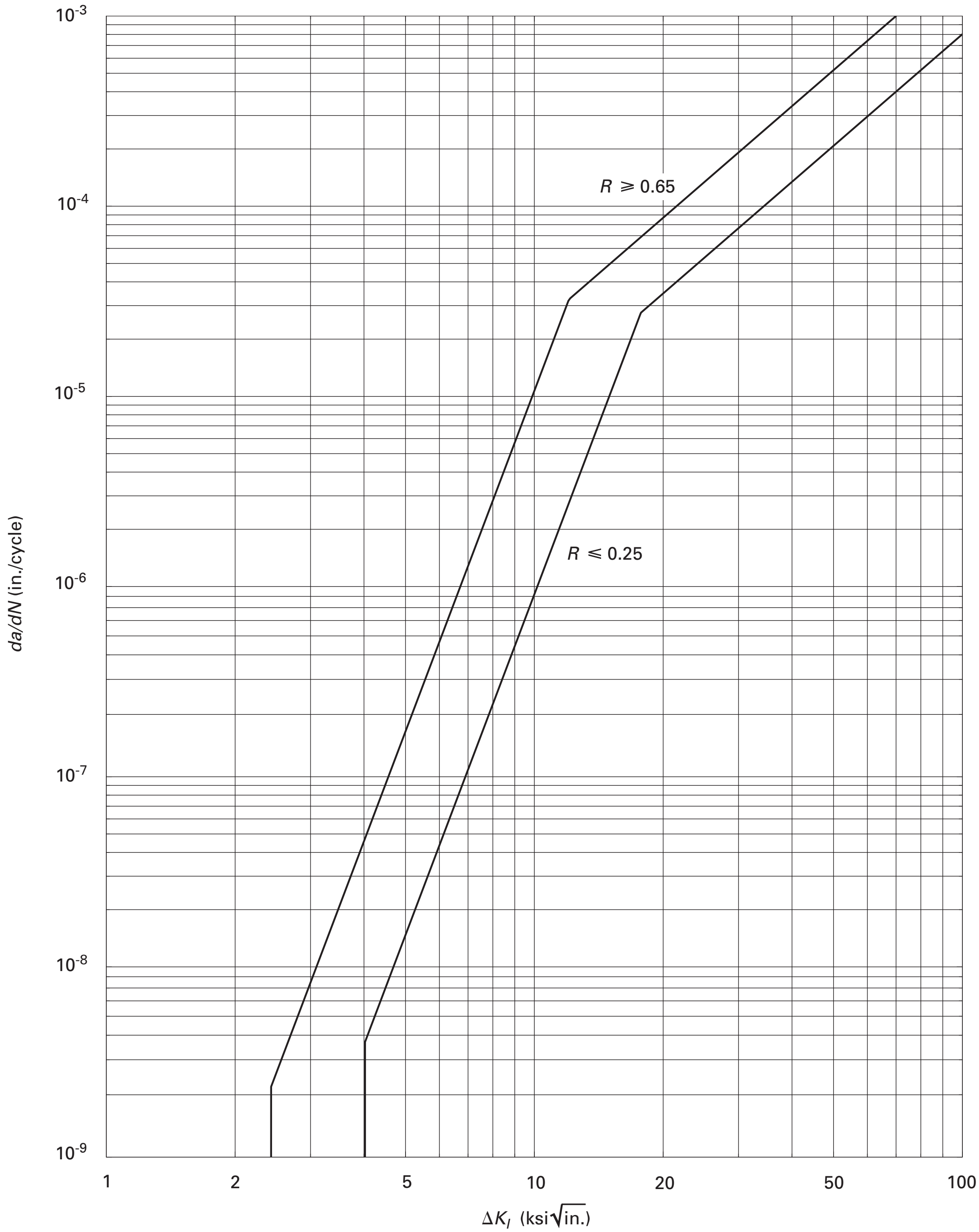
If the range of applied stress intensity factor is lower than this value, the low ΔK_I parameters apply; otherwise, the high ΔK_I parameters should be used. The scaling constant C_o from either eq. (-a)(3) or (4) produces fatigue crack growth rates in the units of in./cycle (mm/cycle) when ΔK_I is in the units ksi$\sqrt{\text{in.}}$ (MPa$\sqrt{\text{m}}$) and is intended for use when data from the actual product are not available. Reference fatigue crack growth rate curves given by eqs. (a)(1), (-a)(3), and (4) are provided in Figure A-4300-2 (Figure A-4300-2M).

A-4400 IRRADIATION EFFECTS

(a) For materials that are subjected to fast neutron fluence, the degradation of the material fracture toughness due to irradiation must be accounted for. The degree of degradation depends upon the neutron fluence, the irradiation temperature, and the relative sensitivity of the particular steel. Radiation induced changes in fracture toughness should be determined from surveillance specimens of the actual material and product form, irradiated according to the surveillance techniques of ASTM E185, Standard Practice for the Design of Surveillance Programs for Light-Water Moderated Nuclear Power Reactor Vessels, and ASTM E2215, Standard Practice for the Evaluation of Surveillance Capsules from Light-Water Moderated Nuclear Power Reactor Vessels. Measurement of RT_{T0} of unirradiated or irradiated materials as defined in A-4200(b) is permitted, including use of the procedures given in ASTM E1921 to obtain direct measurement of irradiated T_0. Given only an unirradiated value of either RT_{NDT} or RT_{T0}, an irradiation-induced shift in these values may be calculated from standard Charpy V-notch impact data obtained from irradiated surveillance specimens.

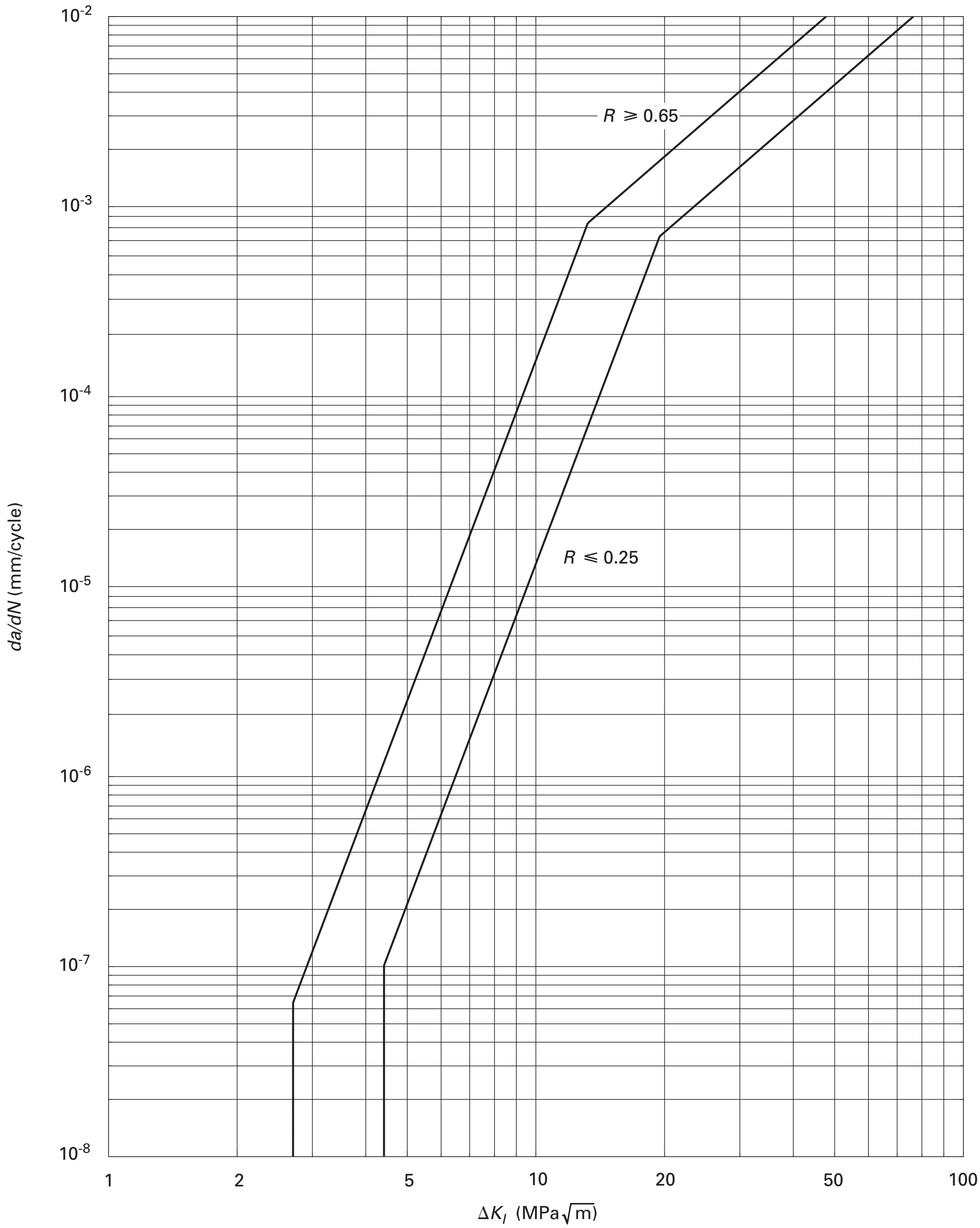
(b) Where surveillance data are not available, the effects of neutron irradiation should be considered for both K_{Ia} and K_{Ic} by shifting the reference nil-ductility temperature RT_{NDT} as a function of irradiation, based on data and methods acceptable to the regulatory authority having jurisdiction at the plant site.

Figure A-4300-2
Reference Fatigue Crack Growth Curves for Carbon and Low Alloy Ferritic Steels Exposed to Water Environments



GENERAL NOTE: For other R ratios, see A-4300(b)(2).

Figure A-4300-2M
Reference Fatigue Crack Growth Curves for Carbon and Low Alloy Ferritic Steels Exposed to Water Environments



GENERAL NOTE: For other R ratios, see A-4300(b)(2).

ARTICLE A-5000 ANALYSIS

A-5100 SCOPE

This Article provides the method to be used in applying the analyses to the normal (including upset and test), emergency, and faulted conditions.

(15) A-5200 END-OF-PERIOD FLAW SIZE

(a) In order to determine the maximum potential for fatigue flaw growth of the observed flaw indication during normal operation, a cumulative fatigue flaw growth study of the component should be performed using appropriate fatigue crack growth rates given in A-4300. The design transients prescribed in the system Design Specification that apply to the remainder of the evaluation period for the component should be included. Cumulative fatigue crack growth analysis of components need not include emergency and faulted conditions. Stress intensity factors should be determined for each transient using the bounding elliptical or semielliptical flaw model described in Article A-2000 and consistent with the methods for K_I determination outlined in Article A-3000. The plastic zone correction need not be taken into account in calculating K_I. K_I can be determined by setting the plastic zone correction factor q_y = 0 in Article A-3000. Each transient should be considered in approximate chronological order in the following manner.

(1) Determine the range of K_I fluctuation associated with the transient, ΔK_I.

(2) Find the incremental flaw growth Δa and $\Delta \ell$ corresponding to ΔK_I from the fatigue flaw growth rate data.

(3) Update the flaw dimensions a and ℓ.

(4) Repeat these calculations for the next transient using the updated flaw dimensions.

(b) For surface flaws, either of the following two methods is acceptable for determining Δa and $\Delta \ell$ for the increment of time in the calculation.

(1) Linearized Stress Ratio Approach

(-a) Calculate the incremental flaw growth Δa at Point 1 in Figure A-3100-1, illustration (b), by integration of eq. A-4300(a)(1).

(-b) Determine the parameters A and B from the ranges of membrane stress, $\Delta\sigma_m$, and bending stress, $\Delta\sigma_b$, obtained in accordance with A-3200 and Figure A-3210-3, illustration (b) as follows:

$$A = 0.92 + 0.03\,R_b$$

$$B = 0.10 + 0.80R_b$$

where

$$R_b = \Delta\sigma_b / \left(\Delta\sigma_m + \Delta\sigma_b\right)$$

(-c) Calculate the parameters e and f from the initial flaw dimensions a_0 and ℓ_0 for the increment, as follows:

$$e = \left(\ell_0 / 2t\right)^m - \left(At / a_0 - B\right)^{-m}$$

$$f = \left(a_0 / t\right)^m - \left[A / \left(2t / \ell_0 + B\right)\right]^m$$

where t is the component wall thickness and m = 2.8.

(-d) Calculate the flaw length $\ell = \ell_0 + \Delta\ell$ as illustrated by Point 2 in (b), at the end of the increment, as a function of the flaw depth $a = a_0 + \Delta a$ at the end of the increment, as follows:

$$\ell = 2a\left[\left(A - Ba/t\right)^{-m} + e\left(a/t\right)^{-m}\right]^{1/m}$$
$$\text{if } 2a_0/\ell_0 \leq \left(A - Ba_0/t\right)$$

$$\ell = 2a/\left\{A\left[1 - f\left(a/t\right)^{-m}\right]^{-1/m} - Ba/t\right\}$$
$$\text{if } 2a_0/\ell_0 > \left(A - Ba_0/t\right)$$

(2) Generalized Stress Approach

(-a) Calculate the incremental flaw growth, Δa, at Point 1 in Figure A-3100-1, illustration (b), by integration of eq. A-4300(a)(1).

(-b) Calculate the incremental flaw growth, $\Delta\ell$, at Point 2 in Figure A-3100-1, illustration (b), by integration of the following equation:

$$d\ell/dN = 2\,C_0\left(\Delta K_I\right)^n$$

where n and C_0 are as defined in A-4300.

The above procedure, after all transients have been considered, yields the expected end-of-period flaw size a_f and ℓ_f.

A-5300 NORMAL CONDITIONS

(a) Normal conditions include all transients expected to occur during the course of system testing and operation, as well as upset conditions anticipated to occur frequently enough that the system should be designed to accommodate them.

(b) The minimum critical flaw size for normal conditions a_c should be established. The procedure for determining critical flaw size for each transient is as follows.

(1) Determine the maximum end-of-period irradiation level at the flaw location.

(2) Using irradiated fracture toughness data, determine the crack initiation fracture toughness, K_{Ic}, as a function of temperature.

(3) Calculate stress intensity factors (using the methods outlined in Article A-3000 or some other documented procedure) for various penetration depths of an assumed flaw, geometrically similar to the ellipse or semiellipse defined by the shape a_f/ℓ_f.

(4) Compare the calculated stress intensity factors to the material fracture toughness, K_{Ic}, for the appropriate temperature to determine the critical flaw size a_c corresponding to $K_I = K_{Ic}$ for the transient.

(5) Proceed to the next transient.

(c) The smallest value of a_c determined by the above procedure, after all transients have been considered, represents the minimum critical flaw size for normal conditions at the location of the observed flaw.

A-5400 EMERGENCY AND FAULTED CONDITIONS

(a) Emergency and faulted conditions refer to very low probability postulated incidents whose consequences are such that subsequent plant operation is not required and safe system shutdown is the only consideration.

(b) The minimum critical flaw size for emergency and faulted conditions a_i should be established using K_{Ic} data for flaw initiation considerations and K_{Ia} data for flaw arrest considerations. Each postulated incident should be considered for critical flaw size as follows.

(1) Determine the maximum end-of-period irradiation profile through the thickness of the component at the observed flaw location.

(2) Determine temperature and stress profiles through the thickness of the component at the observed flaw location as a function of time following the postulated incident.

(3) Using the irradiated fracture toughness data, determine the flaw arrest K_{Ia} and flaw initiation K_{Ic} fracture toughness profiles through the thickness of the component as a function of time following the postulated incident.

(4) Calculate stress intensity factors (using the methods outlined in Article A-3000 or some other documented procedure) for various penetration depths of an assumed flaw, geometrically similar to the ellipse or semiellipse defined by the shape a_f/ℓ_f.

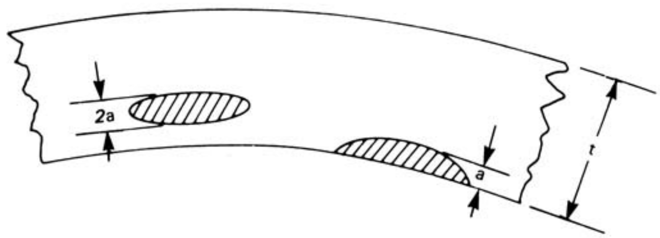
(5) The flaw penetration at which the calculated stress intensity factor exceeds the K_{Ic} profile corresponds to the critical flaw size for initiation a_i, and the penetration at which the stress intensity factor goes below the K_{Ia} curve corresponds to the critical flaw size for arrest a_a. This comparison is illustrated in Figure A-5400-1 for both an arrest and a nonarrest situation.

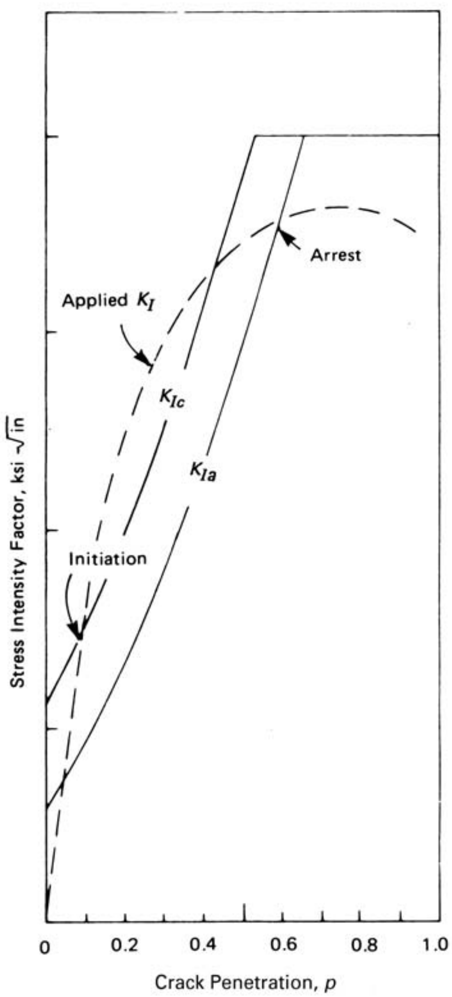
(6) Curves such as in Figure A-5400-1 should be prepared for a number of selected times following each postulated accident to establish the critical time.

(7) For those transients where K_I is monotonically decreasing with time (e.g., where system repressurization is limited), warm prestressing may be credited to preclude flaw initiation or reinitiation at times in the transient beyond the time of the peak stress intensity factor.

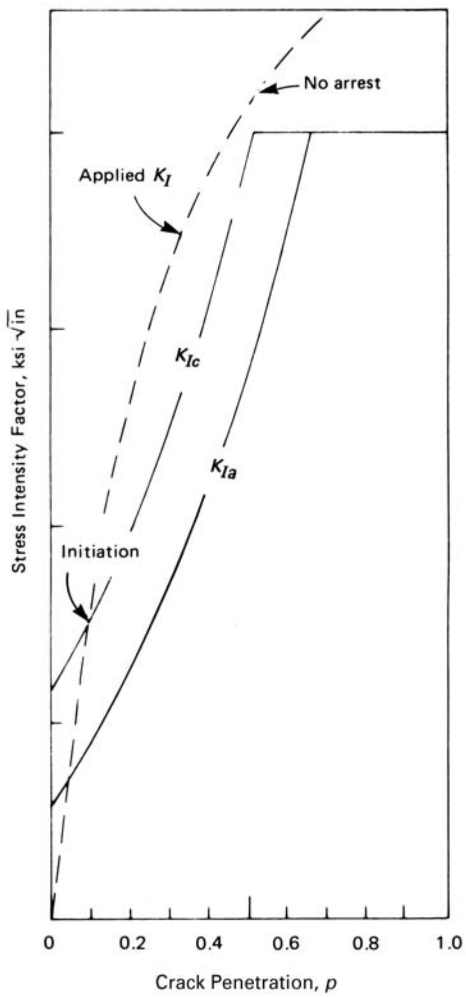
(c) The smallest value of a_i determined by the above procedure (and for which the flaw arrest penetration p is greater than 0.75) after all postulated accidents have been considered represents the minimum critical initiation flaw size for emergency and faulted conditions at the location of the observed flaw.

Figure A-5400-1
Determination of Critical Flaw Sizes for Postulated Conditions





(a) Example of Arrest Configuration



(b) Example of Nonarrest Configuration

GENERAL NOTES:

(a) ksi$\sqrt{\text{in.}}$ = 1.1 MPa$\sqrt{\text{m}}$

(b) $p = 2a/t$ for subsurface flaws and $p = a/t$ for surface flaws; t = wall thickness.

(15)

ARTICLE A-9000 GLOSSARY

bending stress correction factor (M_b): a factor used in the stress intensity factor equation derived from relationships between flaw eccentricity ratio, ratio of flaw depth to wall thickness, and flaw depth to wall thickness as a function of flaw depth to length ratios.

clad or cladding: a layer, usually an austenitic alloy, on the surface of a component to minimize corrosion.

coplanar flaws: two or more flaws which are oriented in the through-wall direction of a component lying in the same plane. The flaws may be defined as surface or subsurface, continuous or discontinuous, depending on their proximity. (see Figure IWA-3380-1.)

crack initiation: the onset of flaw extension due to an increase in component loading.

crack penetration (P): the ratio of crack depth to component thickness — $2a/t$ for subsurface flaws and a/t for surface flaws.

cumulative fatigue crack growth: the total incremental growth of a flaw over a period of time determined through use of the design transients.

discontinuity stress: the stress distribution through a component wall resulting from gross structural discontinuities such as head-to-shell junctions where net bending and membrane forces are produced.

end-of-life irradiation: the predicted fluence at the end of component life.

end-of-period flaw size: the maximum size (depth, a_f, and length, ℓ_f) to which a detected flaw is calculated to grow in a specified time period, such as the next scheduled examination of the component or until end of component life.

fatigue crack growth rate (da/dN): the rate of flaw growth due to fatigue in terms of the range of the applied stress intensity factor.

fatigue crack growth threshold (ΔK_{th}): the value of the range of applied stress intensity factor, ΔK_I, below which fatigue crack growth is negligible.

flaw acceptance criteria: the equations or bases for acceptance by fracture mechanics evaluations of flaws of a size exceeding the flaw acceptance standards.

flaw acceptance standards: specified values of flaw length, depth, depth-to-component thickness ratio, or areas as specified in IWA-3100.

flaw characterization: the process of circumscribing a flaw in a rectangle parallel to the component surface or in the plane of the wall perpendicular to the component surface for comparison with flaw acceptance standards.

flaw eccentricity (e): the distance of the center line of a flaw from the neutral axis, usually the center line of the wall of a component.

flaw eccentricity ratio (2e/t): the ratio of twice the flaw eccentricity to the component wall thickness.

flaw length: the length *(ℓ)* of the rectangle circumscribing the flaw when drawn parallel to the surface of the component.

flaw location: the site of a flaw in the wall of a component.

flaw major axis (ℓ or c): the long dimension (length) of a flaw.

flaw minor axis (a, 2a): the short dimension (depth) of a flaw.

flaw orientation: the position of the plane of the flaw with respect to the plane perpendicular to the maximum principal stress direction. For purpose of analysis, the flaw plane is projected onto the perpendicular plane.

flaw shape factor: the relationship between flaw aspect ratio (a/ℓ) and the stress ratio $[(\sigma_m + \sigma_b)/\sigma_y]$ providing values of the flaw shape parameter (Q).

flaw shape parameter (Q): a value obtained from the flaw shape factor and stress ratio.

irradiation effect: the change in material properties due to neutron fluence.

linear elastic fracture mechanics: the analytical procedure that relates the stress-field magnitude and distribution in the vicinity of a crack tip, resulting from the nominal stress applied to the structure, to the size of a crack that would cause nonductile failure.

linear elastic fracture mechanics: the analytical procedure that relates the stress-field magnitude and distribution in the vicinity of a crack tip, resulting from the nominal stress applied to the structure, to the size of a crack that would cause nonductile failure.

nonlinear stress distribution: the curvilinear stress distribution across a component wall, resulting from the algebraic addition of stresses (e.g., bending, membrane, residual). (See Figure A-3210-3.)

normal stress: the component of stress normal to the plane of reference, also referred to as *direct stress*.

primary stress: any normal stress or shear stress developed by an imposed loading that is necessary to satisfy the laws of equilibrium of external and internal forces and moments.

R ratio (K_{min}/K_{max}): the algebraic ratio of calculated stress intensity factor (minimum and maximum) in a stress cycle.

residual stress: remaining tensile or compressive stresses within a material under unloaded conditions.

secondary stress: the normal or shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting.

(15)

NONMANDATORY APPENDIX C
ANALYTICAL EVALUATION OF FLAWS IN PIPING

ARTICLE C-1000
INTRODUCTION

(15)
C-1100 SCOPE

This Article provides the general scope and application of the analytical evaluation methodology for flawed pipe.

(a) This Nonmandatory Appendix provides analytical procedures and criteria that may be used for determining acceptability for continued service for a specified evaluation time period of piping containing flaws that exceed the acceptance standards of IWB-3514 or IWC-3514. Analytical evaluations performed using this Nonmandatory Appendix shall meet all the requirements of the Appendix. The analytical evaluation methodology provided in this Nonmandatory Appendix is based on the following conditions that govern pipe failure:

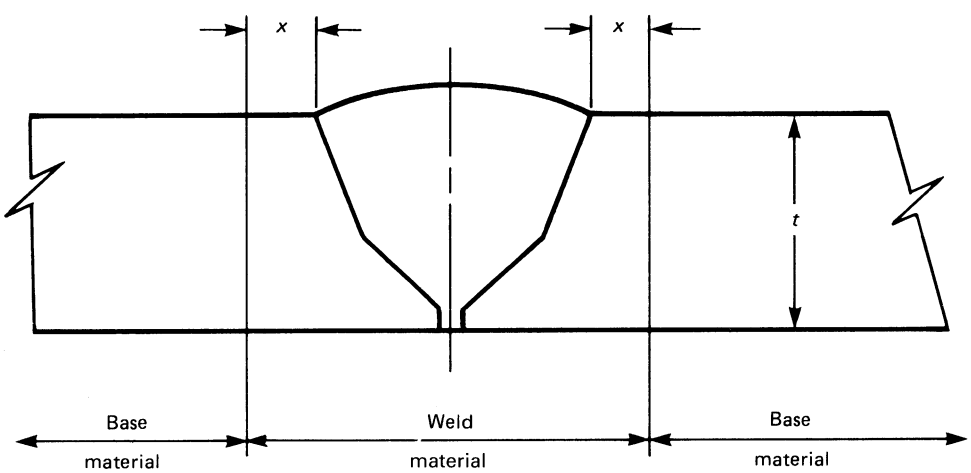
(1) Limit load (fully plastic) analysis of the pipe cross-section which is reduced by the flaw area, for ductile materials when the ability to reach limit load is assured.

(2) Elastic–plastic fracture mechanics when ductile flaw extension occurs prior to reaching limit load.

(3) Linear elastic fracture mechanics for brittle fracture conditions. The procedures are applicable to flaws in weld materials or base material as defined in Figure C-1100-1.

(b) This Nonmandatory Appendix provides a screening procedure to determine the failure mechanism based on metal temperature, applied loads, flaw size, and material properties. Flaws are analytically evaluated by comparing the maximum flaw dimensions at the end of the evaluation period with the allowable flaw size, or by comparing the applied pipe stress with the allowable stress for the flaw size at the end of the evaluation period.

Figure C-1100-1
Weld Material–Base Material Interface Definition for Flaw Location



GENERAL NOTE: x = lesser of $t/2$ or 0.5 in. (13 mm) *(c)* This Nonmandatory Appendix also provides procedures for flaw modeling and analysis. Flaw growth analysis is based on fatigue. When stress corrosion cracking (SCC) is active, the growth shall be added to the growth from fatigue. The flaw acceptance criteria of C-2600 include structural factors on failure for the three failure mechanisms described in (a). The acceptance criteria shall be used to determine acceptability of the flawed piping for continued service for a specified evaluation time period or to determine the time interval until a subsequent inspection.

C-1200 PROCEDURE OVERVIEW (15)

The following is a summary of the analytical procedure.

(a) Determine the configuration of the flaw in accordance with Article IWA-3000 using Article C-2000.

(b) Resolve the flaw into circumferential and axial flaw components using Article C-2000.

(c) Determine the stresses normal to the flaw at the location of the detected flaw for Service Levels A, B (including test conditions), C, and D using C-2500.

(d) Perform a flaw growth analysis in accordance with Article C-3000 to establish the end-of-evaluation-period flaw dimensions a_f and ℓ_f.

(e) Obtain pipe material properties at the temperature required for analysis, σ_y and J_{Ic}. When material properties are not available, the properties in Tables C-8321-1 and C-8322-1 may be used.

(f) Using the screening procedure described in Article C-4000, determine the failure mechanism for the material and temperature for the end-of-evaluation-period flaw dimensions, a_f and ℓ_f.

(g) Using the procedures described in Article C-5000, Article C-6000, or Article C-7000 as applicable to the failure mode, determine the allowable flaw depth, a_{allow}, or the allowable applied stress S_c or S_a, and the allowable flaw length limit ℓ_{allow}.

(h) Using the critical flaw parameters a_f and ℓ_f, or the piping stresses, σ_m and σ_b apply the analytical evaluation criteria of C-2600 to determine the acceptability of the pipe for continued service.

C-1300 NOMENCLATURE (15)

The following nomenclature is used.

a_{allow} = maximum allowable end-of-evaluation-period flaw depth corresponding to the flaw length ℓ_f, in. (mm)
A = pipe geometry factor used to calculate Z load multiplier for ductile flaw extension, dimensionless
a = general depth dimension of a flaw, in. (mm)
A_E = factor used to calculate fatigue crack growth rate parameter S_{ENV} (in./cycles - sec)$^{0.67}$ [(mm/cycle - s)$^{0.67}$]
a_f = max. depth to which the flaw is calculated to grow by the end of the evaluation period, in. (mm)
C = scaling parameter in fatigue crack growth rate for austenitic steel in air, (in./cycle) $\left(\text{ksi}\sqrt{\text{in.}}\right)^{-3.3}$[(mm/cycle) $\left(\text{MPa}\sqrt{\text{m}}\right)^{-3.3}$]
c = half-length for a through-wall flaw, in. (mm)
C_1 = SCC crack growth rate coefficient for K_I dependent crack growth (in./hr) $\left(\text{ksi}\sqrt{\text{in.}}\right)^{-\eta}$[(m/s) $\left(\text{MPa}\sqrt{\text{m}}\right)^{-\eta}$]
C_2 = SCC crack growth rate coefficient for K_I independent crack growth, in./hr (m/s)
C_n = coefficients used to calculate Z_0 for axial flaws
C_o = material constant in. flaw growth equation, (in./cycle) $\left(\text{ksi}\sqrt{\text{in.}}\right)^{-\eta}$[(mm/cycle) $\left(\text{MPa}\sqrt{\text{m}}\right)^{-\eta}$]
C_T = scaling parameter to account for effect of temperature in fatigue crack growth rate (in./cycle) $\left(\text{ksi}\sqrt{\text{in.}}\right)^{-\eta}$[(mm/cycle) $\left(\text{MPa}\sqrt{\text{m}}\right)^{-\eta}$]
CL = orientation of a test specimen loaded in the circumferential direction with longitudinal crack plane orientation
CVN = Charpy V-notch absorbed energy, ft-lb (J)
D = pipe outside diameter, in. (mm)
da/dN = cyclic flaw growth rate, in./cycle (mm/cycle)
da/dt = flaw growth rate, in./hr (m/s)
E = Young's modulus, ksi (MPa)
E' = $E/(1 - \nu^2)$, ksi (MPa)
F = parameter for axial flaw stress intensity factor
F_b = parameter for circumferential flaw bending stress intensity factor
F_m = parameter for circumferential flaw membrane stress intensity factor
F_{TW} = parameter for through-wall axial flaw stress intensity factor

I = moment of inertia, in.^{4} (mm^4)
J_{1mm} = measure of toughness at 1 mm of crack growth at the evaluation temperature [in.-lb/in.^{2} (kJ/m^2)]
J_{Ic} = measure of toughness due to crack extension at the evaluation temperature, (in.-lb/in.^{2} (kJ/m^2))
K_c = critical fracture toughness for the material, $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
K_I = Mode I stress intensity factor, $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
K_{Ib} = Mode I stress intensity factor for bending loading, $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
K_{Im} = Mode I stress intensity factor for membrane loading, $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
$K_{I\max}$ = max. stress intensity factor associated with transient stress range, ΔK_I, $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
$K_{I\min}$ = min. stress intensity factor associated with transient stress range, ΔK_I, $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
K_{Ir} = stress intensity factor for residual stress, $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
K_{Ith} = threshold stress intensity factor for SCC, $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
K_{ITR} = stress intensity factor at the transition from K_I dependent SCC crack growth to K_I independent crack growth, $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
K_{IU} = stress intensity factor at the upper validity limit of the SCC crack growth rate equation, $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
K_{Ic} = static fracture toughness for crack initiation under plane strain conditions, $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
K'_r = a component of screening criteria (SC), the ratio of the stress intensity factor to the material toughness, dimensionless
M = applied moment on the pipe, in.-kip (N-mm)
M_1 = flow stress parameter defined in Note (3) of Table C-6330-2, ksi$^{0.46}$ (MPa$^{0.46}$)
M_2 = bulging factor for axial flaw, dimensionless
M_b = resultant primary bending moment for the appropriate load combinations, in.-kip (N-mm)
M_e = resultant secondary bending moment, including thermal expansion loads and seismic anchor movement, in.-kip (N-mm)
N = number of load cycles in flaw growth analysis, cycles
n = material constant in flaw growth equation
NPS = nominal pipe size, in. (DN)
P = total axial load on pipe including pressure, kips (N)
p = internal pipe pressure, ksi (MPa)
Q = flaw shape parameter, dimensionless
Q_g = thermal activation energy for SCC crack growth, kcal/mole (kJ/mole)
R = load ratio, $K_{I\min}/K_{I\max}$
R_1 = inside radius of pipe, in. (mm)
R_2 = outside radius of pipe, in. (mm)
R_g = universal gas constant, kcal/(mole-R)[kJ/(mole-K)]
R_m = mean radius of pipe, in. (mm)
S_a = allowable hoop membrane stress for an axially flawed pipe, ksi (MPa)
S_c = allowable bending stress for circumferentially flawed pipe, ksi (MPa)
S_{ENV} = scaling parameter to account for effect of reactor water environment on fatigue crack growth rate, dimensionless
S_m = design stress intensity value as given in Section II, ksi (MPa)
S_R = scaling parameter to account for effect of R ratio on fatigue crack growth rate, dimensionless
S_t = allowable membrane stress for a circumferentially flawed pipe, ksi (MPa)
S_u = specified value for material ultimate tensile strength at the evaluation temperature, ksi (MPa)
S_y = specified value for material yield strength at the evaluation temperature, ksi (MPa)
SC = screening criteria parameter for determining the analysis method, dimensionless
SF_b = structural factor for bending stress based on Service Level, dimensionless
SF_m = structural factor for membrane stress based on Service Level, dimensionless
S'_r = component of the screening criteria (SC), the ratio of the applied stress to the stress at limit load, dimensionless
T = metal temperature, °F (°C)
t = pipe wall thickness, in. (mm)
T_{abs} = absolute metal operating temperature, °R (K)

T_{ref} = absolute reference temperature for SCC, °R (K)
x = parameter a/t, dimensionless
Z = load multiplier for ductile flaw extension, dimensionless
Z_0 = function used in calculation of Z-factor for axial flaws
Z_1 = function used in calculation of Z-factor for circumferential flaws
ℓ = general flaw length dimension, in. (mm)
ℓ_{allow} = allowable end-of-evaluation-period flaw length for stability of a through-wall flaw, in. (mm)
ℓ_f = max. length to which the detected flaw is calculated to grow by the end of the evaluation period, in. (mm)
ΔK_I = max. range of K_I fluctuation during a transient, $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
Φ = SCC crack growth rate coefficient (in./hr) $\left(\text{ksi}\sqrt{\text{in.}}\right)^{-\eta}$[(m/s) $\left(\text{MPa}\sqrt{\text{m}}\right)^{-\eta}$]
α = parameter (a/t) / (a/ℓ), dimensionless
β = angle to neutral axis of flawed pipe, radians
η = SCC crack growth rate exponent, dimensionless
θ = one-half of the flaw angle (Figure C-4310-1), radians
θ_{allow} = allowable half angle for stability of a circumferential through-wall flaw, radians
θ_f = half angle to which the detected circumferential flaw is calculated to grow by the end of the evaluation period, radians
λ = normalized flaw length parameter, dimensionless
ν = Poisson's ratio
σ_b = unintensified primary bending stress in the pipe at the flaw location, ksi (MPa)
$\sigma^c{}_b$ = bending stress at incipient plastic collapse, ksi (MPa)
$\sigma^c{}_m$ = membrane stress at incipient plastic collapse, ksi (MPa)
σ_e = unintensified secondary bending stress, including thermal expansion and seismic anchor movement at the flaw location, ksi (MPa)
σ_f = flow stress, ksi (MPa)
σ_h = hoop stress in pipe at the flaw, ksi (MPa)
σ_m = unintensified primary membrane stress in the pipe at the flaw location, ksi (MPa)
σ_u = measured material ultimate tensile strength at temperature, ksi (MPa)
σ_y = measured material yield strength at temperature, ksi (MPa)
σ_ℓ = reference limit load hoop stress, ksi (MPa)
σ'_b = bending stress at limit load for any combination of primary stresses, ksi (MPa)
σ'_m = membrane stress at limit load, ksi (MPa)
τ_r = load rise time, s

(15)

ARTICLE C-2000 ANALYTICAL EVALUATION PARAMETERS

C-2100 SCOPE

This Article provides procedures for defining the flaw geometry (shape, proximity, orientation, and location), applied stress, and acceptance criteria.

C-2200 FLAW SHAPE

The flaw should be completely bounded by a rectangular or circumferential planar area in accordance with the methods of IWA-3300. Figures C-2200-1 and C-2200-2 illustrate flaw characterization for circumferential and axial pipe flaws respectively.

Surface or subsurface flaw characterization shall be used depending on the type of flaw. When the flaw is subsurface, but within the proximity limit of IWA-3340 from the surface of the component, the flaw shall be considered a surface flaw and shall be bounded by a rectangular or circumferential planar area with the base (major length) aligned along the surface.

C-2300 PROXIMITY TO CLOSEST FLAW

For multiple adjacent flaws, when the shortest distance between the boundaries of two adjacent flaws is within the proximity limits specified in IWA-3300, the adjacent flaws shall be bounded by a single rectangular or circumferential planar area in accordance with IWA-3300.

Figure C-2200-1
Flaw Characterization — Circumferential Flaws

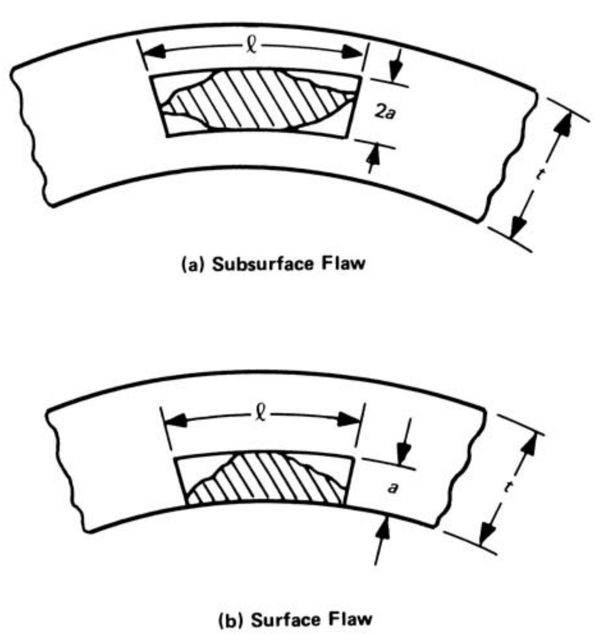
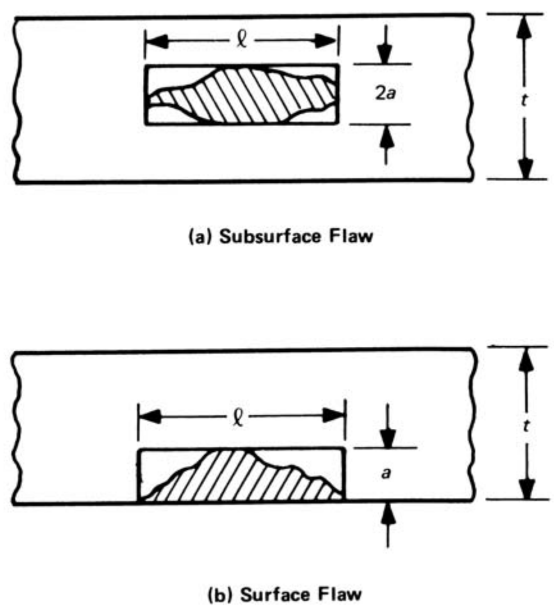


Figure C-2200-2
Flaw Characterization — Axial Flaws



C-2400 FLAW ORIENTATION (15)

Flaws that do not lie in either an axial[46] or a circumferential[47] plane should be projected onto these planes in accordance with the rules of IWA-3340. The axial and circumferential flaws obtained by these projections shall be analytically evaluated separately in accordance with this Appendix.

Figures C-2400-1, C-2400-2, and C-2400-3 illustrate flaw characterization for skewed flaws.

C-2500 DEFINITION OF PIPE STRESS (15)

For the purpose of analysis, the flaw is to be considered in its pipe cross-section location. The stresses due to system loading shall be calculated at this location. The location-specific loading (forces and moments) can be obtained from the piping Design Report for each Service Level loading condition. The stresses to be used in the analytical evaluation are the unintensified pipe stress for membrane, bending, and expansion (thermal and seismic anchor motion) defined as σ_m, σ_b, and σ_e, or pipe hoop stress, σ_h.

(a) For circumferential flaws the unintensified stress can be calculated from the piping Design Report for each Service Level as follows

$$\sigma_m = pD/4t$$

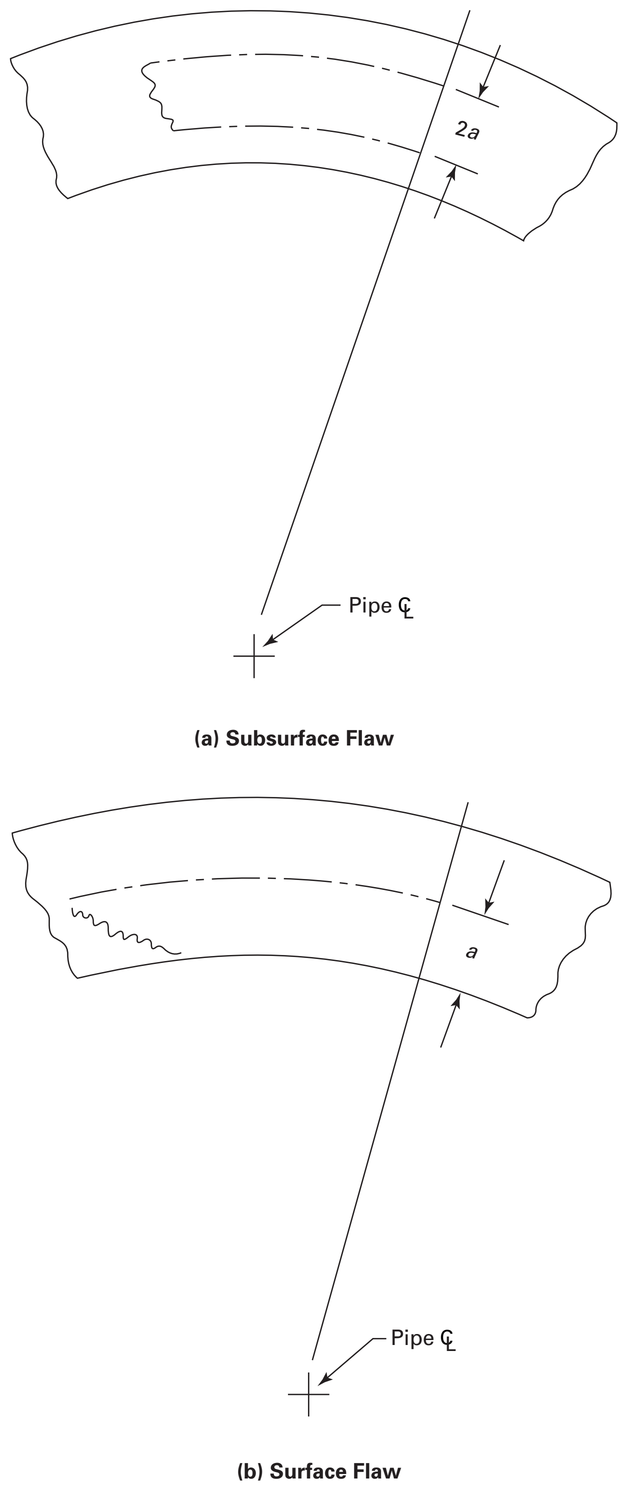
$$\sigma_b = \frac{DM_b}{2I}$$

$$\sigma_e = \frac{DM_e}{2I}$$

where

D = pipe outside diameter
I = pipe moment of inertia

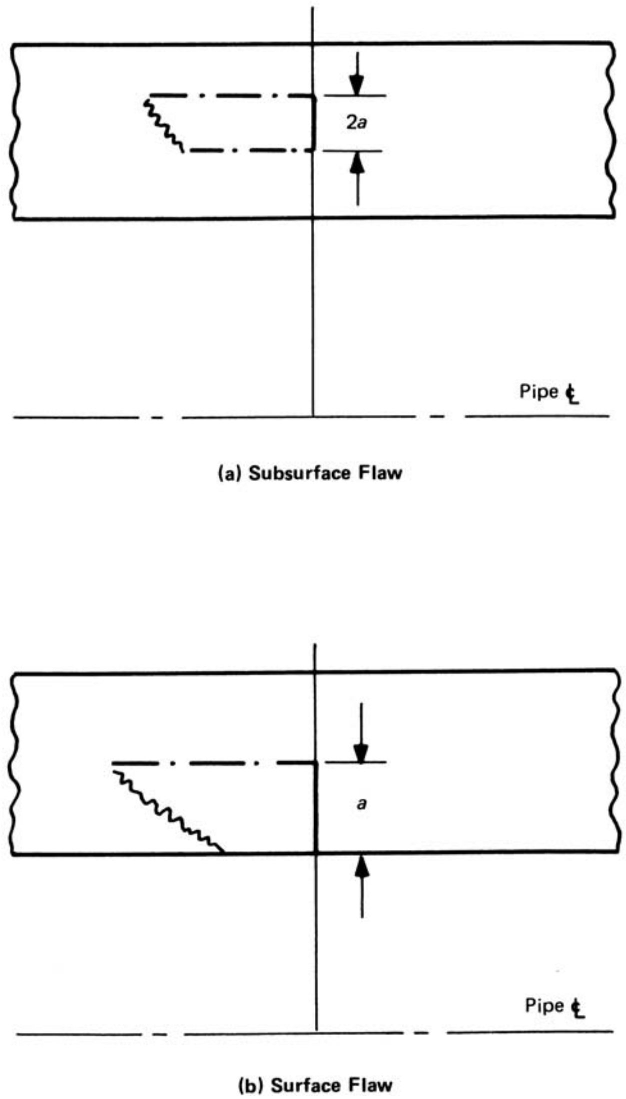
Figure C-2400-1
Flaw Characterization — Skewed Axial Flaws Projected into Axial Plane



(a) Subsurface Flaw

(b) Surface Flaw

Figure C-2400-2
Flaw Characterization — Skewed Circumferential Flaws Projected into Circumferential Plane



M_b = the resultant moment for the appropriate primary load combination for each Service Level in accordance with the design

M_e = the resultant secondary moment, including thermal expansion and seismic anchor loads in accordance with the design
The effects of weld shrinkage from a weld overlay repair shall be included.

p = internal pipe pressure

t = wall thickness

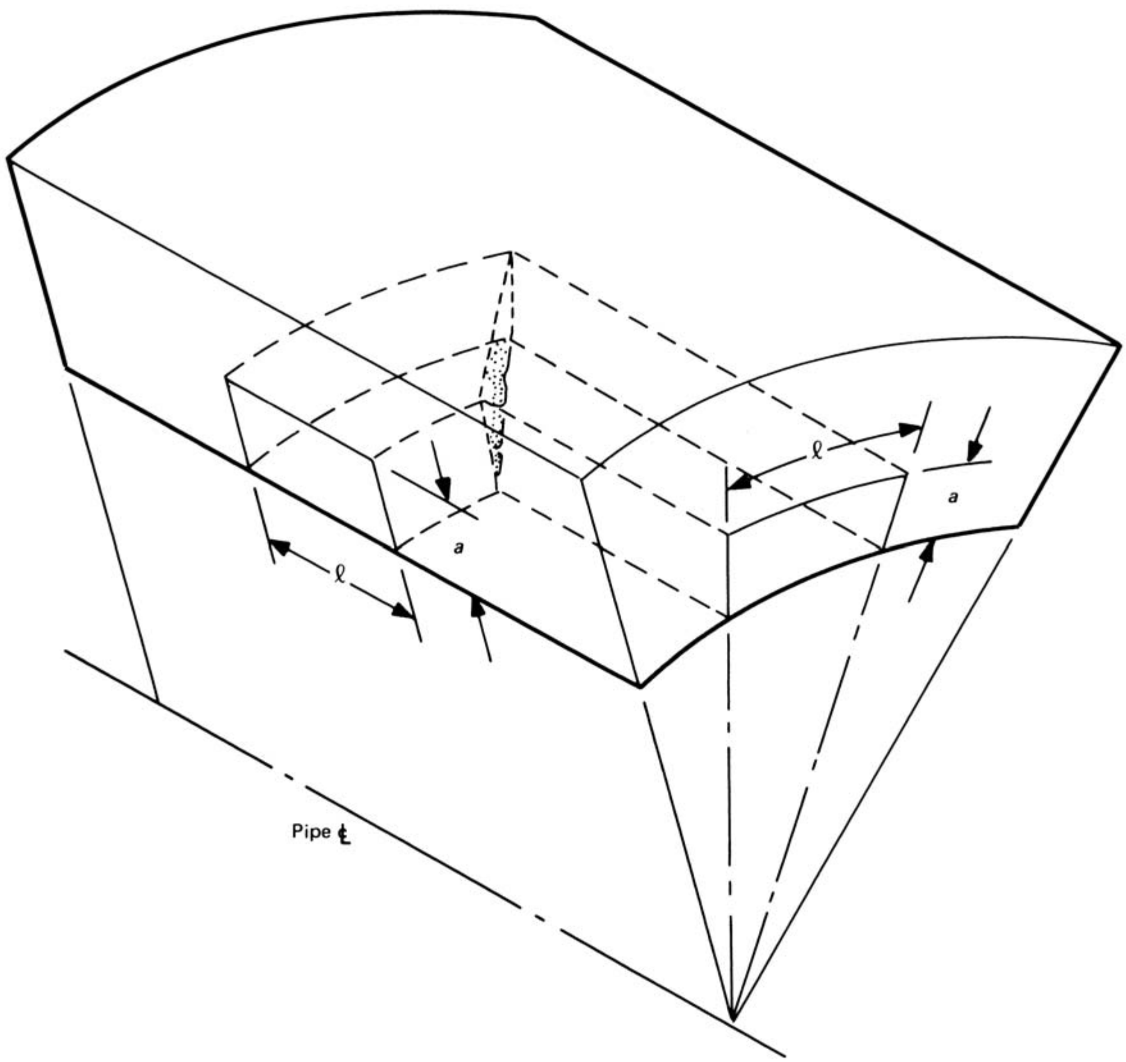
(b) For axial flaws, the hoop (membrane) stress shall be calculated, for each Service Level, using

$$\sigma_h = pR_m/t$$

where

p = max. internal pipe pressure for the appropriate operating conditions

Figure C-2400-3
Flaw Characterization — Compound Skewed Flaw Projected into Circumferential and Axial Planes



C-2600 FLAW ACCEPTANCE CRITERIA

(15) C-2610 ACCEPTANCE CRITERIA

Piping containing flaws exceeding the acceptance standards and analytically evaluated is acceptable for continued service during the evaluated time period if the critical flaw parameters satisfy the criteria in C-2611 or C-2612, and the criteria in C-2613.

C-2611 Final Flaw Depth Criteria

For circumferential and axial flaws, the acceptance criterion on flaw depth shall meet the following:

$$a_f \leq a_{\text{allow}}$$

where

a_{allow} = max. allowable flaw depth corresponding to the flaw length ℓ_f and applied stresses
a_f = max. depth to which the detected flaw is calculated to grow by the end of the evaluation period

ℓ_f = max. length to which the detected flaw is calculated to grow by the end of the evaluation period

The allowable flaw depth for flawed pipe, a_{allow}, is a function of pipe stresses, required structural factors, pipe material properties, the end-of-evaluation-period flaw length (ℓ_f) and depth (a_f), flaw orientation, and pipe failure mode.

C-2612 Applied Stress Criteria

For circumferential and axial flaws, the stresses shall meet the following:

$$\sigma_b \leq S_c \text{ for circumferential flaws}$$

and

$$\sigma_m \leq S_t \text{ for circumferential flaws}$$

or

$$\sigma_h \leq S_a \text{ for axial flaws}$$

where

S_a = allowable pipe hoop stress for a pipe with an axial flaw
S_c = allowable pipe bending stress for a pipe with a circumferential flaw
S_t = allowable pipe membrane stress for a pipe with a circumferential flaw
σ_b = maximum applied pipe primary bending (unintensified) stress
σ_h = maximum applied pipe hoop stress
σ_m = maximum applied pipe primary membrane (unintensified) stress

The allowable stress for the flawed pipe, S_c, S_t, and S_a is a function of pipe stresses, the required structural factors, pipe material properties, end-of-evaluation-period flaw length and depth, flaw orientation, and pipe failure mode.

C-2613 Final Flaw Length Criteria

(a) For axially oriented flaws, the final length of the flaw at the end of the evaluation period shall meet the following:

$$\ell_f \leq \ell_{allow}$$

where

ℓ_{allow} = allowable flaw length for an axial through-wall flaw to remain stable under pressure loading

(b) For circumferentially oriented flaws, when the nominal pipe wall thickness is less than 0.250 in. (6.35 mm), the final length of the flaw shall meet the following:

$$\theta_f \leq \theta_{allow}$$

where

θ_{allow} = allowable half angle for a circumferential through-wall flaw to remain stable
θ_f = final half angle of the flaw

In terms of circumferential flaw length, the following relationship for allowable half angle and allowable length shall be used:

$$\theta_{allow} = \ell_{allow}/D$$

where

ℓ_{allow} = allowable flaw length for a circumferential through-wall flaw to remain stable

(c) The allowable flaw length for circumferential flaws shall not exceed 75% of the outer perimeter of the pipe

$$\ell_{allow} \leq 0.75\pi D \text{ or}$$

$$\theta_{allow} \leq 0.75\pi$$

when the nominal pipe wall thickness is less than 0.250 in. (6.35 mm).

(15) C-2620 Analysis Structural Factors

The analytical evaluation for allowable flaw size or allowable stress requires application of structural factors. The structural factors are applied individually to membrane and bending stresses as SF_m and SF_b, respectively. The structural factors depend on service level and flaw orientation. Loading conditions that are considered are those associated with Service Levels A, B, C, and D, for the piping system design. Test conditions are analytically evaluated as Service Level B.

C-2621 Circumferential Flaws

For Classes 1, 2, and 3 piping, the structural factors to be applied on primary membrane and primary bending stresses in calculating the allowable flaw depth, a_{allow}, or the allowable stress, S_c, are as follows:

Service Level	Membrane Stress, SF_m	Bending Stress, SF_b
A	2.7	2.3
B	2.4	2.0
C	1.8	1.6
D	1.3	1.4

C-2622 Axial Flaws

For Classes 1, 2, and 3 piping, the structural factors to be applied on primary membrane stress for calculating the allowable depth, a_{allow}, or the allowable stress, S_a, are as follows:

Service Level	Membrane Stress, SF_m
A	2.7
B	2.4
C	1.8
D	1.3

ARTICLE C-3000
FLAW GROWTH ANALYSIS

C-3100 SCOPE

This Article provides the methodology for determination of subcritical flaw growth during the evaluation period.

C-3200 SUBCRITICAL FLAW GROWTH ANALYSIS (15)

If a flaw is characterized in terms of an equivalent axial and circumferential flaw, the maximum depth a_f and the maximum length ℓ_f at the end of the evaluation period shall be determined by consideration of subcritical flaw growth. Flaw growth in austenitic piping can be due to cyclic fatigue loading, stress corrosion cracking (SCC) under sustained load, or a combination of both. Flaw growth in ferritic piping can be due to cyclic fatigue loading. SCC has not been observed to be a significant flaw growth mechanism in ferritic piping. Residual stress effects shall be included in the analytical evaluation of both growth mechanisms.

C-3210 FLAW GROWTH DUE TO FATIGUE

(a) Fatigue flaw growth due to cyclic loading in piping can be characterized by the following equation relating the rate of flaw growth, da/dN, to the range of the applied stress intensity factor, ΔK_I:

$$\frac{da}{dN} = C_o\left(\Delta K_I\right)^n \tag{1}$$

where ΔK_I is the range of the applied stress intensity factor and C_o and n are parameters dependent on material and environmental conditions. The flaw growth rate parameters are in C-8400.

(b) A cumulative fatigue flaw growth calculation shall be performed using the appropriate fatigue crack growth rates in C-8400 and the operating conditions and transients that apply during the evaluation period. ΔK_I shall be determined for each transient using the bounding elliptical or semielliptical flaw model described in Article C-2000 and the methods for K_I determination in Article C-7000. Each transient should be considered in approximate chronological order as follows:

(1) Determine ΔK_I, the maximum range of K_I fluctuations associated with the transient.

(2) Determine the incremental flaw growth corresponding to ΔK_I from the fatigue flaw growth rate equation.

(3) Update the flaw dimensions a and ℓ.

(4) Repeat these calculations for the next transient using the updated flaw dimensions.

(c) After all transients have been considered, this procedure yields the final flaw size a_f and ℓ_f at the end of the evaluation period considering only fatigue flaw growth.

C-3220 FLAW GROWTH DUE TO STRESS CORROSION CRACKING

(a) Subcritical flaw growth due to SCC is a function of material condition, environment, stress intensity factor due to sustained loading, and total time that the flaw is exposed to the environment under sustained loading. The procedure for computing SCC flaw growth is based on experimental data relating the flaw growth rate (da/dt) to the sustained load stress intensity factor K_I. Sustained loads resulting from pressure and steady state thermal stresses as well as residual stresses should be included. Appropriate experimental data on residual stress distribution for different pipe sizes and flaw growth rate as a function of sustained K_I should be used. The procedure used for determining the cumulative flaw growth is as follows:

(1) Determine the sustained stress intensity factor K_I for a given steady-state stress condition.

(2) Find the incremental growth of the flaw depth and length corresponding to the period for which the steady-state stress is applied. This can be obtained from the relationship between da/dt and K_I. Relations for da/dt for Alloy 600[48] and associated weld materials Alloys 82, 182, and 132 are provided in C-8510. A sufficiently small time interval should be selected to ensure that the flaw size and the associated K_I value do not change significantly during this interval.

(3) Update the flaw dimensions a and ℓ.

(4) Continue the flaw growth analysis for the period during which the sustained stress exists until the end of the evaluation period.

(b) This procedure yields the final flaw size, a_f and ℓ_f at the end of the evaluation period considering only SCC flaw growth.

C-3230 FLAW GROWTH DUE TO A COMBINATION OF FATIGUE AND SCC

If the service loading, material, and environmental conditions are such that the flaw is subjected to both fatigue and SCC growth, as may occur in austenitic piping, the final flaw sizes a_f and ℓ_f are obtained by adding the increments in flaw size due to fatigue and SCC calculated in accordance with the procedures described in C-3210 and C-3220. The cyclic and sustained loads should be considered in approximately chronological order.

ARTICLE C-4000
DETERMINATION OF FAILURE MODE

C-4100 SCOPE

This Article is used to determine the failure mode and analysis method for the flawed pipe. The end-of-evaluation-period flaw dimensions, temperature, available material properties, and pipe loadings are considered in the screening procedure.

C-4200 SCREENING CRITERIA

C-4210 AUSTENITIC PIPING

The sequence used to determine the failure mode and analysis method for austenitic piping is given in Figure C-4210-1. For flaws in wrought base metal, nonflux welds, weld metal, or cast product in which ferrite content is less than 20%, plastic collapse is the controlling failure mode. For flaws in flux welds of wrought pipe, elastic-plastic analysis methods shall be applied.

C-4220 FERRITIC PIPING

C-4221 Class 1 Ferritic Piping

The sequence used to determine the failure mode and analysis method is given in Figure C-4220-1. The upper part of the figure relates to material toughness determination; the lower part defines the appropriate analysis method [i.e., limit load controlled by plastic collapse, elastic-plastic fracture mechanics (EPFM), or linear elastic fracture mechanics (LEFM)]. The procedures of C-4300 shall be used to calculate the screening parameter (SC) for selecting the analysis method.

C-4222 Classes 2 and 3 Ferritic Piping (15)

The criteria for Classes 2 and 3 ferritic piping are in the course of preparation. The analyst shall establish the failure mode relevant for the flawed pipe under analytical evaluation. Alternatively, the most limiting mode for the flawed pipe can be used to perform the analytical evaluation.

C-4230 BIMETALLIC WELDS (15)

For fusion-line flaws in Ni-Cr-Fe buttered welds, the piping analytical evaluation procedures of C-4220 for the adjacent base metal shall be used. For fusion-line flaws in stainless steel buttered welds, or stainless steel pipe to ferritic pipe welds with no buttering layer, the Owner shall document the basis for the piping analytical evaluation procedure to be used. For flaws in austenitic weld metal or Ni-Cr-Fe weld metal, the austenitic piping analytical evaluation procedures of C-4210 shall be used.

C-4300 ANALYSIS METHOD DETERMINATION

The equations necessary to calculate the components of the screening criteria, K_r' and S_r', for specified applications involving circumferential or axial flaw orientations are in C-4310.

C-4310 SCREENING CRITERIA COMPUTATIONS

The equations for K_r' and S_r' as used in Figure C-4220-1 are as follows:

$$K_r' = \left[1000 K_I^2 / \left(E' J_{Ic} \right) \right]^{0.5}$$

Figure C-4210-1
Flowchart for Selecting Analysis Method for Austenitic Piping

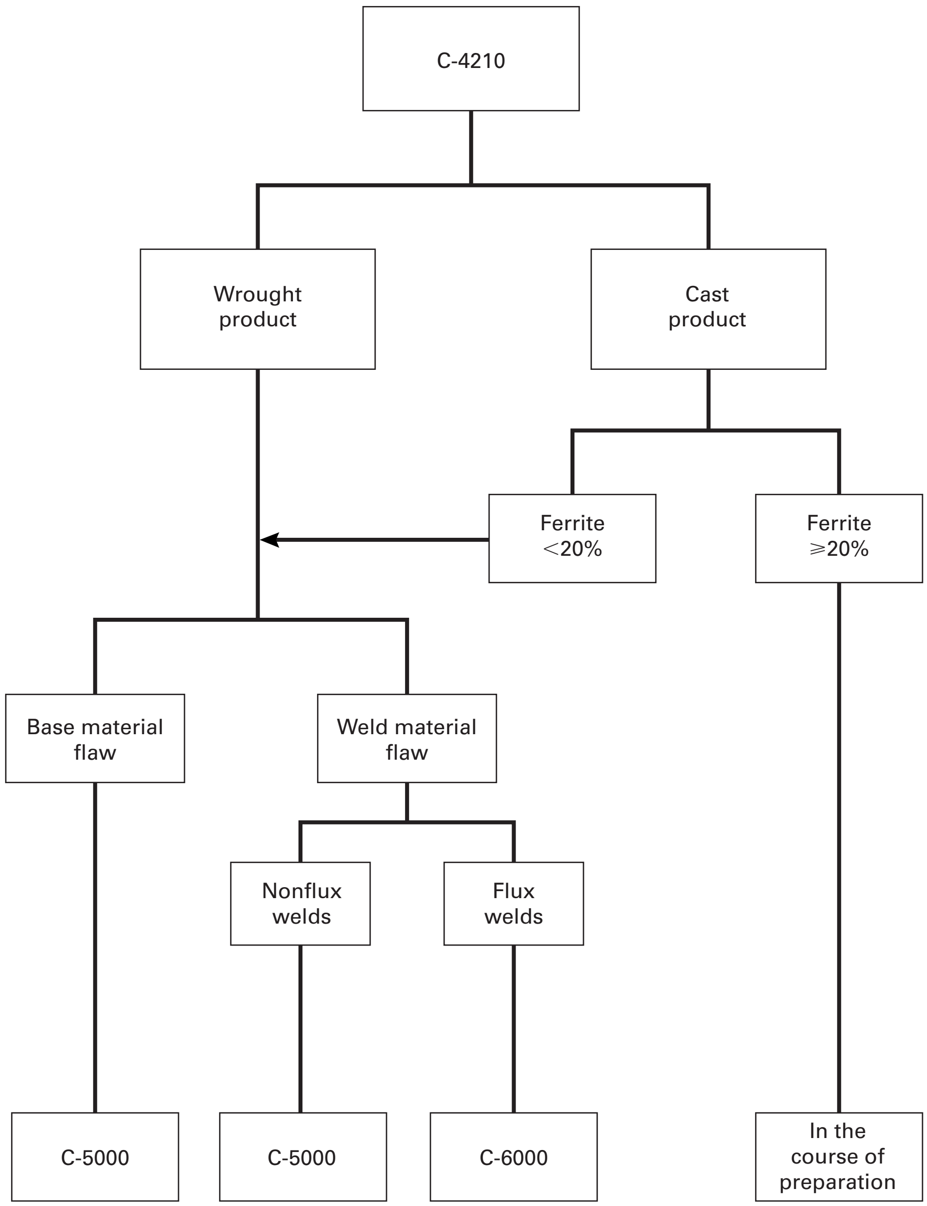
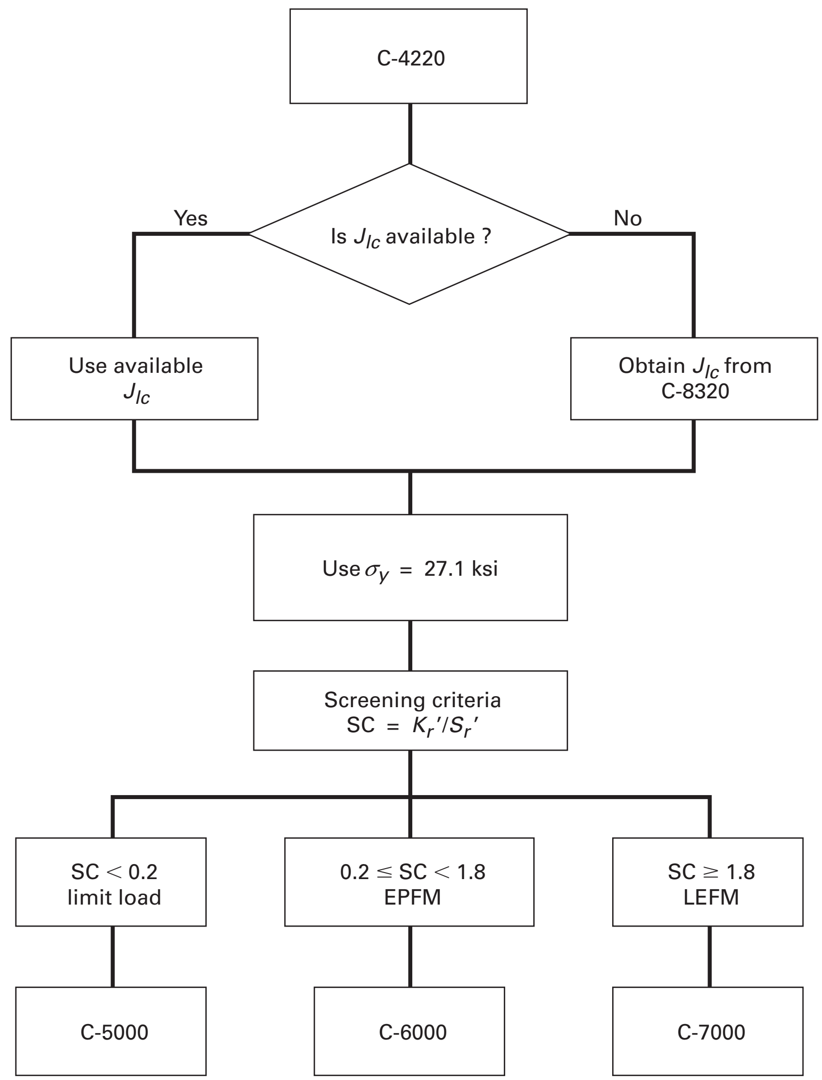


Figure C-4220-1
Flowchart for Selecting Analysis Method for Ferritic Piping



For circumferential flaws, when $(\sigma_b + \sigma_e) \geq \sigma_m$

$$S_r' = (\sigma_b + \sigma_e) / \sigma_b' \tag{2a}$$

otherwise

$$S_r' = \sigma_m / \sigma_m' \tag{2b}$$

For axial flaws,

$$S_r' = (pR_m / t) / \sigma_\ell$$

The relevant crack dimensions for this calculation are in Figures C-4310-1 and C-4310-2. The equations for K_I, σ_b', and σ_m' are in C-4311 for circumferential flaws. The equations for K_I and σ_ℓ are given in C-4312 for axial flaws.

Figure C-4310-1
Circumferential Flaw Geometry

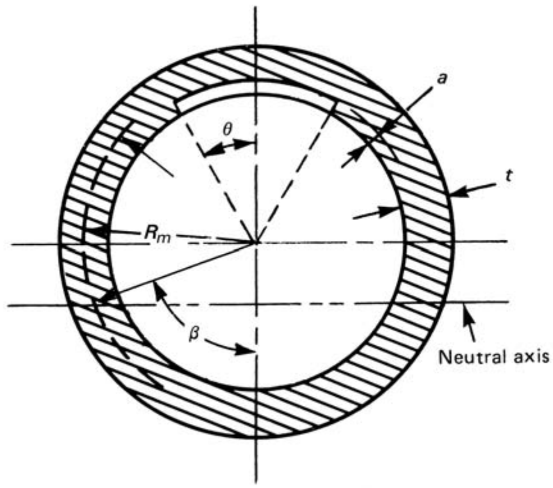
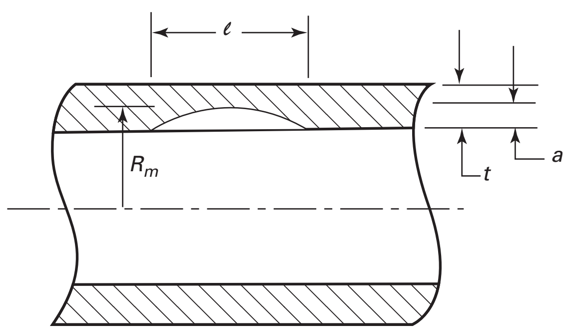


Figure C-4310-2
Axial Flaw Geometry



C-4311 Circumferential Flaws

(a) The stress intensity factor, K_I is defined as follows:

$$K_I = K_{Im} + K_{Ib}$$

where

(U.S. Customary Units)

$$K_{Im} = \left[P/\left(2\pi R_m t\right)\right](\pi a)^{0.5} F_m$$

$$K_{Ib} = \left[M/\left(\pi R_m{}^2 t\right)\right](\pi a)^{0.5} F_b$$

(SI Units)

$$K_{Im} = \left[P/\left(2\pi R_m t\right)\right](\pi a/1000)^{0.5} F_m$$

$$K_{Ib} = \left[M/\left(\pi R_m{}^2 t\right)\right](\pi a/1000)^{0.5} F_b$$

and

$$M = M_b + M_e$$

$$F_m = 1.10 + x\left[0.15241 + 16.772 \left(x\theta/\pi\right)^{0.855} - 14.944\left(x\theta/\pi\right)\right]$$

$$F_b = 1.10 + x\left[-0.09967 + 5.0057 \left(x\theta/\pi\right)^{0.565} - 2.8329\left(x\theta/\pi\right)\right]$$

$$x = \left(\frac{a}{t}\right)$$

θ/π = ratio of crack length to pipe inner circumference

The above expressions for F_m and F_b are valid for the following conditions:

$$\ell/a \geq 2$$

$$0.08 \leq x \leq 0.8$$

$$0.05 \leq \theta/\pi \leq 1.0$$

For $\theta/\pi > 0.5$, use $\theta/\pi = 0.5$ in equations for F_m and F_b.

(b) The reference bending stress at limit load, σ'_b in C-4310(2a), can be obtained for any specific membrane stress, σ_m, by satisfying eqs. (3) and (4). In these equations, σ_y from Table C-8321-1 shall be used.

$$\sigma'_b = \frac{2\sigma_y}{\pi}\left[2\sin\beta - \frac{a}{t}\sin\theta\right] \tag{3}$$

where

$$\beta = \frac{1}{2}\left[\pi - \frac{a}{t}\theta - \pi\frac{\sigma_m}{\sigma_f}\right]$$

or if $(\theta + \beta) > \pi$

$$\sigma_b' = \frac{2\sigma_y}{\pi}\left[\left(2 - \frac{a}{t}\right)\sin\beta\right] \tag{4}$$

where

$$\beta = \pi\left(1 - \frac{a}{t} - \frac{\sigma_m}{\sigma_f}\right)\Big/\left(2 - \frac{a}{t}\right)$$

and where σ_m is in units of ksi (MPa) and σ_f is 43.4 ksi (300 MPa).

(c) The reference membrane stress at limit load, σ'_m in eq. C-4310(2b), is given by the following equation, where σ_y from Table C-8321-1 shall be used.

$$\sigma_m' = \sigma_y\left[1 - \frac{a}{t}\frac{\theta}{\pi} - \frac{2\varphi}{\pi}\right]$$

$$\varphi = \arcsin\left[0.5\,\frac{a}{t}\,\sin\theta\right]$$

C-4312 Axial Flaws

(a) The stress intensity factor, K_I, is calculated from the following:

(U.S. Customary Units)

$$K_I = \left(pR_m/t\right)\left(\pi a/Q\right)^{0.5}F$$

(SI Units)

$$K_I = \left(pR_m/t\right)\left(\pi a/1000Q\right)^{0.5}F$$

where

$F = 1.12 + 0.053\alpha + 0.0055\alpha^2 + (1.0 + 0.02\alpha + 0.0191\alpha^2)\,(20 - R_m/t)^2/1400$

$Q = 1 + 4.593(a/\ell)^{1.65}$

$\alpha = \left(\frac{a}{t}\right)/\left(\frac{a}{\ell}\right)$

(b) Reference limit load hoop stress, σ_ℓ is calculated from:

$$\sigma_\ell = \sigma_y\left\{\left[1 - \left(\frac{a}{t}\right)\right]\Big/\left[1 - \left(\frac{a}{t}\right)\Big/M_2\right]\right\}$$

where

$M_2 = [1 + (1.61/4R_m t)\,\ell^2]^{0.5}$

ARTICLE C-5000 ANALYTICAL EVALUATIONS FOR FULLY-PLASTIC FRACTURE USING LIMIT LOAD CRITERIA (15)

C-5100 SCOPE

This Article provides methodology for determining allowable flaw depths and allowable loads for flawed piping meeting the limit load criteria of C-4200.

C-5200 ANALYTICAL EVALUATION PROCEDURES (15)

A flowchart for the analytical evaluation options is given in Figure C-5200-1 when the failure mode has been determined to be plastic collapse at limit load using the procedures of C-4200.

C-5300 CIRCUMFERENTIAL FLAWS

(a) The allowable flaw depth, a_{allow} and allowable flaw length, ℓ_{allow}, shall be used in the acceptance criteria of C-2600 to determine the acceptability of the flawed pipe for continued service.

(b) Allowable end-of-evaluation-period flaw depths are provided in Tables C-5310-1 through C-5310-5 for austenitic and ferritic piping. Alternatively, analytical equations (from which these tables can be derived) for allowable pipe bending stresses given in C-5320 may be solved using specified or measured (when available) material properties.

(c) Allowable end-of-evaluation-period circumferential flaw length is given in C-5330.

C-5310 ALLOWABLE FLAW DEPTHS (TABULAR SOLUTION) (15)

The allowable flaw depths are determined from tabular values under the condition of combined loading (membrane plus bending) and membrane-only loading. The maximum allowable flaw depth for the analytical evaluation is the lesser of the allowable flaw depth for combined loading as determined in C-5311, and for membrane stress as determined in C-5312.

C-5311 Combined Loading (15)

Allowable flaw depths for a given final flaw length under stress due to combined (membrane plus bending) loading for Service Levels A, B (including test conditions), C, and D shall be obtained from Tables C-5310-1, C-5310-2, C-5310-3, or C-5310-4. Using the maximum value of the applied stress for each service level during the evaluation period and the ℓ_f flaw parameter defined in C-3200, the maximum allowable flaw depth, a_{allow}, of a circumferential flaw shall be determined from Tables C-5310-1, C-5310-2, C-5310-3, or C-5310-4, whichever is the most limiting. The allowable flaw criteria of C-2611 are used to determine the acceptability of the flawed pipe for continued service.

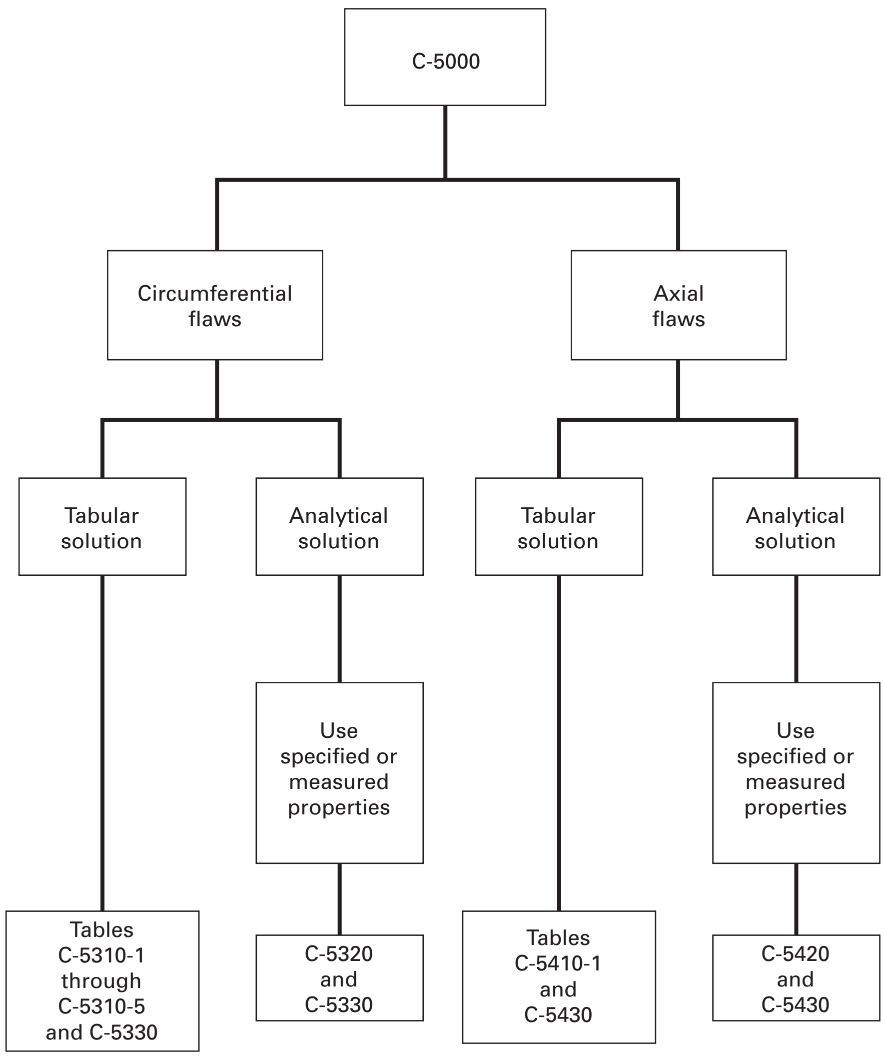
C-5312 Membrane Stress (15)

Allowable flaw depths for a given final flaw length under membrane stress for Service Levels A, B (including test conditions), C, and D shall be obtained from Table C-5310-5. Using the maximum value of the applied membrane stress for the most limiting Service Level condition during the evaluation period, the structural factors, SF_m from C-2621, and the ℓ_f flaw parameter defined in C-3200, the maximum allowable flaw depth, a_{allow}, of a circumferential flaw shall be determined from Table C-5310-5. The allowable flaw criteria of C-2611 are used to determine the acceptability of the flawed pipe for continued service.

C-5320 ALLOWABLE APPLIED STRESSES (ANALYTICAL SOLUTION)

The allowable stresses are determined analytically for the conditions of combined loading (membrane plus bending) and membrane-only loading. The allowable pipe bending and membrane stresses, determined from C-5321 and C-5322, shall be used in the acceptance criteria of C-2612 to determine the acceptability of the flawed pipe for continued service.

Figure C-5200-1
Flowchart for Allowable Flaw Size Determination for Fully Plastic Fracture Using Limit Load Method



C-5321 Combined Loading

The allowable bending stress, S_c, in the flawed pipe for a given end-of-evaluation-period flaw size for each service level under combined loading shall be determined using the following equations. For circumferential flaws not penetrating the compressive side of the pipe such that $(\theta + \beta) \le \pi$, the relation between the applied loads and flaw depth at incipient plastic collapse is given by:

$$\sigma_b^c = \frac{2\sigma_f}{\pi}\left[2\sin\beta - \frac{a}{t}\sin\theta\right]$$

where

$$\beta = \frac{1}{2}\left(\pi - \frac{a}{t}\theta - \pi\frac{\sigma_m}{\sigma_f}\right)$$

and the other terms are defined in C-1300. The flow stress, σ_f, is defined in C-8200. For longer flaws penetrating the compressive bending region when $(\theta + \beta) > \pi$, the relation between the applied loads and the flaw depth at incipient

(15)

Table C-5310-1
Allowable End-of-Evaluation-Period Flaw Depth-to-Thickness Ratio [Note (1)] for Circumferential Flaws — Service Level A Conditions

Stress Ratio [Note (2)]	Ratio of Flaw Length to Pipe Circumference $\ell_f/\pi D$ [Note (3)] 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.75 or Greater
≥ 0.60	0.75	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]
0.55	0.75	0.44	0.23	0.16	0.13	0.12	0.11	0.11
0.50	0.75	0.75	0.44	0.31	0.25	0.23	0.21	0.21
0.45	0.75	0.75	0.65	0.46	0.37	0.33	0.31	0.30
0.40	0.75	0.75	0.75	0.59	0.48	0.42	0.39	0.38
0.35	0.75	0.75	0.75	0.73	0.58	0.51	0.47	0.46
0.30	0.75	0.75	0.75	0.75	0.69	0.60	0.55	0.52
0.25	0.75	0.75	0.75	0.75	0.75	0.68	0.63	0.59
0.20	0.75	0.75	0.75	0.75	0.75	0.75	0.70	0.65
0.15	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.74
≤ 0.10	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75

NOTES:

(1) *Flaw depth* = a_{allow} for a surface flaw
 = $2a_{allow}$ for a subsurface flaw
 t = pipe wall thickness

Linear interpolation is permissible.

(2) *Stress Ratio* = $(\sigma_m + \sigma_b)/\sigma_f$ for limit load analysis
 = $Z\,[\sigma_m + \sigma_b + \sigma_e/SF_b]/\sigma_f$ for EPFM analysis
 Z = Z-factor load multipliers from C-6330
 σ_b = primary bending stress
 σ_e = secondary bending stress
 σ_f = flow stress
 σ_m = primary membrane stress. The tabular values are valid for $\sigma_m \le 0.2\sigma_f$; otherwise use analytical solution method.

(3) Circumference based on pipe outside diameter.

(4) Acceptance standards for the applicable class shall be used.

plastic collapse is given by:

$$\sigma_b^c = \frac{2\sigma_f}{\pi}\left(2 - \frac{a}{t}\right)\sin\beta$$

where

$$\beta = \frac{\pi}{2 - \frac{a}{t}}\left(1 - \frac{a}{t} - \frac{\sigma_m}{\sigma_f}\right)$$

The allowable pipe bending stress, S_c, is

$$S_c = \frac{\sigma_b^c}{SF_b} - \sigma_m\left[1 - \frac{1}{SF_m}\right] \quad (5)$$

where

σ_b^c = bending stress at incipient plastic collapse
S_c = allowable bending stress for circumferentially flawed pipe
SF_b = structural factor for bending stress based on Service Level in C-2621
SF_m = structural factor for membrane stress based on Service Level in C-2621

(15)

Table C-5310-2 Allowable End-of-Evaluation-Period Flaw Depth-to-Thickness Ratio [Note (1)] for Circumferential Flaws — Service Level B Conditions

Stress Ratio [Note (2)]	Ratio of Flaw Length to Pipe Circumference $\ell_f/\pi D$ [Note (3)] 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.75 or Greater
≥ 0.70	0.75	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]
0.65	0.75	0.30	0.15	0.11	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]
0.60	0.75	0.66	0.34	0.24	0.20	0.18	0.17	0.17
0.55	0.75	0.75	0.53	0.37	0.30	0.27	0.25	0.25
0.50	0.75	0.75	0.70	0.49	0.40	0.35	0.33	0.32
0.45	0.75	0.75	0.75	0.61	0.49	0.43	0.40	0.39
0.40	0.75	0.75	0.75	0.73	0.59	0.51	0.48	0.46
0.35	0.75	0.75	0.75	0.75	0.67	0.59	0.54	0.52
0.30	0.75	0.75	0.75	0.75	0.75	0.66	0.61	0.57
0.25	0.75	0.75	0.75	0.75	0.75	0.73	0.67	0.63
0.20	0.75	0.75	0.75	0.75	0.75	0.75	0.74	0.68
≤ 0.15	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75

NOTES:

(1) *Flaw depth* = a_{allow} for a surface flaw
= $2a_{allow}$ for a subsurface flaw
t = pipe wall thickness
Linear interpolation is permissible.

(2) *Stress Ratio* = $(\sigma_m + \sigma_b)/\sigma_f$ for limit load analysis
= $Z[\sigma_m + \sigma_b + \sigma_e/SF_b]/\sigma_f$ for EPFM analysis
Z = Z-factor load multipliers from C-6330
σ_b = primary bending stress
σ_e = secondary bending stress
σ_f = flow stress
σ_m = primary membrane stress. The tabular values are valid for $\sigma_m \leq 0.2\sigma_f$; otherwise use analytical solution method.

(3) Circumference based on pipe outside diameter.

(4) Acceptance standards for the applicable class shall be used.

C-5322 Membrane Stress

The allowable membrane stress, S_t, in the flawed pipe for a given end-of-evaluation-period flaw size for each service level shall be determined using the following equations. The relation between the applied membrane stress and flaw depth at incipient plastic collapse is given by:

$$\sigma_m^c = \sigma_f\left[1 - \left(\frac{a}{t}\right)\left(\frac{\theta}{\pi}\right) - 2\varphi/\pi\right]$$

$$\varphi = \arcsin\left[0.5\left(\frac{a}{t}\right)\sin\theta\right]$$

The flow stress, σ_f, is defined in C-8200. The allowable pipe membrane stress, S_t, is

$$S_t = \sigma_m^c / SF_m \tag{6}$$

where

σ_m^c = membrane stress at incipient plastic collapse
S_t = allowable membrane stress for a circumferentially flawed pipe
SF_m = structural factor for membrane stress from C-2621

The limits of applicability of these equations are: values from acceptance standards < $a/t \leq 0.75$

(15)

Table C-5310-3
Allowable End-of-Evaluation-Period Flaw Depth-to-Thickness Ratio [Note (1)] for Circumferential Flaws — Service Level C Conditions

Stress Ratio [Note (2)]	Ratio of Flaw Length to Pipe Circumference $\ell_f/\pi D$ [Note (3)]							
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.75 or Greater
≥ 0.90	0.75	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]
0.80	0.75	0.41	0.21	0.15	0.12	0.11	0.10	0.10
0.70	0.75	0.75	0.48	0.34	0.27	0.24	0.22	0.22
0.60	0.75	0.75	0.74	0.52	0.42	0.36	0.34	0.32
0.50	0.75	0.75	0.75	0.69	0.55	0.48	0.44	0.42
0.40	0.75	0.75	0.75	0.75	0.69	0.60	0.55	0.51
0.30	0.75	0.75	0.75	0.75	0.75	0.70	0.64	0.59
0.20	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.73
≤ 0.10	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75

NOTES:
(1) *Flaw depth* = a_{allow} for a surface flaw
= $2a_{allow}$ for a subsurface flaw
t = pipe wall thickness
Linear interpolation is permissible.
(2) *Stress Ratio* = $(\sigma_m + \sigma_b)/\sigma_f$ for limit load analysis
= $Z[\sigma_m + \sigma_b + \sigma_e/SF_b]/\sigma_f$ for EPFM analysis
Z = Z-factor load multipliers from C-6330
σ_b = primary bending stress
σ_e = secondary bending stress
σ_f = flow stress
σ_m = primary membrane stress. The tabular values are valid for $\sigma_m \le 0.3\sigma_f$; otherwise use analytical solution method.
(3) Circumference based on pipe outside diameter.
(4) Acceptance standards for the applicable class shall be used.

C-5330 ALLOWABLE FLAW LENGTH

The allowable flaw length for a circumferential flaw, ℓ_{allow}, based on the stability of a through-wall flaw, is defined as

$$\ell_{allow} = \theta_{allow} D$$

where θ_{allow} is the flaw half angle that satisfies the following for each Service Level:

$$2\sin[0.5(\varphi - \theta_{allow})] - \sin\theta_{allow} = \frac{\pi\sigma_b}{2\sigma_f}$$

$$\varphi = \pi[1 - \sigma_m/\sigma_f]$$

where

D = outside diameter
σ_b = maximum applied primary bending stress
σ_f = flow stress defined in C-8200
σ_m = maximum applied axial primary membrane stress

C-5400 AXIAL FLAWS

(a) The allowable flaw depth, a_{allow} and allowable flaw length, ℓ_{allow}, shall be used in the acceptance criteria of C-2600 to determine the acceptability of the flawed pipe for continued service.

(b) Allowable flaw depths shall be determined in accordance with C-5410. Alternatively, equations (from which these tables can be derived) for allowable flaw sizes given in C-5420 may be solved using either specified or measured (when available) material properties.

(15)

Table C-5310-4
Allowable End-of-Evaluation-Period Flaw Depth-to-Thickness Ratio [Note (1)] for Circumferential Flaws — Service Level D Conditions

Stress Ratio [Note (2)]	Ratio of Flaw Length to Pipe Circumference $\ell_f/\pi D$ [Note (3)]							
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.75 or Greater
≥ 1.10	0.75	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]
1.00	0.75	0.19	0.10	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]
0.90	0.75	0.62	0.32	0.22	0.18	0.16	0.15	0.14
0.80	0.75	0.75	0.54	0.38	0.30	0.26	0.24	0.23
0.70	0.75	0.75	0.75	0.52	0.42	0.36	0.33	0.31
0.60	0.75	0.75	0.75	0.66	0.53	0.46	0.42	0.39
0.50	0.75	0.75	0.75	0.75	0.64	0.55	0.50	0.46
0.40	0.75	0.75	0.75	0.75	0.75	0.64	0.59	0.54
0.30	0.75	0.75	0.75	0.75	0.75	0.75	0.71	0.65
≤ 0.20	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75

NOTES:

(1) *Flaw depth* = a_{allow} for a surface flaw
= 2 a_{allow} for a subsurface flaw
t = pipe wall thickness
Linear interpolation is permissible.

(2) *Stress Ratio* = $(\sigma_m + \sigma_b)/\sigma_f$ for limit load analysis
= $Z[\sigma_m + \sigma_b + \sigma_e/SF_b]/\sigma_f$ for EPFM analysis
Z = Z-factor load multipliers from C-6330
σ_b = primary bending stress
σ_e = secondary bending stress
σ_f = flow stress
σ_m = primary membrane stress. The tabular values are valid for $\sigma_m \le 0.4\ \sigma_f$; otherwise use analytical solution method.

(3) Circumference based on pipe outside diameter.

(4) Acceptance standards for the applicable class shall be used.

(c) Allowable end-of-evaluation-period axial flaw length is given in C-5430.

(15) C-5410 ALLOWABLE FLAW DEPTHS (TABULAR SOLUTION)

Allowable flaw depths for a given final flaw length for each Service Level are given in Table C-5410-1. Using the maximum value of pressure circumferential stress for the most limiting Service Level during the evaluation period and the ℓ_f flaw parameter defined in C-3200, the maximum allowable flaw depth a_{allow} of an axial flaw under these conditions shall be determined from Table C-5410-1.

The allowable flaw depth, a_{allow}, and allowable flaw length, ℓ_{allow}, defined in C-5430 shall be used in the acceptance criteria of C-2610 to determine the acceptability of the flawed pipe for continued service.

C-5420 ALLOWABLE FLAW DEPTHS (ANALYTICAL SOLUTIONS)

The allowable flaw depth in the flawed pipe for a given end-of-evaluation-period flaw length, ℓ_f, for each service level condition is determined using the following:

$$\sigma_h = \frac{\sigma_f}{(SF_m)}\left[\frac{1 - \left(\frac{a}{t}\right)}{1 - \left(\frac{a}{t}\right)/M_2}\right] \tag{7}$$

where

$$M_2 = \left[1 + \left(1.61/4R_m t\right)\ell_f^2\right]^{1/2}$$

p = internal pipe pressure for the appropriate Service Level
SF_m = structural factor defined in C-2622

Table C-5310-5
Allowable End-of-Evaluation-Period Flaw Depth-to-Thickness Ratio [Note (1)] for Circumferential Flaws — Pure Membrane Stress (15)

	Ratio of Flaw Length to Pipe Circumference $\ell_f/\pi D$ [Note (3)]							
Stress Ratio [Note (2)]	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.75 or Greater
≥ 1.00	0.75	(4)	(4)	(4)	(4)	(4)	(4)	(4)
0.90	0.75	0.50	0.26	0.18	0.14	0.12	0.11	0.10
0.80	0.75	0.75	0.52	0.36	0.28	0.24	0.22	0.20
0.70	0.75	0.75	0.75	0.54	0.43	0.37	0.33	0.30
0.60	0.75	0.75	0.75	0.71	0.57	0.49	0.44	0.40
0.50	0.75	0.75	0.75	0.75	0.71	0.61	0.55	0.50
0.40	0.75	0.75	0.75	0.75	0.75	0.73	0.66	0.60
0.30	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.70
≤ 0.20	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75

NOTES:
(1) *Flaw depth* = a_{allow} for a surface flaw
= 2 a_{allow} for a subsurface flaw
t = pipe wall thickness
Linear interpolation is permissible.
(2) *Stress Ratio* = $(SF_m\,\sigma_m)/\sigma_f$ for limit load analysis
= $Z(SF_m\,\sigma_m)/\sigma_f$ for EPFM analysis
σ_m = primary membrane stress
σ_f = flow stress
Z = Z-factor load multipliers from C-6330
(3) Circumference based on pipe outside diameter.
(4) Acceptance standards for the applicable class shall be used.

t = pipe wall thickness
σ_f = flow stress defined in C-8200
σ_h = pR_m/t

The limits of applicability of this equation are: values from acceptance standards < $a/t \le 0.75$.

The allowable flaw depth a_{allow}, determined from eq. (7), and allowable flaw length, ℓ_{allow}, defined in C-5430 shall be used in the acceptance criteria of C-2612 to determine the acceptability of the flawed pipe for continued service.

C-5430 ALLOWABLE FLAW LENGTH

The allowable flaw length for an axial flaw, ℓ_{allow}, based on the stability of a through-wall flaw, is defined as

$$\ell_{allow} = 1.58(R_m t)^{1/2}\left[\left(\frac{\sigma_f}{\sigma_h}\right)^2 - 1\right]^{1/2} \qquad (8)$$

where

p = internal pressure for the appropriate Service Level
R_m = mean pipe radius
t = pipe wall thickness
σ_f = flow stress defined in C-8200
σ_h = pR_m/t

(15)

Table C-5410-1
Allowable End-of-Evaluation-Period Flaw Depth-to-Thickness Ratio [Note (1)] for Axial Flaws

Stress Ratio [Note (2)]	Nondimensional Flaw Length, $\ell_f/(R_m\ t)^{0.5}$ [Note (3)]										
	0.0	0.5	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0	12.0 or Greater
≥ 1.00	0.75	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]
0.90	0.75	0.70	0.42	0.23	0.17	0.15	0.14	0.13	0.12	0.12	0.11
0.80	0.75	0.75	0.62	0.40	0.32	0.28	0.26	0.25	0.24	0.23	0.22
0.70	0.75	0.75	0.73	0.53	0.44	0.40	0.38	0.36	0.35	0.34	0.33
0.60	0.75	0.75	0.75	0.64	0.55	0.51	0.49	0.47	0.45	0.44	0.43
0.50	0.75	0.75	0.75	0.72	0.65	0.61	0.59	0.57	0.55	0.54	0.53
0.40	0.75	0.75	0.75	0.75	0.74	0.70	0.68	0.67	0.65	0.64	0.63
0.30	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.74	0.73	0.73
≤ 0.20	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75

NOTES:
(1) *Flaw depth* = a_{allow} for a surface flaw
= 2 a_{allow} for a subsurface flaw
t = pipe wall thickness
Linear interpolation is permissible.
(2) *Stress Ratio* = $SF_m\sigma_h/\sigma_f$ for limit load analysis
= $Z(SF_m)\ \sigma_h/\sigma_f$ for EPFM analysis
σ_h = pR_m/t, where R_m = mean pipe radius, p = internal pressure
σ_f = flow stress
Z = Z-factor load multiplier for axial part-through-wall flaw from C-6430
(3) ℓ_f = end-of-evaluation-period flaw length
ℓ_f shall be limited to less than ℓ_{allow}, where
$\ell_{allow} = 1.58(R_m t)^{0.5}[(\sigma_f/\sigma_h)^2 - 1]^{0.5}$ for limit load analysis
$\ell_{allow} = 1.58(R_m t)^{0.5}[(\sigma_f/Z\sigma_h)^2 - 1]^{0.5}$ for EPFM analysis
Z = Z-factor load multiplier for axial part-through-wall flaw from C-6430
(4) Acceptance standards for the applicable class shall be used.

ARTICLE C-6000 ANALYTICAL EVALUATION FOR DUCTILE FRACTURE USING EPFM CRITERIA (15)

C-6100 SCOPE

This Article provides the methodology for determining allowable flaw depths and loads for flawed piping meeting the criteria of C-4200 for materials for which fracture by ductile flaw extension may occur prior to reaching limit load.

C-6200 ANALYTICAL EVALUATION PROCEDURES (15)

A flowchart for the analytical evaluation options is given in Figure C-6200-1 when the failure mode has been determined to be ductile flaw extension prior to reaching limit load.

C-6300 CIRCUMFERENTIAL FLAWS

(a) The allowable flaw depth, a_{allow}, and allowable flaw length, ℓ_{allow}, shall be used in the acceptance criteria of C-2600 to determine the acceptability of the flawed pipe for continued service.

(b) The tabular solutions for circumferential flaws shall be used to determine the allowable flaw depths from the limit load solution of C-5310 with the ordinate stress ratio modified by Z-factors given in C-6330. Alternatively, equations for allowable pipe bending stresses given in C-6320 shall be satisfied.

(c) Allowable end-of-evaluation-period circumferential flaw length is given in C-6340.

C-6310 ALLOWABLE FLAW DEPTHS (TABULAR SOLUTION) (15)

The allowable flaw depths are determined from tabular values under the conditions of combined load (membrane plus bending) and membrane-only loading. The maximum allowable flaw depth for the analytical evaluation is the lesser of the allowable flaw depth for combined loading as determined in C-6311 and for membrane stress as determined in C-6312.

C-6311 Combined Loading (15)

Allowable flaw depths for a given final flaw length under combined loading for Service Levels A, B (including test conditions), C, and D shall be obtained from Tables C-5310-1 through C-5310-4 with the ordinate stress ratio for the tables modified by the Z-factors in C-6330. Using the maximum value of the applied stress for each service level during the evaluation period (as modified by load multiplier Z) and the ℓ_f flaw parameter defined in C-3200, the maximum allowable flaw depth, a_{allow}, of a circumferential flaw shall be determined from Tables C-5310-1, C-5310-2, C-5310-3, or C-5310-4, whichever is the most limiting.

The Z-factors in C-6330 shall be used as load multipliers to the stress ratio in Tables C-5310-1 through C-5310-4 to determine the allowable flaw depth for the appropriate material, pipe size, and operating condition as follows:

Step 1. Determine the stress ratio for the appropriate operating condition as follows:

$$\text{Stress Ratio} = Z\left[\sigma_m + \sigma_b + \sigma_e / SF_b\right] / \sigma_f$$

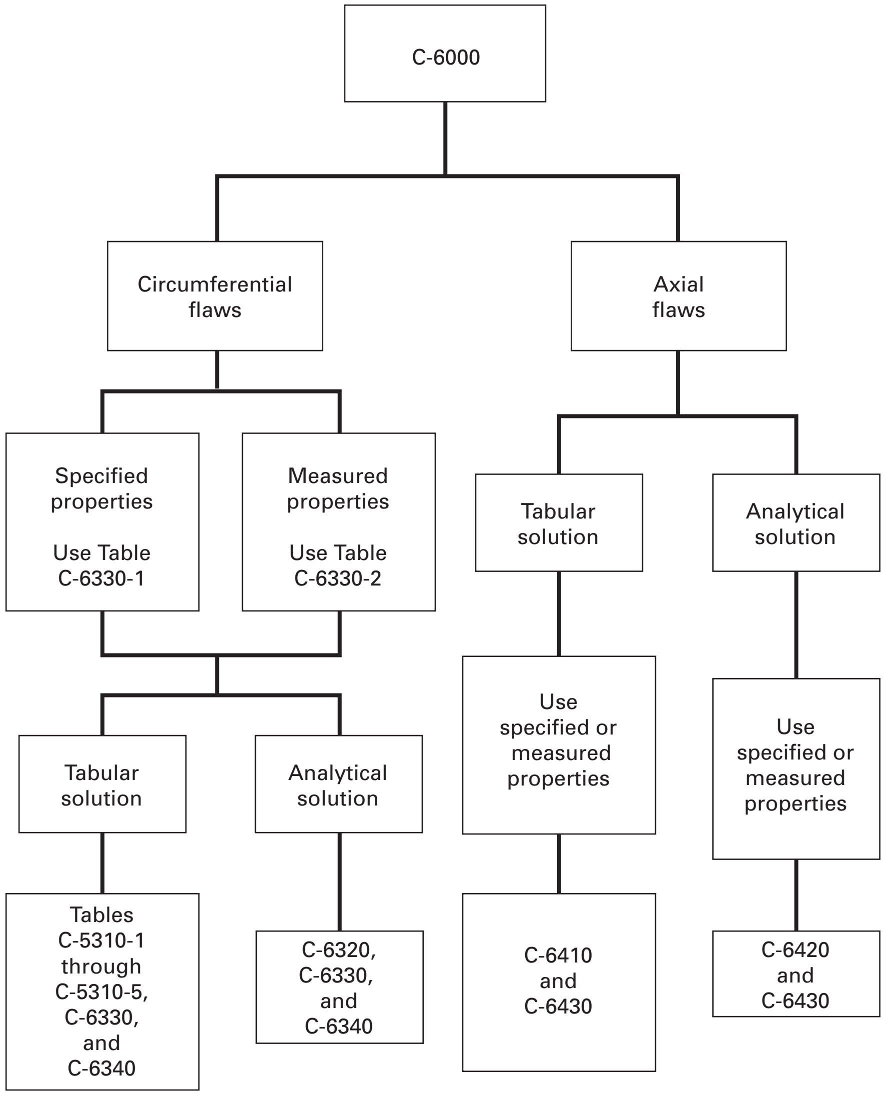
for Service Levels A, B, C, and D conditions.

Step 2. Use Tables C-5310-1 through C-5310-4 for the analytical evaluation, using the stress ratio computed from Step 1. Determine the allowable flaw depth, using linear interpolation, if necessary.

C-6312 Membrane Stress (15)

Allowable flaw depths for a given final flaw length under membrane stress for Service Levels A, B (including test conditions), C, and D shall be obtained from Table C-5310-5 with the ordinate stress ratio for the tables modified by the Z-factors of C-6330. Using the maximum value of the applied membrane stress for each service level during the

Figure C-6200-1
Flowchart for Allowable Flaw Size Determination for Ductile Fracture Using EPFM Method



evaluation interval, as modified by the load multiplier Z, and the ℓ_f flaw parameter defined in C-3200, the maximum allowable flaw depth a_{allow} of a circumferential flaw shall be determined from Table C-5310-5 for which Service Level is the most limiting.

The Z-factors in C-6330 shall be used as load multipliers to the stress ratio in Table C-5310-5 to determine the allowable flaw depth for the appropriate material, pipe size, and operating condition as follows:

Step 1. Determine the stress ratio for the appropriate operating condition as follows:

$$\text{Stress Ratio} = Z(SF_m\sigma_m)/\sigma_f$$

for Service Levels A, B, C, and D conditions.

Step 2. Use Table C-5310-5 for the analytical evaluation, using the stress ratio computed from Step 1. Determine the allowable flaw depth, using linear interpolation, if necessary.

C-6320 ALLOWABLE APPLIED STRESSES (ANALYTICAL SOLUTION)

The allowable stresses are determined analytically for the conditions of combined loading (membrane plus bending) and membrane-only loading. The allowable pipe bending and membrane stresses, determined from C-6321 and C-6322, shall be used in the acceptance criteria of C-2612 to determine the acceptability of the flawed pipe for continued service.

C-6321 Combined Loading

The allowable bending stress, S_c, in the flawed pipe for a given end-of-evaluation-period flaw size for each combined loading service level shall be determined using:

$$S_c = \frac{1}{(SF_b)}\left[\frac{\sigma_b^c}{Z} - \sigma_e\right] - \sigma_m\left[1 - \frac{1}{Z(SF_m)}\right] \tag{9}$$

where

σ_b^c = bending stress at incipient plastic collapse from C-5320
S_c = allowable bending stress for circumferentially flawed pipe
SF_b = structural factor for bending stress based on service level in C-2621
SF_m = structural factor for membrane stress based on service level in C-2621

C-6322 Membrane Stress

The allowable membrane stress, S_t, in the flawed pipe for a given end-of-evaluation-period flaw size for each Service Level shall be determined using:

$$S_t = \sigma_m^c / \left[Z\left(SF_m\right)\right] \tag{10}$$

where

σ_m^c = membrane stress at incipient plastic collapse from C-5320
S_t = allowable membrane stress for a circumferentially flawed pipe
SF_m = structural factor for membrane stress from C-2621

The limits of applicability of these equations are: values from acceptance standards < $a/t \leq 0.75$

C-6330 *Z*-FACTORS LOAD MULTIPLIERS

(a) For austenitic weldments fabricated by shielded metal-arc welds (SMAW) or submerged-arc welds (SAW), the load multiplier is given by:

(U.S. Customary Units)

$$Z = 1.0, \text{ for } 1 \leq \text{NPS} \leq 2$$

$$Z = 1.30\left[1 + 0.15\left(\text{NPS} - 4\right)\right], \text{ for } 2 < \text{NPS} \leq 4$$

$$Z = 1.30\left[1 + 0.010\left(\text{NPS} - 4\right)\right], \text{ for NPS} > 4$$

(SI Units)

$$Z = 1.0, \text{ for } 25 \leq \text{DN} \leq 50$$

$$Z = 1.30\left[1 + 0.006\left(\text{DN} - 100\right)\right], \text{ for } 50 < \text{DN} \leq 100$$

$$Z = 1.30\left[1 + 0.0004\left(\text{DN} - 100\right)\right], \text{ for DN} > 100$$

where NPS (DN) is the nominal pipe size.

(b) For ferritic steels and associated weld metals, the load multipliers are given in Table C-6330-1 for materials defined as either Category 1 or 2. For user-specified data on strength and toughness, if available, the load multiplier equations given in Table C-6330-2 (Table C-6330-2M) may be used to define the Z-factor.

(c) For Alloy 600 and associated weld materials Alloys 82, 182, and 132, the load multiplier is given by:

(U.S. Customary Units)

$$Z = 6.5 \times 10^{-4}D^3 - 0.01386D^2 + 0.1034D + 0.902$$

for 2 in. ≤ D ≤ 8 in.

$$Z = 2.2 \times 10^{-6}D^3 - 2.0 \times 10^{-4}D^2 + 0.0064D + 1.1355$$

for 8 in. < D ≤ 40 in. For 1.315 in. ≤ D < 2 in., use Z = 1.06.

(SI Units)

$$Z = 3.967 \times 10^{-8}D^3 - 2.148 \times 10^{-5}D^2 + 0.004071D + 0.902$$

for 51 mm ≤ D ≤ 203 mm

$$Z = 1.343 \times 10^{-10}D^3 - 3.10 \times 10^{-7}D^2 + 2.52 \times 10^{-4}D + 1.1355$$

for 203 mm < D ≤ 1 016 mm. For 33 mm ≤ D < 51 mm, use Z = 1.06.

Flow stress, σ_f, for austenitic piping material shall be used in the calculation of limit load in C-5300.

C-6340 ALLOWABLE FLAW LENGTH

The allowable flaw length for a circumferential flaw, ℓ_{allow}, based on the stability of a through-wall flaw, is defined as

$$\ell_{allow} = \theta_{allow} D$$

Table C-6330-1
Load Multipliers for Ferritic Steel Base Metals and Weldments

Material Category [Note (1)], [Note (2)]	Z-Factor [Note (3)] U.S. Customary Units	Z-Factor [Note (3)] SI Units
1	Z = 1.0, for 1 ≤ NPS ≤ 2 $Z = Z_1$ [(NPS/2) − 1] − NPS/2 + 2, for 2 < NPS ≤ 4 $Z = Z_1$, for NPS > 4 where Z_1 = 1.20[1 + 0.021A (NPS − 4)]	Z = 1.0, for 25 ≤ DN ≤ 50 $Z = Z_1$ [(DN/50) − 1] − DN/50 + 2, for 50 < DN ≤ 100 $Z = Z_1$, for DN > 100 where Z_1 = 1.20[1 + 0.00084A (DN − 100)]
2	Z = 1.0, for 1 ≤ NPS ≤ 2 $Z = Z_1$ [(NPS/2) − 1] − NPS/2 + 2, for 2 < NPS ≤ 4 $Z = Z_1$, for NPS > 4 where Z_1 = 1.35[1 + 0.0184A (NPS − 4)]	Z = 1.0, for 25 ≤ DN ≤ 50 $Z = Z_1$ [(DN/50) − 1] − DN/50 + 2, for 50 < DN ≤ 100 $Z = Z_1$, for DN > 100 where Z_1 = 1.35[1 + 0.00074A (DN − 100)]

NOTES:
(1) Material Category 1: Seamless or welded wrought ferritic steel pipe and pipe fittings that have a specified minimum yield strength not greater than 40 ksi (280 MPa) and welds made with E7015, E7016, and E7018 electrodes in the as-welded or postweld heat treated conditions.
(2) Material Category 2: All other ferritic shielded metal arc and submerged arc welds with a specified minimum tensile strength not greater than 80 ksi (550 MPa) in the as-welded or postweld heat treated conditions.
(3) Z is a nondimensional term and
$A = [0.125(R_m/t) - 0.25]^{0.25}$ for $5 \le R_m/t \le 10$
$A = [0.4(R_m/t) - 3.0]^{0.25}$ for $10 < R_m/t < 20$
For Z < 1.0, set Z = 1.0.

Table C-6330-2
Load Multipliers for Ferritic Steel Base Metals and Weldments for User-Specified Data

Material Category [Note (1)]	Material Properties [Note (2)]	Z-Factor [Note (3)]
1	$27.1 < \sigma_y \le 40.0$	...
	$600 \le J_{Ic} < 1{,}050$	$Z = 1.0$, for $1 \le \text{NPS} \le 2$ $Z = Z_1\left[(\text{NPS}/2) - 1\right] - \text{NPS}/2 + 2$, for $2 < \text{NPS} \le 4$ $Z = Z_1$, for $\text{NPS} > 4$ where, $Z_1 = 2.281M_1\left[1 + 0.0210A(\text{NPS} - 4)\right]/\sigma_y^{0.46}$
	$J_{Ic} \ge 1{,}050$	$Z = 1.0$, for $1 \le \text{NPS} \le 2$ $Z = Z_1\left[(\text{NPS}/2) - 1\right] - \text{NPS}/2 + 2$, for $2 < \text{NPS} \le 4$ $Z = Z_1$, for $\text{NPS} > 4$ where, $Z_1 = 1.958M_1\left[1 + 0.0152A(\text{NPS} - 4)\right]/\sigma_y^{0.46}$
2	$27.1 < \sigma_y \le 40.0$	...
	$350 \le J_{Ic} < 600$	$Z = 1.0$, for $1 \le \text{NPS} \le 2$ $Z = Z_1\left[(\text{NPS}/2) - 1\right] - \text{NPS}/2 + 2$, for $2 < \text{NPS} \le 4$ $Z = Z_1$, for $\text{NPS} > 4$ where, $Z_1 = 2.566M_1\left[1 + 0.0184A(\text{NPS} - 4)\right]/\sigma_y^{0.46}$
	$600 \le J_{Ic} < 1{,}050$	$Z = 1.0$, for $1 \le \text{NPS} \le 2$ $Z = Z_1\left[(\text{NPS}/2) - 1\right] - \text{NPS}/2 + 2$, for $2 < \text{NPS} \le 4$ $Z = Z_1$, for $\text{NPS} > 4$ where, $Z_1 = 2.281M_1\left[1 + 0.0210A(\text{NPS} - 4)\right]/\sigma_y^{0.46}$
	$J_{Ic} \ge 1{,}050$	$Z = 1.0$, for $1 \le \text{NPS} \le 2$ $Z = Z_1\left[(\text{NPS}/2) - 1\right] - \text{NPS}/2 + 2$, for $2 < \text{NPS} \le 4$ $Z = Z_1$, for $\text{NPS} > 4$ where, $Z_1 = 1.958M_1\left[1 + 0.0152A(\text{NPS} - 4)\right]/\sigma_y^{0.46}$

NOTES:
(1) Material categories are defined in Table C-6330-1.

Table C-6330-2
Load Multipliers for Ferritic Steel Base Metals and Weldments for User-Specified Data (Cont'd)

NOTES (CONT'D):
(2) σ_y and J_{Ic} are in units of ksi and in.-lb/in.^{2} respectively. σ_y = 0.2% offset yield strength at temperature or the Section II, Part D yield strength value at temperature.
(3) M_1 is the ratio of the flow stress (σ_f, in units of ksi) used in the limit load calculation to a reference stress of 18.1 ksi (i.e., $M_1 = \sigma_f/18.1$). When Z is calculated to be less than 1.0, use Z = 1.0. Z is a nondimensional term and
$A = [0.125(R_m/t) - 0.25]^{0.25}$ for $5 \le R_m/t \le 10$
$A = [0.4(R_m/t) - 3.0]^{0.25}$ for $10 < R_m/t < 20$

where θ_{allow} is the flaw half-angle that satisfies the following for each Service Level:

$$2\sin\left[0.5\left(\varphi - \theta_{allow}\right)\right] - \sin\theta_{allow} = \frac{\pi Z\left(\sigma_b + \sigma_e\right)}{2\sigma_f}$$

$$\varphi = \pi[1 - \sigma_m/\sigma_f]$$

where

D = outside diameter
Z = Z-factor load multiplier defined in C-6330
σ_b = maximum applied primary bending stress
σ_e = maximum applied secondary bending stress
σ_f = flow stress defined in C-8200
σ_m = maximum applied axial primary membrane stress

C-6400 AXIAL FLAWS

(a) The allowable flaw depth, a_{allow}, and allowable flaw length, ℓ_{allow}, shall be used in the acceptance criteria of C-2600 to determine the acceptability of the flawed pipe for continued service.

(b) Allowable flaw depths shall be determined using specified or reported material properties in accordance with C-6410. Alternatively, equations for allowable flaw depths given in C-6420 shall be satisfied. Specified or reported material properties and actual piping system loadings shall be used.

(c) Allowable end-of-evaluation-period axial flaw length is given in C-6410 or C-6420, as appropriate.

(d) The provisions of C-6400 apply to ferritic piping with operating temperatures exceeding 70°F (21°C).

(15) C-6410 ALLOWABLE FLAW DEPTHS (TABULAR SOLUTIONS)

Allowable flaw depths for each Service Level are given in Table C-5410-1. Using the maximum value of pressure circumferential stress for the most limiting Service Level during the evaluation period and the ℓ_f flaw parameter defined in C-3200, the maximum allowable flaw depth, a_{allow}, of an axial flaw under these conditions shall be determined from Table C-5410-1. The allowable flaw length, ℓ_{allow}, for the stability of a through-wall flaw is defined as

$$\ell_{allow} = 1.58\left(R_m t\right)^{1/2}\left[\left(\frac{\sigma_f}{Z\sigma_h}\right)^2 - 1\right]^{1/2} \quad (11)$$

where

p = internal pressure for the appropriate Service Level
R_m = mean pipe radius
t = pipe wall thickness
Z = Z-factor load multiplier for an axial through-wall flaw given in C-6430
σ_f = flow stress defined in C-8200
σ_h = pR_m/t

Table C-6330-2M
Load Multipliers for Ferritic Steel Base Metals and Weldments for User-Specified Data

Material Category [Note (1)]	Material Properties [Note (2)]	Z Factor [Note (3)]
1	$187 < \sigma_y \leq 280$	...
	$105 \leq J_{Ic} < 185$	$Z = 1.0$, for $25 \leq DN \leq 50$ $Z = Z_1[(DN/50) - 1] - DN/50 + 2$, for $50 < DN \leq 100$ $Z = Z_1$, for $DN > 100$ where, $Z_1 = 5.544M_1[1 + 0.000840A(DN - 100)]/\sigma_y^{0.46}$
	$J_{Ic} \geq 185$	$Z = 1.0$, for $25 \leq DN \leq 50$ $Z = Z_1[(DN/50) - 1] - DN/50 + 2$, for $50 < DN \leq 100$ $Z = Z_1$, for $DN > 100$ where, $Z_1 = 4.759M_1[1 + 0.000608A(DN - 100)]/\sigma_y^{0.46}$
2	$187 < \sigma_y \leq 280$	...
	$61 \leq J_{Ic} < 105$	$Z = 1.0$, for $25 \leq DN \leq 50$ $Z = Z_1[(DN/50) - 1] - DN/50 + 2$, for $50 < DN \leq 100$ $Z = Z_1$, for $DN > 100$ where, $Z_1 = 6.237M_1[1 + 0.000736A(DN - 100)]/\sigma_y^{0.46}$
	$105 \leq J_{Ic} < 185$	$Z = 1.0$, for $25 \leq DN \leq 50$ $Z = Z_1[(DN/50) - 1] - DN/50 + 2$, for $50 < DN \leq 100$ $Z = Z_1$, for $DN > 100$ where, $Z_1 = 5.544M_1[1 + 0.000840A(DN - 100)]/\sigma_y^{0.46}$
	$J_{Ic} \geq 185$	$Z = 1.0$, for $25 \leq DN \leq 50$ $Z = Z_1[(DN/50) - 1] - DN/50 + 2$, for $50 < DN \leq 100$ $Z = Z_1$, for $DN > 100$ where, $Z_1 = 4.759M_1[1 + 0.000608A(DN - 100)]/\sigma_y^{0.46}$

NOTES:
(1) Material categories are defined in Table C-6330-1.

Table C-6330-2M
Load Multipliers for Ferritic Steel Base Metals and Weldments for User-Specified Data (Cont'd)

NOTES (CONT'D):
(2) σ_y and J_{Ic} are in units of MPa and kJ/m^2, respectively. σ_y = 0.2% offset yield strength at temperature or the Section II, Part D yield strength value at temperature.
(3) M_1 is the ratio of the flow stress (σ_f, in units of MPa) used in the limit load calculation to a reference stress of 125 MPa (i.e., $M_1 = \sigma_f/125$). When Z is calculated to be less than 1.0, use Z = 1.0. Z is a nondimensional term and
$A = [0.125(R_m/t) - 0.25]^{0.25}$ for $5 \le R_m/t \le 10$
$A = [0.4(R_m/t) - 3.0]^{0.25}$ for $10 < R_m/t < 20$

The allowable flaw depth, a_{allow}, and allowable flaw length, ℓ_{allow}, shall be used in the acceptance criteria of C-2610 to determine the acceptability of the flawed pipe for continued service.

C-6420 ALLOWABLE FLAW DEPTHS (ANALYTICAL SOLUTIONS)

The allowable flaw depths in the flawed pipe for a given end-of-evaluation-period flaw depth, a_f, and length, ℓ_f, defined in C-3200 for each Service Level is determined using the following:

$$\sigma_h = \frac{\sigma_f}{(SF_m)Z}\left[\frac{1-(a_f/t)}{1-(a_f/t)/M_2}\right] \quad (12)$$

where

$M_2 = [1 + (1.61/4R_m t)\ell_f^{\,2}]^{1/2}$
p = internal pressure for the appropriate Service Level
R_m = mean pipe radius
SF_m = structural factor defined in C-2622
t = pipe wall thickness
Z = Z-factor load multiplier for an axial part-through-wall flaw given in C-6430
σ_f = flow stress defined in C-8200
σ_h = pR_m/t

The limits of applicability of this equation are values from acceptance standards < $a_f/t \le 0.75$ and

$$\ell_f = \ell_{allow}$$

where ℓ_{allow} is determined by the condition for the stability of through-wall flaws given by eq. C-6410(11). The allowable flaw depths determined from eq. (12) shall be used in the acceptance criteria of C-2611 to determine the acceptability of the flawed pipe for continued service.

C-6430 *Z*-FACTOR LOAD MULTIPLIERS

(a) For axial part-through-wall and through-wall flaws in ferritic materials with Charpy V-notch (CVN) data available in the CL direction

(U.S. Customary Units)

$$Z = \frac{(\pi/2)}{\cos^{-1}\left[\exp\left(-(\pi/4)\frac{(CVN)E}{10.3\sigma_f^2\ell_f}\right)\right]}$$

for $CVN \ge 51.6$ ft-lb

where

CVN = Charpy V-notch upper shelf energy, full-size (0.394 in. × 0.394 in.) (ft-lb)
E = elastic modulus (ksi)
ℓ_f = flaw length (in.)
σ_f = flow stress defined in C-8200 (ksi)

(SI Units)

$$Z = \frac{(\pi/2)}{\cos^{-1}\left[\exp\left(-(\pi/4)\frac{12.48(CVN)E}{\sigma_f^2 \ell_f}\right)\right]}$$

for $CVN \geq 70 J$

where

CVN = Charpy V-notch upper shelf energy, full-size (10 mm × 10 mm) (J)
E = elastic modulus (MPa)
ℓ_f = flaw length (mm)
σ_f = flow stress defined in C-8200 (MPa)

(b) For axial part-through-wall flaws in ferritic materials with fracture toughness, J_{Ic}, available in the CL direction

(U.S. Customary Units)

$$Z = Z_0 - 0.000366(J_{Ic} - 600)$$

where

J_{Ic} = fracture initiation toughness (in.-lb/in.^{2})

(SI Units)

$$Z = Z_0 - 0.00209(J_{Ic} - 105)$$

where

J_{Ic} = fracture initiation toughness (kJ/m^2)

For the above equations for Z,

$$Z_0 = C_1x^3 + C_2x^2 + C_3x + C_4y^3 + C_5y^2 + C_6y + C_7x^2y + C_8xy^2 + C_9xy + C_{10}$$

where

$x = a/t$

$y = \ell_f/(R_mt)^{1/2}$

Z_0 is valid for $0 < x \le 0.75$. Coefficients C_n are given in Table C-6430-1. For $Z < 1.0$, set Z equal to 1.0.

(c) Z-factor load multiplier for axial through-wall flaws for ferritic materials with available fracture toughness, J_{Ic}, is in the course of preparation.

Table C-6430-1
Coefficients C_n of Z_0 Equation for Z-Factor Based on Fracture Toughness, J_{Ic}

Nondimensional Flaw Length	R_m/t	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
$\ell_f/(R_m t)^{1/2} \leq 2.8$	5	1.5700	−1.5620	0.7831	0.0156	−0.1034	0.1596	−0.7631	−0.0207	0.5519	0.7910
	10	2.2310	−2.4120	1.2010	0.0488	−0.2528	0.3643	−0.7709	−0.1040	0.7692	0.6681
	15	3.2920	−3.5640	1.7440	0.0597	−03008	0.4357	−0.7965	−0.1145	0.7584	0.5959
	20	3.9620	−4.5130	2.1270	0.0717	−0.3262	0.4408	−0.6657	−0.1835	0.8411	0.5729
	25	3.3980	−3.7760	1.9000	0.0832	−0.3662	0.4787	−0.7276	−0.2062	0.9203	0.5877
	30	3.8300	−4.0400	1.9400	0.0857	−0.3633	0.4554	−0.8577	−0.2358	1.0620	0.5991
	35	3.8690	−4.0140	1.9020	0.0951	−0.3841	0.4650	−0.8807	−0.2811	1.1760	0.6035
$2.8 < \ell_f/(R_m t)^{1/2} \leq 4.4$	5	2.4010	−4.2110	2.3490	0.0103	−0.1081	0.3903	−0.0738	−0.0026	−0.0089	0.2970
	10	1.5700	−2.7560	2.6590	−0.0135	0.1503	−0.5016	−0.2710	0.0487	−0.3255	1.3290
	15	0.8640	−2.6340	2.6830	0.0155	−0.1384	0.5120	−0.1541	0.0131	−0.2407	0.1413
	20	1.4250	−2.9550	1.9840	−0.0142	0.2135	−0.7955	−0.2578	−0.0600	0.2732	1.7260
	25	0.9485	−1.1910	1.4750	−0.0126	0.1943	−0.6910	−0.6639	−0.0274	0.2672	1.6180
	30	1.0610	1.1730	−0.6045	−0.0117	0.1895	−0.6791	−1.5030	−0.1092	1.2130	1.6530
	35	2.0710	0.0051	2.1150	−0.0162	0.1953	−0.4961	−1.4800	0.0807	−0.1483	1.2010

GENERAL NOTES:
(a) Linear interpolation of Z_0 over R_m/t is permissible.
(b) Linear interpolation of coefficients C_n over R_m/t is not permitted.

(15)

ARTICLE C-7000 ANALYTICAL EVALUATION FOR NONDUCTILE FRACTURE USING LEFM CRITERIA

C-7100 SCOPE

This Article provides the methodology for determining allowable flaw depths in flawed piping meeting the linear elastic fracture mechanics criteria of C-4200, when ductile crack extension does not occur prior to fracture. Solutions are given for both axial and circumferential flaws and are presented in the form of equations that shall be used with the material properties obtained in accordance with C-8310 or C-8320, for austenitic or ferritic materials, respectively. Applied stresses shall include residual stresses.

(15)

C-7200 ANALYTICAL EVALUATION PROCEDURES

(a) The allowable end-of-evaluation-period flaw depth, a_{allow}, and allowable end-of-evaluation-period flaw length, ℓ_{allow}, shall be used in the acceptance criteria of C-2611 and C-2613 to determine the acceptability of the flawed pipe for continued service.

(b) A flowchart for the analytical evaluation is given in Figure C-7200-1, when the failure mode has been determined to be linear elastic fracture, using the procedures of C-4200. The allowable end-of-evaluation-period flaw depth, a_{allow}, for each Service Level, shall be obtained by solving eq. (13) for the flaw depth, a.

$$K_I = \left(J_{Ic} E' / 1000\right)^{0.5} \tag{13}$$

where K_I contains the flaw depth, a, and is defined for a circumferential flaw in C-7300 and for an axial flaw in C-7400.

Conversely, eq. (13) may be rewritten as equivalent criteria in terms of the stress intensity factor.

$$K_I \le \left(J_{Ic} E' / 1000\right)^{0.5} = K_c \tag{14}$$

For this criterion, the end-of-evaluation-period flaw depth, a_f, and flaw length, l_f, shall be used to determine K_I in C-7310 and C-7410.

(c) Allowable end-of-evaluation-period flaw length, ℓ_{allow}, is given in C-7320 for circumferential flaws and C-7420 for axial flaws.

C-7300 CIRCUMFERENTIAL FLAWS

C-7310 ALLOWABLE FLAW DEPTHS

The stress intensity factor for a circumferential flaw, including the appropriate structural factor, is given by the following:

$$K_I = K_{Im} + K_{Ib} + K_{Ir} \tag{15}$$

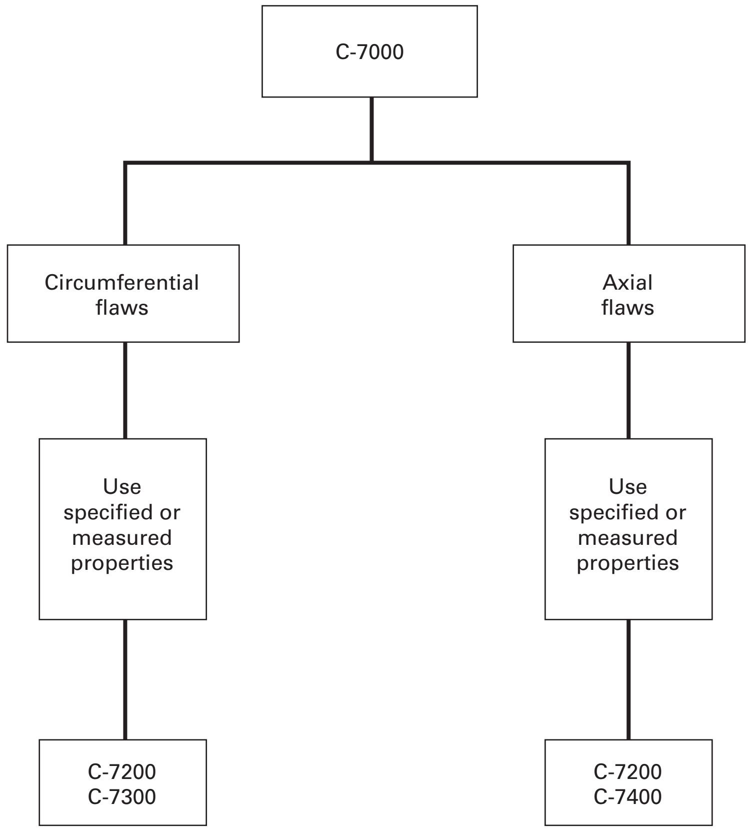
where

(U.S. Customary Units)

$$K_{Ib} = \left[\left(SF_b\right) \sigma_b + \sigma_e\right] F_b \left(\pi a\right)^{0.5}$$

$$K_{Im} = \left(SF_m\right) F_m \sigma_m \left(\pi a\right)^{0.5}$$

Figure C-7200-1
Flowchart for Allowable Flaw Size Determination for Nonductile Fracture Using LEFM Methods



K_{Ir} = K_I from residual stresses at the flaw location
SF_m and SF_b = structural factors from C-2621

(SI Units)

$$K_{Ib} = \left[(SF_b)\,\sigma_b + \sigma_e\right]F_b\left(\pi a / 1\,000\right)^{0.5}$$

$$K_{Im} = (SF_m)F_m\,\sigma_m\,\left(\pi a / 1\,000\right)^{0.5}$$

The other terms are defined in C-4311. Residual stress shall be included with a structural factor of 1.0 in determining K_{Ir}.

C-7320 ALLOWABLE FLAW LENGTH

The allowable flaw length for a circumferential flaw, ℓ_{allow}, for through-wall flaw stability shall be determined from the stress intensity factor relationship for each Service Level.

$$K_I = K_{Im} + K_{Ib} \le K_c$$

where

(U.S. Customary Units)

$K_{Ib} = F_b\left[\sigma_b + \sigma_e\right](\pi c)^{0.5}$

$K_{Im} = F_m\sigma_m(\pi c)^{0.5}$

(SI Units)

$K_{Ib} = F_b\left[\sigma_b + \sigma_e\right](\pi c/1\,000)^{0.5}$

$K_{Im} = F_m\sigma_m(\pi c/1\,000)^{0.5}$

and

$A_b = -3.26543 + 1.52784(R_m/t) - 0.072698(R_m/t)^2 + 0.0016011(R_m/t)^3$

$A_m = -2.02917 + 1.67763(R_m/t) - 0.07987(R_m/t)^2 + 0.00176(R_m/t)^3$

$B_b = 11.36322 - 3.91412(R_m/t) + 0.18619(R_m/t)^2 - 0.004099(R_m/t)^3$

$B_m = 7.09987 - 4.42394(R_m/t) + 0.21036(R_m/t)^2 - 0.00463(R_m/t)^3$

$C_b = -3.18609 + 3.84763(R_m/t) - 0.18304(R_m/t)^2 + 0.00403(R_m/t)^3$

$C_m = 7.79661 + 5.16676(R_m/t) - 0.24577(R_m/t)^2 + 0.00541(R_m/t)^3$

$c = \ell/2$

$F_b = 1 + A_b(\theta/\pi)^{1.5} + B_b(\theta/\pi)^{2.5} + C_b(\theta/\pi)^{3.5}$

$F_m = 1 + A_m(\theta/\pi)^{1.5} + B_m(\theta/\pi)^{2.5} + C_m(\theta/\pi)^{3.5}$

R_m = mean pipe radius
t = pipe wall thickness
θ = half flaw angle = $2c/D$

Equations for F_m and F_b are accurate for R_m/t between 5 and 20 and become increasingly conservative for R_m/t greater than 20. Alternative solutions for F_m and F_b may be used when R_m/t is greater than 20.

C-7400 AXIAL FLAWS

C-7410 ALLOWABLE FLAW DEPTHS

The stress intensity factor for an axial flaw, including the appropriate structural factor, is given by the following:

$$K_I = K_{Im} + K_{Ir} \tag{16}$$

where

(U.S. Customary Units)

$K_{Im} = (SF_m)\,F\,\sigma_h\,(\pi a/Q)^{0.5}$

K_{Ir} = K_I from residual stresses at the flaw location
SF_m = structural factor from C-2622
$\sigma_h = pR_m/t$

(SI Units)

$K_{Im} = (SF_m)\,F\,\sigma_h\left[\pi a/(1\,000Q)\right]^{0.5}$

The other terms are defined in C-4312. Residual stress shall be included with a structural factor of 1.0 in determining K_{Ir}.

C-7420 ALLOWABLE FLAW LENGTH

The allowable flaw length, ℓ_{allow}, for an axial flaw based on through-wall flaw stability shall be determined from the stress intensity factor relationship for each Service Level.

$$K_I \le K_c \tag{17}$$

where

(U.S. Customary Units)

$c = \ell/2$

$K_I = F_{TW}\,\sigma_h(\pi c)^{\frac{1}{2}}$

$\sigma_h = pR_m/t$

$F_{TW} = 1 + 0.072449\lambda + 0.64856\lambda^2 - 0.2327\lambda^3 + 0.038154\lambda^4 - 0.0023487\lambda^5$

$\lambda = c/(R_m t)^{0.5}$

(SI Units)

$K_I = F_{TW}\,\sigma_h(\pi c/1\,000)^{0.5}$

The equation for F_{TW} is accurate for $0 \le \lambda \le 5$. Alternative solutions for F_{TW} may be used when λ is greater than 5.

ARTICLE C-8000
MATERIAL PROPERTY PARAMETERS

C-8100 SCOPE

This Article provides requirements for determining the material properties used in the analysis.

(15) C-8200 MECHANICAL STRENGTH

(a) The yield and ultimate tensile strengths shall be obtained from Section II, Part D for the pipe material and service temperature under analytical evaluation. The material flow stress for austenitic and ferritic pipe is defined as follows.

$$\sigma_f = \left(S_y + S_u\right)/2$$

(b) If actual (measured) material properties for the pipe are known, the flow stress shall be defined as

$$\sigma_f = \left(\sigma_y + \sigma_u\right)/2$$

where σ_y and σ_u are the measured yield and ultimate strengths for the pipe material at the service temperature.

(15) C-8300 MATERIAL TOUGHNESS

The material toughness J_{Ic}, K_{Ic}, or K_c, is required to perform the analytical evaluations for EPFM and LEFM failure modes. The material toughness shall be determined at upper-shelf, transition, and lower-shelf temperature regions, as applicable. When available, heat-specific properties for the piping may be used to establish the material toughness at the evaluation temperature.

(15) C-8310 AUSTENITIC MATERIALS

(a) The fracture toughness of wrought austenitic stainless steel pipe and nonflux weldments is very high. For these high-toughness materials, limit load failure mode is assumed for the analytical evaluation, and fracture toughness is not required in the determination of allowable flaw size.

(b) For flux welds, the fracture toughness may be lower than for wrought pipe. For EPFM analysis, the Z-factors of C-6330 include the toughness properties required for the analytical evaluation. For other cases, the procedures of C-8330 may be applied to establish material-specific fracture toughness properties.

C-8320 FERRITIC MATERIALS

For ferritic piping materials, the following procedures may be applied to establish the fracture toughness at the appropriate flaw location and orientation.

C-8321 Toughness Properties for Circumferentially-Oriented Flaws

(a) The toughness, J_{Ic}, shall be obtained directly from heat-specific experiments or reasonable lower-bound fracture toughness data or from Table C-8321-1.

(b) The correlation at upper-shelf temperatures for use with Charpy V-notch (CVN) data is

(U.S. Customary Units)

$$J_{I\text{mm}} = 10\text{CVN}$$

(SI Units)

$$J_{Imm} = 1.3\text{CVN}$$

Table C-8321-1
Material Properties for Ferritic Steel Base Metals and Weldments — Circumferential Flaws

Material Category [Note (1)], [Note (2)]	Temp. ≥ Upper-Shelf Temp.		Temp. < Upper-Shelf Temp.	
	σ_y	J_{Ic}	σ_y	J_{Ic}
1	27.1 (187)	600 (105)	27.3 (188)	45 (8)
2	27.1 (187)	350 (61)	27.3 (188)	45 (8)

NOTES:
(1) Material Category 1: Seamless or welded wrought ferritic steel pipe and pipe fittings that have a specified minimum yield strength not greater than 40 ksi (280 MPa) and welds made with E7015, E7016, and E7018 electrodes in the as-welded or postweld heat treated conditions.
(2) Material Category 2: All other ferritic shielded metal arc and submerged arc welds with a specified minimum tensile strength not greater than 80 ksi (550 MPa) in the as-welded or postweld heat treated conditions.

Table C-8321-2
Temperature for Onset of Upper-Shelf Behavior for Axial and Circumferential Flaws in Ferritic Steel Base Metals and Weldments

Wall Thickness	Surface Flaws	Through-Wall Flaws
	Temperature	Temperature
in. (mm)	°F (°C)	°F (°C)
≤0.25 (≤6)	−45 (−43)	6 (−14)
0.375 (10)	−4 (−20)	49 (9)
0.50 (13)	22 (−6)	73 (23)
0.625 (16)	35 (2)	86 (30)
0.75 (19)	43 (6)	94 (35)
1.00 (25)	52 (11)	104 (40)
1.25 (32)	58 (15)	110 (43)
1.50 (38)	63 (17)	114 (46)
1.75 (44)	66 (19)	118 (48)
2.00 (51)	70 (21)	121 (50)

GENERAL NOTES:
(a) This table is applicable to piping and portions of adjoining pipe fittings within a distance of $(R_2t)^{1/2}$ from the weld centerline. The weld geometry and weld-base-metal interface are defined in Figure C-1100-1. Applicability of this table to wrought carbon steel pipe fittings is limited to those fittings that have been hot-formed and subsequently normalized or annealed in accordance with the requirements of the material specification (e.g., Section II , Part A).
(b) The values of temperature in this table may be interpolated to determine temperatures for intermediate values of wall thickness.

and J_{Imm} shall replace J_{Ic} when this Charpy correlation is used. In the absence of specific data, the upper-shelf temperature for ferritic piping steels shall be 200°F (95°C), or the upper-shelf temperatures in Table C-8321-2 may be used for flaws in wall thickness less than or equal to 2.0 in. (51 mm). A lower temperature may be used to define upper-shelf behavior when it is determined from valid heat-specific CVN tests.

C-8322 Toughness Properties for Axially Oriented Flaws

The toughness, J_{Ic}, in the CL direction shall be obtained directly from heat-specific experiments or from correlations with heat-specific CVN data or reasonable lower-bound CVN data. If heat-specific or reasonable lower-bound K_{Ic} data for ferritic piping materials with specified minimum yield not greater than 40 ksi (280 MPa) are available for the CL direction, a conservative estimate for J_{Ic} shall be determined from the following:

$$J_{Ic} = 1000\left(K_{Ic}\right)^2 / E'$$

Alternatively, values for J_{Ic} shall be obtained from Table C-8322-1. In the absence of specific data, the upper-shelf temperature for ferritic piping steels shall be 200°F (95°C), or the upper-shelf temperatures in Table C-8321-2 may be used for flaws in wall thickness less than or equal to 2.0 in. (51 mm). A lower temperature may be used to define upper-shelf behavior when determined from valid heat-specific CVN test.

(15) C-8330 OTHER PIPING MATERIALS

For other piping materials, including nonferrous alloys and cast austenitic stainless steel with high ferrite content, similar procedures may be used to establish J_{Ic}, K_{Ic}, or K_c. Material condition, testing parameters, test results, and toughness correlations shall be appropriate for the pipe material and flaw orientation under analytical evaluation.

C-8400 FATIGUE CRACK GROWTH RATE

C-8410 AUSTENITIC STEELS

The fatigue crack growth behavior of austenitic stainless steels is affected by temperature, R ratio ($K_{I\min}/K_{I\max}$), and environment. Reference fatigue crack growth rates for air and water environments are given by the following:

(a) Reference fatigue crack growth behavior of cast and wrought austenitic stainless steels and their welds exposed to air environments (e.g., subsurface flaws) are given by eq. C-3210(a)(1) with n = 3.3 and

$$C_o = CS \tag{18}$$

where C is a scaling parameter to account for temperature and is given by

(U.S. Customary Units)

$$C = 10^{\left[-10.009 + 8.12 \times 10^{-4}T - 1.13 \times 10^{-6}T^2 + 1.02 \times 10^{-9}T^3\right]}$$

Table C-8322-1
Material Properties for Ferritic Steel Base Metals and Weldments — Axial Flaws

Temp. ≥ Upper-Shelf Temp.		Temp. < Upper-Shelf Temp.	
σ_y	J_{Ic}	σ_y	J_{Ic}
27.1 (187)	300 (53)	27.3 (188)	45 (8)

(SI Units)

$$C = 10^{\left[-8.714 + 1.34 \times 10^{-3}T - 3.34 \times 10^{-6}T^2 + 5.95 \times 10^{-9}T^3\right]}$$

where T is the metal temperature in °F (°C) [for $T \le 800$°F (430°C)], and S is a scaling parameter to account for R ratio and is given by:

$$\begin{aligned} S &= 1.0 \text{ when } R \le 0 \\ &= 1.0 + 1.8R \text{ when } 0 < R \le 0.79 \\ &= -43.35 + 57.97R \text{ when } 0.79 < R < 1.0 \end{aligned}$$

The scaling constant C_o from eq. (18) produces fatigue crack growth rates in the units of in./cycle (mm/cycle) when ΔK_I is in the units of $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$ and is intended for use when data from the product form are not available. Reference fatigue crack growth rate curves using eq. C-3210(a)(1) and eq. (18) are provided in Figure C-8410-1 (Figure C-8410-1M).

(b) Reference fatigue crack growth rates for austenitic stainless steels exposed to water environments are in the course of preparation.

C-8411 Alloy 600

The fatigue crack growth rate of Alloy 600 material is affected by temperature, R ratio, load rise time, and environment. Reference fatigue crack growth rates for PWR and BWR water environments, as well as for air environment, are given by the following. Reference curves for a temperature of 608°F (320°C) are provided in Figure C-8410-2 (Figure C-8410-2M).

(a) The reference fatigue crack growth rate of Alloy 600 exposed to water environments is given by eq. C-3210(a)(1) with n = 4.1 and

$$C_o = C_T S_R S_{ENV} \tag{19}$$

where

$$S_{ENV} = 1 + A_E\left[C_T S_R\left(\Delta K_I\right)^n\right]^{-0.67} \tau_r^{0.67}$$

$$S_R = \left(1 - 0.82R\right)^{-2.2}$$

and

(U.S. Customary Units)

$$C_T = 2.606 \times 10^{-12} + 7.060 \times 10^{-15}T - 3.080 \times 10^{-17}T^2 + 4.327 \times 10^{-20}T^3$$

$$A_E = 5.155 \times 10^{-6} \left(\text{in./cycles} - \text{sec}\right)^{0.67}$$

(SI Units)

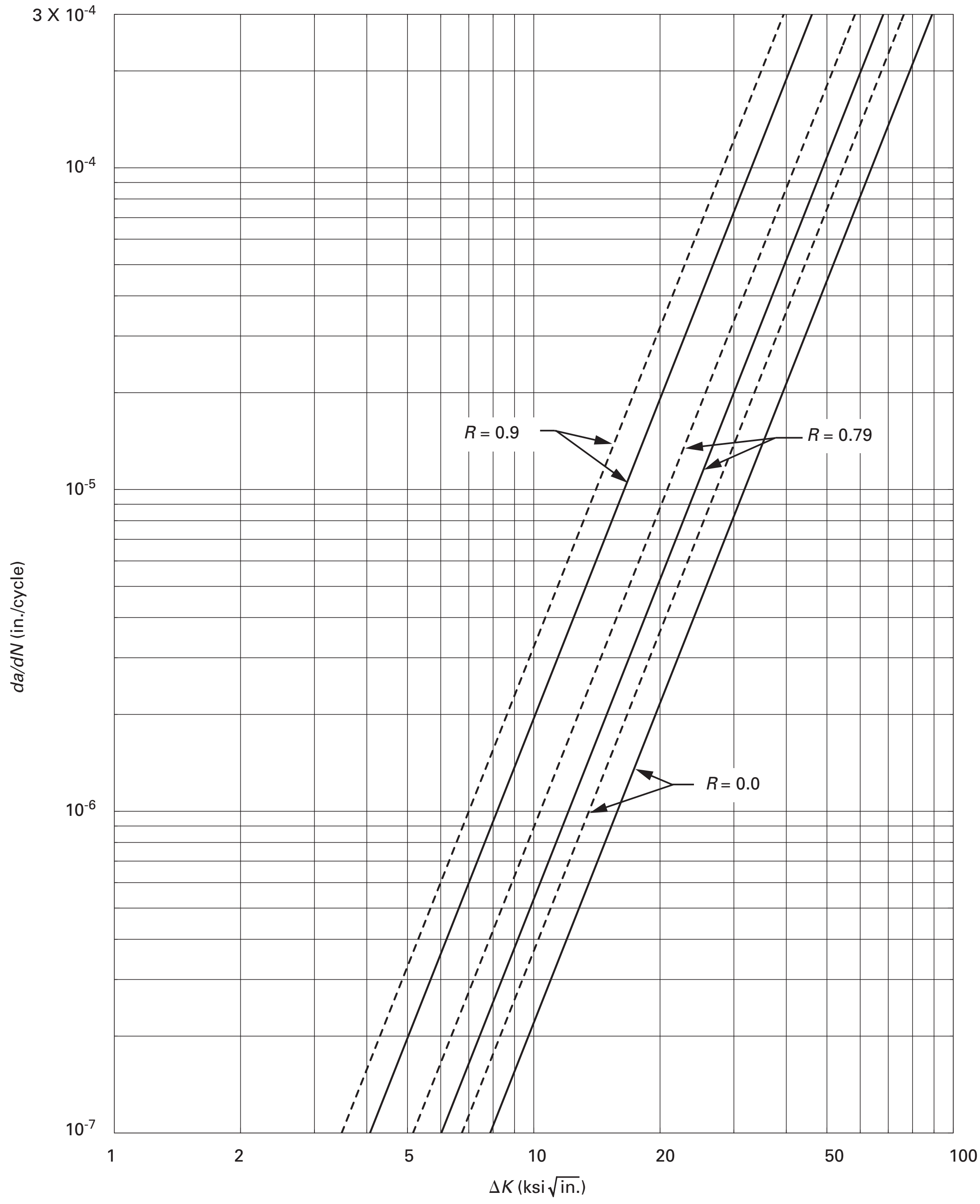
$$C_T = 4.835 \times 10^{-11} + 1.622 \times 10^{-13}T - 1.490 \times 10^{-15}T^2 + 4.355 \times 10^{-18}T^3$$

$$A_E = 4.503 \times 10^{-5} \left(\text{mm/cycles} - \text{s}\right)^{0.67}$$

where

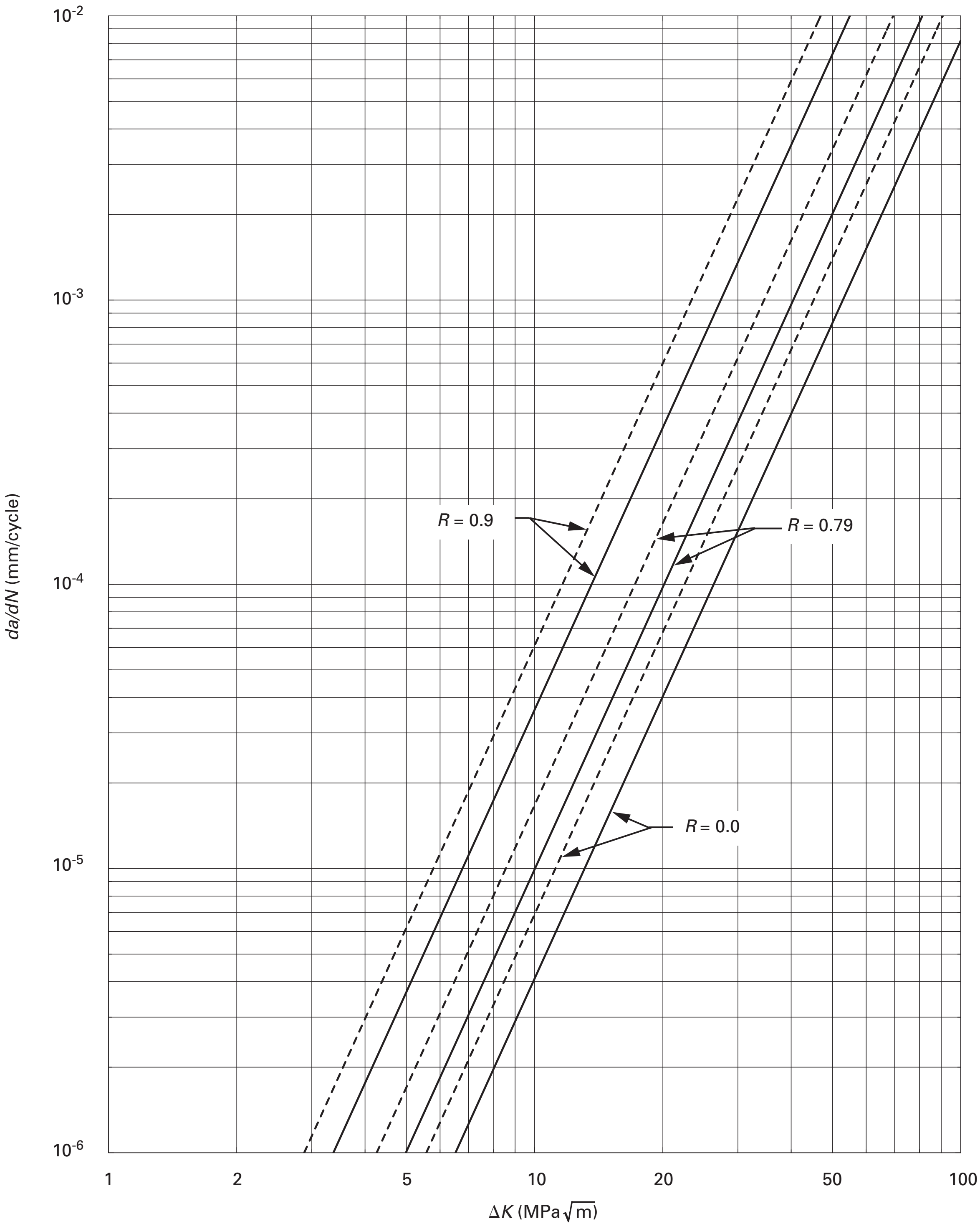
A_E = factor used to calculate fatigue crack growth rate environment parameter S_{ENV}
C_T = scaling parameter to account for temperature

Figure C-8410-1
Reference Fatigue Crack Growth Curves for Austenitic Stainless Steels in Air Environments



GENERAL NOTES:
(a) Solid lines for 70°F; dashed lines for 550°F.
(b) For other *R* ratios and temperatures, see C-8410.

Figure C-8410-1M
Reference Fatigue Crack Growth Curves for Austenitic Stainless Steels in Air Environments



GENERAL NOTES:
(a) Solid lines for 21°C; dashed lines for 290°C.
(b) For other R ratios and temperatures, see C-8410.

n = fatigue crack growth rate exponent
R = R ratio $= K_{I\min}/K_{I\max}$
S_{ENV} = scaling parameter to account for reactor water environment
S_R = scaling parameter to account for R ratio
T = metal temperature in °F (°C)
ΔK_I = maximum range of K_I fluctuation during a transient in $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
τ_r = load rise time in s

When τ_r exceeds 30 s, τ_r shall be set equal to 30 s. The scaling factor C_o in eq. (19) produces fatigue crack growth rate in units of in./cycle (mm/cycle) when ΔK_I is in units of $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$

(b) The reference fatigue crack growth rate of Alloy 600 exposed to air environment (e.g., subsurface flaws) is given by eq. C-3210(a)(1), with n = 4.1, and C_o calculated in accordance with (a) above with S_{ENV} = 1.

C-8420 FERRITIC STEELS

The fatigue crack growth behavior of ferritic steels is affected by temperature, R ratio ($K_{I\min}/K_{I\max}$), and environment. Reference fatigue crack growth rates for air and water environments are in the course of preparation. The reference fatigue crack growth curves for ferritic vessel steels in A-4300 may be used.

C-8430 OTHER MATERIALS

The fatigue crack growth rates for materials not covered by C-8410 or C-8420 may be obtained from other sources. The growth rate curve should represent conservative values of fatigue crack growth rates for the appropriate environment, cyclic loading, and R ratio.

C-8500 STRESS CORROSION CRACKING GROWTH RATE

C-8510 ALLOY 600 AND ASSOCIATED WELD MATERIALS

The SCC crack growth rate of Alloy 600 and associated weld materials is a function of the material condition, temperature, environment, and stress intensity factor due to sustained loading. Reference SCC crack growth rates for PWR environment are given in C-8511 and for BWR environment in C-8512.

C-8511 Alloy 600 and Associated Weld Materials Alloys 82, 182, and 132 in PWR Environment

The rate of stress corrosion cracking in a PWR environment is given by:

$$\frac{da}{dt} = \exp\left[-\frac{Q_g}{R_g}\left(\frac{1}{T_{abs}} - \frac{1}{T_{ref}}\right)\right]\phi\left(K_I - K_{I\text{th}}\right)^{\eta}$$

where

da/dt = SCC crack growth rate in in./hr (m/s)
K_I = stress intensity factor in $\text{ksi}\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
K_{Ith} = threshold stress intensity factor for SCC, given in Table C-8510-1 (Table C-8510-1M)
Q_g = thermal activation energy for SCC crack growth
R_g = universal gas constant
T_{abs} = absolute metal operating temperature in R (K)
T_{ref} = absolute reference temperature for SCC
ϕ = SCC crack growth rate coefficient, given in Table C-8510-1
η = SCC crack growth rate exponent, given in Table C-8510-1

and

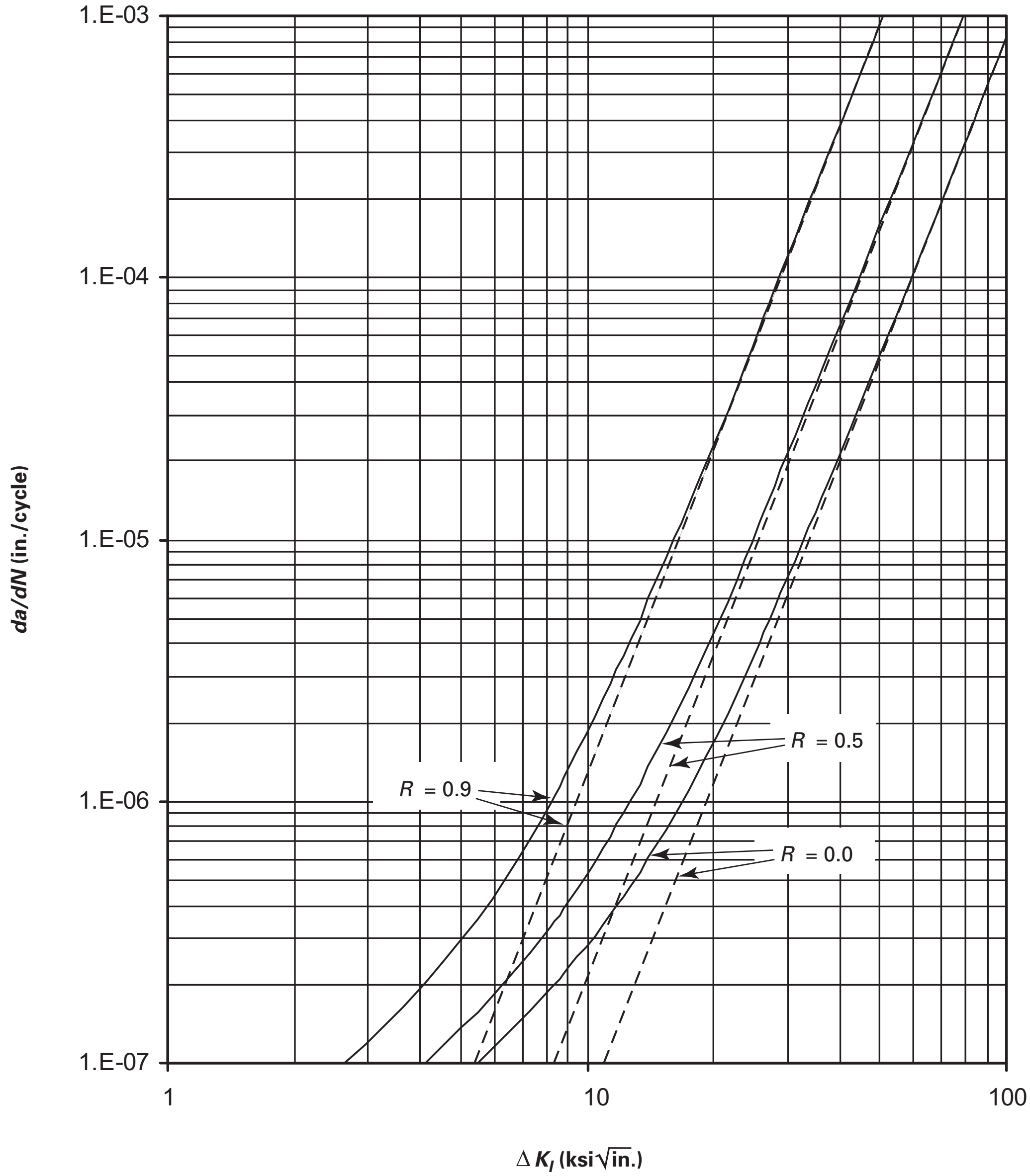
(U.S. Customary Units)

Q_g = 31.0 kcal/mole

R_g = 1.103×10^{-3} kcal/(mole - R)

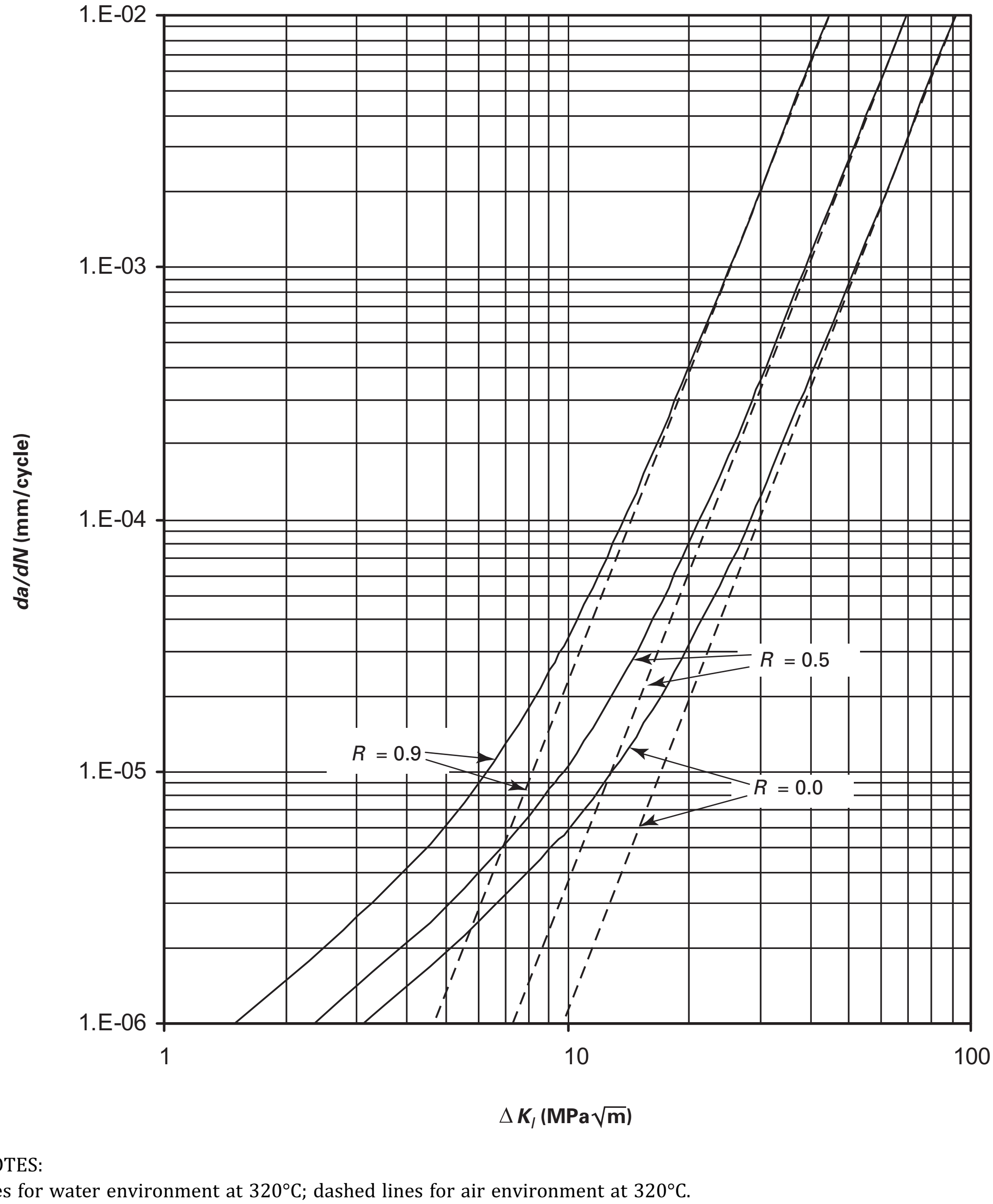
T_{ref} = 1076.7 R

Figure C-8410-2
Reference Fatigue Crack Growth Rate Curves for Alloy 600 at 608°F



GENERAL NOTES:
(a) Solid lines for water environment at 608°F; dashed lines for air environment at 608°F.
(b) For other R ratios and temperatures, see C-8411.

Figure C-8410-2M
Reference Fatigue Crack Growth Rate Curves for Alloy 600 at 320°C



GENERAL NOTES:
(a) Solid lines for water environment at 320°C; dashed lines for air environment at 320°C.
(b) For other R ratios and temperatures, see C-8411.

(SI Units)

Q_g = 130 kJ/mole

R_g = 8.314×10^{-3} kJ/(mole - K)

T_{ref} = 598.15 K

Reference SCC crack growth rate curves for a temperature of 617°F (325°C) are provided in Figure C-8510-1 (Figure C-8510-1M).

C-8512 Alloy 600 and Associated Weld Materials Alloys 182 and 132 in BWR Environment

(a) The rate of stress corrosion cracking in a BWR environment in the flaw depth direction is given by eq. (20). The rate of stress corrosion cracking in a BWR environment in the flaw length direction at each end of the flaw is 5×10^{-5} in./hr (3.5×10^{-10} m/s).

$$\frac{da}{dt} = C_1 K_I^{\eta} \quad \text{for } K_I \le K_{I\text{TR}} \tag{20}$$

$$\frac{da}{dt} = C_2 \quad \text{for } K_{I\text{TR}} < K_I \le K_{I\text{U}}$$

where

C_1 = SCC crack growth rate coefficient for K_1 dependent crack growth
C_2 = SCC crack growth rate coefficient for K_I independent crack growth
da/dt = SCC crack growth rate in in./hr (m/s)
K_I = stress intensity factor in $\text{ksi}\sqrt{\text{in.}}$ $(\text{MPa}\sqrt{\text{m}})$
K_{ITR} = stress intensity factor at the transition from K_I dependent SCC crack growth to K_I independent crack growth
K_{IU} = stress intensity factor at the upper validity limit of the SCC crack growth rate equation
η = SCC crack growth rate exponent

and

(U.S. Customary Units)

K_{ITR} = $25\ \text{ksi}\sqrt{\text{in.}}$

K_{IU} = $45\ \text{ksi}\sqrt{\text{in.}}$

(SI Units)

K_{ITR} = $27.5\ \text{MPa}\sqrt{\text{m}}$

K_{IU} = $49.5\ \text{MPa}\sqrt{\text{m}}$

Equation (20) is valid for K_I not exceeding K_{IU}.

Table C-8510-1
Constants for SCC Model for PWR Environment (U.S. Customary Units)

Material	ϕ $\left[(\text{in./hr})(\text{ksi}\sqrt{\text{in.}})^{-\eta}\right]$	η	K_{Ith} $(\text{ksi}\sqrt{\text{in.}})$
Alloy 600	4.21×10^{-7}	1.16	8.19
Alloy 82	9.50×10^{-8}	1.6	0
Alloy 182	2.47×10^{-7}	1.6	0
Alloy 132	2.47×10^{-7}	1.6	0

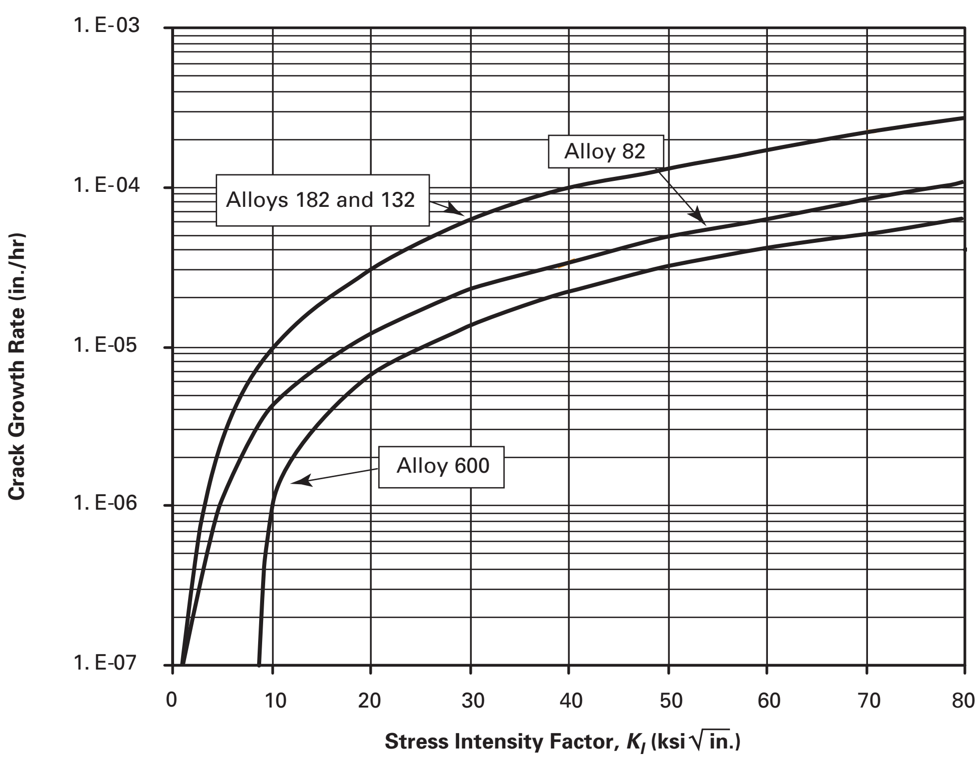
GENERAL NOTE: Factor ϕ is for da/dt in units of in./hr and K_I in units of $\text{ksi}\sqrt{\text{in.}}$.

Table C-8510-1M
Constants for SCC Model for PWR Environment (SI Units)

Material	ϕ $\left[(\text{m/s})(\text{MPa}\sqrt{\text{m}})^{-\eta}\right]$	η	K_{Ith} $(\text{MPa}\sqrt{\text{m}})$
Alloy 600	2.67×10^{-12}	1.16	9.0
Alloy 82	5.77×10^{-13}	1.6	0
Alloy 182	1.5×10^{-12}	1.6	0
Alloy 132	1.5×10^{-12}	1.6	0

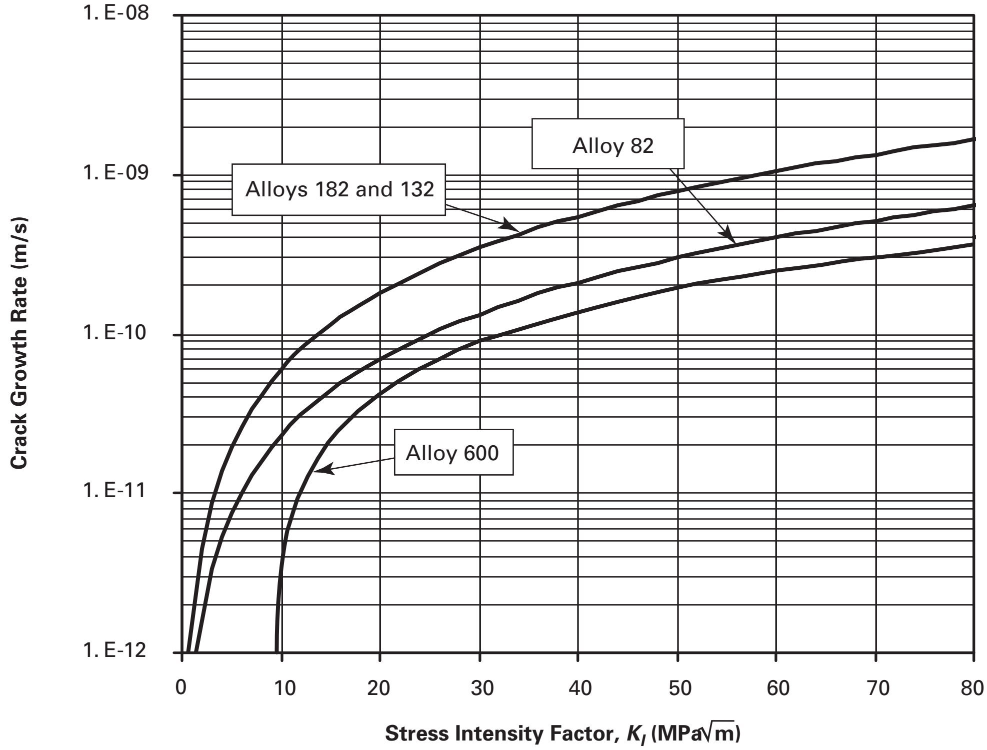
GENERAL NOTE: Factor ϕ is for da/dt in units of m/s and K_I in units of $\text{MPa}\sqrt{\text{m}}$.

Figure C-8510-1
SCC Curves for Alloy 600, 82, 182, and 132 in PWR Environment at 617°F



GENERAL NOTE: For other temperatures, see C-8511.

Figure C-8510-1M
SCC Curves for Alloy 600, 82, 182, and 132 in PWR Environment at 325°C



GENERAL NOTE: For other temperatures, see C-8511.

(b) For a BWR environment with *Normal Water Chemistry,* which is defined by conductivity ≤ 0.3 μS/cm

(U.S. Customary Units)

$$C_1 = 1.6 \times 10^{-8} \left(\text{in./hr}\right)\left(\text{ksi}\sqrt{\text{in.}}\right)^{-\eta}$$

$$C_2 = 5.0 \times 10^{-5}\ \text{in./hr}$$

$$\eta = 2.5$$

(SI Units)

$$C_1 = 8.92 \times 10^{-14} \left(\text{m/s}\right)\left(\text{MPa}\sqrt{\text{m}}\right)^{-\eta}$$

$$C_2 = 3.53 \times 10^{-10}\ \text{m/s}$$

$$\eta = 2.5$$

Reference SCC crack growth rate curves for *Normal Water Chemistry* are provided in Figure C-8510-2 (Figure C-8510-2M).

(c) For a BWR environment with *Hydrogen Water Chemistry,* which is defined by ECP (electrochemical potential) ≤ −230 mV SHE (standard hydrogen electrode)

(U.S. Customary Units)

$$C_1 = 3.2 \times 10^{-10} \left(\text{in./hr}\right)\left(\text{ksi}\sqrt{\text{in.}}\right)^{-\eta}$$

$$C_2 = 5.0 \times 10^{-6}\ \text{in/hr}$$

$$\eta = 3.0$$

(SI Units)

$$C_1 = 1.70 \times 10^{-15} \left(\mathrm{m/s}\right)\left(\mathrm{MPa}\sqrt{\mathrm{m}}\right)^{-\eta}$$

$$C_2 = 3.53 \times 10^{-11}\ \mathrm{m/s}$$

$$\eta = 3.0$$

Reference SCC crack growth rate curves for *Hydrogen Water Chemistry* are provided in Figure C-8510-2.

C-8520 IGSCC IN AUSTENITIC STAINLESS STEEL IN BWR REACTOR WATER ENVIRONMENTS

(a) The following equation provides the IGSCC growth rate in the depth direction for fluence less than or equal to 5×10^{20} n/cm^2 at $E > 1.0$ MeV:

(U.S. Customary Units)

$$\left(\frac{da}{dt}\right) = \exp\left[-0.787\ Cond^{-0.586} + 0.00362\ ECP + \frac{6730}{0.5556\ T_F + 255.2} - 28.073\right](K_I)^{2.181}$$

where

$Cond$ = average conductivity (μS/cm)
da/dt = crack growth rate (in./hr)
ECP = corrosion potential [mV(SHE)]
K_I = stress intensity factor $\left(\mathrm{ksi}\sqrt{\mathrm{in.}}\right)$

Figure C-8510-2
SCC Curves for Alloy 600, 182, and 132 in BWR Environment

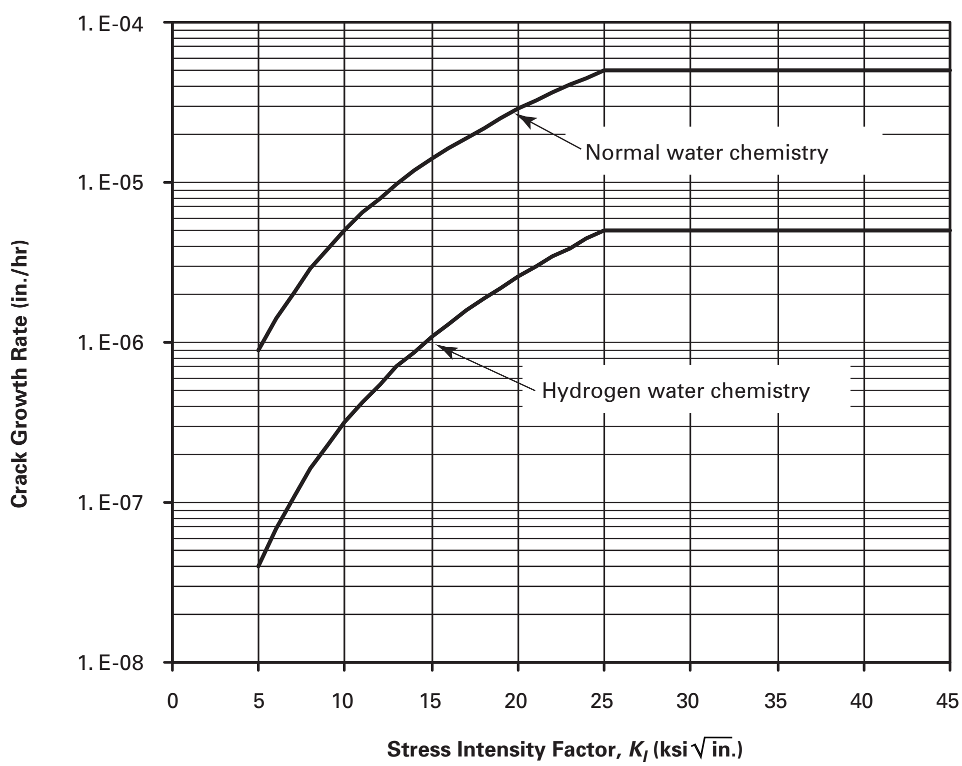
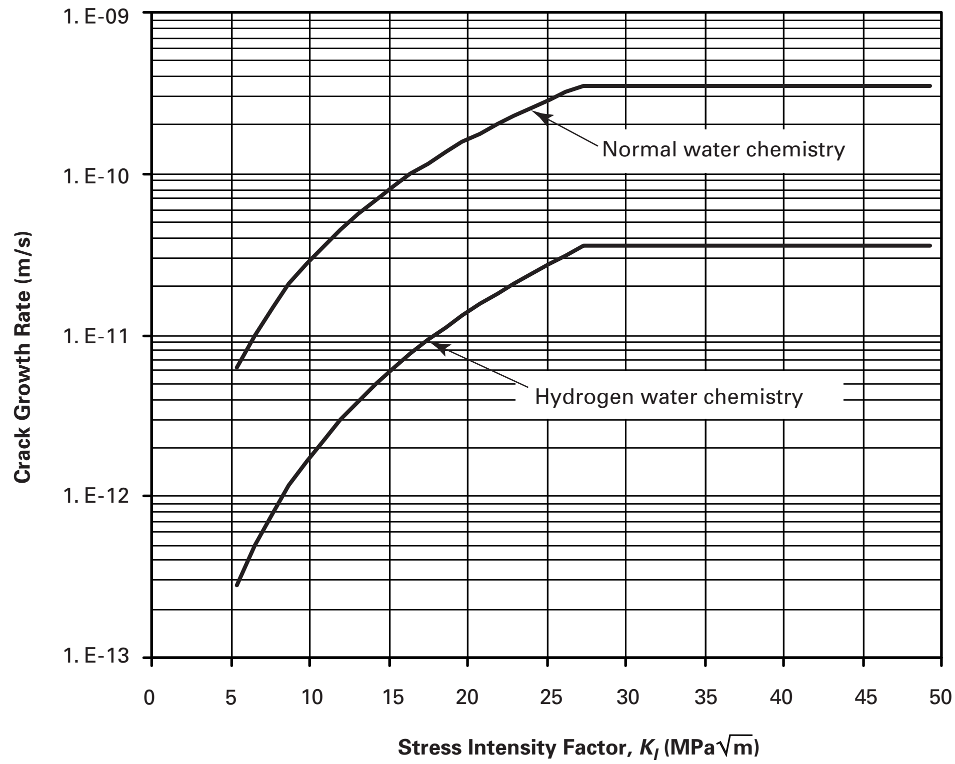


Figure C-8510-2M
SCC Curves for Alloy 600, 182, and 132 in BWR Environment



T_F = temperature (°F)

This equation is valid for $Cond$ between 0.055 and 0.30 μS/cm, ECP between −575 and 250 mV(SHE), T_F between 200°F and 552°F, and chloride and sulfate concentrations each less than or equal to 5 ppb, at the flaw location.

The following equation provides the IGSCC flaw growth rate in the depth direction for fluence less than or equal to 5×10^{20} n/cm^2 at E > 1.0 MeV:

(SI Units)

$$\left(\frac{da}{dt}\right) = \exp\left[-0.787\ Cond^{-0.586} + 0.00362\ ECP + \frac{6730}{T_{abs}} - 33.235\right](K_I)^{2.181}$$

where

$Cond$ = average conductivity (μS/cm)
da/dt = crack growth rate (mm/s)
ECP = corrosion potential [mV(SHE)]
K_I = stress intensity factor (MPa$\sqrt{\text{m}}$)
T_{abs} = temperature (K)

This equation is valid for $Cond$ between 0.055 and 0.30 μS/cm, ECP between −575 and 250 mV(SHE), T_{abs} between 366K and 562K, and chloride and sulfate concentrations each less than or equal to 5 ppb, at the flaw location.

(b) The growth rate for flaw length shall be set at 5.0×10^{-5} in./hr (3.5×10^{-7} mm/s).

(c) The following simplified equation for flaw growth rate in the depth direction with the parameters specified in Table C-8520-1 may be used as an alternative to the equation for the IGSCC flaw depth growth rate in (a). The simplified equation may be used when Cond, ECP, temperature, and chloride and sulfate concentrations, at the flaw location, are within the limits specified in Table C-8520-1.

$$\frac{da}{dt} = A_{SCC}\left(K_I\right)^{\eta}$$

where

A_{SCC} = SCC crack growth rate coefficient given in Table C-8520-1
da/dt = crack growth rate, in./hr (mm/s)
K_I = stress intensity factor, $\text{ksi}\sqrt{\text{in.}}$ $(\text{MPa}\sqrt{\text{m}})$
η = SCC crack growth rate exponent given in Table C-8520-1

Using the parameters specified in Table C-8520-1, reference SCC growth rate curves for Normal Water Chemistry (NWC) and Hydrogen Water Chemistry (HWC) are provided in Figure C-8520-1.

(15)

Table C-8520-1
BWR SCC Growth Rate Parameters (U.S. Customary Units)

Environment [Note (1)]	Limits [Note (2)]	A_{SCC} [(in./hr) $(\text{ksi}\sqrt{\text{in.}})^{-\eta}$]	η
Normal water chemistry outside reactor pressure vessel	Conductivity [Note (3)] ≤ 0.15 µS/cm ECP ≤ 50 mV(SHE) T_F ≥ 530°F	1.46 x 10^{-8}	2.181
Normal water chemistry inside reactor pressure vessel	Conductivity [Note (3)] ≤ 0.15 µS/cm ECP ≤ 200 mV(SHE) T_F ≥ 530°F	2.52 x 10^{-8}	2.181
Hydrogen water chemistry	Conductivity [Note (3)]≤ 0.15 µS/cm ECP ≤ −230 mV(SHE) T_F ≥ 530°F	5.31 x 10^{-9}	2.181

GENERAL NOTE: K_I is in $\text{ksi}\sqrt{\text{in.}}$, and da/dt is in in./hr.

NOTES:
(1) Fluence shall be less than or equal to 5 x 10^{20} n/cm^2 at E > 1.0 MeV.
(2) The specified applicability limits define the environmental conditions at the location of the flaw. Chloride and sulfate concentrations shall each be less than or equal to 5 ppb.
(3) Average conductivity for more than 80% of the evaluation period at the location of the flaw.

Table C-8520-1M BWR SCC Growth Rate Parameters (SI Units)

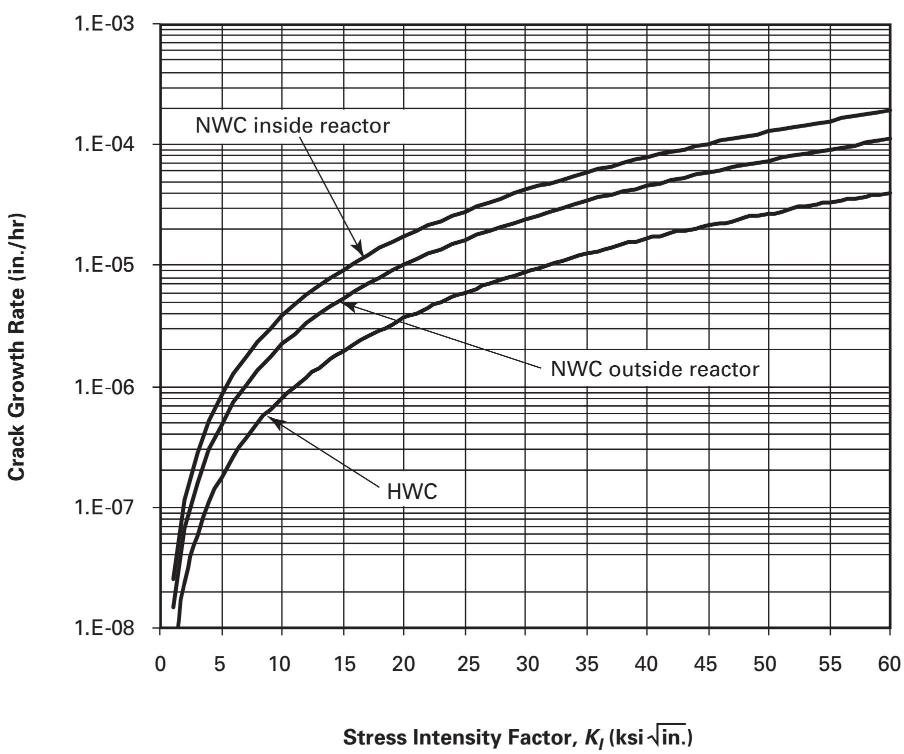
(15)

Environment [Note (1)]	Limits [Note (2)]	A_{SCC} [(mm/s) $(MPa\sqrt{m})^{-\eta}$]	η
Normal water chemistry outside reactor pressure vessel	Conductivity [Note (3)] ≤ 0.15 μS/cm ECP ≤ 50 mV(SHE) T_{abs} ≥ 550K	8.38 x 10^{-11}	2.181
Normal water chemistry inside reactor pressure vessel	Conductivity [Note (3)] ≤ 0.15 μS/cm ECP ≤ 200 mV(SHE) T_{abs} ≥ 550K	1.44 x 10^{-10}	2.181
Hydrogen water chemistry	Conductivity [Note (3)] ≤ 0.15 μS/cm ECP ≤ −230 mV(SHE) T_{abs} ≥ 550K	3.04 x 10^{-11}	2.181

GENERAL NOTE: K_I is in $MPa\sqrt{m}$, and da/dt is in mm/s.

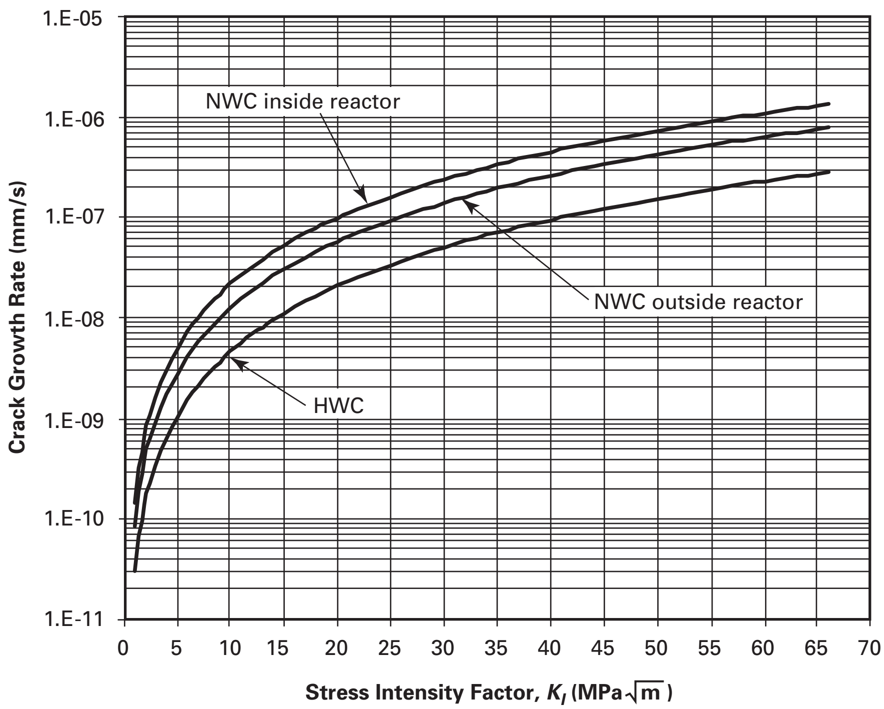
NOTES:
(1) Fluence shall be less than or equal to 5 x 10^{20} n/cm^2 at E > 1.0 MeV″.
(2) The specified applicability limits define the environmental conditions at the location of the flaw. Chloride and sulfate concentrations shall each be less than or equal to 5 ppb.
(3) Average conductivity for more than 80% of the evaluation period at the location of the flaw.

Figure C-8520-1 IGSCC Reference Curves for Austenitic Stainless Steel in BWR Environments



GENERAL NOTE: Environmental limits are defined in Table C-8520-1.

Figure C-8520-1M
IGSCC Reference Curves for Austenitic Stainless Steel in BWR Environments



GENERAL NOTE: Environmental limits are defined in Table C-8520-1M.

(15)

NONMANDATORY APPENDIX D
CONDITIONING OF WELDS THAT REQUIRE ULTRASONIC EXAMINATION

ARTICLE D-1000
APPLICATION OF THIS NONMANDATORY APPENDIX

D-1100 GENERAL

If the Owner chooses to use this Appendix for conditioning a weld requiring ultrasonic examination, all of the applicable provisions shall be met.

D-1200 WELD CONDITIONING

(a) Weld conditioning shall be performed as required to meet the conditions qualified during the Mandatory Appendix VIII demonstration applicable to the ultrasonic examination to be performed. Alternatively, the requirements of (b) through (d) may be used.

(b) If the ultrasonic examination is performed from the outside surface, to allow for adequate scanning over the weld, the weld crown shall be conditioned flush with the base metal.

(c) If the ultrasonic examination is performed from the inside surface, to allow for adequate scanning over the weld, the weld root (or weld crown for a double bevel joint), if accessible, shall be conditioned flush with the base metal.

(d) Flush is defined as no more than a $^{1}/_{32}$-in. (0.8-mm) gap between the search unit and examination surface at any location of the scan surface.

D-1300 SURFACE FINISH

(a) Surface finishing shall be performed as required to meet the surface finish qualified during the Mandatory Appendix VIII demonstration applicable to the ultrasonic examination to be performed. Alternatively, the requirements of (b) may be used.

(b) The ultrasonic examination surface finish shall be 250-μin. (6.3-μm) RMS or better for the weld crown plus a distance of at least two times the nominal wall plus 4 in. (100 mm) from the edge of the weld crown on each side of the weld where examination is to be performed.

NONMANDATORY APPENDIX E
EVALUATION OF UNANTICIPATED OPERATING EVENTS

ARTICLE E-1000
INTRODUCTION

(15) E-1100 SCOPE

This Nonmandatory Appendix provides acceptance criteria and guidance for performing an evaluation of the effects of an out-of-limit condition on the structural integrity of the reactor vessel beltline region. Showing compliance with the criteria in either E-1200 or E-1300 assures that the beltline region has adequate structural integrity for the unit to return to service. Evaluations performed using this Nonmandatory Appendix shall meet all the requirements of the Appendix.

E-1200 ACCEPTANCE CRITERIA[49,50]

Adequate structural integrity of the reactor vessel beltline region is assured if the following applicable criterion is satisfied throughout the event:

(a) For isothermal pressure transients [i.e., $\Delta T_c/\Delta t < 10°F/hr$ (5.5°C/hr)], the maximum pressure does not exceed the allowable values of Table E-1 at any value of $T_c - RT_{NDT}$.

(b) For pressurized thermal transients [i.e., $\Delta T_c/\Delta t \geq 10°F/hr$ (5.5°C/hr)], the maximum pressure does not exceed the design pressure and $T_c - RT_{NDT}$ is not less than 55°F (31°C).

If compliance with the above applicable criterion is not shown, adequate structural integrity can be assured by satisfying the guidelines and criteria specified in E-1300.

(15) E-1300 EVALUATION BY ANALYSIS

(a) Adequate structural integrity of the reactor vessel beltline region is assured if it can be shown by analysis using the input of Table E-2 that the following criterion is met throughout the event:

$$1.4\left(K_{Im} + K_{It}\right) + K_{Ir} \leq K_{Ic}$$

where

K_{Ic} = fracture toughness per Article IWA-9000
K_{Im} = stress intensity factor due to membrane stress
K_{Ir} = stress intensity factor due to residual stress
K_{It} = stress intensity factor due to thermal stress

(b) If compliance with the above criterion cannot be shown, additional analyses or other actions shall be taken to ensure that acceptable margins of safety will be maintained during subsequent operation.

Table E-1
Maximum Allowable Pressure as a Function of $T_c - RT_{NDT}$ for Isothermal Pressure Transients [$\Delta T_c/\Delta t < 10°F/hr$ (5.5°C/h)] for Design Pressures Greater Than 2,400 psig (16.5 MPa)

$T_c - RT_{NDT}$ °F (°C)	Maximum Allowable Pressure, psig (MPa)
+ 25 (14) and greater	1.1 × Design
+ 15 (8)	2400 (16.5)
+ 10 (5.5)	2250 (15.5)
0 (0)	2000 (13.8)
−10 (−5.5)	1750 (12.1)
−25 (−14)	1500 (10.3)
−50 (−28)	1200 (8.3)
−75 (−42)	1000 (6.9)
−105 (−58)	850 (5.9)
−130 (−72)	800 (5.5)
−200 (−111)	750 (5.2)

GENERAL NOTE: Linear interpolation is permitted.

Table E-2
Input for Plant and Event Specific Linear Elastic Fracture Mechanics Analysis (15)

Variable	Value
Pressure	Event pressure time history
Temperature	Event temperature time history
Heat transfer	Event/plant specific flow/mixing conditions
Crack type	Semi-elliptical surface flaw
Minimum initiation crack size	$0.0 < a \leq 1.0$ in. (25 mm) [Note (1)]
Crack orientation	Longitudinal
K_{Ic}/K_I location	Surface and maximum depth
Clad effects	Clad to be considered in the thermal, stress, and fracture mechanics analyses [Note (2)]
Transition toughness	K_{Ic} per Article IWA-9000
Upper shelf toughness	(In course of preparation)
Fluence	Fluence at the time of the transient
Shift curve	Regulatory Guide 1.99 Rev. 2
Residual stress	Appropriate distribution for the fabrication process, or linear distribution with +10 ksi (+69 MPa) at the inside surface and −10 ksi (−69 MPa) at the outside surface

NOTES:
(1) a = the maximum crack depth in the base metal
(2) The stresses due to the difference between the base metal and cladding thermal expansion coefficients need not be considered in the isothermal pressure transient analysis [i.e., $\Delta T_c/\Delta t$ < 10°F/hr (5.5°C/h)].

NONMANDATORY APPENDIX G
FRACTURE TOUGHNESS CRITERIA FOR PROTECTION AGAINST FAILURE

ARTICLE G-1000
INTRODUCTION

G-1100 SCOPE

This Nonmandatory Appendix presents a procedure for obtaining the allowable loadings for ferritic pressure-retaining materials in components. This procedure is based on the principles of linear elastic fracture mechanics. At each location being investigated a maximum postulated flaw is assumed. At the same location the *mode I stress intensity factor*[51] K_I is produced by each of the specified loadings as calculated and the summation of the K_I values is compared to a reference value K_{Ic} which is the highest critical value of K_I that can be ensured for the material and temperature involved. Different procedures are recommended for different components and operating conditions. Evaluations performed using this Nonmandatory Appendix shall meet all the requirements of the Appendix.

ARTICLE G-2000 VESSELS

G-2100 GENERAL REQUIREMENTS

G-2110 REFERENCE CRITICAL STRESS INTENSITY FACTOR (15)

(a) Figure G-2210-1 is a curve showing the relationship that can be conservatively expected between the critical, or reference, stress intensity factor K_{Ic}, $\text{ksi}\sqrt{\text{in.}}$, $\left(\text{MPa}\sqrt{\text{m}}\right)$ and a temperature which is related to the reference nil-ductility temperature RT_{NDT} determined in NB-2331. Alternatively, if a material-specific temperature value, T_0, determined in accordance with ASTM E1921, Standard Test Method for the Determination of Reference Temperature, T_0, for Ferritic Steels in the Transition Range, is available, a reference temperature, RT_{T0}, may be used in place of RT_{NDT}. The reference temperature RT_{T0} is defined as

(U.S. Customary Units)

$$RT_{T0} = T_0 + 35°\text{F}$$

(SI Units)

$$RT_{T0} = T_0 + 19.4°\text{C}$$

Determination of RT_{T0} shall be the responsibility of the Owner and subject to the approval of the regulatory authority having jurisdiction at the plant site. The K_{Ic} curve is based on the lower bound of static critical K_I values measured as a function of temperature on specimens of SA-533 Grade B Class 1, and SA-508-1, SA-508-2, and SA-508-3 steel. No available data points for static tests fall below the curve. An analytical approximation to the curve is:

(U.S. Customary Units)

$$K_{Ic} = 33.2 + 20.734\exp\left[0.02\left(T - RT_{NDT}\right)\right]$$

(SI Units)

$$K_{Ic} = 36.5 + 22.783\exp\left[0.036\left(T - RT_{NDT}\right)\right]$$

Unless higher K_{Ic} values can be justified for the particular material and circumstances being considered, Figure G-2210-1 may be used for ferritic steels which meet the requirements of NB-2331 and which have a specified minimum yield strength at room temperature of 50 ksi (350 MPa) or less.

(b) For materials which have specified minimum yield strengths at room temperature greater than 50 ksi (350 MPa) but not exceeding 90 ksi (620 MPa), Figure G-2210-1 may be used provided fracture mechanics data are obtained on at least three heats of the material on a sufficient number of specimens to cover the temperature range of interest, including the weld metal and heat-affected zone, and provided that the data are equal to or above the curve of Figure G-2210-1. These data shall be documented by the Owner. Where these materials of higher yield strengths (specified minimum yield strength greater than 50 ksi (350 MPa) but not exceeding 90 ksi (620 MPa) are to be used in conditions where radiation may affect the material properties, the effect of radiation on the K_{Ic} curve shall be determined for the material. This information shall be documented by the Owner.

G-2120 MAXIMUM POSTULATED DEFECT

The postulated defects used in this recommended procedure are sharp, surface defects oriented axially for plates, forgings, and axial welds, and circumferentially for circumferential welds. For section thicknesses of 4 in. to 12 in. (100 mm to 300 mm), the postulated defects have a depth of one-fourth of the section thickness and a length of $1\frac{1}{2}$ times the section thickness. Defects are postulated at both the inside and outside surfaces. For sections greater than 12 in. (300 mm) thick, the postulated defect for the 12 in. (300 mm) section is used. For sections less than 4 in. (100 mm) thick, the 1 in. (25 mm) deep defect is conservatively postulated. Smaller defect sizes[52] may be used on an individual case basis if a smaller size of maximum postulated defect can be ensured. Due to the structural factors recommended here, the prevention of nonductile fracture is ensured for some of the most important situations even if the defects were to be about twice as large in linear dimensions as this postulated maximum defect.

G-2200 LEVELS A AND B SERVICE LIMITS

G-2210 SHELLS AND HEADS REMOTE FROM DISCONTINUITIES

G-2211 Recommendations

The assumptions of this Subarticle are recommended for shell and head regions during Level A and B Service Limits.

G-2212 Material Fracture Toughness

G-2212.1 Reference Critical Stress Intensity Factor for Material. The K_{Ic} values of Figure G-2210-1 (Figure G-2210-1M) are recommended.

G-2212.2 Irradiation Effects. Subarticle A-4400 of Nonmandatory Appendix A is recommended to define the change in reference critical stress intensity factor due to irradiation.

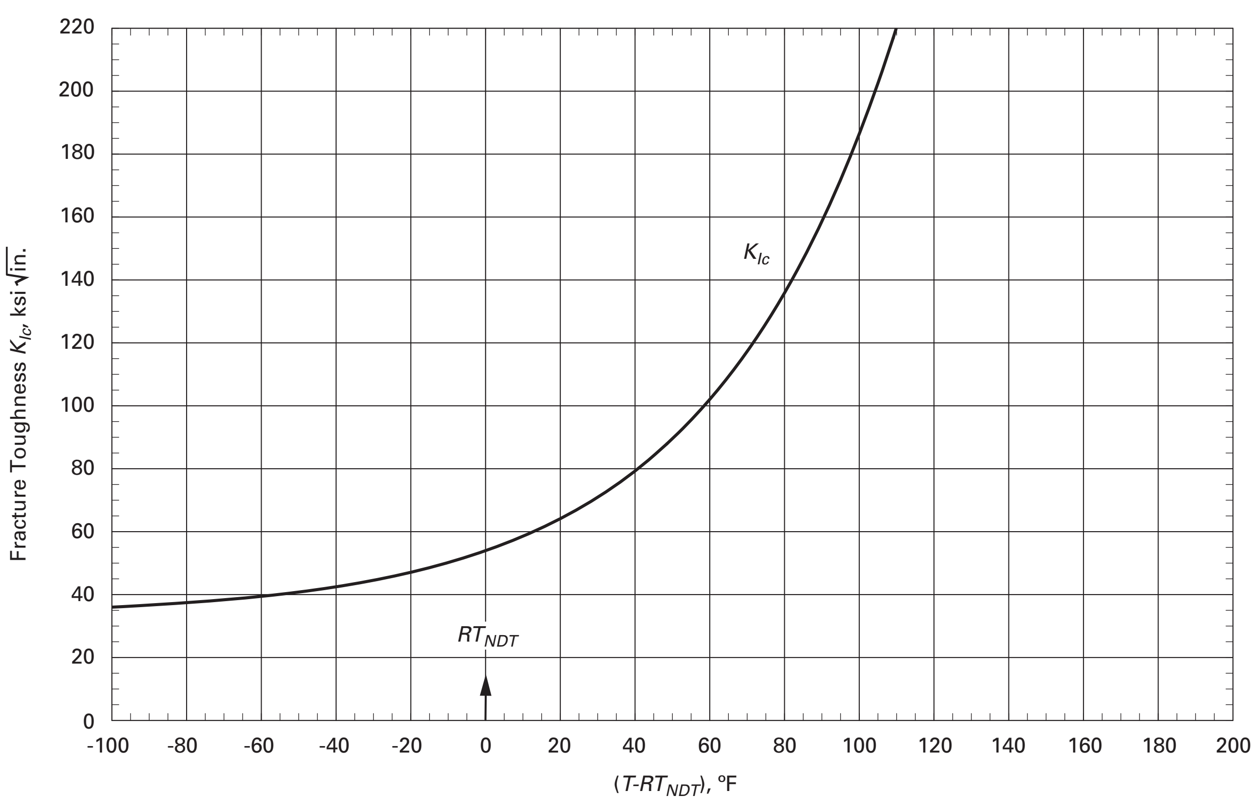
G-2213 Maximum Postulated Defects

The recommended maximum postulated defects are described in G-2120.

G-2214 Calculated Stress Intensity Factors

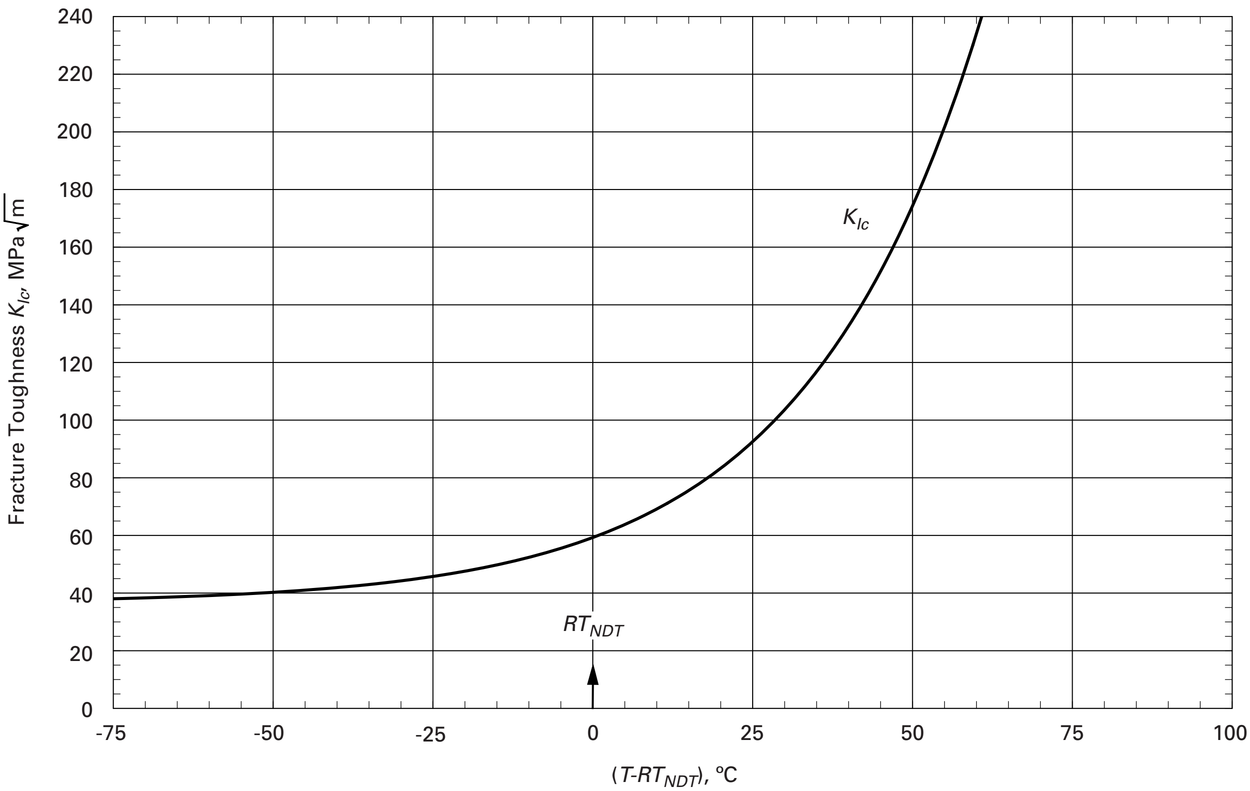
G-2214.1 Membrane Tension. The K_I corresponding to membrane tension for the postulated axial defect of G-2120 is $K_{Im} = M_m \times (pR_i/t)$, where M_m for an inside axial surface flaw is given by

Figure G-2210-1
Reference Critical Stress Intensity Factor for Material



GENERAL NOTE: $1 \text{ ksi}\sqrt{\text{in.}} = 1.1 \text{ MPa}\sqrt{\text{m}}$

Figure G-2210-1M
Reference Critical Stress Intensity Factor for Material



(U.S. Customary Units)
M_m = 1.85 for t < 4 in.
$M_m = 0.926\sqrt{t}$ for 4 in. $\leq t \leq$ 12 in.
M_m = 3.21 for t > 12 in.

(SI Units)
M_m = 0.296 for t < 102 mm
$M_m = 0.0293\sqrt{t}$ for 102 mm $\leq t \leq$ 305 mm
M_m = 0.51 for t > 305 mm

Similarly, M_m for an outside axial surface flaw is given by

(U.S. Customary Units)
M_m = 1.77 for t < 4 in.
$M_m = 0.893\sqrt{t}$ for 4 in. $\leq t \leq$ 12 in.
M_m = 3.09 for t > 12 in.

(SI Units)
M_m = 0.285 for t < 102 mm
$M_m = 0.0282\sqrt{t}$ for 102 mm $\leq t \leq$ 305 mm
M_m = 0.493 for t > 305 mm

where

p = internal pressure, ksi (MPa)
R_i = vessel inner radius, in. (mm)
t = vessel wall thickness, in. (mm)

The K_I corresponding to membrane tension for the postulated circumferential defect of G-2120 is $K_{Im} = M_m \times (pR_i/t)$, where M_m, for an inside or an outside circumferential surface defect is given by

(U.S. Customary Units)
M_m = 0.89 for $t < 4$ in.
$M_m = 0.443\sqrt{t}$ for 4 in. $\leq t \leq$ 12 in.
M_m = 1.53 for $t > 12$ in.

(SI Units)
M_m = 0.141 for $t < 102$ mm
$M_m = 0.0140\sqrt{t}$ for 102 mm $\leq t \leq$ 305 mm
M_m = 0.245 for $t > 305$ mm

G-2214.2 Bending Stress. The K_I corresponding to bending stress for postulated axial or circumferential defect of G-2120 is $K_{Ib} = M_b \times$ maximum bending stress, where M_b is two-thirds of M_m for the axial defect.

G-2214.3 Radial Thermal Gradient. The maximum K_I produced by a radial thermal gradient for a postulated axial or circumferential inside surface defect of G-2120 is

(U.S. Customary Units)
$$K_{It} = 0.953 \times 10^{-3} \times CR \times t^{2.5}$$

(SI Units)
$$K_{It} = 0.579 \times 10^{-6} \times CR \times t^{2.5}$$

where CR is the cooldown rate in °F/hr (°C/hr), t is the thickness in in. (mm), and K_{It} is in ksi $\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$ or, for a postulated axial or circumferential outside surface defect

(U.S. Customary Units)
$$K_{It} = 0.753 \times 10^{-3} \times HU \times t^{2.5}$$

(SI Units)
$$K_{It} = 0.458 \times 10^{-6} \times HU \times t^{2.5}$$

where HU is the heatup rate in °F/hr (°C/h).

The through-wall temperature difference associated with the maximum thermal K_I can be determined from Figure G-2214-1. The temperature at any radial distance from the vessel surface can be determined from Figure G-2214-2 for the maximum thermal K_I.

(a) The maximum thermal K_I and the temperature relationship in Figure G-2214-1 are applicable only for the conditions in (1) and (2), as follows:

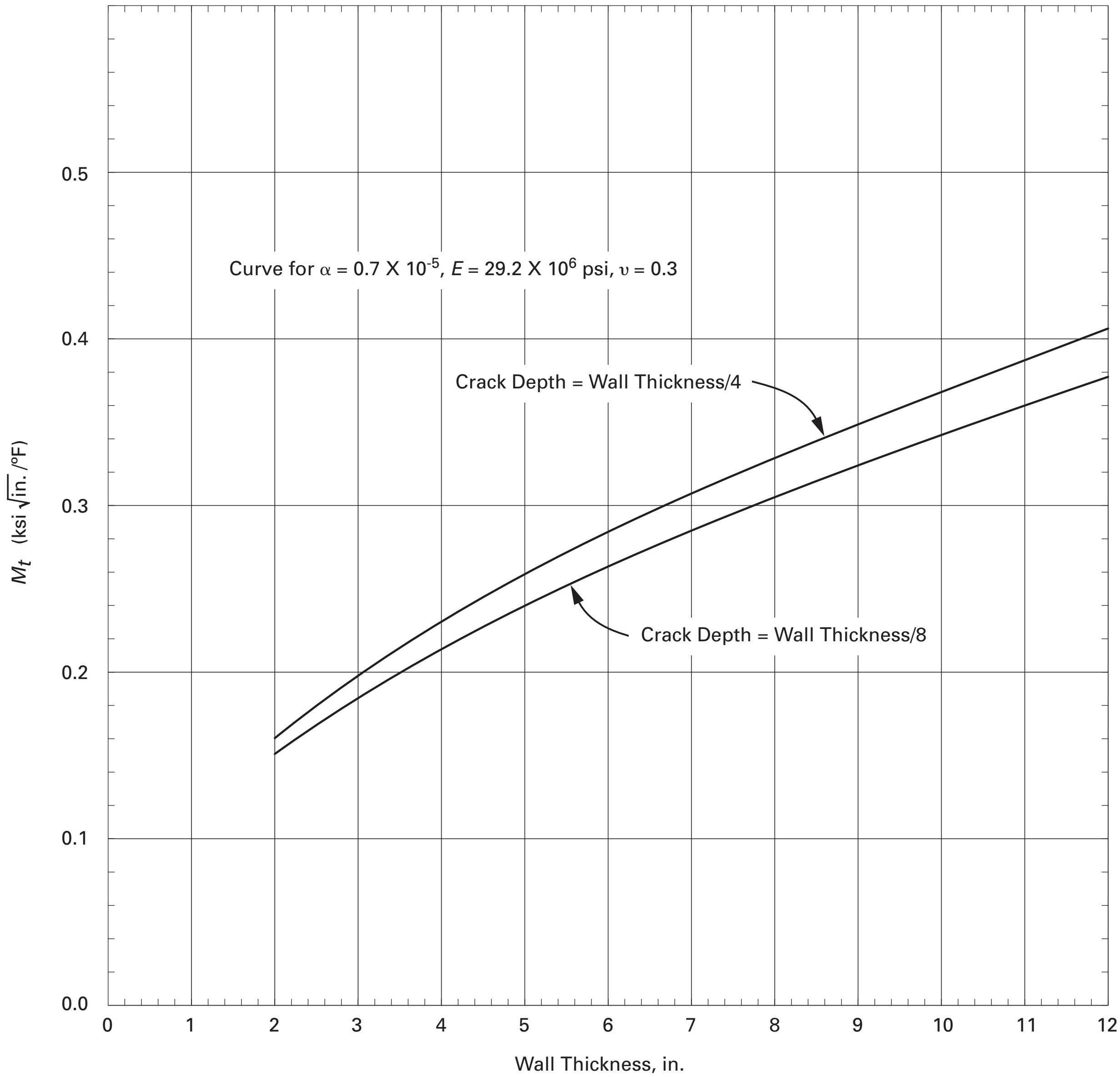
(1) An assumed shape of the temperature gradient is approximately as shown in Figure G-2214-2.

(2) The temperature change starts from a steady state condition and has a rate, associated with startup and shutdown, less than about 100°F/hr (56°C/hr). The results would be overly conservative if applied to rapid temperature changes.

(b) Alternatively, the K_I for radial thermal gradient can be calculated for any thermal stress distribution at any specified time during cooldown for a 1/4-thickness axial or circumferential surface defect.

For an inside surface defect during cooldown

Figure G-2214-1
M_t vs. Wall Thickness for Postulated Inside Surface Reference Flaws



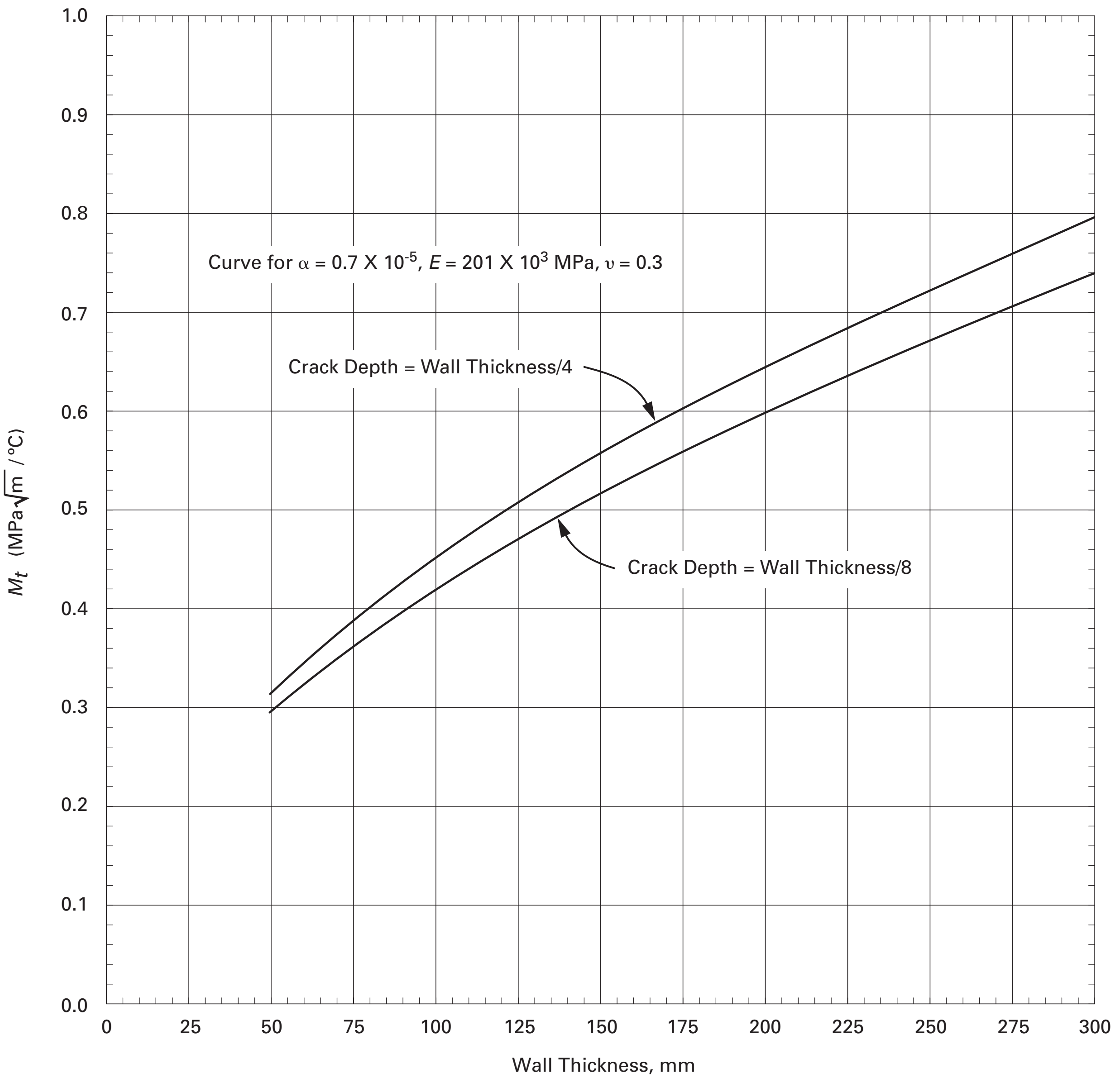
GENERAL NOTE:

$$\Delta T_w = K_{It}/M_t$$

where

K_{It} = stress intensity factor, ksi $\sqrt{\text{in.}}$
ΔT_w = temperature difference through the wall, °F

Figure G-2214-1M
M_t vs. Wall Thickness for Postulated Inside Surface Reference Flaws



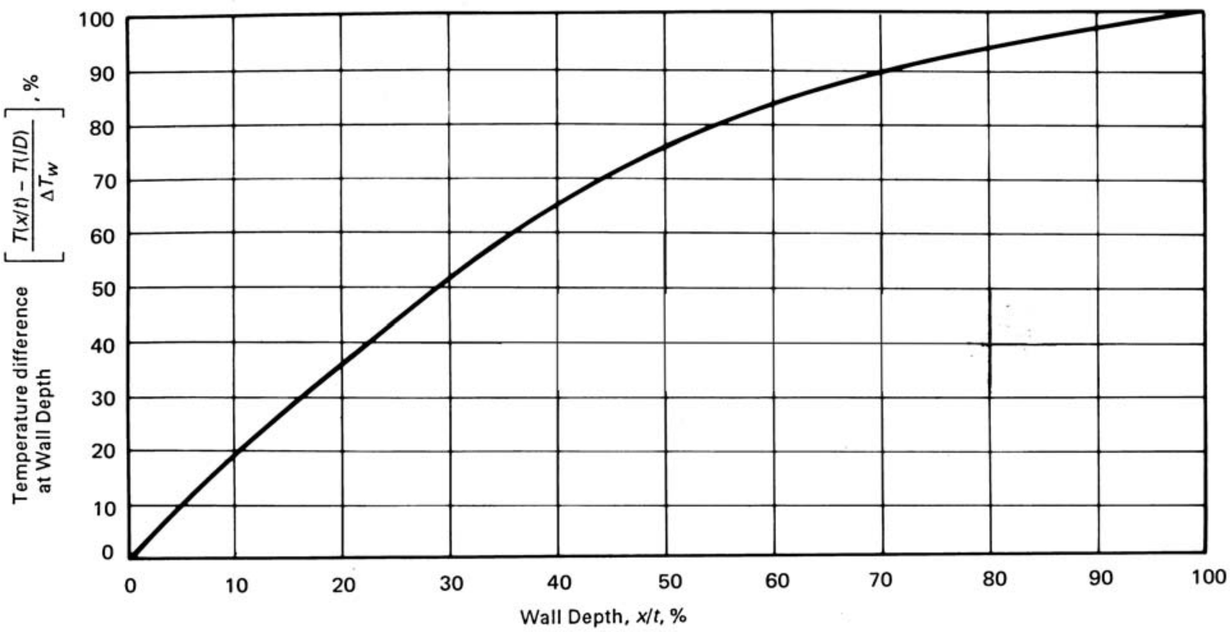
GENERAL NOTE:

$$\Delta T_w = K_{It}/M_t$$

where

K_{It} = stress intensity factor, MPa $\sqrt{m}$
ΔT_w = temperature difference through the wall, °C

Figure G-2214-2
Through-Wall Temperature Difference vs. Wall Depth for Heatup or Cooldown



GENERAL NOTE:

$$\text{Temperature difference} = \frac{T(x/t) - T(\text{I.D.})}{\Delta T_W}, \%$$

where

ΔT_w = temperature (O.D.) − temperature (I.D.)

(U.S. Customary Units)

$$K_{It} = \left(1.0359C_0 + 0.6322C_1 + 0.4753C_2 + 0.3855C_3\right)\sqrt{\pi a}$$

(SI Units)

$$K_{It} = \left(0.2259C_0 + 0.1378C_1 + 0.1036C_2 + 0.08405C_3\right)\sqrt{\pi a}$$

For an outside surface defect during heatup

(U.S. Customary Units)

$$K_{It} = \left(1.043C_0 + 0.630C_1 + 0.481C_2 + 0.401C_3\right)\sqrt{\pi a}$$

(SI Units)

$$K_{It} = \left(0.227C_0 + 0.137C_1 + 0.105C_2 + 0.0874C_3\right)\sqrt{\pi a}$$

The coefficients C_0, C_1, C_2, and C_3 are determined from the thermal stress distribution at any specified time during the heatup or cooldown using

$$\sigma(x) = C_0 + C_1(x/a) + C_2(x/a)^2 + C_3(x/a)^3$$

where x is a dummy variable that represents the radial distance, in. (mm), from the appropriate (i.e., inside or outside) surface and a is the maximum crack depth, in.

(c) For the startup condition, the allowable pressure vs. temperature relationship is the minimum pressure at any temperature, determined from

(1) the calculated steady state results for the $^1/_4$-thickness inside surface defect

(2) the calculated steady state results for the $^1/_4$-thickness outside surface defect

(3) the calculated results for the maximum allowable heatup rate using a $^1/_4$-thickness outside surface defect

G-2215 Allowable Pressure

The equations given in this Subarticle provide the basis for determination of the allowable pressure at any temperature at the depth of the postulated defect during Service Conditions for which Levels A and B Service Limits are specified. In addition to the conservatism of these assumptions, it is recommended that a factor of 2 be applied to the calculated K_I values produced by primary stresses. In shell and head regions remote from discontinuities, the only significant loadings are: (1) general primary membrane stress due to pressure; and (2) thermal stress due to thermal gradient through the thickness during startup and shutdown. Therefore, the requirement to be satisfied and from which the allowable pressure for any assumed rate of temperature change can be determined is

$$2K_{Im} + K_{It} < K_{Ic} \tag{1}$$

throughout the life of the component at each temperature with K_{Im} from G-2214.1, K_{It} from G-2214.3, and K_{Ic} from Figure G-2210-1.

The allowable pressure at any temperature shall be determined as follows:

(a) For the startup condition,

(1) consider postulated defects in accordance with G-2120;

(2) perform calculations for thermal stress intensity factors due to the specified range of heat-up rates from G-2214.3;

(3) calculate the K_{Ic} toughness for all vessel beltline materials from G-2212 using temperatures and RT_{NDT} values for the corresponding locations of interest; and

(4) calculate the pressure as a function of coolant inlet temperature for each material and location. The allowable pressure-temperature relationship is the minimum pressure at any temperature determined from

(-a) the calculated steady-state (K_{It} = 0) results for the $^1/_4$-thickness inside surface postulated defects using the equation

$$P = \frac{K_{Ic}}{2M_m}\left(t / \mathrm{R_i}\right)$$

(-b) the calculated results from all vessel beltline materials for the heatup stress intensity factors using the corresponding $^1/_4$-thickness outside-surface postulated defects and the equation

$$P = \frac{K_{Ic} - K_{It}}{2M_m}\left(t / \mathrm{R_i}\right)$$

(b) For the cooldown condition,

(1) consider postulated defects in accordance with G-2120;

(2) perform calculations for thermal stress intensity factors due to the specified range of cooldown rates from G-2214.3;

(3) calculate the K_{Ic} toughness for all vessel beltline materials from G-2212 using temperatures and RT_{NDT} values for the corresponding location of interest; and

(4) calculate the pressure as a function of coolant inlet temperature for each material and location using the equation.

$$P = \frac{K_{Ic} - K_{It}}{2M_m}\left(t / \mathrm{R_i}\right)$$

The allowable pressure–temperature relationship is the minimum pressure at any temperature, determined from all vessel beltline materials for the cooldown stress intensity factors using the corresponding $^1/_4$-thickness inside-surface postulated defects.

Those plants having low temperature overpressure protection (LTOP) systems can use the following load and temperature conditions to provide protection against failure during reactor start-up and shutdown operation due to low temperature overpressure events that have been classified as Service Level A or Level B events. LTOP systems shall be effective at coolant temperatures less than 200°F (95°C) or at coolant temperatures corresponding to a reactor vessel metal temperature less than RT_{NDT} + 50°F (28°C), whichever is greater.[53,54] LTOP systems shall limit the maximum pressure in the vessel to 100% of the pressure determined to satisfy eq. (1).

G-2216 Risk-Informed Allowable Pressure

The equations given in this paragraph provide an alternative risk-informed methodology to compute allowable pressure as a function of inlet temperature for reactor heat-up and cool-down at rates not to exceed 100°F/hr (56°C/hr). The allowable pressure is defined as

(U.S. Customary Units)

$$p = \{33.2 + 20.734 \times \exp\left[0.02(T - RT_{NDT} - 110)\right] - K_{It}\} \times t/R_i \times 1/M_m$$

where

p = pressure (ksi)
RT_{NDT} = $RT_{NDT(u)} + \Delta RT_{NDT}$, and is the reference nil ductility temperature adjusted for irradiation effects at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3, °F
$RT_{NDT(u)}$ = equivalent to the unirradiated RT_{NDT} calculated in accordance with NB-2300, °F
ΔRT_{NDT} = an adjustment for irradiation effects, °F
T = temperature at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3, °F

(SI Units)

$$p = \{36.5 + 22.783 \times \exp\left[0.036(T - RT_{NDT} - 61)\right] - K_{It}\} \times t/R_i \times 1/M_m$$

where

p = pressure, MPa
RT_{NDT} = $RT_{NDT(u)} + \Delta RT_{NDT}$, and is the reference nil ductility temperature adjusted for irradiation effects at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3, °C
$RT_{NDT(u)}$ = equivalent to the unirradiated RT_{NDT} calculated in accordance with NB-2300, °C
ΔRT_{NDT} = an adjustment for irradiation effects, °C
T = temperature at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3, °C

K_{It} is as stipulated in G-2214.3, and t, R_i, M_m are as stipulated in G-2214.1. The evaluation is to be performed for all conditions, materials, and locations as described in G-2215.

The operational pressure-temperature limits are based on the temperature at the reactor coolant inlet temperature, which is assumed to equal the temperature at the vessel inner surface. Figure G-2214-1 or Figure G-2214-1M and Figure G-2214-2 can be used to determine the temperature at the vessel inner surface corresponding to the temperature at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3.

ΔRT_{NDT} is determined from plant-specific surveillance data, or the irradiation degradation model used to compute the risk-informed allowable pressure as shown in eq. (2), or other irradiation degradation models acceptable to the regulatory authority having jurisdiction at the plant site.

$$\Delta RT_{NDT} = MF + CRP \tag{2}$$

(U.S. Customary Units)

$$MF = A(1 - 0.001718T_i)(1 + 6.13P\,Mn^{2.471})(\Phi_e)^{1/2}$$

where

A = 1.140×10^{-7} for forgings
= 1.561×10^{-7} for plates
= 1.417×10^{-7} for welds
Mn = bulk material manganese content, wt. %
P = bulk material phosphorus content, wt. %

T_i = irradiation temperature, °F

$$\Phi_e = \begin{Bmatrix} \Phi \text{ for } \phi \geq 4.39 \times 10^{10} \\ \Phi \left(\dfrac{4.39 \times 10^{10}}{\phi} \right)^{0.2595} \text{ for } \phi < 4.39 \times 10^{10} \end{Bmatrix}$$

Φ = neutron fluence, cm^{-2}
= neutron flux, $cm^{-2}s^{-1}$
Φ_e = effective neutron fluence, cm^{-2}

$$CRP = B\left(1 + 3.77Ni^{1.191}\right) f(Cu_e, P) g(Cu_e, Ni, \Phi_e)$$

where

B = 102.3 for forgings
= 135.2 for plates in vessels manufactured by Combustion Engineering (CE)
= 102.5 for non-CE plates
= 155.0 for welds
Ni = bulk material nickel content, wt. %

$$Cu_e = \begin{Bmatrix} 0 \text{ for } Cu < 0.072 \\ \min\left[Cu, Cu_{max}\right] \text{ for } Cu > 0.072 \end{Bmatrix}$$

= effective material copper content, wt. %
Cu = bulk material copper content, wt. %
Cu_{max} = 0.243 for Linde 80 welds with Ni > 0.5
= 0.301 for all other materials

$$f(Cu_e, P) = \begin{Bmatrix} 0 \text{ for } Cu \leq 0.072 \\ \left[Cu_e - 0.072\right]^{0.668} \\ \text{for } Cu > 0.072 \text{ and } P \leq 0.008 \\ \left[Cu - 0.072 + 1.359\left(P - 0.008\right)\right]^{0.668} \\ \text{for } Cu > 0.072 \text{ and } P > 0.008 \end{Bmatrix}$$

$$g(Cu_e, Ni, \Phi_e) = \frac{1}{2} + \frac{1}{2} \tanh\left[\frac{\left(\log_{10}\left(\Phi_e\right) + 1.139Cu_e - 0.448Ni - 18.120 \right)}{0.629} \right]$$

(SI Units)

$$MF = A(0.945 - 0.003092T_i)(1 + 6.13P\,Mn^{2.471})(\Phi_e)^{1/2}$$

where

A = 6.333×10^{-8} for forgings
= 8.672×10^{-8} for plates
= 7.872×10^{-8} for welds
Mn = bulk material manganese content, wt. %
P = bulk material phosphorus content, wt. %
T_i = irradiation temperature, °C

$$\Phi_e = \left\{ \begin{array}{l} \Phi \text{ for } \phi \geq 4.39 \times 10^{10} \\ \Phi \left(\dfrac{4.39 \times 10^{10}}{\phi} \right)^{0.2595} \quad \text{for } \phi < 4.39 \times 10^{10} \end{array} \right\}$$

Φ_e = effective neutron fluence, cm^{-2}
Φ = neutron fluence, cm^{-2}
ϕ = neutron flux, cm^{-2}s^{-1}

$$CRP = B\left(1 + 3.77Ni^{1.191}\right)f(Cu_e, P)g(Cu_e, Ni, \Phi_e)$$

where

B = 56.83 for forgings
= 75.11 for plates in vessels manufactured by Combustion Engineering (CE)
= 56.94 for non-CE plates
= 86.11 for welds

Ni = bulk material nickel content, wt. %

$$Cu_e = \left\{ \begin{array}{l} 0 \text{ for } Cu < 0.072 \\ \text{minimum}\left[Cu, Cu_{max}\right] \text{ for } Cu > 0.072 \end{array} \right\}$$

= effective material copper content, wt. %

Cu = bulk material copper content, wt. %

Cu_{max} = 0.243 for Linde 80 welds with $Ni > 0.5$
= 0.301 for all other materials

$$f(Cu_e, P) = \left\{ \begin{array}{l} 0 \text{ for } Cu \leq 0.072 \\ \left[Cu_e - 0.072 \right]^{0.668} \\ \text{for } Cu > 0.072 \text{ and } P \leq 0.008 \\ \left[Cu - 0.072 + 1.359(P - 0.008) \right]^{0.668} \\ \text{for } Cu > 0.072 \text{ and } P > 0.008 \end{array} \right\}$$

$$g(Cu_e, Ni, \Phi_e) = \frac{1}{2} + \frac{1}{2}\tanh\left[\frac{\left(\log_{10}\left(\Phi_e\right) + 1.139Cu_e - 0.448Ni - 18.120 \right)}{0.629} \right]$$

G-2220 NOZZLES, FLANGES, AND SHELL REGIONS NEAR GEOMETRIC DISCONTINUITIES

G-2221 General Requirements

The same general procedure as was used for the shell and head regions in G-2210 may be used for areas where more complicated stress distributions occur, but certain modifications of the procedures for determining allowable applied loads shall be followed in order to meet special situations, as stipulated in G-2222 and G-2223.

G-2222 Consideration of Membrane and Bending Stresses

(a) Equation G-2215(1) requires modification to include the bending stresses which may be important contributors to the calculated K_I value at a point near a flange or nozzle. The terms whose sum must be $< K_{Ic}$ for Levels A and B conditions are:

(1) $2K_{Im}$ from G-2214.1 for primary membrane stress;
(2) $2K_{Ib}$ from G-2214.2 for primary bending stress;
(3) K_{Im} from G-2214.1 for secondary membrane stress;
(4) K_{Ib} from G-2214.2 for secondary bending stress.

(b) For purposes of this evaluation, stresses from bolt or stud preloading shall be considered as primary.

(c) It is recommended that when the flange and adjacent shell region are stressed by the full intended bolt or stud preload and by pressure not exceeding 20% of the preoperational system hydrostatic test pressure, minimum metal temperature in the stressed region should be at least the initial RT_{NDT} temperature for the material in the stressed regions plus any effects of irradiation at the stressed regions.

(d) Thermal stresses shall be considered as secondary except as provided in NB-3213.13(b). The K_I of G-2214.3(b) is recommended for the evaluation of thermal stress.

(15) G-2223 Toughness Requirements for Nozzles

(a) A defect shall be postulated at the corner of the nozzle and cylindrical shell. The postulated defect is defined as circular in shape, with a depth equal to one-fourth of the length of a path oriented 45 deg to the nozzle flow axis that extends from the center point on the surface of the nozzle inner corner to the outside surface of the RPV wall ($^1/_4$-thickness), as shown in Figure G-2223-1. A smaller defect size may be postulated, appropriately considering the combined effects of internal pressure, external loading, thermal stresses, and flaw shape. Postulated defect sizes other than $^1/_4$-thickness shall be no smaller than the applicable inservice inspection acceptance standards in Table IWB-3410-1 and compatible with examination detection capabilities demonstrated in accordance with IWA-2230 or other appropriate standards.

(b) The sources of stresses that may be significant for consideration in the corner region of a nozzle are those due to internal pressure loading, external nozzle attachment loading, and thermal loading. For Levels A and B Service conditions, the following shall be satisfied for the postulated defect:

$$2K_{Ip} + K_{It} < K_{Ic} \tag{3}$$

where K_{Ip} and K_{It} are stress intensity factors due to internal pressure plus external loading and thermal loading, respectively.

(c) The stress intensity factor from internal pressure loading for a nozzle corner crack may be calculated using the equation[55]

$$K_{Ip} = F(a/r_n)\sigma_h\sqrt{\pi a} \tag{4}$$

where

$F(a/r_n)$ = $2.4582 - 5.4782\,(a/r_n) + 9.6492\,(a/r_n)^2 - 8.80\,(a/r_n)^3 + 3.1446\,(a/r_n)^4$

and

a = crack depth, determined in accordance with (a)

r_c = nozzle corner radius

r_j = actual inner radius of nozzle

r_n = apparent radius of nozzle = $r_j + 0.29r_c$

σ_h = shell hoop stress

Alternately, the method of (d) may be used to calculate stress intensity factor due to internal pressure.

(d) The stress intensity factor for any arbitrary stress distribution through the nozzle corner cross-section may be determined by curve fitting the stress distribution as a function of the distance into the cross-section, x, from the nozzle inner corner to a third order polynomial of the form.

$$\sigma = A_0 + A_1(x/a) + A_2(x/a)^2 + A_3(x/a)^3 \tag{5}$$

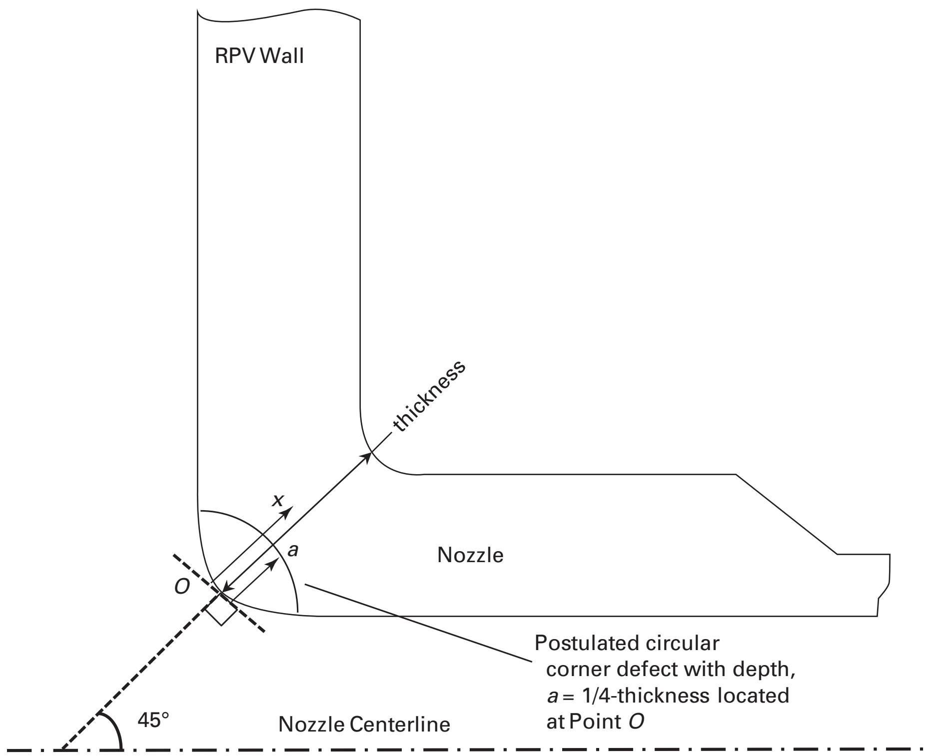
The stress intensity factor may be calculated using the following:

$$K_I = \sqrt{\pi a}\left[0.723A_0 + 0.551\left(\frac{2a}{\pi}\right)A_1 + 0.462\left(\frac{a^2}{2}\right)A_2 + 0.408\left(\frac{4a^3}{3\pi}\right)A_3\right] \tag{6}$$

where K_I is the stress intensity factor. The stress intensity factors resulting from each loading type may be superimposed. This method may be used for external loading, thermal loading, and for internal pressure loading when the stress distribution through the nozzle throat section is available.

(e) Fracture toughness analysis to demonstrate protection against nonductile failure is not required for portions of nozzles and appurtenances having a thickness of 2.5 in. (63 mm) or less, provided the lowest service temperature is not lower than RT_{NDT} plus 60°F (33°C).

Figure G-2223-1
Postulated Nozzle Corner Defect



G-2300 LEVELS C AND D SERVICE LIMITS

G-2310 RECOMMENDATIONS

The possible combinations of loadings, defect sizes, and material properties which may be encountered during Levels C and D Service Limits are too diverse to allow the application of definitive rules, and it is recommended that each situation be studied on an individual case basis. The principles given in this Appendix may be applied, where applicable, with any postulated loadings, defect sizes, and material toughness which can be justified for the situation involved.

G-2400 HYDROSTATIC TEST TEMPERATURE (15)

(a) For system and component hydrostatic tests performed prior to loading fuel in the reactor vessel, it is recommended that hydrostatic tests be performed at a temperature not lower than RT_{NDT} plus 60°F (33°C). The 60°F (33°C) margin is intended to provide protection against nonductile failure at the test pressure.

(b) For system and component hydrostatic tests performed subsequent to loading fuel in the reactor vessel, the minimum test temperature should be determined by calculating K_I. The terms given in (1) through (4) below should be summed in determining K_I:

(1) $1.5K_{Im}$ from G-2214.1 for primary membrane stress;

(2) $1.5K_{Ib}$ from G-2214.2 for primary bending stress;

(3) K_{Im} from G-2214.1 for secondary membrane stress;

(4) K_{Ib} from G-2214.2 for secondary bending stress.

K_I, calculated by summing the four values given in (1) through (4) above, shall not exceed the applicable K_{Ic} value.

(c) The system hydrostatic test to satisfy (a) or (b) should be performed at a temperature not lower than the highest required temperature for any component in the system.

G-2500 RISK-INFORMED HYDROSTATIC LEAK TESTING

G-2510 HYDROSTATIC LEAK TEST TEMPERATURE

For heat-up and cool-down rates not to exceed 40°F/hr (22°C/hr), an alternative risk-informed leak test temperature, T, may be determined as the larger of

(U.S. Customary Units)

$$T = RT_{NDT} + 60 + \ln\left[\left(K_{Im} + K_{It} - 33.2\right)/20.734\right]/0.02$$

for an outside surface flaw or

$$T = RT_{NDT} + 60 + \ln\left[\left(K_{Im} - 33.2\right)/20.734\right]/0.02$$

for an inside surface flaw

where

RT_{NDT} = $RT_{NDT(u)} + \Delta RT_{NDT}$ and is the reference nil ductility temperature adjusted for irradiation effects at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3, °F
$RT_{NDT(u)}$ = equivalent to the unirradiated RT_{NDT} calculated in accordance with NB-2300, °F
ΔRT_{NDT} = an adjustment for irradiation effects, °F
T = temperature at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3, °F

(SI Units)

$$T = RT_{NDT} + 33 + \ln\left[\left(K_{Im} + K_{It} - 36.5\right)/22.783\right]/0.036$$

for an outside surface flaw or

$$T = RT_{NDT} + 33 + \ln\left[\left(K_{Im} - 36.5\right)/22.783\right]/0.036$$

for an inside surface flaw

where

RT_{NDT} = $RT_{NDT(u)} + \Delta RT_{NDT}$ and is the reference nil ductility temperature adjusted for irradiation effects at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3, °C
$RT_{NDT(u)}$ = equivalent to the unirradiated RT_{NDT} calculated in accordance with NB-2300, °C
ΔRT_{NDT} = an adjustment for irradiation effects, °C
T = temperature at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3, °C

The operational pressure-temperature limits are based on the temperature at the reactor coolant inlet temperature, which is assumed to equal the temperature at the vessel inner surface. Figures G-2214-1 (Figure G-2214-1M) and G-2214-2 can be used to determine the temperature at the vessel inner surface corresponding to the temperature at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3.

ΔRT_{NDT} is determined from plant-specific surveillance data, or the irradiation degradation model used to compute the risk-informed allowable pressure [see eq. G-2216 (2)], or other irradiation degradation models acceptable to the regulatory authority having jurisdiction at the plant site.

G-2520 HYDROSTATIC LEAK TEST HEAT-UP AND COOL-DOWN ALLOWABLE PRESSURE

For heat-up and cool-down rates not to exceed 40°F/hr (22°C/hr), the allowable pressure as a function of temperature during hydrostatic leak test heat-up or cool-down shall be determined using the procedure in G-2216

(U.S. Customary Units)

$$p = \{33.2 + 20.734 \exp\left[0.02(T - RT_{NDT} - 60)\right] - K_{It}\} \times t/R_i \times 1/M_m$$

where

p = pressure (ksi)
RT_{NDT} = $RT_{NDT(u)} + \Delta RT_{NDT}$ and is the reference nil ductility temperature adjusted for irradiation effects at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3, °F

$RT_{NDT(u)}$ = equivalent to the unirradiated RT_{NDT} calculated in accordance with NB-2300, °F
ΔRT_{NDT} = an adjustment for irradiation effects, °F
T = temperature at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3, °F

(SI Units)

$$p = \{36.5 + 22.783 \exp[0.036(T - RT_{NDT} - 33)] - K_{It}\} \times t/R_i \times 1/M_m$$

where

p = pressure (MPa)
RT_{NDT} = $RT_{NDT(u)} + \Delta RT_{NDT}$ and is the reference nil ductility temperature adjusted for irradiation effects at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3, °C
$RT_{NDT(u)}$ = equivalent to the unirradiated RT_{NDT} calculated in accordance with NB-2300, °C
ΔRT_{NDT} = an adjustment for irradiation effects, °C
T = temperature at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3, °C

K_{It} is as stipulated in G-2214.3, and t, R_i, and M_m are as stipulated in G-2214.1. The evaluation is to be performed for all materials and locations as described in G-2215.

The operational pressure-temperature limits are based on the temperature at the reactor coolant inlet temperature, which is assumed to equal the temperature at the vessel inner surface. Figures G-2214-1 (Figure G-2214-1M) and G-2214-2 can be used to determine the temperature at the vessel inner surface corresponding to the temperature at the maximum depth of the postulated quarter thickness flaw stipulated in G-2214.3.

ΔRT_{NDT} is determined from plant-specific surveillance data, or the irradiation degradation model used to compute the risk-informed allowable pressure [see eq. G-2216(2)], or other irradiation degradation models acceptable to the regulatory authority having jurisdiction at the plant site.

ARTICLE G-3000
PIPING, PUMPS, AND VALVES

G-3100 GENERAL REQUIREMENTS

In the case of the materials other than bolting used for piping, pumps, and valves for which impact tests are required (NB-2311), the tests and acceptance standards of Section III, Division 1 are considered to be adequate to prevent nonductile failure under the loadings and with the defect sizes encountered under Levels A and B Service Limits and testing conditions. Levels C and D Service Limits should be evaluated on an individual case basis (G-2300).

ARTICLE G-4000
BOLTING

G-4100 GENERAL REQUIREMENTS

In the case of bolting materials for which impact tests are required, the tests and acceptance standards of Section III, Division 1 are considered to be adequate to prevent nonductile failure under the loadings and with the defect sizes encountered under Levels A and B Service Limits and testing conditions. Levels C and D Service Limits should be evaluated on an individual case basis (G-2300). Welding Research Council Bulletin 175 (WRCB 175) “PVRC Recommendations on Toughness Requirements for Ferritic Materials,” provides procedures in Paragraph 7 for evaluating various defect sizes and associated toughness levels in bolting materials.

(15)
NONMANDATORY APPENDIX H
ANALYTICAL EVALUATION PROCEDURES FOR FLAWS IN PIPING BASED ON USE OF A FAILURE ASSESSMENT DIAGRAM

ARTICLE H-1000
INTRODUCTION

(15) H-1100 SCOPE

This Nonmandatory Appendix provides analytical procedures to support determination of acceptability for continued service of ferritic and austenitic piping containing flaws that exceed allowable flaw standards of IWB-3514 or IWC-3514. Analytical evaluations performed using this Nonmandatory Appendix shall meet all the requirements of the Appendix. Flaws acceptable for continued service shall satisfy the criteria of H-1110. The analytical evaluation methodology is based on a failure assessment diagram approach that includes consideration of the following failure mechanisms:

(a) brittle fracture described by linear elastic fracture mechanics;

(b) elastic-plastic fracture mechanics, when ductile flaw extension occurs prior to reaching limit load; and

(c) limit load failure of the pipe cross section, which is reduced by the flaw area, for ductile materials when the limit load is assured.

Pipe material toughness properties are accounted for through input of either the J_r resistance curve that characterizes ductile flaw extension, or the fracture toughness J_{Ic}. Flaws are analytically evaluated by comparing the calculated pipe stress for the flaw size at the end of the evaluation period with the allowable stress using the failure assessment diagram approach. All applicable combinations of stresses σ_m, σ_b, and σ_e are required in the analytical evaluation.

H-1110 ACCEPTANCE CRITERIA

Flaws acceptable for continued service shall be less than 75% of the wall thickness and shall satisfy the following criteria:

(a) For each specific set of loading conditions, one or more assessment points with coordinates (S_r', K_r') shall be below the failure assessment curve. For lower shelf and transition temperatures, only one assessment point need be calculated. For upper shelf temperatures, a series of assessment points for various amounts of ductile flaw extension shall be calculated to meet this criterion.

(b) For axial flaws, the $S_r{}'$ coordinate of the assessment point that satisfies (a) above shall satisfy

$$S_r' \leq S_r^{\text{cutoff}}$$

where $S_r{}^{\text{cutoff}}$ is the limit load cutoff on the applicable failure assessment diagram. Equations for (S_r', K_r') and $S_r{}^{\text{cutoff}}$ and the structural factors to be applied for ferritic and austenitic piping are given in Article H-4000. The values of (S_r', K_r') and $S_r{}^{\text{cutoff}}$ are functions of calculated pipe stresses, required structural factors, pipe material properties, and end-of-evaluation-period flaw dimensions.

(c) For circumferential flaws, the applied stresses for the $S_r{}'$ that satisfy (a) above shall satisfy the primary stress limits of H-4410.

(d) The applicable failure assessment diagram is independent of flaw orientation, flaw dimensions, and pipe radius-to-thickness ratio, for the range of applicability. The failure assessment diagrams apply for pipe mean-radius-to-thickness ratio, *R/t,* less than or equal to 20. Pipe-specific failure assessment diagrams applicable to the specific geometry of the piping shall be used when *R/t* is greater than 20.

H-1200 PROCEDURE OVERVIEW

The following is a summary of the analytical procedure.

(a) Determine the flaw configuration from the measured flaw, using Article H-2000.

(b) Resolve the actual flaw into circumferential and axial components, using Article H-2000.

(c) Determine the stresses normal to the flaw at the location of the detected flaw for Service Levels A, B, C, and D Loadings, using Article H-2000.

(d) Perform a flaw growth analysis as described in Article H-3000 to establish the end-of-evaluation-period flaw dimensions a_f and ℓ_f.

(e) Obtain pipe material properties E, σ_y, σ_f, and J_R resistance curve or J_{Ic} at the service temperatures. Heat-specific material properties may be used if available.

(f) Calculate the vertical cutoff, S_r^{cutoff}, for an axial flaw configuration, or the primary stress limits for a circumferential flaw configuration, using the equations in H-4400 for the end-of-evaluation-period flaw dimensions a_f and ℓ_f.

(g) Using the equations in H-4500, calculate the assessment point coordinates (S_r', K_r') for the piping stresses σ_m, σ_b, and σ_e for circumferential flaws, or p (pressure) for axial flaws, using the structural factors specified in Table H-4200-1 for circumferential flaws or in Table H-4200-2 for axial flaws, for the end-of-evaluation-period flaw dimensions a_f and ℓ_f.

(h) Plot the assessment points calculated in (g) on the failure assessment diagram in Figure H-4300-1 for ferritic piping or Figure H-4300-2 for austenitic piping.

H-1300 NOMENCLATURE

The following nomenclature is used in this Appendix.

K_r' = brittle fracture component of assessment point defined by ratio of stress intensity factor to material fracture toughness

M_1', M_2', M_3' = geometry correction factors for interior axial part-through-wall flaw in pressurized pipe; accounts for flaw aspect ratio a/ℓ

S_r^{cutoff} = for an axial flaw, maximum value of S_r at vertical (limit load) boundary of failure assessment diagram

S_r' = limit load component of assessment point, defined for circumferential flaws by ratio of applied stress to stress at reference limit load, and for axial flaws as ratio of pressure to reference limit load pressure

σ_b' = bending stress at collapse limit load for any combination of primary and expansion stresses, ksi (MPa)

σ_m' = membrane stress at reference limit load for any combination of primary and expansion stresses, ksi (MPa)

a = flaw depth, in. (mm)

a_f = maximum depth to which the detected flaw is calculated to grow by the end of the evaluation period, in. (mm)

a' = sum of flaw depth plus ductile flaw extension in. (mm)

E = Young's modulus, ksi (MPa)

E' = $E/(1 - \nu^2)$, ksi (MPa)

F_b = parameter for circumferential flaw bending stress intensity factor

f_c = geometry correction term that accounts for flaw depth and wall thickness relative to pipe inside radius

F_I = total geometry correction factor for interior axial part-through-wall flaw in pressurized pipe

F_m = parameter for circumferential flaw membrane stress intensity factor

$f(z)$ = bulging factor correction

J_e = linear elastic J-integral calculated from stress intensity factor K_I, in.-lb/in.^{2} (kJ/m^2)

J_{Ic} = measure of toughness at crack initiation at upper shelf, transition, and lower shelf temperatures, in.-lb/in.^{2} (kJ/m^2)

J_R = J-integral resistance to ductile tearing at prescribed Δa value obtained from accepted test procedures, in.-lb/in.^{2} (kJ/m^2)

K_I = mode I stress intensity factor, ksi $\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$

K_{Ir} = stress intensity factor for residual stress, ksi$\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$

K_r = ordinate of failure assessment diagram curve

M_2 = bulging factor for axial flaw

p = internal pressure, ksi (MPa)

P_o = reference limit load pressure, ksi (MPa)

P_ℓ = internal pressure at collapse limit load for axial flaw, ksi (MPa)

Q = flaw shape parameter
R = mean radius of pipe, in. (mm)
R_1 = inside radius of pipe, in. (mm)
R_2 = outside radius of pipe, in. (mm)
R_c = sum of flaw depth and inside radius of pipe, in. (mm)
S_r = abcissa of failure assessment diagram
SF_b = structural factor on primary bending stress for circumferential flaws
SF_m = structural factor on primary membrane stress for circumferential or axial flaws
t = pipe wall thickness, in. (mm)
z = global limit load geometry factor
ℓ = flaw length, in. (mm)
ℓ_{allow} = allowable flaw length for stability of an axial through-wall flaw, in. (mm)
ℓ_f = maximum length to which detected flaw is calculated to grow at the end of the evaluation period, in. (mm)
Δa = ductile flaw extension, in. (mm)
β = angle to neutral axis of flawed pipe, radians
γ = factor in reference limit load expression for σ'_m reflecting ratio of $\sigma_{m\ell}$ to σ_m
θ = one-half of final flaw angle (see Figure H-4400-1), radians
ν = Poisson's ratio
σ_b = unintensified primary bending stress in the pipe at the flaw, ksi (MPa)
σ_e = unintensified secondary bending stress, including thermal expansion and seismic anchor movement at the flaw location, ksi (MPa)
σ_f = flow stress, ksi (MPa)
σ_h = hoop stress in the pipe at the flaw, ksi (MPa)
σ_m = unintensified primary membrane stress in the pipe at the flaw, ksi (MPa)
$\sigma_{m\ell}$ = membrane stress at collapse limit load with zero primary bending stress, ksi (MPa)
σ_y = yield strength, ksi (MPa)
ψ = angle used in defining $\sigma_{m\ell}$, radians
ψ_m = factor in reference limit load expressions reflecting effect of flaw size

ARTICLE H-2000 ANALYTICAL EVALUATION PARAMETERS (15)

Article C-2000 provides procedures for defining flaw shape, multiple flaws, flaw orientation, flaw location, and pipe stress used to determine acceptance.

(15)

ARTICLE H-3000
FLAW GROWTH ANALYSIS

Article C-3000 provides the methodology for the determination of subcritical flaw growth during the evaluation period.

ARTICLE H-4000
FAILURE ASSESSMENT DIAGRAM PROCEDURE

H-4100 SCOPE (15)

This Article describes the failure assessment diagram procedure for analytical evaluation of flaws in ferritic and austenitic piping. The procedure requires a failure assessment diagram and failure assessment point coordinates. End-of-evaluation-period flaw dimensions shall be used.

H-4200 STRUCTURAL FACTORS (15)

Analytical evaluation of flaws using the failure assessment diagram procedure requires application of structural factors. The structural factors SF_m and SF_b applied to primary membrane stresses and primary bending stresses, respectively, are given in Table H-4200-1 for circumferential flaws and Table H-4200-2 for axial flaws.

H-4300 FAILURE ASSESSMENT DIAGRAMS

Figures H-4300-1 and H-4300-2 give failure assessment diagrams for ferritic piping and austenitic piping, respectively. These figures apply to piping having

(a) part-through-wall circumferential flaws, under any combination of primary membrane, primary bending, and expansion stresses (see Figure H-4400-1); or

(b) part-through-wall axial flaws under internal pressure (see Figure H-4400-2).

Figures H-4300-1 and H-4300-2 apply for circumferential flaws of depths up to 75% of the pipe wall thickness, and for axial flaws of depths up to 75% of the pipe wall thickness and lengths up to ℓ_{allow}, where ℓ_{allow} is given by the limit load stability condition for through-wall flaws:

$$\ell_{allow} = 1.58(Rt)^{1/2}\left[\left(\sigma_f/\sigma_h\right)^2 - 1\right]^{1/2}$$

For axial flaws, the failure assessment diagrams shown in Figures H-4300-1 and H-4300-2 have a vertical cutoff for upper bound limits on S_r. For circumferential flaws, the upper limit on S_r is established by limits on primary stresses. The procedures for calculating the values of the cutoff and limits on primary stress are given in H-4400. The failure assessment diagrams are limited to R/t less than or equal to 20.

Table H-4200-1
Specified Structural Factors for Circumferential Flaws

Service Level	Membrane Stress, SF_m	Bending Stress, SF_b
A	2.7	2.3
B	2.4	2.0
C	1.8	1.6
D	1.3	1.4

Table H-4200-2
Specified Structural Factors for Axial Flaws

Service Level	Membrane Stress, SF_m
A	2.7
B	2.4
C	1.8
D	1.3

H-4400 FAILURE ASSESSMENT DIAGRAM PRIMARY STRESS LIMITS

Limits on the primary stresses in the failure assessment diagram analysis are provided by the following:

(a) direct application of limits on primary stresses for part-through-wall circumferential flaws (see Figure H-4400-1) under any combination of primary membrane and primary bending stresses or

(b) application of a vertical cutoff on the failure assessment diagram for part-through-wall axial flaws (see Figure H-4400-2) under internal pressure

H-4410 CIRCUMFERENTIAL FLAW PRIMARY STRESS LIMITS

(a) The applied primary membrane stress shall satisfy the following equation:

$$\sigma_m \leq \frac{\sigma_{m\ell}}{SF_m}$$

where SF_m is the structural factor on primary membrane stress specified in Table H-4200-1 and

$$\sigma_{m\ell} = \sigma_f\left[1 - \left(\frac{a}{t}\right)\left(\frac{\theta}{\pi}\right) - 2\psi/\pi\right]$$

$$\psi = \arcsin\left[0.5\left(\frac{a}{t}\right)\sin\theta\right]$$

(b) The applied primary bending stress shall satisfy the following equation:

$$\sigma_b \leq \frac{\sigma_b'}{SF_b} - \sigma_m\left(1 - \frac{1}{SF_m}\right)$$

where SF_m and SF_b are the structural factors on primary membrane stress and primary bending stress, respectively, specified in Table H-4200-1. For circumferential flaws not penetrating the compresssive region of the pipe cross-section, $\theta + \beta \leq \pi$, and

$$\sigma_b' = 2\sigma_f/\pi\left[2\sin\beta - \left(\frac{a}{t}\right)\sin\theta\right]$$

where

$$\beta = \frac{1}{2}\left[\pi - \left(\frac{a}{t}\right)\theta - \pi\sigma_m/\sigma_f\right]$$

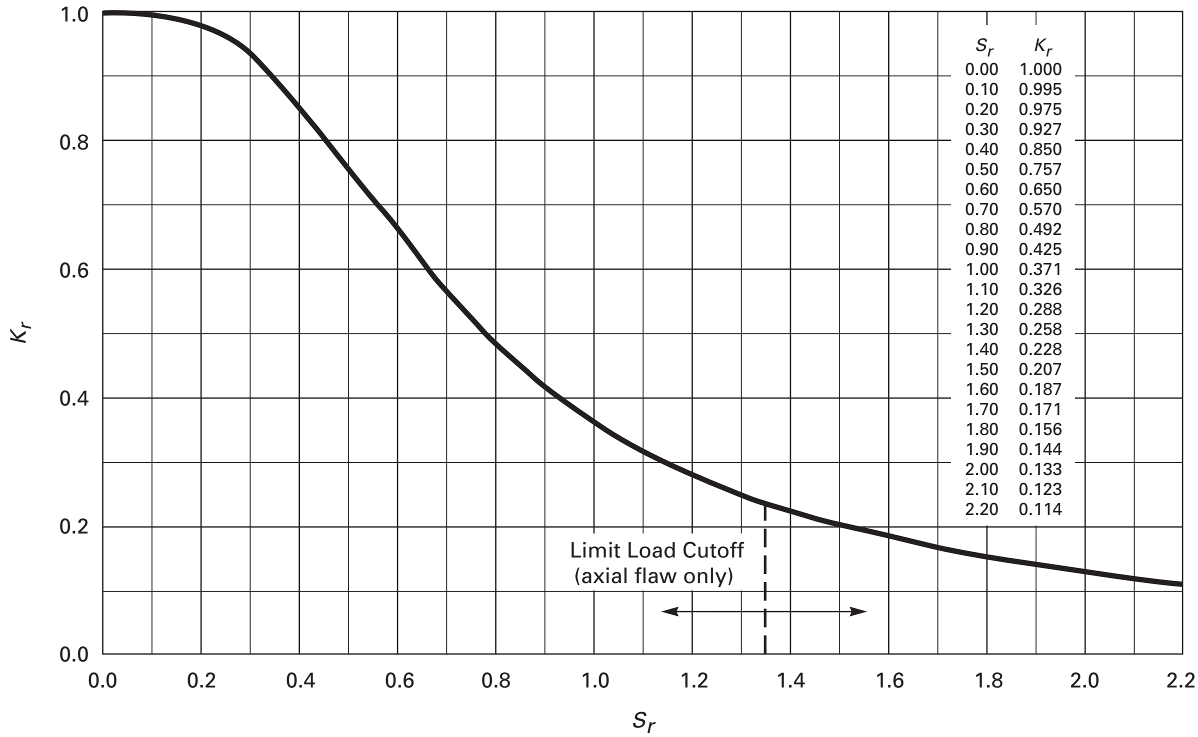
For longer flaws penetrating the compressive region of the pipe cross-section, $\theta + \beta > \pi$, and

$$\sigma_b' = 2\sigma_f/\pi\left(2 - \frac{a}{t}\right)\sin\beta$$

where

$$\beta = \pi/\left(2 - \frac{a}{t}\right)\left[1 - \frac{a}{t} - \sigma_m/\sigma_f\right]$$

Figure H-4300-1
Failure Assessment Diagram for Ferritic Piping



H-4420 AXIAL FLAW CUTOFF

For axial flaws in piping under internal pressure, the limit load cutoff for S_r is given by

$$S_r^{\text{cutoff}} = P_\ell / P_o$$

where

$$f(z) = (1 + 1.61z)^{0.5}$$
$$M_2 = \{1 + [1.61\ell^2 / (4Rt)]\}^{0.5}$$
$$P_o = \left(\frac{2}{\sqrt{3}}\right)\left(\frac{t}{R_1}\right)\left[1 - \frac{a}{t} + \left(\frac{a}{t} / f(z)\right)\right]\sigma_y$$
$$P_\ell = (t / R_1)\,\sigma_f\left[\left(1 - \frac{a}{t}\right) / \left(1 - \left(\frac{a}{t}\right) / M_2\right)\right]$$
$$z = 0.1542\ell^2 / \left[ta\left(\frac{R_1}{t} + 0.5\right)\right]$$

H-4500 FAILURE ASSESSMENT POINT COORDINATES

The failure assessment point coordinates, (S_r', K_r') shall be calculated for the end-of-evaluation-period flaw dimensions and for stresses at the location of, and normal to, the flaw, using the J_R resistance curve data when ductile flaw extension at upper-shelf temperatures may occur prior to reaching limit load, or using J_{Ic} fracture toughness data at transition or lower-shelf temperatures.

Figure H-4300-2
Failure Assessment Diagram for Austenitic Piping

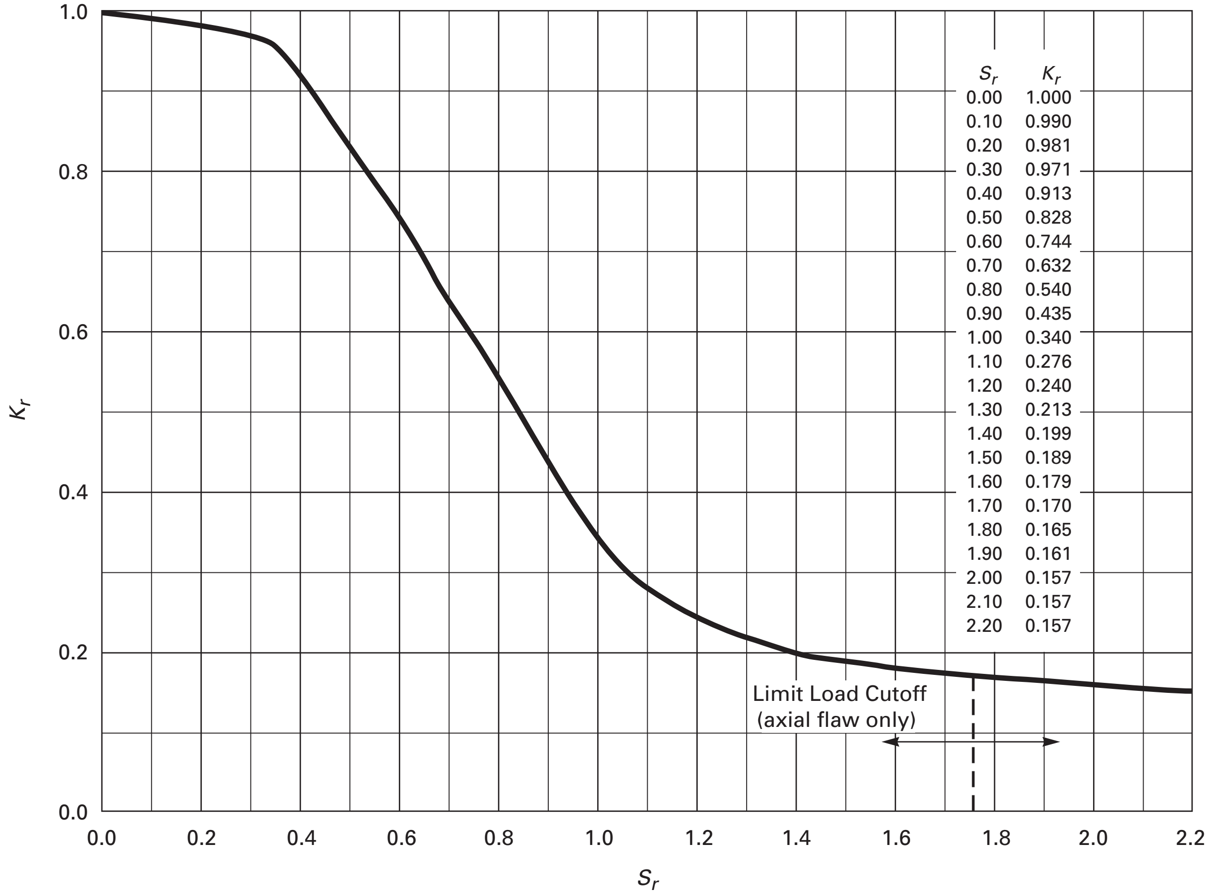


Figure H-4400-1
Circumferential Flaw Geometry

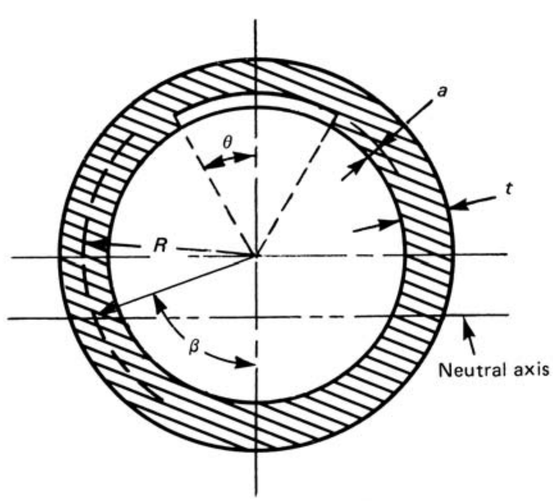
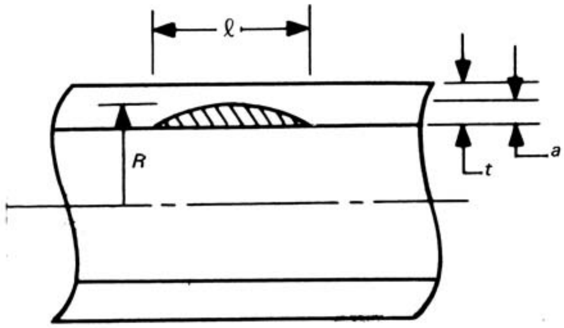


Figure H-4400-2
Axial Flaw Geometry



H-4510 CIRCUMFERENTIAL FLAWS

The equation necessary to calculate the failure assessment point coordinates (S_r', K_r') for part-through-wall circumferential flaws for a specified amount of ductile flaw extension, Δa, is given in (a). When the temperature is in the transition or lower-shelf region, J_R shall be replaced by J_{Ic}, and Δa shall be zero.

(a) The coordinate S_r' is given by the following equation when the primary membrane stress, σ_m, is not zero:

$$S_r' = \left(SF_m\right)\sigma_m / \sigma_m'$$

where SF_m is the structural factor on primary membrane stress specified in Table H-4200-1, σ_m' is recalculated for each value of Δa, and

$$\sigma_m' = \sigma_y \psi \Gamma_m$$
$$R_c = R_1 + a + \Delta a$$
$$\Gamma_m = [R_2^2 - R_c^2 + (1 - \theta/\pi)\,(R_c^2 - R_1^2)]/(R_2^2 - R_1^2)$$
$$\psi = \frac{-\pi\sigma_b}{8\sigma_m} + \left[\left(\frac{\pi\sigma_b}{8\sigma_m}\right)^2 + 1\right]^{0.5}$$

where Γ_m is recalculated for each value of Δa. When the primary membrane stress, σ_m, is zero, the coordinate S_r' is given by

$$S_r' = \pi\left(SF_b\right)\sigma_b / \left(4\sigma_y\Gamma_m\right)$$

where SF_b is the structural factor on primary bending stress specified in Table H-4200-1, and Γ_m is recalculated for each value of Δa.

(b) The coordinate K_r' is given by

$$K_r' = \left(J_e / J_R\right)^{0.5}$$

for any value of σ_m, where J_e and J_R are also recalculated for each value of Δa. The linear elastic J-integral is given by

$$J_e = 1000\,K_I^2 / E'$$

where

(U.S. Customary Units)

$$K_I = \left(SF_m\right)\sigma_m F_m\left(\pi a'\right)^{0.5} + \left[\left(SF_b\right)\sigma_b + \sigma_e\right]F_b\left(\pi a'\right)^{0.5} + K_{Ir}$$

(SI Units)

$$K_I = (SF_m)\sigma_m F_m (\pi a'/1000)^{0.5} + [(SF_b)\sigma_b + \sigma_e] F_b (\pi a'/1000)^{0.5} + K_{Ir}$$

$$F_m = 1.1 + \left(\frac{a'}{t}\right)\left\{0.15241 + 16.722\left[\left(\frac{a'}{t}\right)\left(\frac{\theta}{\pi}\right)\right]^{0.855} - 14.944\left[\left(\frac{a'}{t}\right)\left(\frac{\theta}{\pi}\right)\right]\right\}$$

$$F_b = 1.1 + \left(\frac{a'}{t}\right)\left\{-0.09967 + 5.0057\left[\left(\frac{a'}{t}\right)\left(\frac{\theta}{\pi}\right)\right]^{0.565} - 2.8329\left[\left(\frac{a'}{t}\right)\left(\frac{\theta}{\pi}\right)\right]\right\}$$

$$a' = a + \Delta a$$

In the above equations, a' is updated after each increment of ductile flaw extension, while θ is fixed at its end-of-evaluation-period value. Residual stresses shall be included with a structural factor of 1.0.

H-4520 AXIAL FLAWS

Failure assessment point coordinates (S_r', K_r') for part-through-wall axial flaws with a specified amount of ductile flaw extension, Δa, are given below. When the temperature is in the transition or lower-shelf region, J_R shall be replaced by J_{Ic}, and Δa shall be zero.

(a) The coordinate S_r' is given by

$$S_r' = (SF_m)\,p/P_o$$

where SF_m is the structural factor on primary membrane stress specified in Table H-4200-2, and P_o is recalculated for each value of Δa.

$a' = a + \Delta a$

$f(z) = (1 + 1.61z)^{0.5}$

$P_o = \left(\frac{2}{\sqrt{3}}\right)\left(\frac{t}{R_1}\right)\left[1 - \frac{a'}{t} + \left(\frac{a'}{t}/f(z)\right)\right]\sigma_y$

$z = 0.1542\,\ell^2/[ta(R_1/t + 0.5)]$

(b) The coordinate K_r' is given by

$$K_r' = (J_e/J_R)^{0.5}$$

where J_e and J_R are calculated for each value of Δa. The linear elastic J-integral is given by

$$J_e = 1000\,K_I^2/E'$$

and

(U.S. Customary Units)

$$K_I = (SF_m)\,p\,(R_1/t)F_1(\pi a'/Q)^{0.5} + K_{Ir}$$

(SI Units)

$$K_I = (SF_m)\, p\,(R_1/t) F_1 (\pi a'/1000Q)^{0.5} + K_{Ir}$$

$$Q = 1 + 4.593(a/\ell)^{1.65}$$

$$F_1 = 0.97\left[M_1' + M_2'(a'/t)^2 + M_3'(a'/t)^4\right] f_c$$

$$f_c = \left[\left(R_2^2 + R_1^2\right)/\left(R_2^2 - R_1^2\right) + 1 - 0.5(a'/t)^{0.5}\right] t/R_1$$

$$M_1' = 1.13 - 0.18(a/\ell)$$

$$M_2' = -0.54 + 0.445/(0.1 + a/\ell)$$

$$M_3' = 0.5 - 1/(0.65 + 2a/\ell) + 14(1 - 2a/\ell)^{24}$$

In the preceding equations, a' is updated after each increment of ductile flaw extension, while a/ℓ is fixed at its end-of-evaluation-period value. Residual stresses shall be included with a structural factor of 1.0.

NONMANDATORY APPENDIX J
GUIDE TO PLANT MAINTENANCE ACTIVITIES AND SECTION XI REPAIR/REPLACEMENT ACTIVITIES

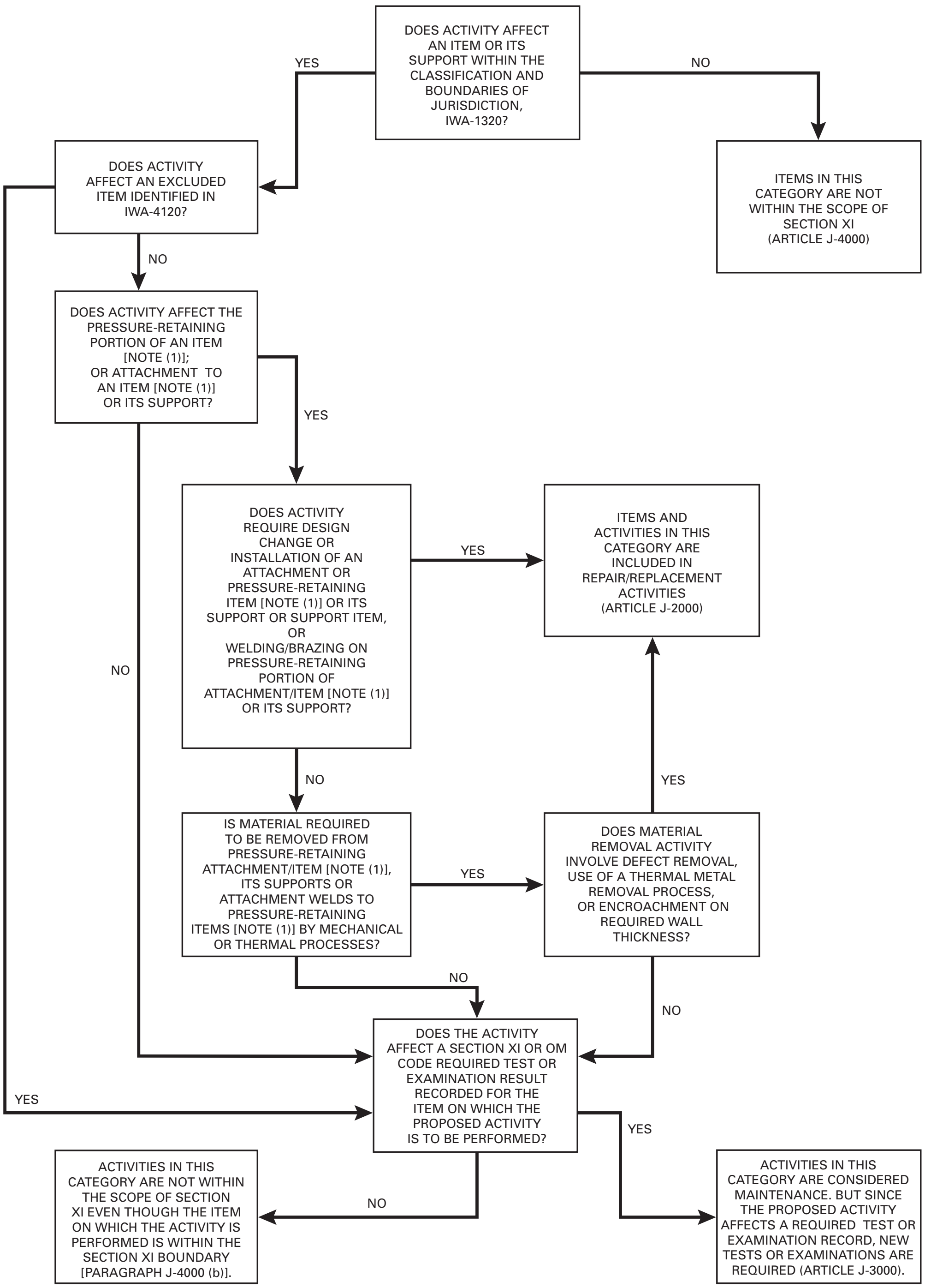
ARTICLE J-1000
SCOPE

(a) This Nonmandatory Appendix provides guidance to determine the applicability of Article IWA-4000. For the purpose of this Appendix, repair/replacement activities are separate from maintenance activities.

(b) Figure J-1000-1 may be used to distinguish between repair/replacement activities and maintenance activities. Maintenance activities may be categorized as activities requiring subsequent tests or examinations or as activities for which Section XI is not applicable.

(c) Article J-2000, Article J-3000, and Article J-4000 provide clarification or examples for certain decision blocks in Figure J-1000-1.

Figure J-1000-1
Decision Tree



NOTE:
(1) Also includes those nonstructural pump and valve internals constructed to construction codes or code cases and which are within the Section XI boundary.

ARTICLE J-2000
REPAIR/REPLACEMENT ACTIVITIES

(a) Article IWA-4000 requires that repair/replacement activities comply with the requirements of Article IWA-4000 and the Repair/Replacement Program.

(b) The following are some examples of repair/replacement activities when performed on items within the Section XI scope.

(1) removing weld or material defects

(2) reducing the size of defects to a size acceptable to the applicable flaw evaluation criteria

(3) performing welding or brazing

(4) adding items

(5) system changes, such as rerouting of piping

(6) modifying items

(7) rerating

(8) metal removal using thermal processes

ARTICLE J-3000 MAINTENANCE REQUIRING SUBSEQUENT TEST OR EXAMINATION

(a) Maintenance activities within this category are not within the scope of Section XI but are performed and controlled in accordance with the Owner's procedures. However, due to the nature of the work or item involved, tests or examinations are required to be performed subsequent to completion of the maintenance work activity.

(b) The maintenance activities within this category differ from the maintenance activities described in Article J-4000 in that these activities are performed on items within the Section XI boundary and these activities affect the existing inspection, test, or examination record required by this Division or other ASME codes.

(c) The following are some examples of maintenance activities that may require subsequent Section XI test or examination:

(1) grinding or machining on valve disk seating surfaces;

(2) removing arc strikes or weld spatter, in the area of previous PSI/ISI surface examinations; and

(3) preparing welds for NDE.

(d) The following are some examples of maintenance activities that may require subsequent testing or examination as required by the ASME Code For Operation and Maintenance of Nuclear Power Plants:

(1) for valves, adjustment of packing, removal of bonnet, stem assembly or actuator, or disconnection of hydraulic or electrical lines;

(2) for pumps, adjusting packing, adding packing rings, mechanical seal maintenance, or replacement or cleaning of the rotating element;

(3) adjustment of pressure relief device set points in accordance with existing design requirements; and

(4) for snubbers, replacement of internal seals or adjustment of hydraulic control valves.

ARTICLE J-4000
MAINTENANCE NOT REQUIRING SUBSEQUENT TEST OR EXAMINATION

(a) Work activities on items not within the classification and boundaries of jurisdiction (IWA-1320) are not within the scope of this Division. These activities are performed and controlled in accordance with the Owner's procedures.

(b) Work activities not defined as repair/replacement activities that are performed on items within the classification of boundaries of jurisdiction of this Division (IWA-1320), but which do not affect a Section XI or OM Code required test or examination, are not within the scope of this Division. These activities are performed and controlled in accordance with the Owner's procedures. Replacing handwheels on manually operated valves is an example of a maintenance activity.

NONMANDATORY APPENDIX K ASSESSMENT OF REACTOR VESSELS WITH LOW UPPER SHELF CHARPY IMPACT ENERGY LEVELS

ARTICLE K-1000 INTRODUCTION

K-1100 SCOPE

This Nonmandatory Appendix provides acceptance criteria and evaluation procedures for determining acceptability for continued operation of a reactor vessel when the vessel metal temperature is in the upper shelf range. Evaluations performed using this Nonmandatory Appendix shall meet all the requirements of the Appendix. The methodology is based on the principles of elastic-plastic fracture mechanics. Flaws shall be postulated in the reactor vessel at locations of predicted low upper shelf Charpy impact energy, and the applied J-integral for these flaws shall be calculated and compared with the J-integral fracture resistance of the material to determine acceptability. All specified design transients for the reactor vessel shall be considered.

K-1200 PROCEDURE

The following analytical procedure shall be used.

(a) Reactor vessel flaws shall be postulated in accordance with the criteria of Article K-2000.

(b) Loading conditions at the locations of the postulated flaws shall be determined for Levels A, B, C, and D Service Loadings.

(c) Material properties, including E, σ_y, and the J-integral resistance curve (J-R curve), shall be determined at the locations of the postulated flaws. Requirements for determining the J-R curve are provided in K-3300.

(d) The postulated flaws shall be evaluated in accordance with the acceptance criteria of Article K-2000. Requirements for evaluating the applied J-integral are provided in K-3200, and for determining flaw stability in K-3400. Three permissible evaluation methods are described in K-3500. Detailed calculation procedures for Levels A and B Service Loadings are provided in Article K-4000. Procedures for Levels C and D Service Loadings are provided in Article K-5000.

K-1300 GENERAL NOMENCLATURE

a_e^* = effective flaw depth at onset of flaw instability, including ductile flaw extension and a plastic-zone correction, in. (mm)

F_1^*, F_2^*, F_3^* = geometry factors used to calculate the stress intensity factor at onset of flaw instability (dimensionless)

F_1, F_2, F_3 = geometry factors used to calculate the stress intensity factor (dimensionless)

K_{Ip}^* = K_{Ip} at onset of flaw instability, calculated with a plastic-zone correction, ksi $\sqrt{\text{in.}}$, $\left(\text{MPa}\sqrt{\text{m}}\right)$

K_{Ip}' = K_{Ip} calculated with a plastic-zone correction, ksi $\sqrt{\text{in.}}$, $\left(\text{MPa}\sqrt{\text{m}}\right)$

K_{It}^* = K_{It} at onset of flaw instability, calculated with a plastic-zone correction, ksi $\sqrt{\text{in.}}$, $\left(\text{MPa}\sqrt{\text{m}}\right)$

K_{It}' = K_{It} calculated with a plastic-zone correction, ksi $\sqrt{\text{in.}}$, $\left(\text{MPa}\sqrt{\text{m}}\right)$

K_r' = ratio of the stress intensity factor to the fracture toughness for the material (dimensionless)

S_r' = ratio of internal pressure to reference limit-load internal pressure (dimensionless)

(CR) = cooldown rate,°F/hr, (°C/h)

(SF) = structural factor (dimensionless)

A = area parameter for tensile stability evaluation, in.^{2} (mm^2)
a = flaw depth that includes ductile flaw extension, in. (mm)
A_c = area of the flaw, in.^{2} (mm^2)
a_e = effective flaw depth that includes ductile flaw extension and a plastic-zone correction, in. (mm)
a_o = postulated initial flaw depth, in. (mm)
C_1, C_2 = material constants used to describe the power-law fit to the J-integral resistance curve for the material, $J_R = C_1\ (\Delta a)^{C_2}$
C_m = material coefficient for calculation of stress intensity factor due to radial thermal gradient, ksi-hr/(in.^{2}-°F), [MPa-h/(mm^2-°C)]
d = thermal diffusivity, in.^{2}/hr (mm^2/h)
E = Young's modulus, ksi (MPa)
E' = $E/(1 - \nu^2)$, ksi (MPa)
J = J-integral due to the applied loads, in.-lb/in.^{2} (kJ/m^2)
$J_{0.1}$ = J-integral fracture resistance for the material at a ductile flaw extension of 0.10 in. (2.5 mm), in.-lb/in.^{2} (kJ/m^2)
J_1 = applied J-integral at a flaw depth of a_o + 0.10 in. (2.5 mm), in.-lb/in.^{2} (kJ/m^2)
J_R = J-integral fracture resistance for the material, in.-lb/in.^{2} (kJ/m^2)
J^* = J-integral at onset of flaw instability, in.-lb/in.^{2} (kJ/m^2)
K_I = mode I stress intensity factor, ksi $\sqrt{\text{in.}}$, $\left(\text{MPa}\sqrt{\text{m}}\right)$
K_{Ip} = mode I stress intensity factor due to internal pressure, calculated with no plastic-zone correction, ksi $\sqrt{\text{in.}}$, $\left(\text{MPa}\sqrt{\text{m}}\right)$
K_{It} = mode I stress intensity factor due to a radial thermal gradient through the vessel wall, calculated with no plastic-zone correction, ksi $\sqrt{\text{in.}}$, $\left(\text{MPa}\sqrt{\text{m}}\right)$
K_r = ordinate of the failure assessment diagram curve (dimensionless)
p = internal pressure, ksi (MPa)
P_a = accumulation pressure as defined in the plant specific Overpressure Protection Report, but not exceeding 1.1 times the design pressure, ksi (MPa)
P_I = internal pressure at tensile instability of the remaining ligament, ksi (MPa)
P_o = reference limit-load internal pressure, ksi (MPa)
P_s = pressure used to calculate the applied J-integral/tearing modulus line, ksi (MPa)
P^* = internal pressure at onset of flaw instability, ksi (MPa)
R_i = inner radius of the vessel, in. (mm)
R_m = mean radius of the vessel, in. (mm)
S_r = abscissa of the failure assessment diagram curve (dimensionless)
T = tearing modulus due to the applied loads (dimensionless)
t = vessel wall thickness, in. (mm)
T_R = tearing modulus resistance for the material (dimensionless)
W = parameter used to relate the applied J-integral to the applied tearing modulus (dimensionless)
ℓ = total length of the flaw, in. (mm)
Δa = amount of ductile flaw extension, in. (mm)
Δa^* = amount of ductile flaw extension at onset of flaw instability, in. (mm)
α = coefficient of thermal expansion, in./in./°F (mm/mm/°C)
ν = Poisson's ratio (dimensionless)
σ_f = reference flow stress, specified as 85 ksi (585 MPa)
σ_o = flow stress for the material for the tensile stability evaluation, including the effects of temperature and fluence, ksi (MPa)
σ_u = ultimate tensile strength for the material, including the effects of temperature and fluence, ksi (MPa)
σ_y = yield strength for the material, including the effects of temperature and fluence, ksi (MPa)

ARTICLE K-2000 ACCEPTANCE CRITERIA

K-2100 SCOPE

Adequacy of the upper shelf toughness of the reactor vessel shall be determined by analysis. The reactor vessel is acceptable for continued service when the criteria of K-2200, K-2300, and K-2400 are satisfied.

K-2200 LEVELS A AND B SERVICE LOADINGS

(a) When evaluating adequacy of the upper shelf toughness for the weld material for Levels A and B Service Loadings, an interior semi-elliptical surface flaw with a depth one-quarter of the wall thickness and a length six times the depth shall be postulated, with the flaw's major axis oriented along the weld of concern, and the flaw plane oriented in the radial direction. When evaluating adequacy of the upper shelf toughness for the base material, both interior axial and circumferential flaws with depths one-quarter of the wall thickness and lengths six times the depth shall be postulated, and toughness properties for the corresponding orientation shall be used. Smaller flaw sizes may be used when justified. Two criteria shall be satisfied:

(1) The applied J-integral evaluated at a pressure 1.15 times the accumulation pressure as defined in the plant specific Overpressure Protection Report, with a structural factor of 1 on thermal loading for the plant specific heatup and cooldown conditions, shall be less than the J-integral of the material at a ductile flaw extension of 0.1 in. (2.5 mm).

(2) Flaw extensions at pressures up to 1.25 times the accumulation pressure of (1) shall be ductile and stable, using a structural factor of 1 on thermal loading for the plant specific heatup and cooldown conditions.

(b) The J-integral resistance versus flaw extension curve shall be a conservative representation for the vessel material under evaluation.

K-2300 LEVEL C SERVICE LOADINGS

(a) When evaluating adequacy of the upper shelf toughness for the weld material for Level C Service Loadings, interior semi-elliptical surface flaws with depths up to $^1/_{10}$ of the base metal wall thickness, plus the cladding thickness, with total depths not exceeding 1 in. (25 mm), and a surface length 6 times the depth, shall be postulated, with the flaw's major axis oriented along the weld of concern, and the flaw plane oriented in the radial direction. When evaluating adequacy of the upper shelf toughness for the base material, both interior axial and circumferential flaws shall be postulated, and toughness properties for the corresponding orientation shall be used. Flaws of various depths, ranging up to the maximum postulated depth, shall be analyzed to determine the most limiting flaw depth. Smaller maximum flaw sizes may be used when justified. Two criteria shall be satisfied:

(1) The applied J-integral shall be less than the J-integral of the material at a ductile flaw extension of 0.10 in. (2.5 mm), using a structural factor of 1 on loading.

(2) Flaw extensions shall be ductile and stable, using a structural factor of 1 on loading.

(b) The J-integral resistance versus flaw extension curve shall be a conservative representation for the vessel material under evaluation.

K-2400 LEVEL D SERVICE LOADINGS

(a) When evaluating adequacy of the upper shelf toughness for Level D Service Loadings, flaws as specified for Level C Service Loadings in K-2300 shall be postulated, and toughness properties for the corresponding orientation shall be used. Flaws of various depths, ranging up to the maximum postulated depth, shall be analyzed to determine the most

limiting flaw depth. Smaller maximum flaw sizes may be used when justified. Flaw extensions shall be ductile and stable, using a structural factor of 1 on loading.

(b) The J-integral resistance versus flaw extension curve shall be a best estimate representation for the vessel material under evaluation.

(c) The total flaw depth after stable flaw extension shall be less than or equal to 75% of the vessel wall thickness, and the remaining ligament shall not be subject to tensile instability.

ARTICLE K-3000
ANALYSIS

K-3100 SCOPE

This Article contains a description of procedures for evaluating applied fracture mechanics parameters, as well as requirements for determining the J-R curve for the material.

K-3200 APPLIED J-INTEGRAL

Calculation of the J-integral due to applied loads shall account for elastic-plastic behavior of the stress-strain curve for the material. When elastic fracture mechanics with small scale yielding applies, the J-integral may be calculated using crack-tip stress intensity factor equations with a plastic-zone correction. The method of calculation shall be documented.

K-3300 SELECTION OF THE J-INTEGRAL RESISTANCE CURVE

When evaluating the vessel for Levels A, B, and C Service Loadings, the J-integral resistance versus crack-extension curve (J-R curve) shall be a conservative representation of the toughness of the controlling beltline material at upper shelf temperatures in the operating range. When evaluating the vessel for Level D Service Loadings, the J-R curve shall be a best estimate representation of the toughness of the controlling beltline material at upper shelf temperatures in the operating range. One of the following options shall be used to determine the J-R curve.

(a) A J-R curve shall be generated for the material by following accepted test procedures. The J-R curve shall be based on the proper combination of crack orientation, temperature, and fluence level. Crack extension shall be ductile tearing with no cleavage.

(b) A J-R curve shall be generated from a J-integral database obtained from the same class of material with the same orientation using correlations for effects of temperature, chemical composition, and fluence level. Crack extension shall be ductile tearing with no cleavage.

(c) When (a) or (b) cannot be used, an indirect method of estimating the J-R curve shall be used provided the method is justified for the material.

K-3400 FLAW STABILITY

(a) The equilibrium equation for stable flaw extension is:

$$J = J_R$$

where J is the J-integral due to applied loads for the postulated flaw in the vessel, and J_R is the J-integral resistance to ductile tearing for the material.

(b) The inequality for flaw stability due to ductile tearing is:

$$\frac{\partial J}{\partial a} < \frac{dJ_R}{da}$$

where $\partial J/\partial a$ is the partial derivative of the applied J-integral with respect to flaw depth, a, with constant load, and dJ_R/da is the slope of the J-R curve. Under increasing load, stable flaw extension will continue as long as $\partial J/\partial a$ remains less than dJ_R/da.

K-3500 EVALUATION METHOD FOR LEVELS A AND B SERVICE LOADINGS

(a) The procedure provided in K-4200 shall be used to evaluate the applied J-integral for a specified amount of ductile flaw extension.

(b) There are three acceptable methods for applying flaw stability acceptance criteria in accordance with the governing flaw stability rules in K-3400. The first is a J-R curve — crack driving force diagram method. In this method flaw stability is evaluated by a direct application of the flaw stability rules provided in K-3400. Guidelines for using this method are provided in K-4310. The second is a failure assessment diagram method. A procedure based on this method for the postulated initial one-quarter wall thickness flaw is provided in K-4320. The third is a J-integral/tearing modulus method. A procedure based on this method for the postulated initial one-quarter wall thickness flaw is provided in K-4330.

ARTICLE K-4000 EVALUATION PROCEDURES FOR LEVELS A AND B SERVICE LOADINGS

K-4100 SCOPE

This Article contains calculation procedures to satisfy the acceptance criteria in Article K-2000 for Levels A and B Service Loadings. A procedure to satisfy the J-integral criteria for a specified amount of flaw extension of 0.1 in. is provided in K-4200. Procedures to satisfy the flaw stability criteria are provided in K-4300. These procedures include axial and circumferential flaw orientations.

K-4200 EVALUATION PROCEDURE FOR THE APPLIED J-INTEGRAL

K-4210 CALCULATION OF THE APPLIED J-INTEGRAL

Calculation of the applied J-integral consists of two steps: Step 1 calculates effective flaw depth, including a plastic-zone correction; and Step 2 calculates the J-integral for small scale yielding based on this effective flaw depth.

Step 1. See below

(a) For an axial flaw of depth a, the stress intensity factor due to internal pressure shall be calculated with a structural factor (SF) on pressure using the following:

(U.S. Customary Units)

$$K_{Ip} = (SF)\,p\,(1 + R_i/t)\,(\pi a)^{0.5}\,F_1 \tag{1}$$

(SI Units)

$$K_{Ip} = (SF)\,p\,(1 + R_i/t)\,(\pi a/1\,000)^{0.5}\,F_1 \tag{1}$$

where

F_1 = 0.982 + 1.006 $(a/t)^2$

This equation for K_{Ip} is valid for $0.2 \le a/t \le 0.5$, and includes the effect of pressure acting on the flaw faces.

(b) For a circumferential flaw of depth, a, the stress intensity factor due to internal pressure shall be calculated with a structural factor (SF) on pressure using the following:

(U.S. Customary Units)

$$K_{Ip} = (SF)\,p\,(1 + R_i/2t)\,(\pi a)^{0.5}\,F_2 \tag{2}$$

(SI Units)

$$K_{Ip} = (SF)\,p\,(1 + R_i/2t)\,(\pi a/1\,000)^{0.5}\,F_2 \tag{2}$$

where

F_2 = 0.885 + 0.233 (a/t) + 0.345 $(a/t)^2$

This equation for K_{Ip} is valid for $0.2 \le a/t \le 0.5$, and includes the effect of pressure acting on the flaw faces.

(c) For an axial or circumferential flaw of depth a, the stress intensity factor due to radial thermal gradients shall be calculated using the following:

(U.S. Customary Units)

$$K_{It} = C_m(CR)\,t^{2.5}\,F_3 \qquad (3)$$

(SI Units)

$$K_{It} = 0.0316C_m(CR)\,t^{2.5}\,F_3 \qquad (3)$$

where

$C_m = \dfrac{E\alpha}{\left[(1 - \nu)d\right]}$

$F_3 = 0.1181 + 0.5353\,(a/t) - 1.273\,(a/t)^2 + 0.6046(a/t)^3$

For SA-302 Grades A and B, SA-533 Grade B, Class 1, and SA-508 Classes 2 and 3 steels, and their associated weldments, C_m equal to 0.0051 (ksi-hr)/(in.^{2}-°F) [98.1 × 10^{-6} (MPa · h)/(mm^2 ·°C)] can be used. Properties given in Section II, Part D can be used to determine C_m for other materials.

This equation for K_{It} is valid for $0.20 \le a/t \le 0.50$, and $0 \le (CR) \le$ 100°F/hr (56°C/h).

(d) The effective flaw depth for small scale yielding, a_e, shall be calculated using the following:

(U.S. Customary Units)

$$a_e = a + \left[1/(6\pi)\right]\left[\left(K_{Ip} + K_{It}\right)/\sigma_y\right]^2$$

(SI Units)

$$a_e = a + \left[1\,000/(6\pi)\right]\left[\left(K_{Ip} + K_{It}\right)/\sigma_y\right]^2$$

Step 2. See Below.

(a) For an axial flaw, the stress intensity factor due to internal pressure for small scale yielding, K'_{Ip}, shall be calculated, substituting a_e for a in eq. Step 1(a)(1), including the equation for F_1. For a circumferential flaw, K'_{Ip} shall be calculated, substituting a_e for a in eq. Step 1(b)(2), including the equation for F_2. For an axial or circumferential flaw, the stress intensity factor due to radial thermal gradients for small scale yielding, K'_{It}, shall be calculated, substituting a_e for a in eq. Step 1(c)(3), including the equation for F_3. Equations Step 1(a)(1), Step 1(b)(2), and Step 1(c)(3) are valid for $0.2 \le a_e/t \le 0.5$.

(b) The J-integral due to applied loads for small scale yielding shall be calculated using the following:

$$J = 1000\left(K'_{Ip} + K'_{It}\right)^2/E'$$

K-4220 EVALUATION USING CRITERION FOR FLAW EXTENSION OF 0.1 in. (2.5 mm)

The J-integral due to applied loads, J_1, shall be calculated in accordance with K-4210. A flaw depth a of $0.25t$ + 0.1 in. (2.5 mm), a pressure p equal to the accumulation pressure for Levels A and B Service Loadings, P_a, and a structural factor (SF) on pressure of 1.15 shall be used. Acceptance criteria for Levels A and B Service Loadings based on a ductile flaw extension of 0.10 in. (2.5 mm) in K-2200(a)(1) are satisfied when the following inequality is satisfied.

$$J_1 < J_{0.1}$$

where

J_1 = the applied J-integral for a structural factor on pressure of 1.15, and a structural factor of 1 on thermal loading
$J_{0.1}$ = the J-integral resistance at a ductile flaw extension of 0.1 in. (2.5 mm)

K-4300 EVALUATION PROCEDURES FOR FLAW STABILITY

K-4310 J-R CURVE — CRACK DRIVING FORCE DIAGRAM PROCEDURE

Flaw stability shall be evaluated by direct application of the flaw stability rules in K-3400. The applied J-integral shall be calculated for a series of flaw depths corresponding to increasing amounts of ductile flaw extension. The applied J-integral for Levels A and B Service Loadings shall be calculated using the procedures provided in K-4210. The applied pressure p shall be equal to the accumulation pressure for Levels A and B Service Loadings, P_a; and the structural factor (SF) on pressure shall be 1.25. The applied J-integral shall be plotted against crack depth on the crack driving force diagram to produce the applied J-integral curve, as illustrated in Figure K-4310-1. The J-R curve shall be plotted on the crack driving force diagram, and shall intersect the horizontal axis at the initial flaw depth, a_o. Flaw stability at a given applied load is verified when the slope of the applied J-integral curve is less than the slope of the J-R curve at the point on the J-R curve where the two curves intersect.

K-4320 FAILURE ASSESSMENT DIAGRAM PROCEDURE

Use of this procedure shall be limited to a postulated initial flaw depth of one-quarter of the wall thickness.

K-4321 Failure Assessment Diagram Curve

The corresponding failure assessment diagram curve of Figure K-4320-1 shall be used for axial and circumferential flaws. The coordinates S_r and K_r of the failure assessment diagram curves are provided in Table K-4320-1. These curves are based on material properties which are characteristic of reactor pressure vessel steels.

K-4322 Failure Assessment Point Coordinates (15)

The flaw depth a for ductile flaw extension Δa is given by the following:

$$a = 0.25t + \Delta a$$

Figure K-4310-1
Comparison of the Slopes of the Applied J-Integral Curve and the J-R Curve

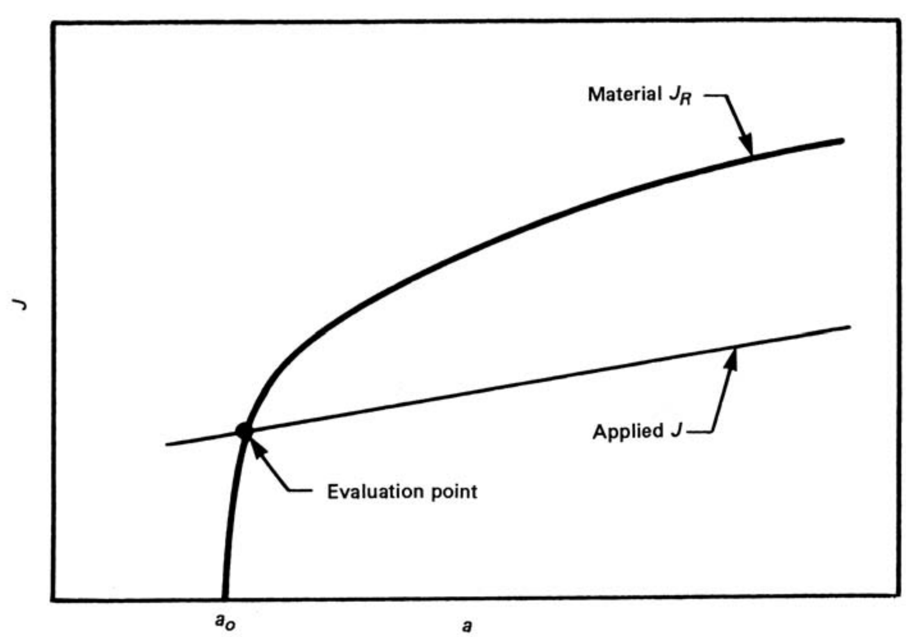


Figure K-4320-1
Failure Assessment Diagram for the One-Quarter Wall Thickness Flaw

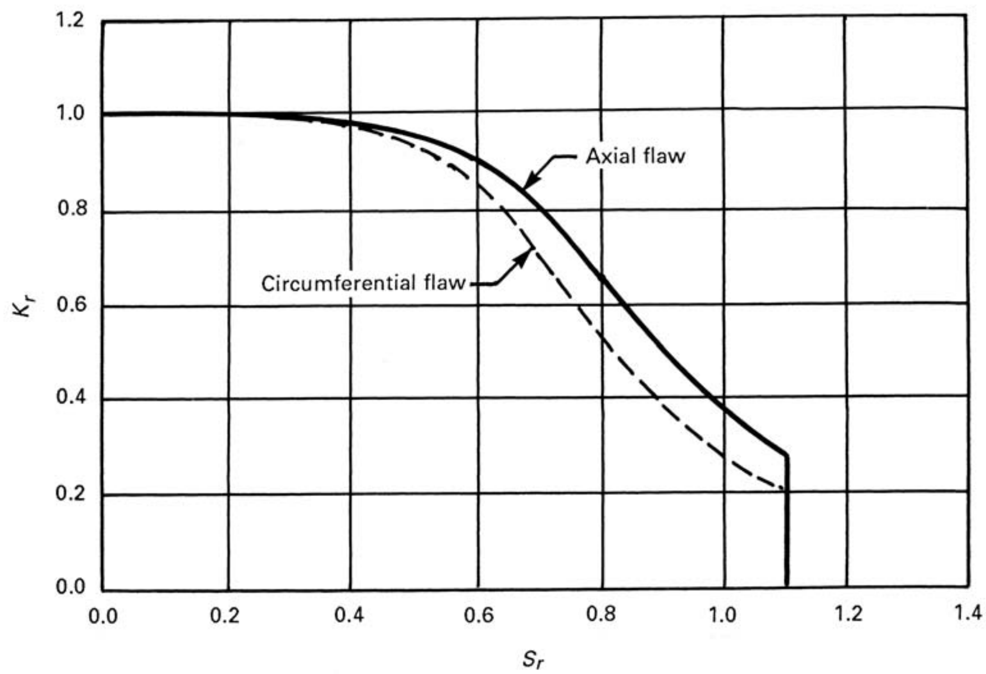


Table K-4320-1
Coordinates of the Failure Assessment Diagram Curves of Figure K-4320-1

S_r	K_r For Axial Flaw Curve	K_r For Circumferential Flaw Curve
0.000	1.000	1.000
0.050	1.000	1.000
0.100	0.999	0.999
0.150	0.998	0.998
0.200	0.996	0.996
0.250	0.993	0.994
0.300	0.990	0.991
0.350	0.987	0.986
0.400	0.981	0.978
0.450	0.973	0.965
0.500	0.960	0.943
0.550	0.939	0.908
0.600	0.908	0.856
0.650	0.864	0.788
0.700	0.807	0.706
0.750	0.737	0.618
0.800	0.660	0.532
0.850	0.581	0.452
0.900	0.505	0.383
0.950	0.435	0.323
1.000	0.374	0.274
1.050	0.321	0.232
1.100	0.276	0.198

The failure assessment point coordinates, S_r' and K_r', for ductile flaw extension Δa shall be calculated as follows:

$$K_r' = K_I\left[1000/\left(E'J_R\right)\right]^{0.5}$$

where the stress intensity factor shall be calculated using flaw depth a without the plastic-zone correction, and is given by the following:

$$K_I = K_{Ip} + K_{It}$$

and

$$S_r' = \left(SF\right)p/P_o$$

where (SF) is the required structural factor on pressure. The procedure for calculating K_{Ip}, K_{It}, and P_o for axial flaws is provided by K-4322.1, and for circumferential flaws by K-4322.2.

K-4322.1 Axial Flaws.

(a) The stress intensity factor due to internal pressure for axial flaws with a structural factor (SF) on pressure is given by eq. K-4210, Step 1(a)(1). The stress intensity factor due to radial thermal gradients is given by eq. K-4210, Step 1(c)(3).

(b) The reference limit-load pressure is given by the following:

$$P_o = \frac{\left(2/\sqrt{3}\right)\sigma_y\left[0.905 - 0.379\left(\Delta a/t\right)\right]}{\left[0.379 + \left(R_i/t\right) + 0.379\left(\Delta a/t\right)\right]}$$

(c) For materials with yield strength σ_y greater than 85 ksi (586 MPa), σ_y in this equation shall be 85 ksi (586 MPa). This equation for P_o is valid for $0 \le \Delta a/t \le 0.10$.

K-4322.2 Circumferential Flaws.

(a) The stress intensity factor due to internal pressure for circumferential flaws with a structural factor (SF) on pressure is given by eq. K-4210, Step 1(b)(2). The stress intensity factor due to radial thermal gradients is given by eq. K-4210, Step 1(c)(3).

(b) The reference limit-load pressure is given by the following:

$$P_o = \frac{\sigma_y\left[1 - 0.91\left(0.25 + \left(\Delta a/t\right)\right)^2\left(t/R_i\right)\right]}{1 + \left(R_i/2t\right)}$$

(c) For materials with yield strength σ_y greater than 85 ksi (586 MPa), σ_y in this equation shall be 85 ksi (586 MPa). This equation for P_o is valid for $0 \le \Delta a/t \le 0.25$.

K-4323 Evaluation Using Criterion for Flaw Stability

Assessment points shall be calculated for each loading condition in accordance with K-4322, and shall be plotted on Figure K-4320-1 as follows. A series of assessment points for various amounts of ductile flaw extension, Δa, up to the validity limit of the J-R curve shall be plotted. Pressure p equal to the accumulation pressure for Levels A and B Service Loadings, P_a, and structural factor (SF) on pressure of 1.25 shall be used. When one or more assessment points lie inside the failure assessment curve, the acceptance criteria based on flaw stability in K-2200(a)(2) are satisfied.

K-4330 J-INTEGRAL/TEARING MODULUS PROCEDURE

Use of this procedure shall be limited to a postulated initial flaw depth of one-quarter of the wall thickness.

K-4331 J-Integral at Flaw Instability (15)

(a) In Figure K-4330-1, the onset of flaw instability is the point of intersection of the applied and material curves plotted on a graph of the J-integral versus tearing modulus (J versus T). The expression for the applied J versus T curve is given by the following:

(U.S. Customary Units)

$$J = \left(1000\,W\,t\,\sigma_f^2/E\right)T \quad (4)$$

(SI Units)

$$J = \left(W\,t\,\sigma_f^2 / E\right)T$$

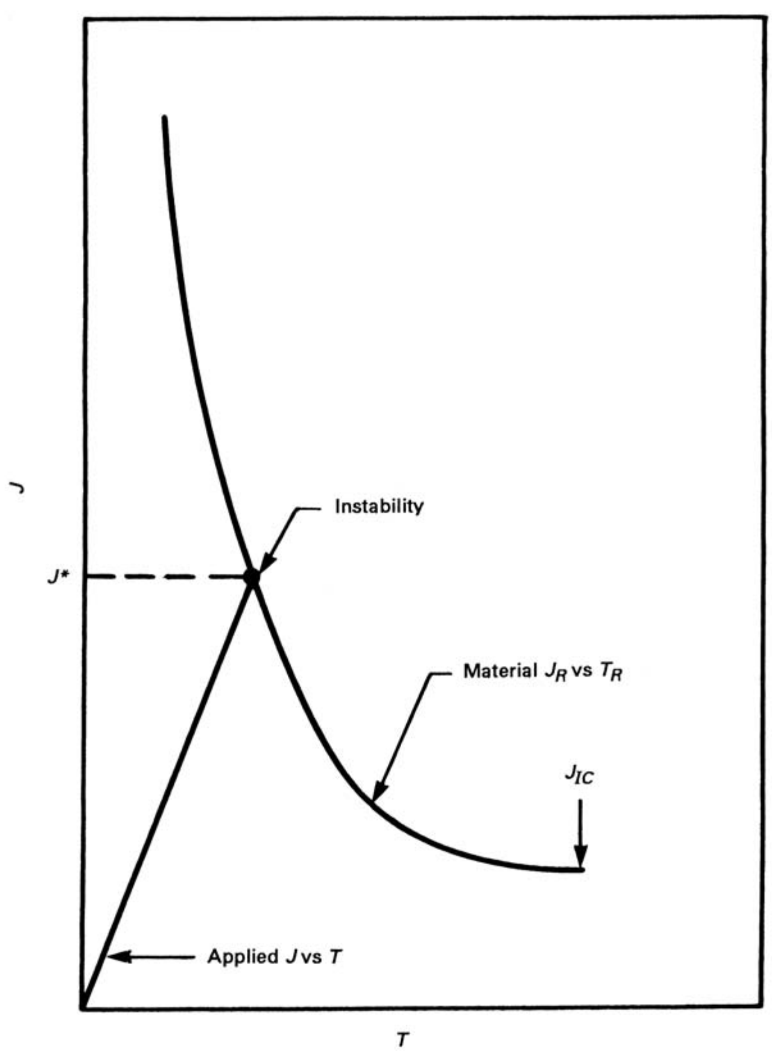
where σ_f is a reference flow stress of 85 ksi (586 MPa).

(b) For axial flaws eq. (5) applies:

(U.S. Customary Units)

$$W = 0.235\left\{1 + \left(0.083 \times 10^{-3}\right)(CR)t^2 / \left[(SF)P_s\right]\right\} \tag{5}$$

Figure K-4330-1
Illustration of the J-Integral/Tearing Modulus Procedure



(SI Units)

$$W = 0.235\left\{1 + \left(1.6 \times 10^{-6}\right)(CR)t^2 / \left[(SF)P_s\right]\right\}$$

where P_s is the pressure under evaluation. eq. (5) is valid for 6 in. $\leq t \leq$ 12 in. (150 mm $\leq t \leq$ 300 mm), 2.25 ksi (15.5 MPa) $\leq$ $(SF)P_s \leq$ 5.00 ksi (34 MPa), and $0 \leq (CR) \leq$ 100°F/hr (56°C/h). For circumferential flaws eq. (6) applies:

(U.S. Customary Units)

$$W = 0.21\left[1 + \left(0.257 \times 10^{-3}\right)(CR)t^2 / \left((SF)P_s\right)\right] \tag{6}$$

(SI Units)

$$W = 0.21\left[1 + \left(4.94 \times 10^{-6}\right)(CR)t^2 / \left((SF)P_s\right)\right]$$

Equation (6) is valid for 6 in. (152 mm) $\leq t \leq$ 12 in. (305 mm), 2.25 ksi (15.5 MPa) $\leq (SF)P_s \leq$ 9.00 ksi (62 MPa), and $0 \leq (CR) \leq$ 100°F/hr (56°C/h). Equations (a)(4), (5), and (6) are based on material properties which are characteristic of reactor pressure vessel steels.

(c) The tearing modulus for the material is determined by differentiation of the J-R curve with respect to flaw depth a.

(U.S. Customary Units)

$$T_R = \left[E / \left(1000\,\sigma_f^2\right)\right] dJ_R / da \tag{7}$$

(SI Units)

$$T_R = \left[\left(E / \sigma_f^2\right)\right] dJ_R / da$$

The same values for E and σ_f shall be used in eqs. (a)(4) and (7). The J-integral versus tearing modulus J_R versus T_R curve for the material is obtained by plotting J_R against T_R for a series of increments in ductile flaw extension. Each coordinate for J_R shall be evaluated at the same ductile flaw extension as the coordinate for T_R.

(d) The value of the J-integral at the onset of flaw instability, J^*, corresponds to the intersection of the applied J versus T curve given by eq. (a)(4) with the material J_R versus T_R curve, as illustrated in Figure K-4330-1.

(e) The J-integral at the onset of flaw instability may be determined analytically when a power-law curve fit to the J-R curve of the form

$$J_R = C_1 (\Delta a)^{C_2}$$

is available. The J-integral at the onset of flaw instability, J^*, is given by the following:

$$J^* = C_1 \left(W\, t\, C_2\right)^{C_2}$$

K-4332 Internal Pressure at Flaw Instability

(a) Calculation of the internal pressure at the onset of flaw instability is based on J^*. Ductile flaw extension at the onset of flaw instability, Δa^*, is taken from the J-R curve. The effective flaw depth at the onset of flaw instability includes Δa^*, and is given by the following:

(U.S. Customary Units)

$$a_e^* = 0.25t + \Delta a^* + \left[1 / (6\pi)\right]\left[J^* E' / \left(1000\,\sigma_y^2\right)\right]$$

(SI Units)

$$a_e^* = 0.25t + \Delta a^* + \left[1 / (6\pi)\right]\left[J^* E' / \left(\sigma_y^2\right)\right]$$

(b) The stress intensity factor due to radial thermal gradients at the onset of flaw instability, K^*_{It}, for axial or circumferential flaws is given by the following:

(U.S. Customary Units)

$$K^*_{It} = C_m(CR)t^{2.5} F^*_3$$

(SI Units)

$$K^*_{It} = 0.03\, C_m(CR)t^{2.5} F^*_3$$

where

$$F^*_3 = 0.1181 + 0.5353\left(a^*_e/t\right) - 1.273\left(a^*_e/t\right)^2 + 0.6046\left(a^*_e/t\right)^3$$

$$C_m = \frac{E\alpha}{\left[(1 - \nu)d\right]}$$

For SA-302 Grades A and B, SA-533 Grade B, Class 1, and SA-508 Classes 2 and 3 steels, and their associated weldments, C_m equal to 0.0051 (ksi-hr)/ (in.^{2}-°F) [98.1 × 10^{-6} (MPa · h) / (mm^2 ·°C)] can be used. Properties given in Section II, Part D can be used to determine C_m for other materials. This equation for K^*_{It} is valid for $0.2 \leq a^*_e / t \leq 0.5$, and $0 \leq (CR) \leq 100$°F/hr (56°C/h). The stress intensity factor for small scale yielding due to internal pressure at the onset of flaw instability, K^*_{Ip}, is given by the following:

$$K^*_{Ip} = \left(J^*E' / 1000\right)^{0.5} - K^*_{It}$$

(c) For a given value of K^*_{Ip}, the internal pressure at the onset of flaw instability for axial flaws is given by the following:

(U.S. Customary Units)

$$P^* = K^*_{Ip} / \left[\left(1 + (R_i / t)\right)\left(\pi a^*_e\right)^{0.5} F^*_1\right]$$

(SI Units)

$$P^* = K^*_{Ip} / \left[\left(1 + (R_i / t)\right)\left(\pi a^*_e / 1000\right)^{0.5} F^*_1\right]$$

where

$$F^*_1 = 0.982 + 1.006\left(a^*_e / t\right)^2$$

and for circumferential flaws is given by the following:

(U.S. Customary Units)

$$P^{*} = K_{Ip}^{*} / \left[\left(1 + \left(R_i / 2t\right)\right) \left(\pi a_e^{*}\right)^{0.5} F_2^{*} \right]$$

(SI Units)

$$P^{*} = K_{Ip}^{*} / \left[\left(1 + \left(R_i / 2t\right)\right) \left(\pi a_e^{*} / 1000\right)^{0.5} F_2^{*} \right]$$

where

$$F_2^{*} = 0.885 + 0.233\left(a_e^{*} / t\right) + 0.345\left(a_e^{*} / t\right)^2$$

These equations for P^* are valid for $0.2 \leq a_e^{*} / t \leq 0.5$, and include the effect of pressure acting on the flaw faces.

K-4333 Evaluation Using Criteria for Flaw Stability

The value of J^* shall be calculated in accordance with K-4331 using pressure P_s in eqs. K-4331(b)(5) and K-4331(b)(6) equal to the accumulation pressure for Levels A and B Service Loadings, P_a, and structural factor (SF) on pressure of 1.25. The value of P^* shall be calculated in accordance with K-4332. The acceptance criteria based on flaw stability in K-2200(a)(2) are satisfied when the following inequality is satisfied:

$$P^{*} > 1.25\, P_a$$

ARTICLE K-5000
EVALUATION PROCEDURES FOR LEVELS C AND D SERVICE LOADINGS

K-5100 SCOPE

This Article contains evaluation procedures that may be used to satisfy the acceptance criteria in Article K-2000 for Levels C and D Service Loadings. A procedure to satisfy the J-integral criteria for a specified amount of flaw extension of 0.1 in. (2.5 mm) is provided in K-5200. A procedure to satisfy the flaw stability criteria is provided in K-5300. These procedures are applicable to axial and circumferential flaw orientations, and shall be used when this approach is selected.

K-5200 EVALUATION PROCEDURE FOR THE APPLIED J-INTEGRAL

K-5210 CALCULATION OF THE APPLIED J-INTEGRAL

(a) Stress intensity factors shall be calculated as a function of flaw depth, a for Levels C and D Service Loadings for each applicable stress component, as follows. Calculate K_I due to internal pressure, radial thermal gradient through the vessel wall, and cladding/ base metal differential thermal expansion.

(b) The effective flaw depth for small-scale yielding, a_e shall be calculated using

(U.S. Customary Units)

$$a_e = a + [1/(6\pi)](K_I/\sigma_y)^2$$

(SI Units)

$$a_e = a + [1\,000/(6\pi)](K_I/\sigma_y)^2$$

(c) The stress intensity factor for small-scale yielding, K'_I, shall be calculated by substituting a_e for a in (a) above.

(d) The J-integral due to applied loads for small-scale yielding shall be calculated using

$$J = 1000(K'_I)^2/E'$$

K-5220 EVALUATION USING CRITERION FOR FLAW EXTENSION OF 0.1 in. (2.5 mm)

(a) For Level C Service Loadings, the J-integral due to applied loads, J_1, shall be calculated in accordance with K-5210. Flaw depth a, equal to a_o + 0.1 in. (2.5 mm), shall be used to calculate the applied J-integral. Acceptance criteria for Level C Service Loadings based on a ductile flaw extension of 0.1 in. (2.5 mm) in K-2300(a)(1) are satisfied when the following inequality is satisfied at each value of J_1 for the range in a_o specified in K-2300.

$$J_1 < J_{0.1}$$

(b) For time-dependent Level C Service Loadings, evaluation shall be in accordance with K-5400.

K-5300 EVALUATION PROCEDURE FOR FLAW STABILITY

(a) For Levels C and D Service Loadings, flaw stability shall be evaluated by direct application of the flaw stability requirements of K-3400. The applied J-integral for Levels C and D Service Loadings shall be calculated in accordance with K-5210 for a series of flaw depths corresponding to increasing amounts of ductile flaw extension, Δa. A flaw depth a equal to $a_0 + \Delta a$ shall be used to calculate the applied J-integral. The J-integral resistance at each value of Δa shall be determined from the J-R curve. Flaw stability at a given applied load is verified when K-3400(a) and K-3400(b)

are satisfied. Acceptance criteria based on flaw stability for Level C Service Loadings in K-2300(a)(2), and for Level D Service Loadings in K-2400(a), are satisfied when flaw stability is verified for the range in a_0 specified in K-2300 and K-2400.

(b) For Level D Service Loadings, for the range in a_0 specified in K-2400, demonstrate that the total flaw depth after stable flaw extension is less than or equal to 75% of the vessel wall thickness, and the remaining ligament is not subject to tensile instability. The internal pressure p shall be less than P_I, where P_I is the internal pressure at tensile instability of the remaining ligament. Equations for P_I are given in (1) for the axial flaw, and in (2) for the circumferential flaw.

(1) For the axial flaw,

$$P_I = 1.07\sigma_o\left[\frac{1 - (A_c/A)}{(R_i/t) + (A_c/A)}\right]$$

where

$$\sigma_o = \frac{\sigma_y + \sigma_u}{2} \quad (8)$$

$$A = t(\ell + t) \quad (9)$$

and σ_y is the yield strength for the material, σ_u is the ultimate tensile strength for the material, σ_o is the flow stress for the material for the tensile stability evaluation, R_i is the inner radius of the vessel, t is the wall thickness of the vessel, ℓ is the total length of the flaw, A_c is the area of the flaw, and A is an area parameter. The material properties σ_y, σ_u, and σ_o include the effects of temperature and fluence. This equation for P_I includes the effect of pressure on the flaw face. For a semi-elliptical flaw of depth a, the relation for A_c is given by

$$A_c = \frac{\pi a \ell}{4} \quad (10)$$

(2) For the circumferential flaw,

$$P_I = 1.07\sigma_o\left[\frac{1 - (A_c/A)}{\left(R_i^2/(2R_m t)\right) + (A_c/A)}\right]$$

where R_m is the mean radius of the vessel, σ_o is given in eq. (1)(8), A is given by eq. (1)(9), and A_c for a semi-elliptical flaw is given by eq. (1)(10). This equation for P_I includes the effect of pressure on the flaw face. This equation is valid for internal pressures not exceeding the pressure at tensile instability caused by the applied hoop stress acting over the nominal wall thickness of the vessel. This validity limit on pressure for the circumferential flaw equation for P_I is

$$P_I \leq 1.07\sigma_o\frac{t}{R_i}$$

(c) For time-dependent Levels C and D Service Loadings, evaluation shall be in accordance with K-5400.

K-5400 TIME-DEPENDENT LEVELS C AND D SERVICE LOADINGS

When the applicable stress components vary with time during Level C or Level D Service Loadings, evaluation shall be performed at various times during the postulated loading to determine the limiting conditions for the flaw extension and flaw stability criteria. The J-integral resistance shall be determined at each of the times the evaluation is performed using the metal temperature associated with each flaw depth evaluated.

NONMANDATORY APPENDIX L
OPERATING PLANT FATIGUE ASSESSMENT

ARTICLE L-1000
INTRODUCTION

L-1100 SCOPE

This Nonmandatory Appendix provides methods for performing fatigue assessments to determine acceptability for continued service of reactor coolant system and primary pressure boundary components and piping subjected to cyclic loadings. This Nonmandatory Appendix is applicable only in the absence of any flaw at the location of concern which is larger than allowed by the applicable acceptance standard referenced in Table IWB-3410-1. Evaluations performed using this Nonmandatory Appendix shall meet all the requirements of the Appendix.

L-1200 EVALUATION METHODS

(a) One of the following evaluation methods shall be used to determine acceptability for continued service of reactor coolant system and primary pressure boundary components and piping:

(1) The fatigue usage factor evaluation procedures and acceptance criteria in Article L-2000.

(2) The flaw tolerance evaluation procedures and acceptance criteria in Article L-3000.

(b) The evaluations of (a)(1) and (a)(2) shall be documented in accordance with the provisions of Article L-4000.

L-1300 NOMENCLATURE

The following nomenclature is used:

a = general depth dimension for the postulated flaw, in. (mm)

a_c = minimum critical flaw depth for normal (including upset and test) conditions, in. (mm)

a_f = maximum depth by which the postulated flaw in L-3200 is calculated to grow by the end of the evaluation period, in. (mm)

a_i = minimum critical flaw depth for emergency and faulted conditions, in. (mm)

a_n = maximum allowable flaw depth for normal (Service Level A) and upset and test (Service Level B) conditions, in. (mm)

a_o = maximum allowable flaw depth for emergency (Service Level C) and faulted (Service Level D) conditions, in. (mm)

n = fatigue crack growth rate exponent in eq. C-3210(a)(1).

N_i = number of cycles for i^{th} load pair or transient loading condition

P = minimum allowable operating period calculated for the postulated flaw in L-3200 to grow to the maximum depth allowed in L-3312, L-3320 (in the course of preparation), L-3332, or L-3342, years

P_n = allowable operating period calculated for the postulated flaw for normal (including upset and test) conditions, years

P_o = allowable operating period calculated for the postulated flaw for emergency and faulted conditions, years

t = nominal thickness, in. (mm)

ℓ = general length dimension for the postulated flaw, in. (mm)

ℓ_f = maximum postulated flaw length at the end of the evaluation period, in. (mm)

$\Delta\sigma_g$ = cyclic linear and nonlinear gradient stress, psi (MPa)

$\Delta\sigma_m$ = cyclic membrane stress, psi (MPa)

θ = postulated circumferential flaw half-angle length, deg

ARTICLE L-2000 FATIGUE USAGE EVALUATION

L-2100 SCOPE

This Article provides procedures for performing fatigue usage factor evaluations for reactor coolant system primary pressure boundary components and piping in operating plants.

L-2200 EVALUATION PROCEDURES AND ACCEPTANCE CRITERIA

(15) L-2210 EVALUATION PROCEDURES

(a) The Section III, Class 1 fatigue usage factor procedures shall be used to determine a cumulative fatigue usage factor (CUF) at the end of the evaluation period.

(b) Editions and addenda of Section III later than the original Construction Code may be used.

(c) The loadings in the Design Specification, plant specific loading cycles consistent with the plant design and operating practices, or actual plant operating data, shall be used, as appropriate.

L-2220 ACCEPTANCE CRITERIA

The primary pressure boundary component or piping is acceptable for continued service throughout the evaluation period if the CUF in L-2210 is less than or equal to 1.0.

ARTICLE L-3000 FLAW TOLERANCE EVALUATION

L-3100 SCOPE

This Article provides procedures for performing flaw tolerance evaluations for operating plant components and piping. It includes procedures for shape, location, and orientation of the postulated flaw used in the evaluation; the methodology for determination of the growth of the postulated flaw during the evaluation period; end-of-evaluation-period acceptance criteria; and examination.

L-3110 GENERAL PROCEDURE

(a) A flowchart for the flaw tolerance evaluation is shown in Figure L-3110-1.

(b) Using the examination provisions in L-3400, verify the absence of any flaw exceeding the applicable acceptance standard referenced in L-3410(a) at the component locations of concern.

(c) Postulate an initial flaw in accordance with L-3200.

(d) Determine the stresses at the location of the postulated flaw under normal operating (including upset and test), emergency, and faulted conditions.

(e) Determine the postulated end-of-evaluation-period flaw sizes, critical flaw sizes, allowable flaw depths, and allowable operating period, using the analytical procedures in L-3300.

(f) Apply the successive examination provisions of L-3420 to the component or piping at the location of concern.

L-3200 FLAW MODEL

L-3210 FLAW SHAPE AND DEPTH

L-3211 Flaw Shape

(a) For vessel components, the postulated flaw is a planar, semi-elliptical surface flaw with an aspect ratio a/ℓ equal to 0.167.

(b) For circumferential flaws in ferritic piping, the postulated flaw is a planar, semi-elliptical surface flaw with an aspect ratio that shall be determined from Table L-3210-1.

(c) For circumferential flaws in austenitic piping, the postulated flaw is a planar, semi-elliptical surface flaw with a shape that shall be determined from Table L-3210-2.

(d) For axial flaws in ferritic and austenitic piping, the postulated flaw is a planar, semi-elliptical surface flaw with an aspect ratio as specified in Table L-3210-1 for ferritic material or Table L-3210-2 for austenitic material.

L-3212 Flaw Depth

(a) The flaw depth for piping and vessel components shall be determined from the applicable inservice inspection acceptance standards in Table IWB-3410-1 using a flaw aspect ratio, a/ℓ, equal to 0.167. Section thicknesses of 4 in. to 12 in. (100 mm to 300 mm) shall have a minimum flaw depth of 0.25 in. (6 mm) for Examination Categories B-A, B-B, and B-D.

(b) The flaw depth for other components shall be no smaller than the applicable inservice inspection acceptance standards in Table IWB-3410-1 and compatible with examination detection capabilities demonstrated in accordance with IWA-2230 or other appropriate standards.

(c) The flaw depth for statically or centrifugally cast austenitic stainless steel base metal, dissimilar metal welds with limited access, stainless steel welds in which ultrasonic examination cannot be made from the same side of the weld as the fatigue sensitive location, and stainless steel piping having corrosion resistant cladding (CRC) shall be no smaller than the applicable acceptance standards in Table IWB-3410-1 and compatible with examination detection capabilities demonstrated in accordance with IWA-2230 or other appropriate standards.

L-3220 FLAW LOCATION AND ORIENTATION

(a) The postulated flaw shall be located on the component surface at the location of concern.

(b) The plane of the flaw shall be oriented perpendicular to the maximum principal stress. When the direction of the maximum principal stress varies throughout the stress cycle, the perpendicular direction corresponding to the point in the cycle where the maximum principal stress is greatest shall be chosen, and maximum principal stresses throughout the cycle shall be assumed to act in this direction.

Figure L-3110-1
Flowchart for Flaw Tolerance Evaluation

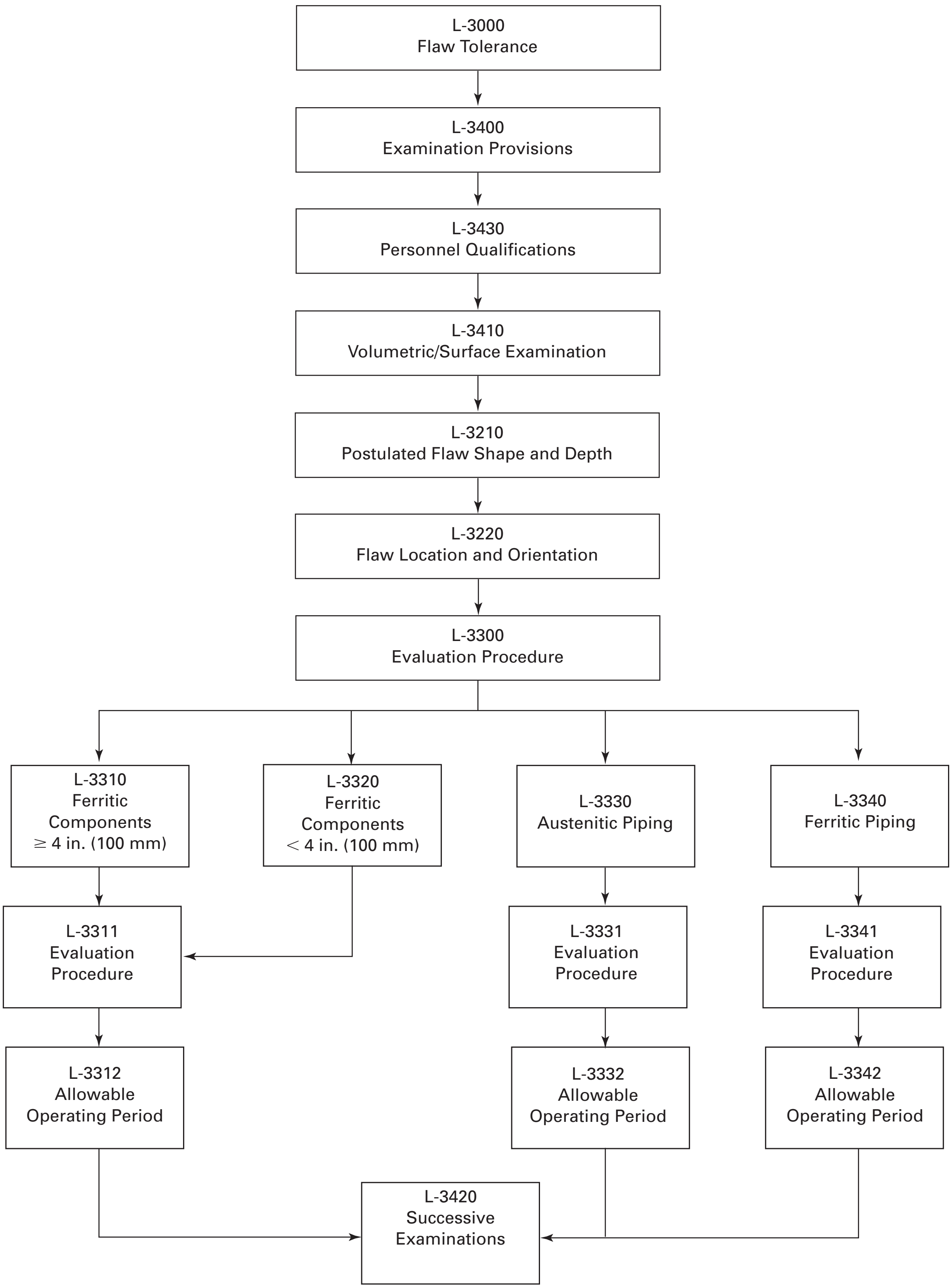


Table L-3210-1
Ferritic Piping Postulated Equivalent Single Crack Aspect Ratios (a/ℓ)

$\Delta\sigma_m / \Delta\sigma_g$ [Note (1)]	Nominal Wall Thickness, t, in. (mm)				
	≤0.218 (5.5)	0.344 (8.7)	0.719 (18.3)	1.125 (28.6)	≥2.125 (54)
0	0.0178	0.0149	0.0078	0.0071	0.0065
0.1	0.0371	0.0307	0.0240	0.0176	0.0146
0.25	0.0578	0.0592	0.0397	0.0280	0.0291
1	0.0606	0.0741	0.0735	0.0629	0.0714
3	0.0637	0.0794	0.0935	0.0917	0.1087
∞	0.1667	0.1667	0.1667	0.1667	0.1667

GENERAL NOTE: Linear interpolation is permissible.

NOTE:
(1) The membrane-to-gradient cyclic stress ratio is stated as follows:

$$\frac{\Delta\sigma_m}{\Delta\sigma_g} = \sum_i \frac{\Omega_i}{\Omega_{\text{total}}} \times \left(\frac{\Delta\sigma_m}{\Delta\sigma_g}\right)_i$$

$$\Omega_i = \left(\Delta\sigma_m + \Delta\sigma_g\right)_i^n \times N_i$$

$$\Omega_{\text{total}} = \sum_i \Omega_i$$

Summation is over all types of transient loading conditions.

Table L-3210-2
Austenitic Piping Postulated Equivalent Single Crack Aspect Ratios (a/ℓ)

$\Delta\sigma_m / \Delta\sigma_g$ [Note (1)]	Nominal Wall Thickness, t, in. (mm)				
	≤0.218 (5.5)	0.344 (8.7)	0.719 (18.3)	1.125 (28.6)	≥2.125 (54)
0	0.0105	0.0107	0.0081	0.0082	0.0088
0.1	0.0280	0.0253	0.0265	0.0289	0.0362
0.25	0.0410	0.0446	0.0654	0.0807	0.1667
1	0.0556	0.0833	0.1351	0.1639	0.1667
3	0.0588	0.1031	0.1539	0.1667	0.1667
∞	0.1667	0.1667	0.1667	0.1667	0.1667

GENERAL NOTE: Linear interpolation is permissible.

NOTE:
(1) The membrane-to-gradient cyclic stress ratio is stated as follows:

$$\frac{\Delta\sigma_m}{\Delta\sigma_g} = \sum_i \frac{\Omega_i}{\Omega_{\text{total}}} \times \left(\frac{\Delta\sigma_m}{\Delta\sigma_g}\right)_i$$

$$\Omega_i = \left(\Delta\sigma_m + \Delta\sigma_g\right)_i^n \times N_i$$

$$\Omega_{\text{total}} = \sum_i \Omega_i$$

Summation is over all types of transient loading conditions.

L-3300 EVALUATION PROCEDURES AND ALLOWABLE OPERATING PERIOD

The loadings in the Design Specification, plant specific loading cycles consistent with the plant design and operating practices, or actual plant operating data, shall be used, as appropriate, for evaluations in this Subarticle.

L-3310 EVALUATION PROCEDURES AND ALLOWABLE OPERATING PERIOD FOR FERRITIC STEEL COMPONENTS 4 in. (100 mm) OR GREATER IN THICKNESS

L-3311 Evaluation Procedures

(a) Nonmandatory Appendix A analytical procedures for fatigue crack growth may be used for ferritic steel components 4 in. (100 mm) or greater in thickness.

(b) The procedures in Article A-5000 may be used to calculate a_f and ℓ_f for the postulated flaw in L-3200 during the evaluation period.

(c) The procedures in Article A-5000 may be used to calculate the minimum critical flaw sizes a_c and a_i.

L-3312 Allowable Operating Period

(a) Calculate the operating periods P_n and P_o for the postulated flaw in L-3200 to grow to the allowable flaw depth corresponding to the acceptance criteria in IWB-3610(d) or IWB-3613, as appropriate.

(b) The allowable operating period P is equal to the smaller of P_n or P_o in (a).

L-3320 EVALUATION PROCEDURES AND ALLOWABLE OPERATING PERIOD FOR FERRITIC STEEL COMPONENTS LESS THAN 4 in. (100 mm) THICK

These procedures and criteria are in the course of preparation. In the interim, the procedures and criteria of L-3310 may be applied.

L-3330 EVALUATION PROCEDURES AND ALLOWABLE OPERATING PERIOD FOR AUSTENITIC PIPING

L-3331 Evaluation Procedures

(a) Nonmandatory Appendix C analytical procedures may be used for austenitic stainless steel piping.

(b) The procedures in C-3200 for fatigue crack growth may be used to calculate a_f and ℓ_f for the postulated flaw in L-3200 during the evaluation period.

(c) The allowable flaw depths a_n and a_o shall be determined using the limit load procedures in Article C-5000 or EPFM procedures in Article C-6000 as applicable.

L-3332 Allowable Operating Period

(a) Calculate the operating periods P_n and P_o for the postulated flaw in L-3200 to grow to the allowable flaw depths defined in L-3331(c).

(b) The allowable operating period P is equal to the smaller of P_n or P_o in (a).

L-3340 EVALUATION PROCEDURES AND ALLOWABLE OPERATING PERIOD FOR FERRITIC PIPING

L-3341 Evaluation Procedures

(a) Nonmandatory Appendix C analytical procedures may be used for ferritic piping.

(b) The procedures in C-3200 for fatigue crack growth may be used to calculate a_f and ℓ_f for the postulated flaw in L-3200.

(c) The allowable flaw depths a_n and a_o shall be determined using the limit load procedures in Article C-5000, EPFM procedures in Article C-6000, or LEFM procedures in Article C-7000, as applicable.

L-3342 Allowable Operating Period

(a) Calculate the operating periods P_n and P_o for the postulated flaw in L-3200 to grow to the maximum allowable flaw depth defined in L-3341(c).

(b) The allowable operating period P is equal to the smaller of P_n or P_o in (a).

L-3400 EXAMINATION PROVISIONS

L-3410 EXAMINATIONS

(a) The absence of any flaw larger than the applicable acceptance standard referenced in Table IWB-3410-1, at the location of concern, shall be verified by surface or volumetric examination. Otherwise, this Appendix is not applicable, and the flaw shall be evaluated in accordance with IWB-3400.

(b) Examinations shall be conducted in accordance with IWA-2220, IWA-2230, or IWA-2240, as applicable.

L-3420 SUCCESSIVE EXAMINATIONS

The component shall be examined at the location of concern in accordance with the successive inspection schedule provisions in Table L-3420-1. The successive inspection period shall not exceed that specified in Table L-3420-1 or IWB-2410.

L-3430 PERSONNEL QUALIFICATIONS

Personnel performing surface or volumetric examinations specified in L-3410 and L-3420 shall be qualified and certified in accordance with the applicable provisions of IWA-2300.

Table L-3420-1
Successive Inspection Schedule

Allowable Operating Period, *P*, yr [Note (1)]	Successive Inspection Provisions
≥ 10	Component locations of concern shall be examined at the end of each inspection interval listed in the schedule of inspection programs in IWB-2410.
< 10	Component locations of concern shall be examined at the end of *P* operating years [Note (2)].

NOTES:
(1) See L-1300.
(2) See L-3312, L-3332, or L-3342.

ARTICLE L-4000 RECORDS AND REPORTS

L-4100 SCOPE

This Article contains records and report provisions for evaluations and examinations specified in Article L-2000 and Article L-3000.

L-4200 EVALUATION RECORDS AND REPORTS

The evaluations specified in Article L-2000 and Article L-3000 shall be documented.

L-4300 EXAMINATION RECORDS AND REPORTS (15)

(a) The reporting provisions of the Owner's Activity Report in IWA-6230 shall apply to the examinations specified in L-3400.

(b) The examination record retention provisions of IWA-6300 shall apply to the examinations required by L-3400.

NONMANDATORY APPENDIX M
APPLYING MATHEMATICAL MODELING TO ULTRASONIC EXAMINATION OF PRESSURE-RETAINING COMPONENTS

ARTICLE M-1000
INTRODUCTION

(15) M-1100 SCOPE

This Appendix provides criteria for validation of mathematical models used to predict equivalence in examination coverage and misorientation angle. This Article will ensure that extensions of examination procedures, based upon predictions of a mathematical model, to geometries not specifically addressed in performance demonstrations by the ultrasonic system, are valid. This Nonmandatory Appendix provides guidance. However, if used, all provisions of the appendix are mandatory.

ARTICLE M-2000 VALIDATION OF MATHEMATICAL MODELS

M-2100 APPLICABILITY OF MODEL

The mathematical model shall have a statement of scope that defines the limits of applicability of the model, e.g., the model applies to nozzle geometries that involve a cylinder intersecting a cylinder or a cylinder intersecting a hemispherical head.

(15) M-2200 MODEL VERIFICATION

The mathematical model shall be tested to verify its capability to produce valid results for the range of permitted usage defined by the Scope. The verification process shall be controlled by the Owner's quality assurance program. The verification process for the model shall include test results from at least one of the following testing methods:

(a) analysis without computer assistance, e.g., hand calculations

(b) calculations using other validated, proven computer programs, if available

(c) experiments and tests

(d) standard problems with known solutions

In addition, confirmed published data, information, and correlations may be used.

M-2300 DOCUMENTATION

The verification test problems and results developed in accordance with M-2200 shall be documented.

M-2400 VERIFICATION FREQUENCY

Verification testing shall be performed whenever changes are made to the computer program or when significant hardware or operating system configuration changes are made.

M-2500 MATHEMATICAL MODEL ACCEPTANCE (15)

The mathematical model shall be considered acceptable when the test problems included in the verification process agree with known solutions within the greater of 1 in. (25 mm) or 10% of the metal path.

NONMANDATORY APPENDIX N
WRITTEN PRACTICE DEVELOPMENT FOR QUALIFICATION AND CERTIFICATION OF NDE PERSONNEL

ARTICLE N-1000
SCOPE

This Nonmandatory Appendix provides information which may be useful in preparation of written practice documents in accordance with IWA-2300. This Nonmandatory Appendix provides guidance; consequently, it may be used in whole or in part.

Changes to the personnel qualification and certification references of IWA-2300 may require changes to the employer's written practice when implementing the requirements of this Division. Table N-1000 summarizes the significant requirements of the references.

(a) SNT-TC-1A, 1984 Edition (SNT 1984)
(b) CP-189, 1991 Edition
(c) CP-189, 1995 Edition

Table N-1000-1 also includes a summary of requirements of SNT-TC-1A, 1992 (SNT 1992) Edition, which has been referenced by Section III, and a summary of related requirements of Mandatory Appendix VII for comparison.

Table N-1000-1
Selected Personnel Qualification Requirements from Referenced Sources

Requirement	SNT 1984			SNT 1992		CP-189-1991				CP-189-1995				Sec. XI–1998 Ed. w/ 2000 Addenda	Sec. XI–2001 Ed. w/ 2003 Addenda
Min. Education for Level I/II	Grammar School			High School (or equiv.)		n/a				n/a				No change from 1995 Ed. w/1996 Addenda	No change from 1998 Ed. w/2000 Addenda
NDE Instructor	n/a			n/a		Four options for qualification				Four options for qualification				No change from 1995 Ed. w/1996 Addenda	No change from 1998 Ed. w/2000 Addenda
ET Training	Hours Level I/II			Hours Level I/II		Hours Level I/II				Hours Level I/II				No change from 1995 Ed. w/1996 Addenda	No change from 1998 Ed. w/2000 Addenda
	GS	HS	2CL	HS	2CL	...				...					
	48/24	8/12	8/8	40/40	24/24	12/40				12/40					
ET Experience	Level I	Level II		Level I	Level II	Level I (hr)		Level II (hr)		Level 1 (hr)		Level II (hr)		IWA-2300 references CP-189-1995	No change from 1998 Ed. w/2000 Addenda
	months	months		months	months	Method	Total	Method	Total	Method	Total	Method	Total		
	1	9		1	9	65	130	600	1200	65	130	600	1200		
MT Training	Hours Level I/II			Hours Level I/II		Hours Level I/II				Hours Level I/II				IWA-2300 references CP-189-1995	No change from 1998 Ed. w/2000 Addenda
	GS	HS	2CL	HS	2CL	...				...					
	24/16	12/8	8/4	12/8	8/4	12/8				12/8					
MT Experience	Level I	Level II		Level I	Level II	Level I (hr)		Level II (hr)		Level I (hr)		Level II (hr)		IWA-2300 references CP-189-1995	No change from 1998 Ed. w/2000 Addenda
	months	months		months	months	Method	Total	Method	Total	Method	Total	Method	Total		
	1	3		1	3	65	130	200	400	65	130	200	400		
PT Training	Hours Level I/II			Hours Level I/II		Hours Level I/II				Hours Level I/II				IWA-2300 references CP-189-1995	No change from 1998 Ed. w/2000 Addenda
	GS	HS	2CL	HS	2CL	...				...					
	12/16	4/8	4/4	4/8	4/4	8/8				8/8					
PT Experience	Level I	Level II		Level I	Level II	Level I (hr)		Level II (hr)		Level I (hr)		Level II (hr)		IWA-2300 references CP-189-1995	No change from 1998 Ed. w/2000 Addenda
	months	months		months	months	Method	Total	Method	Total	Method	Total	Method	Total		
	1	2		1	9	35	130	135	270	35	130	135	270		
RT Training	Hours Level I/II			Hours Level I/II		Hours Level I/II				Hours Level I/II				IWA-2300 references CP-189-1995	No change from 1998 Ed. w/2000 Addenda
	GS	HS	2CL	HS	2CL	...				...					
	88/80	39/40	29/35	39/40	29/35	39/40				40/40					
RT Experience	Level I	Level II		Level I	Level II	Level I (hr)		Level II (hr)		Level I (hr)		Level II (hr)		IWA-2300 references CP-189-1995	No change from 1998 Ed. w/2000 Addenda
	months	months		months	months	Method	Total	Method	Total	Method	Total	Method	Total		
	3	9		3	9	200	400	600	1200	200	400	600	1200		

Table N-1000-1
Selected Personnel Qualification Requirements from Referenced Sources (Cont'd)

Requirement	SNT 1984			SNT 1992		CP-189-1991				CP-189-1995				Sec. XI–1998 Ed. w/ 2000 Addenda	Sec. XI–2001 Ed. w/ 2003 Addenda
UT Training	Hours Level I/II			Hours Level I/II		Hours Level I/II				Hours Level I/II				No change from 1995 Ed. w/1996 Addenda	No change from 1998 Ed. w/2000 Addenda
	GS	HS	2CL	HS	2CL	...				...					
	$^{40}/_{80}$	$^{40}/_{40}$	$^{24}/_{40}$	$^{40}/_{40}$	$^{30}/_{40}$	$^{40}/_{40}$				$^{40}/_{40}$					
	...	...	...	...	...	...				...				8 Hours Annual Practice [Note (4)]	No change from 1998 Ed. w/2000 Addenda
UT Experience	Level I	Level II		Level I	Level II	Level I (hr)		Level II (hr)		Level I (hr)		Level II (hr)		No change from 1995 Ed. w/1996 Addenda	No change from 1998 Ed. w/2000 Addenda
	months	months		months	months	Method	Total	Method	Total	Method	Total	Method	Total		
	3	9		3	9	200	400	600	1200	200	400	600	1200		
VT Training	No Rules Provided: IWA-2300, required qualification comparable to SNT-TC-1A			Hours Level I/II		No Rules Provided: IWA-2300, requires qualification comparable to CP-189 for other methods				Hours Level I/III				IWA-2300, requires CP-189-1995 for combined VT-1,2,3 qualification: only one VT type is a limited cert per IWA-2350;	No change from 1998 Ed. w/2000 Addenda
				HS	2CL					...					
				$^{8}/_{16}$	$^{4}/_{8}$					$^{8}/_{12}$					
VT Experience	No Rules Provided: IWA-2300, required qualification comparable to SNT-TC-1A			Level I	Level II	No Rules Provided: IWA-2300, requires qualification comparable to CP-189 for other methods				Level I (hr)		Level I (hr)		also provided are alternate qualification requirements for VT-2 (IWA-2316) and VT-3 (IWA-2317)	No change from 1998 Ed. w/2000 Addenda
				months	months					Method	Total	Method	Total		
				1	2					65	130	130	270		
Level III Education, Experience	4 yr college, 1 yr exper. or 2 yr college, 2 yr exper. or 4 yr exp.			4 yr college, 1 yr exper. or 2 yr college, 2 yr exper. or 4 yr exp.		No specific education, experience requirements — but current ASNT Level III Certificate is required				No specific education, experience requirements — but current ASNT Level III Certificate is required				IWA-2300 references CP-189-1995, but does not require ASNT Level III Certificate	No change from 1998 Ed. w/2000 Addenda
Level II Examinations	General, Specific, & Practical			General, Specific, & Practical		General, Specific, & Practical (2 sam.); (note 10 extra questions required on ET Level II Specific)				General, Specific, & Practical (2 samples)				IWA-2300 references CP-189-1995	IWA-2300 references CP-189-1995, but ACCP satisfies the general and practical examination
Level III Examination	Employer may waive			Examination Required: Basic, Method, Specific		Examination Required: Basic, Method (ASNT), Specific, Practical, & Demonstration (note 10 extra questions on the Level III Specific)				Examination Required: Basic, Method (ASNT), Specific, Practical, & Demonstration				No change from 1995 Ed. w/1996 Addenda	No change from 1998 Ed. w/2000 Addenda
Grading of Examinations (Employer)	70% each part, 80% composite — Weighting Factors Allowed			70% each part, 80% composite — Simple Average Required		70% each part, 80% composite — Simple Average Required				70% each part, 80% composite — Simple Average Required				No change from 1995 Ed. w/1996 Addenda	No change from 1998 Ed. w/2000 Addenda
Written Practice	Required			Required		Required				Required				Required	Required or use ACCP

Table N-1000-1
Selected Personnel Qualification Requirements from Referenced Sources (Cont'd)

NOTES:
(1) Education: GS - grammar school, HS - high school, 2CL - 2 yr college.
(2) For college credit, education must be in engineering or science.
(3) IWA-2300 allows employer-administered Basic and Method exams in lieu of an ASNT Level III Certificate.
(4) The 10 hr annual training requirement was changed to 8 hours annual practice in the 1999 Addenda (VII-4240).

ARTICLE N-2000 ITEMS ADDRESSED BY THE WRITTEN PRACTICE

A comprehensive written practice prepared to implement the requirements of this Division should address the following:

(a) levels of qualification
(b) vision test requirements
(c) training course content
(d) required training time
(e) experience time
(f) administration and grading of examinations
(g) requirements for initial certification
(h) requirements for recertification
(i) revocation and suspension of certification
(j) reinstatement of certification
(k) limited certification

NONMANDATORY APPENDIX O
EVALUATION OF FLAWS IN PWR REACTOR VESSEL HEAD PENETRATION NOZZLES

ARTICLE O-1000
INTRODUCTION

O-1100 SCOPE

(a) This Nonmandatory Appendix provides a method for determining the acceptability for continued service of pressurized water reactor vessel head penetration nozzles. The evaluation methodology is based on the conclusion that head penetration nozzles are ductile materials, where the ability to reach limit load is assured. Flaws shall be evaluated by comparing the maximum flaw dimensions determined by flaw growth analysis with the maximum allowable flaw dimensions at the end of a selected evaluation period. Evaluations performed using this Nonmandatory Appendix shall meet all the requirements of the Appendix.

(b) This Nonmandatory Appendix provides rules for flaw modeling and evaluation. Flaw growth analysis is based on growth due to fatigue, stress corrosion cracking (SCC), or both, as appropriate to the flaw under evaluation. The flaw acceptance criteria of IWB-3660 provide a structural margin on failure for plastic limit load. The criteria may be used to determine the acceptability of flawed head penetration nozzles for continued service until the next inspection, or conversely, to determine the time interval until a subsequent inspection.

O-1200 PROCEDURE (15)

The following is a summary of the analytical procedure.

(a) Determine the actual flaw configuration from the measured flaw in accordance with Article IWA-3000.

(b) Using Article O-2000, resolve the actual flaw into circumferential and axial flaw components.

(c) Determine the stresses at the location of the detected flaw for Service Levels A and B conditions including weld residual stresses. For weld residual stresses, the reported yield strength of the head penetration nozzle at room temperature shall be used, if known. If not known, a yield strength of 64 ksi (441 MPa) shall be used. Code minimum values for the nozzle material shall not be used when determining the weld residual stress.

(d) Using the analytical procedures described in Article O-3000, determine the flaw parameters a_f and ℓ_f.

(e) Using the flaw parameters a_f and ℓ_f apply the evaluation criteria of IWB-3660 to determine the acceptability of the flawed nozzle for continued service.

ARTICLE O-2000
FLAW MODEL FOR ANALYSIS

O-2100 SCOPE

This Article provides criteria for flaw shape, consideration of multiple flaws, flaw orientation, and flaw location, which are used in the comparison with the allowable flaw size.

O-2200 FLAW SHAPE

The flaw shall be completely bounded by a rectangular or circumferential planar area in accordance with the methods described in IWA-3300. Figures O-2200-1 and O-2200-2 illustrate flaw characterization for circumferential and axial flaws.

O-2300 PROXIMITY TO CLOSEST FLAW

For multiple neighboring flaws, if the shortest distance between the boundaries of two neighboring flaws is within the proximity limits specified in IWA-3300, the neighboring flaws shall be bounded by a single rectangular or circumferential planar area in accordance with IWA-3300.

O-2400 FLAW ORIENTATION

Flaws that do not lie in either an axial[56] or a circumferential[57] plane shall be projected into these planes in accordance with the provisions of IWA-3340. The axial and circumferential flaws obtained by these projections shall be evaluated separately in accordance with Article O-3000.

O-2500 FLAW LOCATION

For the purpose of analysis, the flaw shall be considered in its actual location. The applicable stress, including weld residual stress, shall be determined at this location. Surface or subsurface flaw characterizations shall be used, depending on the type of flaw. If the flaw is subsurface but within the proximity limit of IWA-3340 of the surface of the component, the flaw shall be considered a surface flaw and bounded by a rectangular or circumferential planar area with the base on the surface.

Figure O-2200-1
Flaw Characterization — Circumferential Flaws

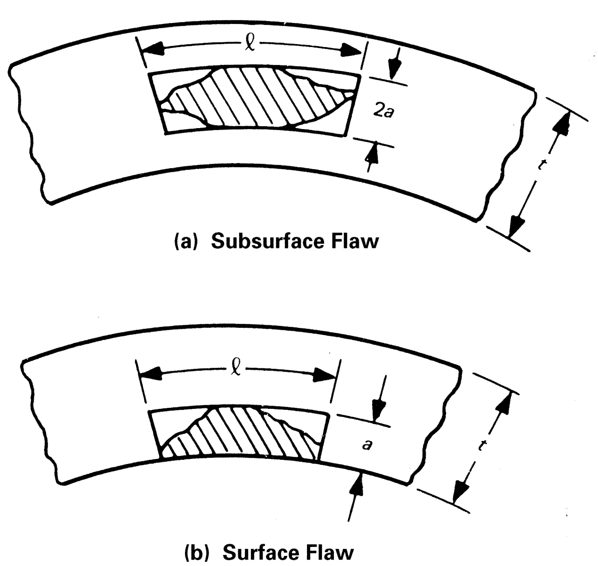
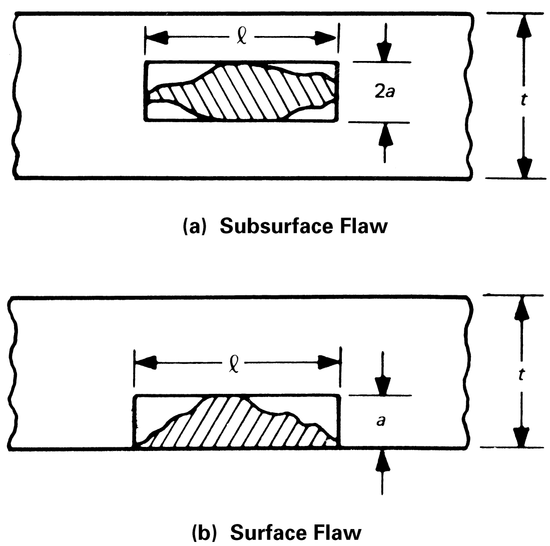


Figure O-2200-2
Flaw Characterization — Axial Flaws



ARTICLE O-3000 ANALYSIS

(15) ## O-3100 SCOPE

This Article provides the methodology for evaluation and describes the procedures to determine the flaw size at the end of the evaluation period.

O-3200 FLAW GROWTH ANALYSIS

(a) The maximum depth a_f and the maximum length ℓ_f to which the detected flaw will grow in the plane of the flaw by the end of the evaluation period shall be determined. This Article describes the procedures for the flaw growth analysis.

(b) Crack growth in austenitic head penetration nozzles can be due to cyclic fatigue flaw growth, SCC under sustained load, or a combination of both. Flaw growth analysis shall be performed for normal operating conditions, as defined in A-5200 of Nonmandatory Appendix A. Flaw growth is governed by the applied stress intensity factor.

O-3210 STRESS INTENSITY FACTOR DETERMINATION

(a) Because the total stresses in this region are typically nonlinear, it is recommended that the distribution be fit to a polynomial, as shown in eq. (1).

$$\sigma(x) = A_0 + A_1x + A_2x^2 + A_3x^3 + ... + A_mx^m \tag{1}$$

where

A_i = coefficients of the polynomial fit
x = the coordinate distance into the nozzle wall
σ = stress perpendicular to the plane of the crack that produces the maximum K_I along the crack tip

The following general expression is used to determine the stress intensity factor, K_I, along the crack front for a surface flaw with the m^{th} order polynomial stress distribution. This general expression uses the influence coefficients, G_j, and shape factor, Q, which may be determined using the procedure defined in Article A-3000. Alternative procedures may be used to determine the influence coefficients and shape factor. The technical basis for the influence coefficients and shape factor used to calculate the stress intensity factor shall be documented.

$$K_I = \left[\frac{\pi a}{Q}\right]^{0.5} \sum_{j=0}^{m} G_j\left(a/c, a/t, t/R\right)A_j a^j \tag{2}$$

where

a = crack depth
c = half-crack length
G_j = influence coefficients
m = polynomial order for defined stress distribution
Q = shape factor
R = inside radius of the nozzle
t = wall thickness

(b) Other methods may be used to calculate the stress intensity factor when technically justified and documented.

O-3220 FLAW GROWTH DUE TO FATIGUE

(a) The fatigue crack growth rate of Alloy 600 material in PWR environments can be characterized in terms of the range of the applied stress intensity factor, K_I. This characterization is of the form:

$$da/dN = C_o(\Delta K)^n \tag{3}$$

where n and C_o are constants dependent on the material and environmental conditions. These parameters are based on crack growth data obtained from specimens of the same material specification and product form, or suitable alternative. Material variability, environment, test frequency, mean stress, and other variables that affect the data shall be considered.

(b) The fatigue crack growth behavior of Alloy 600 materials is affected by temperature, R ratio ($K_{\text{min.}}/K_{\text{max.}}$), and environment. Reference fatigue crack growth rates for PWR water environments are given in Nonmandatory Appendix C, C-8411.

(c) To determine the maximum potential for fatigue flaw growth of the detected flaw during normal operating conditions, a cumulative fatigue flaw growth study of the nozzle shall be performed. The design transients prescribed in the system Design Specification that apply during the evaluation period shall be included. Each transient shall be considered in approximate chronological order as follows.

(1) Determine ΔK, the maximum range of K_I fluctuation asociated with the transient.

(2) Find the incremental flaw growth corresponding to ΔK from the fatigue flaw growth rate data.

(3) Update the flaw size and proceed to the next transient.

(d) The above procedure, after all transients have been considered, yields the final flaw size, a_f and ℓ_f at the end of the evaluation period, considering fatigue crack growth alone.

O-3230 FLAW GROWTH DUE TO STRESS CORROSION CRACKING

(a) Flaw growth due to SCC is a function of the material condition, environment, the stress intensity factor due to sustained loading, and the total time that the flaw is exposed to the environment under sustained loading. The procedure for computing SCC flaw growth is based on experimental data relating the flaw growth rate (da/dt) to the sustained load stress intensity factor K_I. Sustained loads resulting from pressure and steady state thermal stresses, as well as weld residual stresses, shall be included. The procedure used for determining the cumulative flaw growth is as follows.

(1) Determine the stress intensity factor K_I for a given steady state stress condition. For an axially oriented flaw, use the hoop stress through-thickness distribution along the flaw length that produces the maximum K_I at the deepest point.

(2) Calculate the incremental growth of the flaw depth and length corresponding to the period for which the steady state stress is applied. This can be obtained from the relationship between da/dt and K_I. A sufficiently small time interval shall be selected to ensure that the flaw size and the associated K_I value do not change significantly during this interval. Alternatively, the flaw length may be determined by maintaining a fixed flaw aspect ratio, α/ℓ, equal to the original flaw aspect ratio, and all of the length change shall be added at the flaw end with the highest stress.

(3) Update the flaw size.

(4) Continue the flaw growth analysis for the period during which the stress exists until the end of the evaluation period.

(b) The above procedure yields the final flaw size, a_f and ℓ_f, at the end of the evaluation period, considering SCC flaw growth alone.

(c) Reference SCC growth rates for Alloy 600 material in PWR water environments are given in Nonmandatory Appendix C, C-8511.

For calculation of crack growth from the outside surface of the nozzle, in the annulus region between the nozzle and the head, a factor of two shall be applied to the crack growth rate above.

O-3240 FLAW GROWTH DUE TO A COMBINATION OF FATIGUE AND SCC

When the service loading and the material and environmental conditions are such that the flaw is subjected to both fatigue and SCC growth, the final flaw size a_f and ℓ_f are obtained by adding the increments in flaw size due to fatigue and SCC computed in accordance with the procedures described above. The cyclic loads shall be considered in approximately chronological order.

O-3300 EVALUATION (**15**)

The allowable end-of-evaluation period flaw sizes are provided in Table IWB-3663-1. The allowable flaw sizes specified in these tables are independent of the applied stress level.

NONMANDATORY APPENDIX P GUIDANCE FOR THE USE OF U.S. CUSTOMARY AND SI UNITS IN THE ASME BOILER AND PRESSURE VESSEL CODE

P-1100 USE OF UNITS IN EQUATIONS

The equations in this Nonmandatory Appendix are suitable for use with either the U.S. Customary or the SI units provided in Mandatory Appendix X, or with the units provided in the nomenclature associated with that equation. It is the responsibility of the individual and organization performing the calculations to ensure that appropriate units are used. Either U.S. Customary or SI units may be used as a consistent set. When necessary to convert from one system of units to another, the units shall be convertedto at least three significant figures for use in calculations and other aspects of construction.

P-1200 GUIDELINES USED TO DEVELOP SI EQUIVALENTS

The following guidelines were used to develop SI equivalents:

(a) SI units are placed in parentheses after the U.S. Customary units in the text.

(b) In general, separate SI tables are provided if interpolation is expected. The table designation (e.g., table number) is the same for both the U.S. Customary and SI tables, with the addition of suffix "M" to the designator for the SI table, if a separate table is provided. In the text, references to a table use only the primary table number (i.e., without the "M"). For some small tables, where interpolation is not required, SI units are placed in parentheses after the U.S. Customary unit.

(c) Separate SI versions of graphical information (charts) are provided, except that if both axes are dimensionless, a single figure (chart) is used.

(d) In most cases, conversions of units in the text were done using hard SI conversion practices, with some soft conversions on a case-by-case basis, as appropriate. This was implemented by rounding the SI values to the number of significant figures of implied precision in the existing U.S. Customary units. For example, 3,000 psi has an implied precision of one significant figure. Therefore, the conversion to SI units would typically be to 20 000 kPa. This is a difference of about 3% from the "exact" or soft conversion of 20 684.27 kPa. However, the precision of the conversion was determined by the Committee on a case-by-case basis. More significant digits were included in the SI equivalent if there was any question. The values of allowable stress in Section II, Part D generally include three significant figures.

(e) Minimum thickness and radius values that are expressed in fractions of an inch were generally converted according to the following table:

Fraction, in.	Proposed SI Conversion, mm	Difference, %
1/32	0.8	−0.8
3/64	1.2	−0.8
1/16	1.5	5.5
3/32	2.5	−5.0
1/8	3	5.5
5/32	4	−0.8
3/16	5	−5.0
7/32	5.5	1.0
1/4	6	5.5
5/16	8	−0.8
3/8	10	−5.0
7/16	11	1.0
1/2	13	−2.4
9/16	14	2.0
5/8	16	−0.8
11/16	17	2.6
3/4	19	0.3
7/8	22	1.0
1	25	1.6

(f) For nominal sizes that are in even increments of inches, even multiples of 25 mm were generally used. Intermediate values were interpolated rather than converting and rounding to the nearest millimeter. See examples in the following table. [Note that this table does not apply to nominal pipe sizes (NPS), which are covered below.]

Size, in.	Size, mm
1	25
1 1/8	29
1 1/4	32
1 1/2	38
2	50
2 1/4	57
2 1/2	64
3	75
3 1/2	89
4	100
4 1/2	114
5	125
6	150

Table continued

Size, in.	Size, mm
8	200
12	300
18	450
20	500
24	600
36	900
40	1 000
54	1 350
60	1 500
72	1 800

Size or Length, ft	Size or Length, m
3	1
5	1.5
200	60

(g) For nominal pipe sizes, the following relationships were used:

U.S. Customary Practice	SI Practice	U.S. Customary Practice	SI Practice
NPS 1/8	DN 6	NPS 20	DN 500
NPS 1/4	DN 8	NPS 22	DN 550
NPS 3/8	DN 10	NPS 24	DN 600
NPS 1/2	DN 15	NPS 26	DN 650
NPS 3/4	DN 20	NPS 28	DN 700
NPS 1	DN 25	NPS 30	DN 750
NPS 1 1/4	DN 32	NPS 32	DN 800
NPS 1 1/2	DN 40	NPS 34	DN 850
NPS 2	DN 50	NPS 36	DN 900
NPS 2 1/2	DN 65	NPS 38	DN 950
NPS 3	DN 80	NPS 40	DN 1000
NPS 3 1/2	DN 90	NPS 42	DN 1050
NPS 4	DN 100	NPS 44	DN 1100
NPS 5	DN 125	NPS 46	DN 1150
NPS 6	DN 150	NPS 48	DN 1200
NPS 8	DN 200	NPS 50	DN 1250
NPS 10	DN 250	NPS 52	DN 1300
NPS 12	DN 300	NPS 54	DN 1350
NPS 14	DN 350	NPS 56	DN 1400
NPS 16	DN 400	NPS 58	DN 1450
NPS 18	DN 450	NPS 60	DN 1500

(h) Areas in square inches (in.^{2}) were converted to square millimeters (mm^2), and areas in square feet (ft^2) were converted to square meters (m^2). See examples in the following table:

Area (U.S. Customary)	Area (SI)
1 in.^{2}	650 mm^2
6 in.^{2}	4 000 mm^2
10 in.^{2}	6 500 mm^2
5 ft^2	0.5 m^2

(i) Volumes in cubic inches (in.^{3}) were converted to cubic millimeters (mm^3) and volumes in cubic feet (ft^3) were converted to cubic meters (m^3). See examples in the following table:

Volume (U.S. Customary)	Volume (SI)
1 in.^{3}	16 000 mm^3
6 in.^{3}	100 000 mm^3
10 in.^{3}	160 000 mm^3
5 ft^3	0.14 m^3

(j) Although the pressure should always be in MPa for calculations, there are cases where other units are used in the text. For example, kPa is used for small pressures. Also, rounding was to one significant figure (two at the most) in most cases. See examples in the following table. (Note that 14.7 psi converts to 101 kPa, while 15 psi converts to 100 kPa. While this may seem at first glance to be an anomaly, it is consistent with the rounding philosophy.)

Pressure (U.S. Customary)	Pressure (SI)
0.5 psi	3 kPa
2 psi	15 kPa
3 psi	20 kPa
10 psi	70 kPa
14.7 psi	101 kPa
15 psi	100 kPa
30 psi	200 kPa
50 psi	350 kPa
100 psi	700 kPa
150 psi	1 MPa
200 psi	1.5 MPa
250 psi	1.7 MPa
300 psi	2 MPa
350 psi	2.5 MPa
400 psi	3 MPa
500 psi	3.5 MPa
600 psi	4 MPa
1,200 psi	8 MPa
1,500 psi	10 MPa

(k) Material properties that are expressed in psi or ksi (e.g., allowable stress, yield and tensile strength, elastic modulus) were generally converted to MPa to three significant figures. See example in the following table:

Strength (U.S. Customary)	Strength (SI)
95,000 psi	655 MPa

(l) In most cases, temperatures (e.g., for PWHT) were rounded to the nearest 5°C. Depending on the implied precision of the temperature, some were rounded to the nearest 1°C or 10°C or even 25°C. Temperatures colder than 0°F (negative values) were generally rounded to

the nearest 1°C. The examples in the table below were created by rounding to the nearest 5°C, with one exception:

Temperature, °F	Temperature, °C
70	20
100	38
120	50
150	65
200	95
250	120
300	150
350	175
400	205
450	230
500	260
550	290
600	315
650	345
700	370
750	400
800	425
850	455
900	480
925	495
950	510
1,000	540
1,050	565
1,100	595
1,150	620
1,200	650
1,250	675
1,800	980
1,900	1 040
2,000	1 095
2,050	1 120

P-1300 SOFT CONVERSION FACTORS

The following table of "soft" conversion factors is provided for convenience. Multiply the U.S. Customary value by the factor given to obtain the SI value. Similarly, divide the SI value by the factor given to obtain the U.S. Customary value. In most cases it is appropriate to round the answer to three significant figures.

U.S. Customary	SI	Factor	Notes
in.	mm	25.4	...
ft	m	0.3048	...
in.^{2}	mm^2	645.16	...
ft^2	m^2	0.09290304	...
in.^{3}	mm^3	16,387.064	...
ft^3	m^3	0.02831685	...
U.S. gal.	m^3	0.003785412	...
U.S. gal.	liters	3.785412	...
psi	MPa/(N/mm^2)	0.0068948	Used exclusively in equations
psi	kPa	6.894757	Used only in text and for nameplate
psi	bar	0.06894757	...
ft-lb	J	1.355818	...
°F	°C	$\frac{5}{9}$ × (°F − 32)	Not for temperature difference
°F	°C	$\frac{5}{9}$ × °F	For temperature differences only
°R	K	$\frac{5}{9}$	Absolute temperature
lbm	kg	0.4535924	...
lbf	N	4.448222	...
in.-lb	N·mm	112.98484	Use exclusively in equations
ft-lb	N·m	1.3558181	Use only in text
$\mathrm{ksi}\sqrt{\mathrm{in.}}$	$\mathrm{MPa}\sqrt{\mathrm{m}}$	1.0988434	...
Btu/hr	W	0.2928104	Use for boiler rating and heat transfer
lb/ft^3	kg/m^3	16.018463	...

NONMANDATORY APPENDIX Q
WELD OVERLAY REPAIR OF CLASSES 1, 2, AND 3 AUSTENITIC STAINLESS STEEL PIPING WELDMENTS

ARTICLE Q-1000
SCOPE

This Nonmandatory Appendix provides an alternative to the requirements of IWA-4420, IWA-4520, IWA-4530, and IWA-4600 for making repairs to, and subsequent examination of Class 1, 2, and 3 austenitic stainless steel pipe weldments by deposition of weld reinforcement (weld overlay) on the outside surface of the pipe. If used, all provisions of this Nonmandatory Appendix are mandatory. After a weld overlay has been installed in accordance with this Nonmandatory Appendix, the inservice examinations identified in Q-4300 shall be performed as long as the repair remains part of the pressure boundary.

ARTICLE Q-2000
PREREQUISITES

(a) Reinforcement weld metal shall be low carbon (0.035% max.) austenitic stainless steel applied 360 deg around the circumference of the pipe, and shall be deposited using a Welding Procedure Specification for groove welding, qualified in accordance with the Construction Code and Owner's Requirements and identified in the Repair/Replacement Plan.

(b) Prior to deposition of the weld reinforcement, the surface to be repaired shall be examined by the liquid penetrant method. Indications greater than $^1/_{16}$ in. (1.5 mm) shall be removed, reduced in size, or corrected in accordance with the following requirements, prior to application of weld reinforcement. One or more layers of weld metal shall be applied to seal unacceptable indications in the area to be repaired with or without excavation. The thickness of these layers shall not be used in meeting weld reinforcement design thickness requirements. Peening the unaceptable indication prior to welding is permitted.

(c) If correction of indications in (b) is required, the area where the weld reinforcement is to be deposited, including any local repairs or initial weld overlay layers, shall be examined by the liquid penetrant method. The area shall contain no indications greater than $^1/_{16}$ in. (1.5 mm) prior to the application of the structural layers of the weld overlay.

(d) The weld reinforcement shall consist of at least two weld layers having as-deposited delta ferrite content of at least 7.5 FN. The first layer of weld metal with delta ferrite content of at least 7.5 FN shall constitute the first layer of the weld reinforcement that may be credited toward the required thickness. Alternatively, first layers of at least 5 FN are acceptable, provided the carbon content of the deposited weld metal is determined by chemical analysis to be less than 0.02%.

(e) The submerged arc welding method shall not be used for weld overlays.

ARTICLE Q-3000
DESIGN CONSIDERATIONS

Design of the weld reinforcement shall provide access for the examinations required by Article Q-4000 and shall be in accordance with (a) and (b).

(a) Flaw characterization and evaluation requirements shall be based on the as-found flaw. However, the size of the as-found flaws shall be projected to the end of design life of the overlay. Crack growth, including stress corrosion cracking and fatigue crack growth, shall be evaluated using IWB-3640.

(1) For determining the combined length of circumferential flaws, multiple flaws shall be treated as one flaw of length equal to the sum of the lengths of the individual flaws characterized in accordance with IWA-3300.

(2) For circumferentially-oriented flaws, when the combined length is greater than 10% of the pipe circumference, the flaws shall be assumed to be 100% through the original pipe wall thickness for the entire circumference of the pipe.

(3) For circumferentially-oriented flaws, when the combined length does not exceed 10% of the pipe circumference, the flaws shall be assumed to be 100% through the original pipe wall thickness for a circumferential length equal to the combined length of the flaws.

(4) For axial flaws 1.5 in. (38 mm) or longer, or for five or more axial flaws of any length, the flaws shall be assumed to be 100% through the original pipe wall thickness for the entire axial length of the flaw for the entire circumference of the pipe.

(5) For weldments with four or fewer axial flaws, each shorter than 1.5 in. (38 mm), and no circumferential flaws, the weld reinforcement shall satisfy the requirements of Q-2000(d). No additional structural reinforcement is required. The axial length of the overlay shall cover the weldment and the heat-affected zones, and shall extend at least $\frac{1}{2}$ in. (13 mm) beyond the ends of the observed flaws. The requirements of (b)(1), (b)(3), and (b)(4) need not be met.

(b) The design of the weld overlay shall satisfy the following, using the assumptions and flaw characterization restrictions in (a). The design analysis required by (1) through (4) shall be completed in accordance with IWA-4311.

(1) The axial length and end slope of the weld overlay shall cover the weldment and the heat-affected zones on each side of the weldment, and shall provide for load redistribution from the pipe into the weld overlay and back into the pipe without violating applicable stress limits for primary local and bending stresses and secondary and peak stresses, as required by the Construction Code. Any laminar flaws in the weld overlay shall be evaluated in the analysis to ensure that load redistribution complies with the preceding information. These requirements will usually be satisfied if the overlay full thickness length extends axially beyond the projected flaw by at least $\frac{3}{4}\sqrt{Rt}$, where R is the outer radius of the pipe and t is the nominal wall thickness of the pipe.

(2) Unless specifically analyzed in accordance with (b)(1), the end transition slope of the overlay shall not exceed 45 deg. A slope of not more than 1:3 is recommended.

(3) The overlay design thickness of items meeting (a)(2), (a)(3), or (a)(4) shall be based on the measured diameter, using the thickness of the weld overlay as restricted by Q-2000(d). The wall thickness at the weld overlay, any planar flaws in the weld overlay, and the effects of any discontinuity (e.g., another weld overlay or reinforcement for a branch connection) within a distance of 2.5 $\sqrt{Rt}$ from the toes of the weld overlay, shall be evaluated and shall meet the requirements of IWB-3640, IWC-3640, or IWD-3640, as applicable.

(4) The effects of any changes in applied loads, as a result of weld shrinkage, on existing flaws previously accepted by analytical evaluation shall be evaluated in accordance with IWB-3640, IWC-3640, or IWD-3640, as applicable.

ARTICLE Q-4000 EXAMINATION AND TESTING

Ultrasonic examination personnel shall be certified in accordance with the Owner's written practice. Procedures and personnel shall be qualified in accordance with Mandatory Appendix VIII.

Q-4100 EXAMINATION

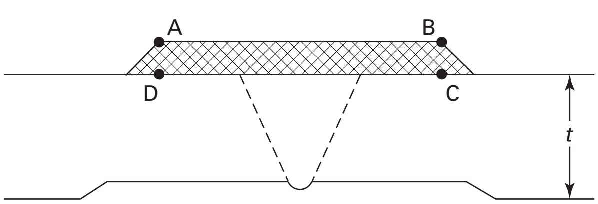
(a) The weld overlay shall have a surface finish of 250 μin. (6.3 μm) RMS or better and a flatness sufficient to allow for adequate examination in accordance with procedures qualified in accordance with Mandatory Appendix VIII. The weld overlay shall be examined to verify acceptable configuration.

(b) The weld overlay and the adjacent base material for at least $\frac{1}{2}$ in. (13 mm) from each side of the weld shall be examined using the liquid penetrant method. The weld overlay shall satisfy the surface examination acceptance criteria for welds of the Construction Code or NB-5300. The adjacent base metal shall satisfy the surface examination acceptance criteria for base material of NB-2500.

(c) The examination volume in Figure Q-4100-1 shall be ultrasonically examined to assure adequate fusion (i.e., adequate bond) with the base metal and to detect welding flaws such as interbead lack of fusion, inclusions, or cracks. Planar flaws in Class 1 piping shall meet the preservice examination standards of Table IWB-3514-1, and planar flaws in Class 2 or 3 piping shall meet the preservice examination standards of Table IWC-3514-1. Laminar flaws shall meet the following:

(1) Laminar flaws shall meet the acceptance standards of Table IWB-3514-3.

Figure Q-4100-1 Examination Volume



Examination Volume A–B–C–D

(2) The reduction in coverage of the examination volume in Figure Q-4300-1, due to laminar flaws, shall be less than 10%. The dimensions of the uninspectable volume are dependent on the coverage achieved with the angle beam examination of the overlay.

(3) Any uninspectable volume in the weld overlay shall be assumed to contain the largest radial planar flaw that could exist within that volume. This assumed flaw shall meet the inservice examination standards of Table IWB-3514-1 for Class 1 piping or Table IWC-3514-1 for Class 2 or 3 piping. Alternatively, the assumed flaw shall meet the requirements of IWB-3640, IWC-3640, or IWD-3640, as applicable. Both axial and circumferential planar flaws shall be assumed.

(4) As an alternative to (3), radiography in accordance with the Construction Code shall be used to examine the uninspectable volume. The radiographic acceptance criteria of the Construction Code shall apply.

(d) After completion of all welding activities, affected restraints, supports, and snubbers shall be VT-3 visually examined to verify that design tolerances are met.

Q-4200 PRESERVICE INSPECTION

(a) The examination volume in Figure Q-4300-1 shall be ultrasonically examined. The angle beam shall be directed perpendicular and parallel to the pipe axis, with scanning performed in four directions to locate and size cracks that have propagated into the upper 25% of the pipe base material or into the overlay.

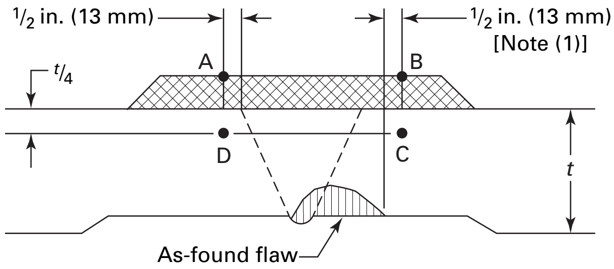
(b) For Class 1 piping, the preservice examination acceptance standards of Table IWB-3514-1 shall be satisfied, and for Class 2 or 3 piping, the preservice examination acceptance standards of Table IWC-3514-1 shall be satisfied for the weld overlay. Cracks in the outer 25% of the pipe base metal shall meet the design analysis requirements of Article Q-3000.

Q-4300 INSERVICE INSPECTION

(a) The weld overlay examination volume in Figure Q-4300-1 shall be added to the inspection plan and shall be ultrasonically examined during the first or second refueling outage following application.

(b) The weld overlay examination volume in Figure Q-4300-1 shall be ultrasonically examined to determine if any new or existing cracks have propagated into the upper 25% of the pipe base material or into the overlay.

Figure Q-4300-1
Preservice and Inservice Examination Volume



Examination Volume A–B–C–D

NOTE:
(1) For axial or circumferential flaws, the axial extent of the examination volume shall extend at least $^1/_2$ in. (13 mm) beyond the as-found flaw and at least $^1/_2$ in. (13 mm) beyond the toes of the original piping weldment, including weld end butter, where applied.

The angle beam shall be directed perpendicular and parallel to the pipe axis, with scanning performed in four directions.

(c) For Class 1 piping, the inservice examination acceptance standards of Table IWB-3514-1 shall be satisfied, and for Class 2 or 3 piping, the inservice examination acceptance standards of Table IWC-3514-1 shall be satisfied for the weld overlay. Alternatively, for Class 1, 2, or 3 piping systems, the acceptance criteria of IWB-3600, IWC-3600, or IWD-3600, as applicable, shall be satisfied for the weld overlay. Cracks in the outer 25% of the pipe base metal shall meet the design analysis requirements of Article Q-3000.

(d) Weld overlay examination volumes that show no indication of crack growth or new cracking shall be placed into a population to be examined on a sampling basis. Twenty-five percent of this population shall be examined once every 10 yr.

(e) If inservice examinations reveal crack growth or new cracking, meeting the acceptance standards, the weld overlay examination volume shall be reexamined during the first or second refueling outage following discovery of the growth or new cracking. Weld overlay examination volumes that show no additional indication of crack growth or new cracking shall be placed into a population to be examined on a sample basis. Twenty-five percent of this population shall be examined once every 10 yr.

(f) For weld overlay examination volumes with unacceptable indications as described in (b) and (c), the weld overlay shall be removed, including the original defective piping weldment, and corrected by a repair/replacement activity in accordance with Article IWA-4000.

Q-4310 ADDITIONAL EXAMINATIONS

If inservice examinations reveal an unacceptable indication, crack growth into the weld overlay design thickness, or axial crack growth beyond the specified examination volumes, additional weld overlays, equal to the number scheduled for the current inspection period, shall be examined prior to return to service. If additional unacceptable indications are found in the second sample, a total of 50% of the total population of weld overlays shall be examined prior to operation. If additional unacceptable indications are found, the entire remaining population of weld overlays shall be examined prior to return to service.

Q-4400 PRESSURE TESTING

Pressure testing shall be conducted in accordance with IWA-4540. Weld overlay of a through-wall flaw shall be considered a welding activity that penetrates the pressure boundary.

NONMANDATORY APPENDIX R
RISK-INFORMED INSPECTION REQUIREMENTS FOR PIPING

ARTICLE R-1000
INTRODUCTION

R-1100 SCOPE

(a) When an Owner chooses to use this Appendix, the requirements of Section XI, Division 1 shall apply, except for the alternatives and exemptions provided by this Appendix. In addition, all of the provisions of this Appendix are mandatory for the piping within the boundaries of the piping for which this Appendix will be used to satisfy the requirements of IWB-2500, IWC-2500, or IWD-2500.

(b) The risk-informed selection processes described in Supplements 1 and 2 may be applied to all Classes 1, 2, and 3 piping systems, an individual Class of piping (e.g., Class 1 piping), to all piping in Examination Category B-F, B-J, C-F-1, or C-F-2, or to one or more individual piping systems (e.g., Reactor Coolant System). Boundaries for the scope of all piping systems, or portions thereof, (i.e., portions of piping needed to include a complete Examination Category of piping, a piping system, or a Class of piping) to be considered for evaluation in accordance with either risk-informed selection process shall be clearly defined. When not applying either process to all systems in a Class of piping, the piping systems that are not evaluated shall be examined in accordance with Examination Category B-F, B-J, C-F-1, or C-F-2, as applicable.

(c) Application of this Appendix for plants that do not have an existing deterministic inservice inspection program is in the course of preparation.

R-1200 PIPING SUBJECT TO EXAMINATION

R-1210 BOUNDARY REQUIREMENTS

As an alternative to the examination requirements of IWB-1210, IWC-1210, or IWD-1210, as applicable, the examination requirements of this Appendix shall be used for Class 1, 2, and 3 piping evaluated by a risk-informed process. Piping in systems evaluated as part of the plant Probabilistic Risk Assessment (PRA), but outside the current Section XI examination boundaries, may be included.

R-1220 PIPING EXEMPT FROM EXAMINATION (15)

Exemption of piping segments and their structural elements from examination shall be in accordance with the requirements of Supplement 1 or 2.

R-1230 RISK-INFORMED SELECTION PROCESS

(a) High Safety Significant (HSS) piping structural elements shall be examined in accordance with R-2500.

(b) The risk-informed selection processes in this Appendix are specified in Supplements 1 and 2. Each process identifies how to classify piping segments and their piping structural elements, based on their safety significance, as HSS or Low Safety Significant (LSS).

(c) If using Supplement 1, HSS or LSS is determined by the process described in 4.2.4 through 4.2.8 of Supplement 1, and if using Supplement 2, HSS is determined to be Risk Category 1, 2, 3, 4, or 5, and LSS is Risk Category 6 or 7 as defined in 3.3.2 of Supplement 2.

R-1300 OWNER'S RESPONSIBILITY (15)

R-1310 ADEQUACY OF THE PRA (SUPPLEMENT 1)

The PRA shall meet the requirements of ASME RA-S with the RA-Sa addenda and the RA-Sb addenda to the extent required to support the development and application of a risk-informed inservice inspection program. All PRA weaknesses or deficiencies identified by regulatory or peer review shall be explicitly accounted for during the analysis used to support the risk-informed inspection program. The resolution of all PRA issues shall be documented.

R-1320 ADEQUACY OF THE PRA (SUPPLEMENT 2)

The Owner shall ensure that the technical adequacy of the PRA is reviewed to confirm that it meets the requirements of Table R-1320-1 or that the Owner has met PRA technical adequacy requirements for RI-ISI applications accepted by the regulatory authority having jurisdiction at the plant site.

R-1330 PROGRAM INTENT AND PRINCIPLES

The development or update of a risk-informed inspection program in accordance with this Appendix shall meet the intent and principles outlined in USNRC Regulatory Guides 1.174 and 1.178.

Table R-1320-1
PRA Technical Adequacy Requirements

Supporting Requirement as Defined in USNRC Regulatory Guide 1.200, r1 [Note (1)]	Capability Category Required
None	III and II
IE-A3a, IE-C11, IE-C12, AS-A7, SY-A7, SY-A15, SY-B2, HR-D7, HR-F1, DA-B2, DA-C9	II and I
AS-A9, SC-B2	II
IE-A4, IE-E4a, IE-A6, IE-A7, IE-B3, AS-A10, SC-A2, SC-A5, SC-B1, SY-A4, SY-A20, SY-B1, SY-B7, SY-B11, HR-B1, HR-C2, HR-D2, HR-D3, HR-E3, HR-E4, HR-F2, HR-G1, HR-G3, HR-G4, HR-G5, HR-H1, DA-B1, DA-C7, DA-C8, DA-C10, DA-C12, DA-D1, DA-D3, DA-D4, DA-D5, DA-D6, DA-D7, QU-A2b, QU-D3, QU-D5a, QU-E3, QU-F3, LE-B1, LE-B2, LE-C1, LE-C2a, LE-C2b, LE-C3, LE-C4, LE-C8a, LE-C8b, LE-C9a, LE-C9b, LE-C10, LE-D1a, LE-D1b, LE-D2, LE-D3, LE-D4, LE-D5, LE-D6, LE-E2, LE-E3, LE-F1a, LE-G3	I
IE-A10, IE-B5, IE-C1, IE-C1a, IE-C2, IE-C3, IE-C4, IE-C5, IE-C13, IE-D3, AS-C3, SC-C3, SY-C3, HR-I3, DA-E3, QU-E1, QU-E2, QU-E4, QU-F4, LE-F2, LE-F3, LE-G4	Need not be met
IE-A1, IE-A2, IE-A3, IE-A5, IE-B1, IE-B2, IE-B4, IE-C1b, IE-C6, IE-C7, IE-C8, IE-C9, IE-C10, IE-D1, IE-D2, AS-A1, AS-A2, AS-A3, AS-A4, AS-A5, AS-A6, AS-A8, AS-A11, AS-B1, AS-B2, AS-B3, AS-B4, AS-B5, AS-B5a, AS-B6, AS-C1, AS-C2, SC-A1, SC-A4, SC-A4a, SC-A6, SC-B3, SC-B4, SC-B5, SC-C1, SC-C2, SY-A1, SY-A2, SY-A3, SY-A5, SY-A6, SY-A8, SY-A10, SY-A11, SY-A12, SY-A12a, SY-A12b, SY-A13, SY-A14, SY-A16, SY-A17, SY-A18, SY-A18a, SY-A19, SY-A21, SY-A22, SY-B3, SY-B4, SY-B5, SY-B6, SY-B8, SY-B10, SY-B12, SY-B13, SY-B14, SY-B15, SY-B16, SY-C1, SY-C2, HR-A1, HR-A2, HR-A3, HR-B2, HR-C1, HR-C3, HR-D1, HR-D4, HR-D5, HR-D6, HR-E1, HR-E2, HR-G2, HR-G6, HR-G7, HR-G9, HR-H2, HR-H3, HR-I1, HR-I2, DA-A1, DA-A1a, DA-A2, DA-A3, DA-C1, DA-C2, DA-C3, DA-C4, DA-C5, DA-C6, DA-C11, DA-C11a, DA-C13, DA-C14, DA-C15, DA-D2, DA-D6a, DA-D8, DA-E1, DA-E2, QU-A1, QU-A2a, QU-A3, QU-A4, QU-B1, QU-B2, QU-B3, QU-B4, QU-B5, QU-B6, QU-B7a, QU-B7b, QU-B8, QU-B9, QU-C1, QU-C2, QU-C3, QU-D1a, QU-D1B, QU-D1C, QU-D4, QU-D5b, QU-F1, QU-F2, QU-F5, QU-F6, LE-A1, LE-A2, LE-A3, LE-A4, LE-A5, LE-B3, LE-C5, LE-C6, LE-C7, LE-E1, LE-E4, LE-F1b, LE-G1, LE-G2, LE-G5, LE-G6	Spans all three categories and needs to be met

NOTE:
(1) For a supporting requirement to be met, all relevant peer review and other independent findings shall have been addressed and necessary changes made to PRA models, methods, and documentation. Due to plant operational status (e.g., after fuel load and prior to commercial operation), some supporting requirements might not be achievable. These supporting requirements shall be met to the extent practical, and the program shall be updated in accordance with para. 7.0. EPRI Report 1021467-A provides one acceptable way of meeting this requirement.

ARTICLE R-2000 EXAMINATION AND INSPECTION

R-2100 DUTIES OF THE INSPECTOR

Duties of the Inspector shall be in accordance with IWA-2110 except that the Owner's augmented programs, such as the Intergranular Stress Corrosion Cracking (IGSCC) program, the Microbiologically Influenced Corrosion (MIC) program, or the Flow Accelerated Corrosion (FAC) program, referenced in Table R-2500-1, Item Nos. R1.16, R1.17, or R1.18, are exempt from these requirements, unless an Owner chooses to select and credit structural elements for examination by one of the risk-informed selection processes defined in Supplement 1 or 2. If selected and credited structural elements are examined for one or more of the degradation mechanisms covered under these Owner's augmented programs, the requirements of IWA-2110 apply to the selection and examination of the credited structural elements.

R-2200 PRESERVICE EXAMINATION

As an alternative to the preservice examination requirements of IWB-2200, IWC-2200, or IWD-2200, as applicable, the following requirements apply.

R-2210 INITIAL EXAMINATION

(a) Examinations (with the exception of VT-2 visual examinations listed in Table R-2500-1) shall be performed in accordance with the requirements defined in Table R-2500-1 at least once prior to initial service. Examinations shall include all piping structural elements classified HSS in accordance with Supplement 1 or 2.

(b) No preservice examination is required for LSS piping structural elements.

R-2220 REPAIR/REPLACEMENT ACTIVITIES

(a) Prior to return to service following a repair/replacement activity on a piping structural element, examinations shall be performed in accordance with the requirements defined in Table R-2500-1. Examinations shall include piping structural elements classified HSS in accordance with Supplement 1 or 2 affected by the repair/replacement activity.

(b) For piping structural elements that become HSS following a reevaluation as a result of a repair/replacement activity the required first inservice examination performed in accordance with Table R-2500-1 shall serve as the preservice examination.

(c) No preservice examination for LSS piping structural elements is required.

R-2400 INSPECTION SCHEDULE

As an alternative to the inspection schedule requirements of IWB-2400, IWC-2400, or IWD-2400, as applicable, the following requirements apply.

R-2410 INSPECTION PROGRAM

(a) Inservice examinations and system pressure tests may be performed on-line or during plant outages such as refueling shutdowns or maintenance shutdowns.

(b) Reevaluation of risk-informed piping structural element selections shall be in accordance with the requirements of Supplement 1 or 2.

(c) The examinations of Examination Category R-A shall be completed during each inspection interval, in accordance with Table IWB-2411-1, with the following exceptions.

(1) If, during the interval, a reevaluation using a risk-informed process of this Appendix is conducted, and scheduled items are no longer required to be examined, the percentage requirements of Table IWB-2411-1 need not be met until the end of the inspection interval.

(2) If, during the interval, a reevaluation using a risk-informed process of this Appendix is conducted, and items are required to be added to the examination program, those items shall be added in accordance with IWB-2411.

R-2420 SUCCESSIVE INSPECTIONS

As an alternative to the successive inspection requirements of IWB-2420, IWC-2420, or IWD-2420, as applicable, the following requirements apply.

(a) The sequence of piping examinations established during the first inspection interval using a risk-informed process shall be repeated during each successive inspection interval to the extent practical. The examination sequence may be modified in a manner that optimizes scaffolding, radiological, insulation removal, or other considerations, provided the percentage requirements of Table IWB-2411-1 are met.

(b) If piping structural elements are accepted for continued service by analytical evaluation in accordance with R-3130, before, during, or after implementation of a

risk-informed Inspection Program, the areas containing flaws or relevant conditions shall be reexamined during the three inspection periods following their discovery.

(c) If the reexaminations required by (b) reveal that the flaws or relevant conditions remain essentially unchanged for three successive inspection periods, the examination schedule may revert to the original schedule of successive inspections.

R-2430 ADDITIONAL EXAMINATIONS

As an alternative to the additional examination requirements of IWB-2430, IWC-2430, or IWD-2430 as applicable, the following requirements apply.

(a) Examinations performed in accordance with R-2500 that reveal flaws or relevant conditions exceeding the acceptance standards of Article R-3000 shall be extended to include a first sample of additional examinations during the current outage.

(1) The piping structural elements to be examined in the first sample of additional examinations shall include HSS elements with the same postulated degradation mechanism in systems whose materials and service conditions are similar to the element that exceeded the acceptance standards of Article R-3000 and are determined to have for Supplement 1 the same or higher failure potential, or for Supplement 2 the same or higher failure potential with a high or medium consequence category.

(2) The number of examinations required is the number of HSS elements with the same postulated degradation mechanism scheduled for the current inspection period. However, if there are not enough HSS elements to equal this number, the Owner shall include remaining HSS elements and LSS elements up to and including this number that are potentially subject to the same degradation mechanism.

(b) If the additional examinations required by (a) reveal flaws or relevant conditions exceeding the acceptance standards of Article R-3000, the examinations shall be further extended to include a second sample of additional examinations during the current outage.

(1) The second sample of additional piping structural elements to be examined shall include all remaining HSS piping structural elements in Table R-2500-1 subject to the same degradation mechanism.

(2) The Owner shall also examine LSS piping structural elements subject to the same degradation mechanism or document the basis for their exclusion.

(c) For the inspection period following the period in which the examinations of (a) or (b) were completed, the examinations shall be performed as originally scheduled in accordance with R-2410.

R-2500 EXAMINATION REQUIREMENTS

As an alternative to the examination requirements of Examination Category B-F, B-J, C-F-1, or C-F-2, as applicable, HSS piping structural elements selected for examination in accordance with Supplement 1 or 2 shall be examined as required by Table R-2500-1.

(15)

Table R-2500-1
Examination Category R-A, Risk-Informed Piping Examinations

Item No.	Parts Examined	Examination Requirement/Fig No. [Note (2)]	Examination Method	Acceptance Standard	Extent and Frequency [Note (3)]		Defer to End of Interval
					1st Interval	Successive Intervals	
R1.10	High Safety Significant piping structural elements						
R1.11	Elements subject to thermal fatigue	IWB-2500-8(c) and IWB-2500-8(d) [Note (1)] IWB-2500-9, IWB-2500-10, IWB-2500-11,	Volumetric [Note (8)], [Note (9)]	IWB-3514	Element [Note (2)], [Note (4)]	Same as 1st	Not permissible
R1.12	Elements subject to high cycle mechanical fatigue	IWB-2500-8(a) and (b)	Visual, VT-2 [Note (8)], [Note (9)]	IWB-3142	Each refueling	Same as 1st	Not permissible
R1.13	Elements subject to erosion cavitation	[Note (6)]	Volumetric [Note (7)]	IWB-3514 [Note (6)]	Element [Note (2)]	Same as 1st	Not permissible
R1.14	Elements subject to crevice corrosion cracking	[Note (5)]	Volumetric [Note (8)], [Note (9)]	IWB-3514	Element [Note (2)]	Same as 1st	Not permissible
R1.15	Elements subject to Primary Water Stress Corrosion Cracking (PWSCC)	[Note (7)]	Volumetric [Note (7)], [Note (8)], [Note (9)]	[Note (7)]	Element [Note (2)], [Note (4)]	Same as 1st	[Note (7)]
R1.16	Elements subject to Intergranular or Transgranular Stress Corrosion Cracking (IGSCC or TGSCC)	IWB-2500-8(c) and IWB-2500-8(d) [Note (1)] IWB-2500-9, IWB-2500-10, IWB-2500-11 [Note (7) for IGSCC]	Volumetric [Note (7) for IGSCC], [Note (8)], [Note (9)]	IWB-3514	Element [Note (2)], [Note (4)]	Same as 1st	Not permissible [Note (7) for IGSCC]
R1.17	Elements subject to Localized Corrosion, Microbiologically Influenced Corrosion (MIC), Pitting Corrosion, or General Corrosion	IWB-2500-8(a), IWB-2500-8(b), IWB-2500-8(c), and IWB-2500-8(d), IWB-2500-9, IWB-2500-10, IWB-2500-11 [Note (6)]	Visual, VT-3, internal surfaces or volumetric [Note (6)] or [Note (7)]	[Note (6)]	Element [Note (2)]	Same as 1st	Not permissible
R1.18	Elements subject to Flow Accelerated Corrosion (FAC)	[Note (7)]	[Note (7)]	[Note (7)]	[Note (7)]	[Note (7)]	[Note (7)]
R1.19	Elements subject to External Chloride Stress Corrosion Cracking (ECSCC)	IWB-2500-8(a), IWB-2500-8(b), IWB-2500-8(c), and IWB-2500-8(d), IWB-2500-9, IWB-2500-10, IWB-2500-11	Surface	IWB-3514	Element [Note (2)]	Same as 1st	Not permissible

Table R-2500-1
Examination Category R-A, Risk-Informed Piping Examinations (Cont'd)

Item No.	Parts Examined	Examination Requirement/Fig No. [Note (2)]	Examination Method	Acceptance Standard	Extent and Frequency [Note (3)]		Defer to End of Interval
					1st Interval	Successive Intervals	
R1.20	Elements not subject to a degradation mechanism	IWB-2500-8(c) and IWB-2500-8(d) [Note (1)], IWB-2500-9, IWB-2500-10, IWB-2500-11	Volumetric [Note (8)], [Note (9)]	IWB-3514	Element [Note (2)], [Note (4)]	Same as 1st	Not permissible

NOTES:

(1) The length of the examination volume shown in Figures IWB-2500-8(c) and IWB-2500-8(d) shall be increased by enough distance [approximately $^1/_2$ in. (13 mm)] to include each side of the base metal thickness transition or counterbore.

(2) Includes examination locations and Class 1 weld examination requirement figures that typically apply to Class 1, 2, 3, or Non-Class welds identified in accordance with the risk-informed selection process described in Supplement 1 or 2.

(3) Includes 100% of the examination location. When the required examination volume or area cannot be examined due to interference by another component or part geometry, limited examinations shall be evaluated for acceptability. Acceptance of limited examinations or volumes shall not invalidate the results of the risk-informed evaluation. Areas with acceptable limited examinations, and their bases, shall be documented.

(4) The examination shall include any longitudinal welds at the location selected for examination in [Note (2)]. The longitudinal weld examination requirements shall be met for both transverse and parallel flaws within the examination volume defined in [Note (2)] for the intersecting circumferential welds.

(5) The examination volume shall include the volume surrounding the weld, weld HAZ, and base metal, as applicable, in the crevice region. Examination shall focus on detection of cracks initiating and propagating from the inner surface.

(6) The examination volume shall include base metal, welds, and weld HAZ in the affected regions of carbon and low allow steel, and the welds and weld HAZ of austenitic steel. Examinations shall verify the minimum wall thickness required. Acceptance criteria for localized thinning are in course of preparation. The examination method and examination region shall be sufficient to characterize the extent of the element degradation.

(7) In accordance with the Owner's existing programs, such as PWSCC, IGSCC, MIC, or FAC inspection programs, for degradation mechanisms as described in Table R-S2-1.

(8) Socket welds of any size and branch pipe connection welds NPS 2 (DN 50) and smaller require only VT-2 visual examination.

(9) The VT-2 visual examination shall be conducted during a system pressure test or a pressure test specific to that weld, in accordance with Examination Category B-P, C-H, or D-B for Class 1, 2, or 3, respectively.

ARTICLE R-3000 STANDARDS FOR EXAMINATION EVALUATION

As an alternative to the acceptance standards of Article IWA-3000, Article IWB-3000, Article IWC-3000, or Article IWD-3000, as applicable, the following requirements apply.

R-3100 STANDARDS

R-3110 CHARACTERIZATION

When a volumetric or surface examination method is used, each flaw or group of flaws shall be characterized in accordance with IWA-3300 to establish the dimensions of the flaws. These dimensions shall be used in conjunction with the evaluation of examination results of R-3130.

R-3120 ACCEPTABILITY

Flaws, areas of degradation, or relevant conditions that do not exceed the allowable acceptance standards of R-3130 are acceptable.

R-3130 EVALUATION OF EXAMINATION RESULTS

For component configurations or examination methods not addressed by Table R-2500-1, the Owner shall develop acceptance criteria consistent with the requirements of Article IWA-3000. The following referenced paragraphs and in Table R-2500-1 shall be applied.

(a) Flaws that exceed the acceptance standards listed in Table R-2500-1, found during surface or volumetric examinations, may be accepted by repair/replacement activities or analytical evaluation, in accordance with IWB-3130.

(b) Flaws or relevant conditions that exceed the acceptance standards listed in R-2500-1, found during visual examinations, may be accepted by supplemental examination, corrective measures, repair/replacement activities, or analytical evaluation, in accordance with IWB-3140.

(c) Other unacceptable conditions not addressed by (a) or (b) may be accepted by repair/replacement activities in accordance with Article R-4000, or by analytical evaluation in accordance with IWB-3600, IWC-3600, or IWD-3600, as applicable.

ARTICLE R-4000
REPAIR/REPLACEMENT ACTIVITIES

R-4100 REPAIR/REPLACEMENT REQUIREMENTS

Repair/replacement activities shall be performed in accordance with Article IWA-4000, except that, in lieu of the preservice inspection requirements of IWA-4530, the preservice examination requirements of R-2220 apply.

ARTICLE R-6000
RECORDS AND REPORTS

R-6100 RECORD AND REPORT REQUIREMENTS

The requirements of Article IWA-6000 apply, except that Owner's augmented programs, such as the Intergranular Stress Corrosion Cracking (IGSCC) program, the Microbiologically Influenced Corrosion (MIC) program, or the Flow Accelerated Corrosion (FAC) program, referenced in Table R-2500-1, Item Nos. R1.16, R1.17, or R1.18, are exempt from these requirements, unless an Owner chooses to select and credit structural elements for examination by one of the risk-informed selection processes specified in Supplement 1 or 2. If selected and credited structural elements are examined for one or more of the degradation mechanisms covered under these Owner's augmented programs, the requirements of Article IWA-6000 apply to documentation of these examinations.

ARTICLE R-9000
GLOSSARY

accident sequence: a representation in terms of an initiating even followed by a sequence of failures or success of events (i.e., system, function, or operator performance) that can lead to undesired consequences, with a specified end state (e.g., core damage or large early release).

core damage: uncovery and heatup of the reactor core to the point at which prolonged oxidation and severe fuel damage are anticipated and involving enough of the core to cause a significant release.

core damage frequency (CDF): expected number of core damage events per unit of time.

degradation mechanism: a phenomena or process that attacks (i.e., wears, erodes, cracks, etc.) the pressure-retaining material and might result in a reduction of component pressure boundary integrity.

event tree: a logic diagram that begins with an initiating event or condition and progresses through a series of branches that represent expected system or operator performance that either succeeds or fails and arrives at either a successful or failed end state.

failure: events involving leakage, rupture, or conditions that would disable a component's ability to perform its intended safety function.

failure mode: a specific functional manifestation of a failure, (i.e., the means by which an observer can determine that a failure has occurred) by precluding the successful operation of a piece of equipment, a component, or a system (e.g., fails to start, fails to run, leaks).

failure modes and effects analysis (FMEA): a process for identifying failure modes of specific components and evaluating their effects on other components, subsystems, and systems.

initiating event: any event either internal or external to the plant that perturbs the steady state operation of the plant, if operating, thereby initiating an abnormal event such as transient or LOCA within the plant. Initiating events trigger sequences of events that challenge plant control and safety systems whose failure could potentially lead to core damage or large early release.

large early release: the rapid, unmitigated release of airborn fission products from the containment to the environment occurring before the effective implementation of off-site emergency response and protective actions such that there is a potential for early health effects.

large early release frequency (LERF): expected number of large early releases per unit of time.

leak detection: detection of a leaking component normally exposed to pressure, usually by instrumentation detecting changing sump levels or radiation levels. Leak detection may be credited only when there is reasonable assurance that a small leak may be detected and mitigated before the loss of water degrades any plant functions.

piping segment (Supplement 1): a continuous portion of piping for which a failure at any point in the segment results in the same consequence (e.g., loss of the system or loss of a pump train).

piping segment (Supplement 2): a portion of piping for which a failure at any point in the segment results in the same consequence (e.g., loss of the system or loss of a pump train) and includes piping structural elements subject to the same degradation mechanism or mechanisms.

piping structural element: an item within a specified piping segment, such as a straight length of pipe, a pipe elbow, a coupling, a fitting, a flanged joint, or a weld.

piping system: an assembly of piping segments, piping supports, and other components that may consist of one or more Code Classes with a defined function as described within the Owner's Final Safety Analysis Report and Technical Specifications.

probabilistic fracture mechanics (PFM) model: a methodology used to determine probability of failure of degraded pressure boundaries. Using a deterministic model of the time to failure for the degraded pressure boundary, the model's essential input variables (such as loads, fracture toughness, density or preexisting flaws, crack growth law, etc.) are evaluated for many individual cases using representative probabilistic distributions of values for the uncertain variables. The number of cases resulting in pressure boundary failure by a given time compared to the total number of cases evaluated is used to determine the time dependent failure probability.

probabilistic risk assessment (PRA): a qualitative and quantitative assessment of the risk associated with plant operation and maintenance that is measured in terms of frequency of occurrence of risk metrics, such as core damage or a radioactive material release and its effects on the health of the public (also referred to as a probabilistic safety assessment, PSA).

range factor: the ratio of a distribution's cumulative 95th percentile point with the cumulative 50th percentile point.

recovery action: a human action performed to regain equipment or system operability from a specific failure or human error in order to mitigate or reduce the consequences of the failure.

spatial effect: a failure consequence affecting other systems or components, such as failures due to pipe whip, jet impingement, or flooding.

NONMANDATORY APPENDIX R SUPPLEMENTS

SUPPLEMENT 1 RISK INFORMED SELECTION PROCESS — METHOD A

1.0 INTRODUCTION AND SCOPE

This Supplement provides the risk-informed selection process to be used for selection of piping segments and piping structural elements (including connections) for preservice and inservice inspection.

2.0 EXPERT PANEL REQUIREMENTS

2.1 General. Each Owner shall establish an expert panel to implement the risk-informed selection process described in this Supplement. The expert panel shall be indoctrinated in the specific requirements to be used under this risk-informed selection process. Risk analysis techniques shall include the use of applicable risk-importance measures, threshold values, failure probability models, failure mode and degradation mechanism assessments, and the use of expert judgment. Each of these techniques shall be covered in the indoctrination to provide the expert panel with a level of knowledge needed to evaluate and approve the scope of the risk-informed selections.

2.2 Expert Panel Formation. Panel members selected for this risk-informed selection process shall include members of the expert panel established to implement other Probabilistic Risk Assessment (PRA) applications such as those associated with maintenance, quality assurance, or inservice testing activities, if such a panel was used. The panel for this risk-informed selection process shall include individuals having expertise in the following fields:

(a) probabilistic safety assessment

(b) inservice examination

(c) nondestructive examination

(d) stress and material considerations

(e) plant operations

(f) plant and industry maintenance, repair, and failure history

(g) system design and operation

The Owner shall define and document quorum requirements. Members may be experts in more than one field, but the Owner shall consider the diversity of the panel make-up, avoiding heavy reliance on any one member's judgment. The Owner is responsible for ensuring adequate experience levels for each expert panel member. This experience shall be documented and maintained by the Owner.

2.3 Expert Panel Leader Selection. The Owner shall select a panel leader who is familiar with the requirements of this risk-informed selection process. The panel leader shall facilitate the panel activities and shall be responsible for ensuring accomplishment of this risk-informed selection process.

2.4 Expert Panel Responsibilities. The expert panel shall be responsible for evaluation and approval of all risk-informed selection results (i.e., system, segment, structural element, and inspection selections) by utilizing their expertise (including knowledge of plant operation, prior inspection results, industry data, and any available stress and fracture mechanics results) and PRA insights to make the final decision on the High Safety Significant (HSS) structural elements to be included for inservice inspection. Selections made in accordance with this process, or any other required input where the judgment of the expert panel is needed, shall be reached by consensus.

The expert panel shall be provided documentation to support a decision making process based on a complete description of the functions endangered by the failure of piping within the scope and the operating conditions of the piping. The documentation should include the functions performed by the system or system parts included in the scope, the degradation mechanism identified in the system, the operator recovery actions credited in the analysis, and all the PRA results.

2.5 Maintenance of the Expert Panel. The Owner shall maintain the expert panel to allow changes, as necessary, to the risk-informed selections, when new information is applied, as directed by the requirements of this Supplement. Members may be added or removed as needed as long as the requirements of 2.2 are satisfied.

2.6 PFM User Training and Qualification. To ensure that the input parameters are consistently assigned and the Probabilistic Fracture Mechanics (PFM) model used in this methodology is properly executed, the users of the PFM model shall be trained and qualified. Acceptable qualification and the scope of training shall be based on the background and experience of the individuals using the model. Qualification should cover the following topics:

(a) overall risk-informed inspection process

(b) how PFM-calculated probabilities are used in the piping segment risk calculations

(c) capabilities and limitations of the PFM model

(d) expertise and type of information required, including applicable sources

(e) how potential degradation mechanisms are considered and combined

(f) the importance of each input parameter on each degradation mechanism and failure mode

(g) examples of PFM model use for different degradation mechanisms and failure modes

(h) how detailed PFM input (e.g., uncertainty) is developed and used

3.0 BOUNDARY REQUIREMENTS

3.1 Boundary Identification.

(a) The Owner shall define the system boundaries included in the scope of the risk-informed inspection program evaluation. Within each system boundary, the risk-informed evaluation may include Class 1, 2, or 3 piping defined in the deterministic inservice inspection program, if applicable, and piping outside the current deterministic program examination boundaries, if applicable. Piping, or portions thereof, included for evaluation shall be based on the deterministic program Class 1, 2, or 3 examination boundaries, if applicable, determined in accordance with the requirements of IWA-1320, and limited by exemptions of IWB-1220, IWC-1220, and IWD-1220. When Examination Category C-F-1 or C-F-2 piping is included, the piping exempt from NDE under the requirements of Tables IWC-2500-1 (C-F-1) and IWC-2500-1 (C-F-2) due to nominal wall thickness limitations shall be evaluated.

(b) Piping, or portions thereof, within the Class 1, 2, or 3 boundaries [including exempt piping in (a)], if applicable, and known from PRA insights to have a high consequence contribution, shall be included.

3.2 Use of the Applicable PRA. The boundary requirements of 3.1 shall be used to identify the piping systems, or portions thereof, to be considered for risk-informed selections of HSS and Low Safety Significant (LSS) piping segments and piping structural elements in accordance with this process. The Owner's PRA and its evaluated safety functions which consist of core damage protection, large early release protection, and the risk measures associated with these safety functions (core damage frequency and large early release frequency), provide the necessary information for the piping system PRA boundaries to be used in this process.

4.0 RISK-INFORMED PROCESS

4.1 General

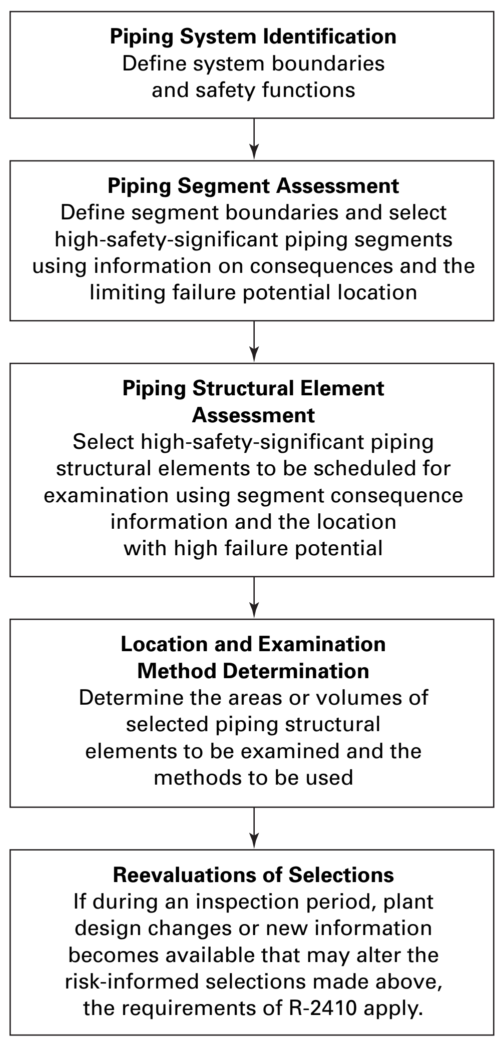
The risk-informed selection of nuclear power plant piping segments and piping structural elements shall be performed using the process described in this Supplement. The final result of this process is to identify those HSS piping structural elements that will be examined in accordance with Table R-2500-1. The basic overview of this process is provided in Figure R-S1-1.

4.2 Quantitative Approach

4.2.1 General. The process for this quantitative approach uses risk-based ranking calculational methods, with established threshold values, and risk-informed considerations of operational and deterministic insights to select a final list of HSS piping structural elements to be included in a risk-informed inspection program. This approach is divided into four major tasks.

(a) Identify and define the piping system boundaries and portions that will be considered in this risk-informed selection process in accordance with the boundary requirements of 3.0.

Figure R-S1-1
Overview Risk-Informed Selection Process



(b) Define, calculate, rank, and select the HSS piping segments within these identified systems using the failure modes and effects analysis (FMEA) technique and relevant plant information, including the plant PRA results.

(c) Assess or calculate, rank, and select the HSS piping structural elements, such as welds, elbows, and tees, within the HSS piping segments that will form the risk-informed inspection program for piping.

(d) Determine the areas or volumes of the selected piping structural elements to be scheduled for examination, and the appropriate examination methods or monitoring techniques to be used, in accordance with Table R-2500-1.

4.2.2 Risk Importance Measures. Risk Reduction Worth (RRW) shall be used as the primary risk importance measure in this risk-informed selection process. In addition, the Risk Achievement Worth (RAW) importance measure shall be considered in accordance with 4.2.6(b)(1). Four RRW and RAW values shall be calculated for each segment, two for CDF and two for LERF. One calculation of RRW and RAW based on CDF and on LERF shall be performed assuming all reasonable recovery actions to isolate the failed segment and mitigate the spatial effects are successful. A second calculation of RRW and RAW based on CDF and on LERF shall be performed assuming that no recovery actions are performed to isolate the failed segment and mitigate the spatial effects. RRW and RAW are used in failure consequence calculations, as discussed in (a) and (b).

(a) Risk Reduction Worth. RRW indicates the reduction factor in risk if the piping is assumed perfectly reliable for all failure modes. The RRW is calculated by reevaluating the PRA model and substituting a value of zero for the unavailability for all modeled components that would be placed in a failed state if the segment failed for each piping segment or structural element of interest. Thus, RRW is represented as follows:

$$RRW = R_o / R_i$$

where

R_i = decreased risk level (total core damage frequency or large early release frequency from piping pressure boundary failures) with the component i assumed to be perfectly reliable

R_o = base risk level (total core damage frequency or large early release frequency from piping pressure boundary failures only)

(1) Fussell-Vesely. Fussell-Vesely (F-V) importance may be used in lieu of RRW because of the mathematical relationship between the measures. The following relationship allows translation of F-V results to RRW if the F-V is less than 0.1:

$$RRW = \frac{1}{\left[1 - (F - V)\right]}$$

(b) Risk Achievement Worth. RAW indicates the increased factor in risk if the piping is assumed failed for all failure modes. The RAW is calculated by reevaluating the PRA model and substituting a value of unity for the unavailability for all modeled components that would be placed in a failed state if the segment failed belonging to the piping segment of interest. Thus, RAW is represented as follows:

$$RAW = R_i^+ / R_o$$

where

R_i^+ = increased risk level (core damage frequency or large early release frequency from piping pressure boundary failures) without component i, or with component i assumed failed

R_o = base risk level (core damage frequency or large early release frequency from piping pressure boundary failures only)

4.2.3 Selection of Systems. The expert panel shall determine, from the boundary requirements of 3.0., the systems and portions thereof that will be considered in this risk-informed selection process. The final system list, along with the rationale for any decisions, including those affected by other PRA application considerations, such as risk significance determinations, shall be documented.

4.2.4 Piping Segment Risk Ranking and Selection. The selected systems (as identified in 4.2.3) shall be further evaluated at the piping segment level. The ranking process is discussed in 4.2.5 and 4.2.6. The ranking process shall include the calculated conditional CDF and conditional LERF determined by the evaluation of piping pressure boundary failures. Four calculations shall be performed, two for CDF and two for LERF. One calculation of CDF and LERF shall be performed assuming all reasonable recovery actions to isolate the failed segment and mitigate the spatial effects are successful. A second calculation of CDF and LERF shall be performed assuming that no recovery actions are performed to isolate the failed segment and mitigate the spatial effects. The following calculations shall be applied as applicable:

(a) Expanded Equations for Use in Risk Evaluation. For a given segment,

$$CDF = FP(FR)_{leak} * CCDF(CCDP)_{leak} + FP(FR)_{disabling\ leak} * CCDF(CCDP)_{disabling\ leak} + FP(FR)_{break} * CCDF(CCDP)_{break}$$

where

$FP(FR)_{leak}$ = probability (dimensionless) or rate (per yr) for the failure mode of small leaks
$FP(FR)_{disabling\ leak}$ = probability (dimensionless) or rate (per yr) for the failure mode of disabling leaks
$FP(FR)_{break}$ = probability (dimensionless) or rate (per yr) for the failure mode of breaks
$CCDF(CCDP)_{leak}$ = conditional core damage frequency or core damage probability given a small leak
$CCDF(CCDP)_{disabling\ leak}$ = conditional core damage frequency or core damage probability given a disabling leak
$CCDF(CCDP)_{break}$ = conditional core damage frequency or core damage probability given a break

Similar calculations apply to the calculation of LERF for piping segments.

(b) Initiating Event Consequence CDF Calculations

$$CDF_{PB} = FR_{PB} * CCDP_{IE}$$

where

$CCDP_{IE}$ = conditional core damage probability (dimensionless)
CDF_{PB} = CDF from piping failure (events/yr)
FP_{EOL} = failure probability at end of life (EOL)
FR_{PB} = FP_{EOL}/EOL
FR_{PB} = piping failure rate (no deterministic inservice inspection) (events/yr)

(c) Mitigating System Consequence CDF Calculations

$$CDF_{PB} = FP_{PB} * CCDF_{PB}$$

where

$CCDF_{PB}$ = $CCDF_{PB=1} - CDF_{\mathrm{BASE}}$
$CCDF_{PB}$ = Conditional CDF with segment failed (=1) (in events/yr)
CDF_{BASE} = base total plant CDF (events/yr)
CDF_{PB} = Core Damage Frequency from a piping failure (in events/yr)
$CDF_{PB=1}$ = new total plant CDF with surrogate component = 1 (in events/yr)
FP_{PB} = piping failure probability (dimensionless)

(1) Continuously Operating Systems

$$FP_{PB} = FR_{PB} * T_m$$

where

FR_{PB} = the failure rate (in events per unit time)
FR_{PB} = $FP_{EOL}/(EOL$ yr* 8760 hr/yr)
T_m = the total defined mission time (24 hr for most PRAs)

(2) Standby Systems

$$FP_{PB} = 1/2(FR_{PB})\,T_t + (FR_{PB})\,T_m$$

where

FR_{PB} = the failure rate (in events per unit time)
T_m = the total defined mission time (24 hr for most PRAs)
T_t = the interval between tests that would identify a piping failure

(d) Initiating Event and System Degradation Consequence CDF Calculations

$$CDF_{PB} = FR_{PB} * CCDP_{IE,SEG} = 1$$

where

$CCDP_{IE,\ SEG=1}$ = conditional core damage probability for the initiator with mitigating system component assumed to fail (initiating event and mitigating system component = 1)
CDF_{PB} = Core Damage Frequency from a piping failure (events per yr)
FR_{PB} = piping failure rate (in events per yr)

4.2.5 Calculate Piping Segment Risk Importances. The FMEA technique shall be used to rank piping segments within the selected systems on the basis of core damage frequency and large early release frequency. Relevant plant information that is used for initial formulation of the FMEA shall be realistic and shall reflect current plant operational practices. The FMEA technique shall include at least the following information.

(a) Piping Segment. A location and boundary description of the segment that includes consideration of the number of structural elements being evaluated only,

usually welds, but may include elements such as elbows, flow reducers, and fittings, within the segment, and their nominal pipe size.

(b) Degradation Mechanism. Identification of the full range of potential degradation mechanisms, such as mechanical fatigue, thermal fatigue, stress corrosion cracking, and flow accelerated corrosion (FAC), that may occur within the piping segment, and the identification of the particular structural elements where these failures are most likely to occur.

(c) Failure Probability. Estimates of the failure probability of a piping segment under consideration assuming no inservice inspection. Failure rates (on demand, per hour, or per year) are required inputs to the risk-importance calculations. The piping segment failure rate is analogous to the active component failure rates that are used in the PRA, where the rate is the number of observed failures divided by the number of years.

Historical or service data, expert judgment, or validated PFM calculations shall be used to estimate the limiting piping segment failure probabilities. The PFM calculations shall be the primary method used to estimate failure probabilities unless the piping materials and operating characteristics assessed are not compatible. When using expert judgment to estimate failure rates, the selected experts shall have sufficient structural reliability knowledge to estimate the failure probability. The process shall integrate information from relevant disciplines. Table R-S1-1 provides definitions that have been found useful in having the selected experts relate their knowledge of piping failures to a failure probability. PFM calculations that are used to estimate piping failure probabilities shall contain the following fundamental parameters:

(1) an appropriate geometric characterization of the piping segment of interest

(2) flaw density and a size distribution after preservice inspection

(3) a characterization of the loading conditions, including mean stress, cyclic stress, number of cycles for both expected and postulated events; a probabilistic treatment of the frequency and loading uncertainty of these events shall also be considered

(4) the failure modes and degradation mechanisms that are identified to potentially occur within the piping segment of interest shall be characterized over the lifetime of the piping system

(5) failure criteria shall be included, such as a limited loss of pipe wall, leaks, and rupture

The above-noted fundamental parameters for the PFM calculations should also be considered if historical or service data or expert judgment processes are used to estimate piping failure probabilities. Only estimates of limiting failure probabilities for the pipe segments are needed. The estimates should be based on the scope of structural elements within the piping segment, and consideration of particular structural elements that will dominate the overall failure probability for the piping segment. To estimate the limiting failure probability of a piping segment, all the significant degradation mechanisms, material attributes, and operating characteristics shall be combined to calculate the failure probability of the segment regardless of the number of elements in the segment.

(d) Failure Consequence. Failure consequences are

(1) those pressure boundary failures affecting the function of the system in question, often referred to as direct effects. The following direct effects shall be considered:

(-a) failures that cause an initiating event such as a LOCA or reactor trip

(-b) failures that disable a single train or system

(-c) failures that disable multiple trains or systems

(-d) failures that cause any combination of the above failures

(2) Pressure boundary failures affecting other systems, components, or piping segments, often referred to as spatial or indirect effects, such as failures that cause pipe whip, jet impingement, or flooding.

The total effect on core damage and large early release, given the failure of the piping segment under consideration, shall be assessed. Consideration shall be given to the failure mode postulated for the piping

Table R-S1-1
Definition of Failure Probability Estimates for Pipe Segments

Definition	Failure Probability (per year)
An event that individually may be expected to occur more than once during the lifetime of the pipe segment.	10^{-1}
An event that individually may be expected to occur during the lifetime of the pipe segment.	10^{-2}
An event that individually is not expected to occur during the lifetime of the pipe segment; however, when considering all piping systems, an event in this category has the credibility of happening once.	10^{-4}
An event of such low probability that an event in this category is rarely expected to occur.	10^{-6}
An event of such extremely low probability that an event in this category is considered to be incredible.	10^{-8}

segment. The consequences must then be measured in the correct terms to ensure proper calculations of the risk measures.

The spatial effects of piping segment failure on other systems, components, or piping segments shall be evaluated to determine their effect on the selection of the equations used in 4.2.4. Previous plant hazard evaluations are useful in this process, along with a plant walkdown. Any assessment performed to determine that the effect on impacted targets would not cause any additional effects, interfere with the system operation, or prevent plant shutdown, shall be documented.

(e) Uncertainty. To address the potential impact of uncertainty in the estimated segment failure probabilities and the PRA results, a simplified uncertainty analysis shall be performed.

(1) The following range factors shall be assigned to each of the values estimated in 4.2.4. If the value is less than 10^{-4}, a range factor of 20 shall be assigned. If the value is greater than 10^{-2}, a range factor of 5 shall be assigned. Otherwise, a range factor of 10 shall be assigned.

(2) Propagation of uncertainty using an acceptable Monte-Carlo technique shall be performed for each of the four calculations.

(f) Recovery Action. The evaluation shall include the consequences of the piping failure, with and without recovery action.

(g) Core Damage Frequency and Large Early Release Frequency. The core damage value provides the risk, in terms of core damage frequency (events per year), associated with the failure of the piping segment under consideration. The conditional core damage frequency or probability per failure is multiplied by the segment failure probability or rate to obtain a core damage frequency due to failures for each segment. The large early release frequency shall be evaluated in a similar manner.

(h) Piping Segment Importance. The risk-importance measures defined in 4.2.2 shall be used to assist in the piping segment risk selection.

(i) Other Modes of Operation. Any other information, including evaluation of external events and other plant operating modes other than at-power, that are appropriate to establish the importance of the piping segment shall be considered by the expert panel.

4.2.6 Select HSS Piping Segments.

(a) The expert panel shall apply the risk-importance measure RRW as described in 4.2.2. Any piping segment that has any of its eight RRW values (two for CDF without analysis of uncertainty, two for CDF with analysis of uncertainty, two for LERF without analysis of uncertainty, and two for LERF with analysis of uncertainty) exceeding 1.005 shall be considered HSS, unless recovery actions are credited. To credit recovery actions, the following requirements shall be met:

(1) The recovery actions shall be documented in plant procedures.

(2) Indications (e.g., alarms, gages, instrumentation) shall be available to alert the operators to take the appropriate action.

(3) There shall be time available for the operator to diagnose and take the action that results in isolating or mitigating the piping failure, prior to the action becoming ineffective, to mitigate the piping failure consequences.

(4) The equipment associated with taking the action shall be available.

(b) If the recovery actions in (a) above are used as the basis for categorizing a segment LSS, and the RRWs determined without recovery actions are quantitatively HSS, the following shall be documented:

(1) identification of the procedure the operators are using.

(2) identification of the instrumentation that would alert the operators to take the appropriate actions.

(3) the estimated time the operators have to respond to the event.

(4) if the recovery action is modeled in the plant PRA, the results of any importance analyses performed on a pipe segment. In these importance analyses, the human error probabilities (HEPs) developed as part of the PRA for the operator action are used instead of assuming that the operators take no action to isolate or mitigate the leak or always take the correct action to isolate or mitigate the leak.

(c) Ideally, the screening criteria established by this quantitative approach should capture the HSS piping segments, but the following condition shall also be considered by the expert panel.

(1) All piping segments not exceeding the screening criteria shall be evaluated by the expert panel to determine whether any piping segment was inappropriately ranked below these threshold values. RAW insights may be considered. Considerations shall be given to the limitations of the PRA implementation approach resulting from the PRA structure and to limitations in the meanings and uncertainty associated with the importance measures. The expert panel shall also consider defense-in-depth, aging, deterministic and operational insights from inspection results, industry data, and available pipe failure data, and other PRA application impacts. The expert panel shall then determine if additional piping segments must be considered HSS.

(d) The final HSS and LSS piping segments list, along with the rationale for any adjustments and decisions, shall be documented. The HSS and LSS piping segments shall be put into the appropriate regions of Figure R-S1-2.

4.2.7 Process for Selecting Piping Structural Elements. The final list of HSS piping segments, as identified in 4.2.6 shall be selected for further evaluation at the piping structural elements level. The selection process is described in 4.2.8.

Figure R-S1-2
Structural Element Selection Matrix

	Low Safety Significant	High Safety Significant
High Failure Importance	3 — Owner Defined Program	1 — (A) Susceptible Location(s) (100%) (B) Inspection Location Selection Process
Low Failure Importance	4 — Only System Pressure Test & Visual Examination	2 — Inspection Location Selection Process

4.2.8 Piping Structural Element Selection.

(a) To complete the element selection process, a determination of segment high and low failure-importance shall be used to rank failure potential for the elements in that segment. HSS segments shall be considered to have a high failure-importance when a piping segment or its elements has either a degradation mechanism that is known to exist, which may be currently monitored as part of an existing Owner's augmented program, or is determined to be highly susceptible to a degradation mechanism that could lead to leakage or rupture. PFM calculation results may be used to determine this high failure importance if any location within which the segment exceeds the following indicator:

$$\text{Probability of Large Leak} > 10^{-4}$$
$$\text{per 40 yr of operation}$$

(b) A set of inspection locations or elements shall be identified for which (1) failures will have the greatest potential impact on safety, and (2) there is a greater likelihood of detectable degradation and consequently a greater potential for identifying, through NDE, piping degradation prior to failure. The final list of structural elements and rationale for any decisions made in establishing this list shall be documented. The following criteria shall be used to make this determination as shown in Figure R-S1-2:

(1) Region 1(A) includes all high-failure-importance locations in each HSS piping segment identified as likely to be susceptible to a known or postulated degradation mechanism and shall be examined. Exceptions include those locations already being examined under existing augmented programs. Region 1(B) includes other portions of these same HSS piping segments containing locations not affected by a known degradation mechanism and evaluated using a statistical evaluation such as the process described in (2). At least one element in this portion of each HSS piping segment shall be examined.

(2) Region 2 includes all HSS piping segments with low-failure-importance locations. For these segments a statistical evaluation shall be used to define the number of random locations to be examined. A sampling plan shall be selected for each of these segments that achieves at least a 95% confidence (no more than 5% risk) of not exceeding an estimated leak (through-wall crack) frequency defined from industry operating experience, based upon the estimates for piping leak frequencies in Table R-S1-2. In the statistical calculations, a leak is a visible leak that does not influence system operation. It shall be estimated as the frequency of a through-wall flaw. This estimate shall be obtained from a PFM model with suitable input and output parameters. In cases where a PFM model cannot be used due to model limitations, such as application to socket welds or specific materials and to account for uncertainty and the possibility of unknown degradation mechanisms in these segments, at least one element in each HSS piping segment shall be examined.

(3) Region 3 includes all LSS piping segments that have a high failure-importance. Locations selected for examination should be based on Owner-defined programs.

(4) Region 4 includes all LSS segments and locations with low failure-importance.

(5) System pressure tests and VT-2 visual examinations are required for all Class 1, 2, and 3 piping, as applicable in Regions 1, 2, 3, and 4, in accordance with Article IWA-5000, and Article IWB-5000, Article IWC-5000, or Article IWD-5000, as applicable, and R-2500.

4.2.9 Change-In-Risk Evaluation.

(a) If a prior deterministic inservice inspection program has been used, change-in-risk evaluation shall be performed prior to the initial implementation of a risk-informed inspection program.

(b) Proposed inspection program changes shall be assessed to quantitatively determine if any adjustments or compensatory measures to the proposed risk-informed inspection program are necessary to provide assurance that the effect of the proposed change results in a risk decrease, risk neutrality, or acceptably small increase. The quantitative assessment shall consider CDF and LERF with and without operator action. Operator recovery action credited in the calculations shall assume perfect performance, which means no human error probabilities are required.

(c) The quantitative assessment shall modify the failure probability used [see 4.2.5(c)] in calculating change in CDF and LERF as follows:

(1) For piping segments that are part of augmented programs (such as erosion-corrosion and stress corrosion cracking), the failure probabilities with examinations credited are used.

(2) For piping segments that have NDE selections proposed or selected, the failure probabilities with examinations credited are used.

Table R-S1-2
Estimates for Piping Leak Frequencies

Material	Size		
	≤ NPS 1 (DN 25)	NPS 1 (DN 25) < Size < NPS 4 (DN 100)	≥ NPS 4 (DN 100)< /entry>
Stainless steel	10^{-5}	10^{-5}	10^{-6}
Ferritic steel	10^{-5}	10^{-6}	5×10^{-6}

(3) For piping segments that have no NDE selections proposed or selected, the failure probabilities without examinations credited are used.

(4) For piping segments within containment, the failure probabilities with and without examinations credited based upon the proposed or selected NDE shall be used along with credit for leak detection. Credit for leak detection may be taken for reactor coolant system leaks and other system leaks that have analogous impact and detection possibilities as primary system leaks.

(5) No additional credit for inspection shall normally be given to piping segments that contain both augmented inspections and inservice inspections in the change-in-risk evaluation. However, for selected piping segments that are in the Inspection Program and an Owner's augmented program, when the Inspection Program requires additional or more stringent examinations beyond the augmented program, an additional factor of 3 improvement shall be used to adjust the failure probability used in the change-in-risk calculation.

(d) The criteria for an acceptable change-in-risk evaluation are as follows:

(1) The total change in piping risk shall be a risk reduction or risk neutral when moving from a deterministic inspection program to a risk-informed inspection program. If not, the dominant system (e.g., the system's contribution to the total risk-informed inservice inspection program risk is greater than 10%) and piping segment contributors shall be reviewed to determine what additional examinations are needed. If additional examinations are proposed, the change-in-risk calculation is to be revised until a risk-neutral position is achieved. This may require several iterations. For the purpose of this evaluation, risk-neutral is defined as essentially equivalent values, which may include acceptably small increases defined by the regulatory authority having jurisdiction at the plant site.

(2) Dominant systems shall be treated in a similar manner to the total change in piping risk, in that for each system, there shall be a risk reduction or risk neutrality when moving from the deterministic inspection program to a risk-informed inspection program.

(3) The results for nondominant systems (i.e., system contribution to the total risk-informed inservice inspection program risk is equal to or less than 10%) shall be reviewed to identify any systems for which there is a risk increase when moving from a deterministic inspection program to a risk-informed inspection program. For these systems, the following evaluation shall be performed to determine if additional examinations are required:

(-a) If the CDF increase for the system is greater than the larger of 1% of the risk-informed inspection CDF for that system or 10^{-8}, at least one dominant segment in that system shall be reevaluated to identify additional examinations.

(-b) If the LERF increase for the system is greater than the larger of 1% of the risk-informed inspection LERF for that system or 10^{-9}, at least one dominant segment in that system shall be reevaluated to identify additional examinations.

(4) If additional examinations are added as a result of the change-in-risk evaluation, the evaluation shall be updated to reflect the additional examinations. Segments for which additional examinations are added shall be categorized HSS, and no statistical evaluation for a sample size or expert panel review and approval is required.

4.2.10 Location and Examination Method Determinations. Once the piping structural elements list is completed in accordance with 4.2.8 and 4.2.9, the areas or volumes of concern for each of the HSS piping structural elements shall be determined and documented. This determination is based on the postulated degradation mechanisms identified in 4.2.5 and the configuration of each piping structural element. The examination methods and techniques for these identified areas or volumes of concern shall be determined in accordance with the requirements of Table R-2500-1 and documented.

5.0 REEVALUATION OF RISK-INFORMED SELECTIONS

5.1 General. Examination selections made in accordance with a risk-informed Inspection Program shall be reevaluated on the basis of inspection periods and inspection intervals that coincide with the Inspection Program requirements of IWA-2431. The third-inspection-period reevaluation will serve as the subsequent inspection interval reevaluation. The performance of each inspection-period or inspection-interval reevaluation may be accelerated or delayed by as much as 1 yr. The reevaluation shall determine if any changes to the risk-informed Inspection Program examination selections need to be made, by evaluation of the following:

(a) Plant design changes (e.g., physical: new piping or equipment installation; programmatic: power uprating / 18- to 24-month fuel cycle; procedural: pump test frequency changes, operating procedure changes)

(b) Changes in postulated conditions or assumptions (e.g., check valve seat leakage greater than previously assumed)

(c) Examination results (e.g., discovery of leakage or flaws)

(d) Piping failures (e.g., plant-specific or industry occurrences of through-wall or through-weld leakage, failure due to a new degradation mechanism, or a nonpostulated mechanism)

(e) PRA updates (e.g., new initiating events, new system functions, more detailed model used, initiating event and failure data changes)

5.2 Periodic Updates.

(a) If the periodic reevaluations of 5.1 indicate that piping structural elements, systems, or portions of systems may now be HSS, and the risk-informed inspection program needs to be updated, the Owner shall update the program by adding examination selections in accordance with the requirements for HSS piping structural elements in 4.2.8, or by using the applicable portions of the same risk-informed selection process previously used to establish the risk-informed inspection program. This reevaluation of the selections shall be performed by inserting the new information at the appropriate level of the analysis. It may not be necessary to reperform the entire risk-informed selection process, but the evaluation for the changes to the selections that occur shall be documented.

(b) If the reevaluations indicate that piping structural elements, systems, or portions of systems may now be LSS, the risk-informed inspection program may remain unchanged, or examination selections may be deleted by using the applicable portions of the same risk-informed selection process that previously established the risk-informed inspection program. This reevaluation of the selections shall be performed by inserting the new information at the appropriate level of the analysis. It may not be necessary to reperform the entire risk-informed selection process, but the evaluation for the changes to the selections that occur shall be documented.

(c) If any portion of the risk-informed selection process is reperformed, a change-in-risk evaluation shall be completed in accordance with 4.2.9.

5.3 Interval Updates. If changes occur during periodic updates, based on qualitative reevaluation results, those changes shall be cumulatively evaluated for inclusion in the subsequent inspection interval update. The subsequent inspection interval update shall include a reevaluation using the applicable portions of the same risk-informed selection process used to establish the risk-informed inspection program. This reevaluation of the selections shall be performed by inserting the new information at the appropriate level of the analysis. It may not be necessary to reperform the entire risk-informed selection process, but the evaluation for the changes to the piping selections that occur shall be documented. The inspection interval update shall meet the requirements of IWA-2400, and a change-in-risk evaluation shall be completed in accordance with 4.2.9.

SUPPLEMENT 2 RISK INFORMED SELECTION PROCESS — METHOD B

1.0 INTRODUCTION

This Supplement provides the risk-informed selection process to be used for selection of piping segments and piping structural elements (including connections) for preservice and inservice inspection. This selection process is based on the risk-significance of locations within an individual system. Figure R-S2-1 illustrates the evaluation process that is summarized in the following text.

1.1 System Identification. Systems shall be selected for analysis and system boundaries, and functions shall be identified.

1.2 Segment Risk Assessment. Each selected system shall be divided into piping segments determined to have similar consequence of failure and potential for failure (common degradation mechanisms, etc.). These segments shall be placed into risk categories based on combinations of consequence and failure potential. Risk-significant segments shall be identified.

1.3 Element Assessment. Potential locations (elements) within the risk-significant segments shall be selected for inspection based on the specific degradation mechanism identified in the segment.

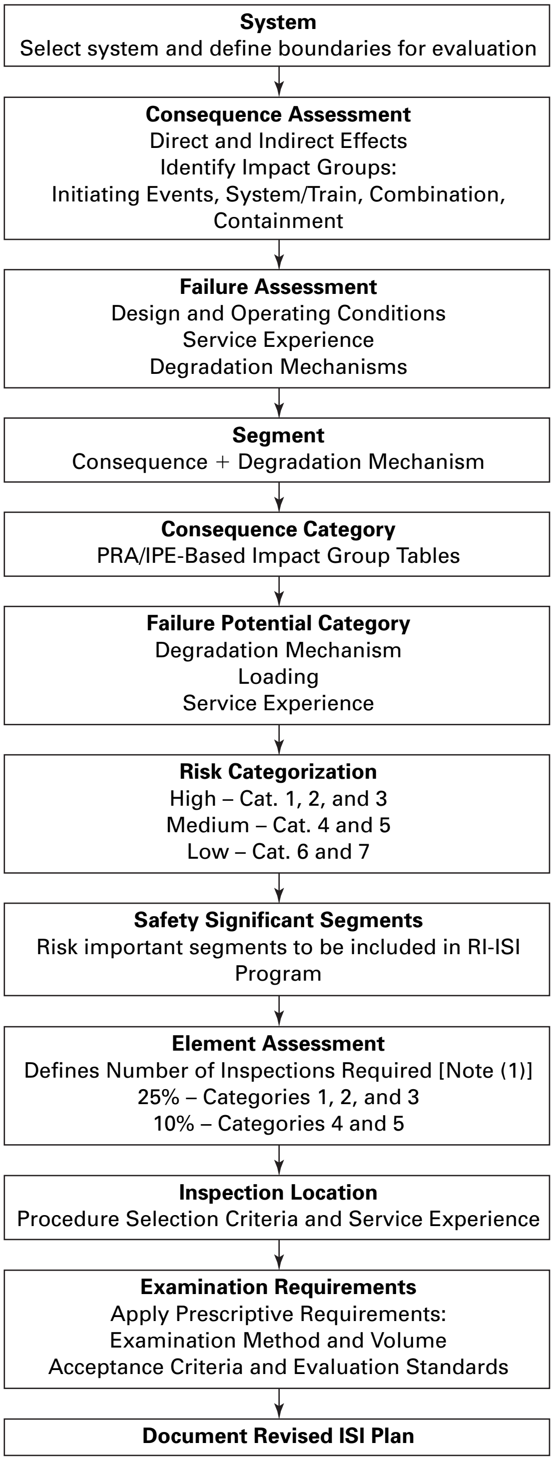
1.4 Inspection Volume and Examination Methods. The inspection volume and method used for each element shall be determined based on the degradation mechanism associated with the element.

1.5 Documentation. The results of this alternative selection process shall be documented. This process shall include a review incorporating plant-specific and industry experience, as well as the results of plant-specific inspections.

2.0 BOUNDARY IDENTIFICATION

The Owner shall define the system boundaries included in the scope of the risk-informed inspection program evaluation. Within each system boundary, the risk-informed evaluation may include Class 1, 2, or 3 piping defined in the deterministic inservice inspection program, if applicable, and piping outside the current deterministic

Figure R-S2-1
Risk Evaluation Process



NOTE:
(1) If the chosen scope of the application applies only to Examination Category B-J welds, excluding socket welds, the following may be applied: Element Assessment: 10% - Examination Category B-J.

program examination boundaries, if applicable. Piping, or portions thereof, included for evaluation shall be based on the deterministic program Class 1, 2, or 3, examination boundaries, if applicable, determined in accordance with the requirements of IWA-1320, and limited by exemptions of IWB-1220, IWC-1220, and IWD-1220. When Examination Category C-F-1 or C-F-2 piping is included, the piping exempt from NDE under the requirements of Tables IWC-2500-1 (C-F-1) and IWC-2500-1 (C-F-2) due to nominal wall thickness limitations shall be evaluated.

3.0 SEGMENT RISK ASSESSMENT

Piping within a system shall be grouped into segments of common failure consequence and susceptibility to common degradation mechanisms. To accomplish this grouping for each pipe segment within a system, both the potential for failure (i.e., susceptibility to potential degradation mechanisms) and the direct and indirect consequence of failure, shall be assessed in accordance with 3.1 and 3.2.

3.1 Failure Potential Assessment

3.1.1 Identification of Degradation Mechanisms. Potential active degradation mechanisms for each pipe segment within the selected system boundaries shall be identified. The following conditions shall be considered:

(a) design characteristics, including material, pipe size and schedule, component type (e.g., fitting type or ANSI standard) and other attributes related to the system configuration

(b) fabrication practices, including welding and heat treatment

(c) operating conditions, including temperatures and pressures, fluid conditions (e.g., stagnant, laminar flow, turbulent flow), fluid quality (e.g., primary water, raw water, dry steam, chemical control), and service environment (e.g., humidity, radiation)[58]

(d) industry-wide service experience with the systems being evaluated

(e) results of preservice, inservice, and augmented examinations, and the presence of prior repairs in the system

(f) degradation mechanisms identified in Table R-S2-1

3.1.2 Failure Potential Categories. Degradation mechanisms shall be categorized as described in Table R-S2-2 in accordance with their probability of causing a large pipe break. Segments susceptible to Flow Accelerated Corrosion (FAC) shall be classified in the high failure potential/large break category. Segments susceptible to any of the other degradation mechanisms shall be classified in the medium failure potential/small leak category. Segments having degradation mechanisms listed in the small leak category shall be upgraded to the high failure potential/large break category, if the pipe segments also have the potential for water hammer loads.

(15)

Table R-S2-1
Degradation Mechanisms

Mechanisms		Chapter Two Attributes	Susceptible Regions
TF	*TASCS*	— piping > NPS 1 (DN 25); and — pipe segment has a slope < 45 deg from horizontal (includes elbow or tee into a vertical pipe); and — potential exists for a low flow in a pipe section connected to a component allowing mixing of hot and cold fluids, or potential exists for leakage flow past a valve (i.e., in-leakage, out-leakage, cross-leakage) allowing mixing of hot and cold fluids, or potential exists for convection heating in dead-end pipe sections connected to a source of hot fluid, or potential exists for two phase (steam/water) flow, or potential exists for turbulent penetration in branch pipe connected to header piping containing hot fluid with high turbulent flow; and — calculated or measured ΔT > 50°F (ΔT > 27°C); and — Richardson number > 4.0	nozzles, branch pipe connections, safe ends, welds, heat-affected zones (HAZ), base metal; and regions of stress concentration
	TT	— operating temperature > 270°F (130°C) for stainless steel, or operating temperature > 220°F (105°C) for carbon steel, and — potential for relatively rapid temperature changes including cold fluid injection into hot pipe segment, or hot fluid injection into cold pipe segment, and — $\|\Delta T\|$ > 200°F ($\|\Delta T\|$ > 111°C) for stainless steel, or $\|\Delta T\|$ > 150°F ($\|\Delta T\|$ > 83°C) for carbon steel, or $\|\Delta T\| > \Delta T$ allowable (applicable to both stainless and carbon)	
SCC	*IGSCC (BWR)*	— evaluated in accordance with the Owner's existing IGSCC inspection program following NRC Generic Letter 88-01 or alternative (e.g., BWRVIP-075)	base metal, welds, and HAZ
	IGSCC (PWR)	— operating temperature > 200°F (93°C); and — susceptible material (carbon content ≥ 0.035%); and — tensile stress (including residual stress) is present; and — oxygen or oxidizing species are present OR — operating temperature < 200°F (93°C), the attributes above apply; and — initiating contaminants (e.g., thiosulfate, fluoride, chloride) are also required to be present	
	TGSCC	— operating temperature > 150°F (65°C), and — tensile stress (including residual stress) is present, and — halides (e.g., fluoride, chloride) are present, or caustic (NaOH) is present, and — oxygen or oxidizing species are present (only required to be present in conjunction w/halides, not required w/caustic)	austenitic stainless steel base metal, welds, and HAZ
	ECSCC	— operating temperature > 150°F (65°C), and — tensile strength is present, and — an outside piping surface is within five diameters of a probable leak path (e.g., valve stems) and is covered with nonmetallic insulation that is not in compliance with NRC Regulatory Guide 1.36, or an outside piping surface is exposed to wetting from chloride-bearing environments (e.g., seawater, brackish water, brine)	austenitic stainless steel base metal, welds, and HAZ
	PWSCC	— evaluated in accordance with the Owner's existing PWSCC inspection program and, as applicable, the requirements endorsed by the regulatory authority having jurisdiction at the plant site [e.g., 10CFR50.55a(g)(6)(ii)(F) dated June 21, 2011]	base metal, welds, and HAZ
LC	*MIC*	— operating temperature < 150°F (65°C), and — low or intermittent flow; and — pH < 10; and — presence/intrusion of organic material (e.g., raw water system), or water source is not treated w/biocides (e.g., refueling water tank)	fittings, welds, HAZ, base metal, dissimilar metal joints (e.g., welds, flanges), and regions containing crevices
	PIT	— potential exists for low flow; and — oxygen or oxidizing species are present; and — initiating contaminants (e.g., fluoride, chloride) are present	
	CC	— crevice condition exists (e.g., thermal sleeves); and — operating temperatures > 150°F (65°C); and — oxygen or oxidizing species are present	

Table R-S2-1
Degradation Mechanisms (Cont'd)

Mechanisms		Chapter Two Attributes	Susceptible Regions
FS	*E-C*	— existence of cavitation source (i.e., throttling or pressure reducing valves or orifices); and — operating temperature < 250°F (120°C); and — flow present > 100 hr/yr; and — velocity > 30 ft/s (9.1 m/s); and — $(P_d - P_v)/\Delta P < 5$ where, P_d = static pressure downstream of cavitation source, P_v = vapor pressure, and ΔP = pressure difference across the cavitation source	fittings, welds, HAZ, and base metal
	FAC	— evaluated in accordance with existing plant FAC program	per plant FAC program
Water Hammer [Note (1)]		— potential for fluid voiding and relief valve discharge	

GENERAL NOTE:
The following is a list of acronyms for terms used in the "Mechanisms" column:

Thermal Fatigue (TF)
- Thermal Stratification, Cycling, and Striping (TASCS)
- Thermal Transients (TT)

Stress Corrosion Cracking (SCC)
- Intergranular Stress Corrosion Cracking (IGSCC)
- Transgranular Stress Corrosion Cracking (TGSCC)
- External Chloride Stress Corrosion Cracking (ECSCC)
- Primary Water Stress Corrosion Cracking (PWSCC)

Localized Corrosion (LC)
- Microbiologically-Influenced Corrosion (MIC)
- Pitting (PIT)
- Crevice Corrosion (CC)

Flow Sensitive (FS)
- Erosion-Cavitation (E-C)
- Flow-Accelerated Corrosion (FAC)

NOTE:
(1) Water hammer is a rare, severe loading condition, as opposed to a degradation mechanism, but its known potential at a location, in conjunction with one or more of the listed mechanisms, is a cause for a higher examination zone ranking.

3.2 Consequence Evaluation

3.2.1 Failure Modes and Effects Analysis (FMEA). Potential failure modes for each pipe segment shall be identified, and their effects shall be evaluated. This evaluation shall consider the following:

(a) Break Size. The consequence analysis shall be performed assuming a large break for most segments. The exceptions are piping for which a smaller leak is more conservative, or when a small leak can be justified through a leak-before-break analysis in accordance with the criteria specified in NUREG-1061, Volume 3, and 10CFR50, Appendix J, General Design Criterion 4.

(b) Isolability of the Break. A break can be automatically isolated by a check valve, a closed isolation valve, or an isolation valve which closes on a given signal or by operator action.

(c) Indirect Effects. Includes spatial and loss of inventory effects.

Table R-S2-2
Degradation Mechanism Category

Failure Potential	Conditions	Degradation Category	Degradation Mechanism
High [Note (1)]	Degradation mechanism likely to cause a large break	Large break	Flow-Accelerated Corrosion
Medium	Degradation mechanism likely to cause a small leak	Small leak	Thermal Fatigue, Erosion-Cavitation, Corrosion, Stress Corrosion Cracking
Low	None	None	None

NOTE:
(1) Refer to 3.1.2.

(d) Initiating Events. These are identified using a plant-specific list of initiating events from the plant Probabilistic Risk Assessment/Individual Plant Examination (PRA/IPE) and the plant design basis.

(e) System Impact/Recovery. The means of detecting a failure, and the Technical Specifications associated with the system and other impacted systems. Possible automatic and operator actions to prevent a loss of systems shall also be evaluated.

(f) System Redundancy. The existence of redundant flowpaths for accident mitigation purposes shall be considered.

3.2.2 Impact Group Assessment. The FMEA impacts for each pipe segment shall be classified into one of three impact groups: initiating event, system, or combination. The consequence category (high, medium, low, none) shall then be selected in accordance with (a) through (e).

(a) Initiating Events (IE) Impact Group Assessment. When a postulated break results in only an initiating event (e.g., loss of coolant accident, loss of feedwater, reactor trip), the consequence shall be classified into one of four categories: high, medium, low, or none. The initiating event categories shall be assigned according to the following:

(1) The initiating event shall be placed into one of the categories in Table R-S2-3.

These shall include all applicable design basis events previously analyzed in the Owners updated final safety analysis report, PRA, or IPE.

(2) Breaks that cause an initiating event classified as routine operation (Category I) are not relevant to this analysis.

(3) For piping segment breaks that result in Category II (Anticipated Event), Category III (Infrequent Event), or Category IV (Limiting Fault or Accident), the consequence category shall be assigned to the initiating event according to the conditional core damage probability (CCDP) criteria specified in Table R-S2-4.

(b) System Impact Group Assessment. The consequence category of a pipe segment failure that does not cause an initiating event, but that degrades or fails a system essential to plant safety, shall be based on the following three attributes:

(1) Frequency of challenge, which determines how often the mitigating function of the system is called upon. This corresponds to the frequency of initiating events that require the system operation.

(2) Number of backup systems available, which determines how many unaffected systems are available to perform the same mitigating function as the degraded or failed system.

(3) Exposure time, which determines the time the system would be unavailable before the plant is changed to a different mode in which the failed system's function is no longer required, the failure is recovered, or other compensatory action is taken. Exposure time is a function of the detection time and Allowed Outage Time, as defined in the plant Technical Specification.

Consequence categories shall be assigned in accordance with Table R-S2-5 as High, Medium, or Low. Consistent with the initiating event group (Table R-S2-3), frequency of challenge is grouped into design basis event categories (II, III, and IV) unless initiating event frequency ranges are not consistent with Table R-S2-3. If this is the case, the frequency of the initiating event shall be used to

Table R-S2-3
Consequence Categories for Initiating Event Impact of Group

Design Basis Event Category	Initiating Event Type	Representative Initiating Event Frequency Range (1/yr)	Example Initiating Events	Consequence Category [Note (1)]
I	Routine operation	> 1	...	n/a
II	Anticipated event	$> 10^{-1}$	Reactor trip, turbine trip, partial loss of feedwater	Low/Medium
III	Infrequency event	10^{-1} to 10^{-2}	Excessive feedwater	Low/Medium
			Steam removal, loss of off-site power	Medium/High
IV	Limiting fault or accident	$< 10^{-2}$	Small LOCA, steam line break, feedwater line break, large LOCA	Medium/High

NOTE:
(1) Refer to 3.2.2(a)(3).

Table R-S2-4 Quantitative Indices for Consequence Categories

Consequence Category	Corresponding Conditional Core Damage Probability Range	Corresponding Conditional Large Early Release Probability Range
High	$> 10^{-4}$	$> 10^{-5}$
Medium	$10^{-6} < \text{CCDP} \le 10^{-4}$	$10^{-7} < \text{CLERP} \le 10^{-5}$
Low	$\le 10^{-6}$	$\le 10^{-7}$

determine the event category. Exposure time shall be obtained from Technical Specification and system operating configuration limits. In lieu of Table R-S2-5, quantitative indices based on conditional core damage probability may be used to assign consequence categories on the basis of the plant's PRA/IPE in accordance with Table R-S2-4. The Owner shall ensure that the quantitative basis of Tables R-S2-4 and R-S2-5 (e.g., train unavailability approximately 10^{-2}) is consistent with the pipe failure scenario under evaluation.

(c) Combination Impact Group Assessment. The consequence category for a pipe segment whose failure results in both an initiating event and the degradation or loss of a system shall be determined using Table R-S2-6. The Owner shall ensure that the quantitative basis of Table R-S2-5 (e.g., train unavailability approximately 10^{-2}) is consistent with the pipe failure scenario under evaluation. The consequence category is a function of two factors.

(1) use of the system as a mitigating function for the induced initiating event

(2) number of unaffected backup systems or trains available to perform the same function

(d) Containment Performance. The previous evaluations determine pipe failure importance relative to core damage. Pipe failure shall also be assessed for its impact on containment performance. This shall be accomplished by addressing two issues both of which are based on an approximate conditional value of $\le 10^{-1}$ between the CCDP and the likelihood of large early release from containment as shown in Table R-S2-4. If there is no margin (i.e., conditional large early release probability (CLERP) given core damage is $> 10^{-1}$), the assigned consequence category shall be increased by one level. The two issues are as follows:

(1) CCDP values for initiating events and safety functions shall be evaluated to determine whether the potential for large early containment failure requires the consequence category to be increased.

(2) The impact on containment isolation shall be evaluated. If there is a containment barrier available, the consequence category from the core damage

Table R-S2-5 Guidelines for Assigning Consequence Categories to Failures Resulting in System or Train Loss

Affected Systems: Frequency of Challenge	Affected Systems: Exposure Time to Challenge	Number of Unaffected Backup Trains: 0.0	0.5	1.0	1.5	2.0	2.5	3.0	≥ 3.5
Anticipated (DB Cat. II)	All Year	High	High	High	High	Medium	Medium	Low*	Low
	Between tests (1–3 months)	High	High	High	Medium*	Medium	Low*	Low	Low
	Long AOT (≤ 1 week)	High	High	Medium*	Medium	Low*	Low	Low	Low
	Short AOT (≤ 1 day)	High	Medium*	Medium	Low*	Low	Low	Low	Low
Infrequent (DB Cat. III)	All Year	High	High	High	Medium	Medium	Low*	Low	Low
	Between tests (1–3 months)	High	High	Medium*	Medium	Low*	Low	Low	Low
	Long AOT (≤ 1 week)	High	Medium*	Medium	Low*	Low	Low	Low	Low
	Short AOT (≤ 1 day)	High	Medium	Low*	Low	Low	Low	Low	Low
Unexpected (DB Cat. IV)	All Year	High	High	Medium	Medium	Low*	Low	Low	Low
	Between tests (1–3 months)	High	Medium	Medium	Low*	Low	Low	Low	Low
	Long AOT (≤ 1 week)	High	Medium	Low*	Low	Low	Low	Low	Low
	Short AOT (≤ 1 day)	High	Low*	Low	Low	Low	Low	Low	Low

GENERAL NOTE: **Containment Performance**: If there is no containment barrier and the consequence category is marked by an asterisk (*), the consequence category should be increased (medium to high or low to medium).

Table R-S2-6
Consequence Categories for Combination Impact Group

Event	Consequence Category
Initiating event and 1 unaffected train of mitigating system available	High
Initiating event and 2 unaffected trains of mitigating systems available	Medium [Note (1)] (or IE Consequence Category from Table R-S2-3)
Initiating event and more than 2 unaffected trains of mitigating systems available	Low [Note (1)] (or IE Consequence Category from Table R-S2-3)
Initiating event and no mitigating systems affected	IE Consequence Category from Table R-S2-3

NOTE:
(1) The higher consequence category from Table R-S2-3 or Table R-S2-6 shall be assigned.

assessment shall be retained. If there is no containment barrier or the barrier failed in determining the consequence category from the core damage assessment, a margin of at least 10^{-1} in the core damage consequence category assignment shall be present for the consequence category to be retained.

For example, if the CCDP for core damage is less than 10^{-5} (i.e., a "Medium" consequence assignment) and there is no containment barrier, the "Medium" consequence assignment is retained because there is a margin of 0.1 to the "High" consequence category threshold (i.e., 10^{-4}). However, if the CCDP for core damage is 5×10^{-5} (i.e., a "Medium" consequence assignment) and there is no containment barrier, the consequence category is increased to "High" because the margin to the "High" consequence category threshold (i.e., 10^{-4}) is less than 10^{-1}. Table R-S2-7 shall be used to assign consequence categories for those piping failures that can lead to a LOCA outside containment.

(e) Other Modes of Operation. Any other information, including evaluation of external events and other plant operating modes other than at-power, that are appropriate to establish the importance of the piping segment shall be considered.

3.3 Segment Risk Categorization

3.3.1 Risk Matrix. The risk of pipe segment failure shall be evaluated on the basis of the expected likelihood of the event and the expected consequence. The likelihood of failure shall be estimated based on the segment exposure to varying degradation mechanisms, and shall be represented by the degradation category assigned to the segment in accordance with 3.1. Consequence shall be represented by the consequence category assigned to the segment in accordance with 3.2. The structure used to document the results of this analysis is called a Risk Matrix and is shown in Table R-S2-8. Each pipe segment shall be assigned to one of the risk categories in Table R-S2-8 based on its degradation and consequence categories.

3.3.2 Risk Categories. The three failure potential (i.e., degradation mechanism) categories and four consequence categories shall be combined into seven risk categories, as follows. Piping segments and piping structural

Table R-S2-7
Consequence Categories for Pipe Failures Resulting in Increased Potential for an Unisolated Loca Outside of Containment

Protection Against LOCA Outside Containment	Consequence Category
One active barrier [Note (1)]	High
One passive barrier [Note (2)]	High
Two active barriers	Medium
One active and one passive barrier	Medium
Two passive barriers	Low
More than two passive barriers	None

NOTES:
(1) An active barrier is presented by a valve that needs to close on demand.
(2) A passive barrier is presented by a valve that needs to remain closed.

Table R-S2-8
Risk Matrix

Risk Groups High: Cat. 1, 2, and 3 Medium: Cat. 4 and 5...Low: Cat. 6 and 7		Consequence Category			
		None	Low	Medium	High
Failure Potential	High	Category 7	Category 5	Category 3	Category 1
	Medium	Category 7	Category 6	Category 5	Category 2
	Low	Category 7	Category 7	Category 6	Category 4

elements determined to be in Risk Category 1, 2, 3, 4, or 5 are HSS, and those that are in Risk Category 6 or 7 are LSS:

Risk Category	Risk Area
1	High Consequence and High Failure Potential Category
2	High Consequence and Medium Failure Potential Category
3	Medium Consequence and High Failure Potential Category
4	High Consequence and Low Failure Potential Category
5	Medium Consequence and Medium Failure Potential Category, or Low Consequence and High Failure Potential Category
6	Medium Consequence and Low Failure Potential Category, or Low Consequence and Medium Failure Potential Category
7	Low Consequence and Low Failure Potential Category, or No Consequence and Any Failure Potential Category

4.0 ELEMENT ASSESSMENT

(15) **4.1 Standard Element Assessment.** The number of elements to be examined in each risk category shall be as follows:

(a) For Segments in Risk Category 1, 3, or 5, in an existing FAC inspection program, with no known degradation mechanisms other than FAC, the number, location, and frequency of inspections shall be in accordance with the existing FAC inspection program. The existing FAC inspection program shall remain unchanged. For the risk-informed inspection program

(1) if segments in the FAC inspection program are to be selected and credited under the risk-informed inspection program, they shall be treated in accordance with (c), or

(2) the segments defined in (a) may be removed from the risk-informed inspection program population used to determine the number and location of inspections under (c), as they are governed by the Owner's existing FAC inspection program

(b) For Segments in Risk Category 1, 2, 3, or 5, in an existing IGSCC inspection program per NRC Generic Letter 88-01 Categories B through G or an Owner's existing PWSCC inspection program for Class 1 PWR piping and vessel nozzle butt welds that are fabricated with UNS N06600, N06082, or W86182 materials with or without the application of mitigation activities, with no known degradation mechanisms other than IGSCC or PWSCC, respectively, the number, location, and frequency of inspections shall be the same as the existing IGSCC or PWSCC inspection program. For the risk-informed inspection program

(1) IGSCC Category A welds shall be treated in accordance with (c), and

(2) if welds in an IGSCC (Categories B through G) or PWSCC inspection program are to be selected and credited under the risk-informed inspection program, they shall be treated in accordance with (c), or

(3) the welds in an IGSCC (Categories B through G) or PWSCC inspection program may be removed from the risk-informed inspection program population used to determine the number and location of inspections under (c), as they are governed by the Owner's existing IGSCC or PWSCC inspection programs

(c) For segments determined to have degradation mechanisms other than those included in the existing FAC, IGSCC, and PWSCC inspection programs, or segments with no known degradation mechanisms, the following number of locations shall be examined as part of the risk-informed inspection program.

(1) For Risk Categories 1, 2, and 3, the number of inspection locations in each category shall be at least 25% of the total number of elements in each risk category applicable to the system evaluated.

(2) For Risk Category 4 or 5, the number of inspection locations in each category shall be at least 10% of the total number of elements in each risk category applicable to the system evaluated.

(d) For segments in Risk Category 6 or 7, volumetric and surface examinations are not required.

(e) All Classes 1, 2, and 3 elements, regardless of risk category, require pressure tests and VT-2 visual examinations, as applicable, in accordance with Article IWA-5000; Article IWB-5000, Article IWC-5000, or Article IWD-5000, as applicable; and R-2500.

4.2 Optional Element Assessment. If the chosen scope applies only to Examination Category B-J welds, excluding socket welds, elements may be selected for examination starting with the elements in the High Risk Group and working toward the Low Risk Group, until the total number of elements are equal to 10% of the Examination Category B-J piping welds, excluding socket welds. Examinations may be concentrated on systems with more high-risk segments, such that a larger percentage of the elements in the High Risk Categories 1, 2, and 3 are examined. No more than 50% of the examinations required by other augmented programs (e.g., IGSCC in BWRs) may be credited toward the required 10% inspection population.

5.0 INSPECTION LOCATIONS AND EXAMINATION METHODS

5.1 Selection of Elements for Inspection. The selection of elements within each risk category shall be documented and shall be based on the following:

(a) elements identified as susceptible to the specific degradation mechanisms in Table R-S2-1

(b) plant-specific inservice cracking or flaw experience

(c) availability of previous examination results for baseline, preservice, and historical records

(d) inspections shall be required for each degradation mechanism and combination of degradation mechanisms (e.g., thermal fatigue and IGSCC) identified. Relative degradation severity for specific degradation mechanisms, when applicable, shall be considered (e.g., wear or erosion rates for flow accelerated corrosion, ΔT or Richardson number for thermal fatigue, BWRVIP-75[59] weld categorization for IGSCC). Examination for elements in Risk Category 4 segments shall be based on areas of significant stress concentration, geometric discontinuities, or terminal ends.

(e) availability of access to the element to ensure the examination method for the relevant degradation mechanism can be used effectively to achieve required coverage for the defined examination volumes

(f) elements should be selected to minimize personnel radiation exposure during inspection

(g) elements should be selected to minimize support services such as scaffolding, insulation, and rigging

5.2 Examination Volumes and Methods. The selection of examination volumes and methods for each element within a Risk Category will depend on the degradation mechanism present. Examination programs developed in accordance with this Appendix shall use NDE techniques suitable for specific degradation mechanisms and examination locations. The examination volumes and methods that are appropriate for each degradation mechanism are provided in Table R-2500-1. The methods and procedures used for the examinations shall be qualified to reliably detect and size the relevant degradation mechanisms identified for each element. Personnel performing the examinations shall be qualified, and examinations shall be conducted and documented, in accordance with Article IWA-2000.

6.0 CHANGE-IN-RISK EVALUATION

(a) If a prior deterministic inspection program has been used, a change-in-risk evaluation shall be performed prior to the initial implementation of a risk-informed inspection program.

(b) Proposed risk-informed inspection program changes shall be qualitatively or quantitatively assessed to determine if any adjustments to the proposed inspection program or compensatory measures are needed to provide assurance that the effect of the proposed change is either risk-neutral, provides a risk reduction, or adds negligible increases in CDF and LERF.

(1) Qualitative Evaluation: For segments categorized as Low Risk (Category 6 or 7), any changes to the number of examinations shall have a negligible impact on risk (EPRI TR-112657 Revision B-A, December 1999, Section 3.7.1). This qualitative assessment shall review all other risk categories to determine if the number of examinations is greater, the same, or less than the previous deterministic inspection program, if applicable. For risk categories for which the number of risk-informed inspection examinations is greater, or the same, the risk impact shall be considered a decrease, or at worse, risk-neutral, and therefore acceptable. For risk categories for which the number of examinations is less than the deterministic inspection program, as applicable, a quantitative evaluation shall be performed.

(2) Quantitative Evaluation: The change in risk shall be estimated for changes in examinations of welds in segments in medium or high risk categories (1, 2, 3, 4, or 5).

(-a) Bounding Failure Frequency: The failure frequencies of 2×10^{-6}/weld-yr for welds in the high-failure-potential category, 2×10^{-7}/weld-yr for welds in the medium-failure-potential category, and 10^{-8}/weld-yr in the low-failure-potential category may be used.

(-b) Location-Specific Failure Frequency: Degradation-mechanism-specific failure frequencies developed from an integrated analysis of observed pipe failure data may be used to develop location- and degradation-specific failure frequencies. An acceptable source of data is provided in EPRI TR-112657, Revision B-A, December 1999, Section 3.7.1. Any other evaluation of data used shall be of comparable scope and quality. These failure frequency estimates shall be used directly or in a sound and appropriate first-order Markov model of pipe rupture. The Markov model shall incorporate the degradation-specific failure frequencies, the time between opportunities to detect a leak, the time between

inspections, and the probability of (flaw) detection. The Markov model may be used to estimate location-specific failure frequencies, or to estimate the factor that inspection could reduce the location-specific failure frequency of the inspection program. When failure frequencies based on degradation mechanisms are used, mechanisms that are in an augmented program unaffected by the proposed risk-informed inspection program need not be included in the location-specific estimates. Failure frequencies for other degradation mechanisms simultaneously present (except for IGSCC and FAC) shall be summed. If IGSCC and FAC are present with any other degradation mechanism, and if the deterministic inspection program or the risk-informed inspection program provides additional or more stringent examination beyond that required by the Owner's augmented inspection program, an additional factor of 3 improvement may be used to adjust the failure probability used in the change-in-risk calculation.

(-c) Conditional Risk Estimates: The conditional core damage probability (CCDP) and conditional large early release probability (CLERP) estimated for each segment may be used, if available. Bounding values of the highest estimated CCDP and CLERP for high-consequence segments, and 10^{-4} (CCDP) and 10^{-5} (CLERP) for medium-consequence segments, and 10^{-6} (CCDP) and 10^{-7} (CLERP) for low-consequence segments shall be used, if segment-specific estimates are not available.

(-d) The following general equations shall be used to estimate the change-in-risk. One estimate shall be made for the change in CDF and one for LERF. The equations illustrate only the change in CDF; the change in LERF due to application of the risk-informed inspection process shall be estimated by substituting the conditional large early release probability (CLERP) for CCDP in the equations.

$$\Delta R_{CDF} = \sum_j \left(I_{rj} - I_{ej}\right)^* PF_j^* CCDP_j$$

where

$CCDP_j$ = conditional core damage probability at location j

I_{ej} = factor of reduction in pipe rupture frequency at location j, associated with a deterministic inspection program

I_{rj} = factor of reduction in pipe rupture frequency at location j, associated with a risk-informed inspection program

PF_j = piping failure frequency at location j, without inspection

ΔR_{CDF} = change in CDF due to replacing a deterministic inspection program with a risk-informed inspection program

In terms of probability of detection

$$\left[POD_j = \left(1 - I_j\right)\right], \text{ the equation becomes}$$

$$\Delta R_{CDF} = \sum_j \left(POD_{ej} - POD_{rj}\right)^* PF_j^* CCDP_j$$

where

POD_{ej} = probability of detection at location j, in a deterministic inspection program

POD_{rj} = probability of detection at location j, in a risk-informed inspection program

It is acceptable to use bounding estimates for pipe failure frequency from (-a) and conditional core damage and large early release probabilities from (-c) to simplify the calculations. If the bounding estimates for both pipe failure frequencies and conditional probabilities are used, the equation becomes

$$\Delta R_{CDF} = \left[\left(POD_e^* N_{efc} - POD_r^* N_{rfc}\right)\right]^* PF_f^* CCDP_c$$
$$\left(POD_e^* N_{efc} - POD_r^* N_{rfc}\right)$$

where

$CCDP_c$ = conditional core damage probability for the high-, medium-, and low-consequence estimates

N_{efc} = number of inspection locations in the consequence f and failure frequency c categories in the previous deterministic inspection program

N_{rfc} = number of inspection locations in the consequence f and failure frequency c categories in the risk-informed inspection program

PF_f = piping failure frequency for the high-, medium-, and low-failure frequency estimates

POD_e = probability of detection in the previous deterministic inspection program, if applicable (may be degradation mechanism specific)

POD_r = probability of detection in the risk-informed inspection program (may be degradation mechanism specific)

(-e) Acceptance Criteria: The estimated change in CDF and LERF for each system shall be less than 10^{-7}/yr and 10^{-8}/yr, respectively, and the total change in CDF and LERF shall be less than 10^{-6}/yr and 10^{-7}/yr respectively. If these requirements are not met, inspection locations shall be added. If this Supplement is applied to only Class 1 welds, the individual systems and system parts in Class 1 may be considered a single system, and the system-level guidelines shall be applied to the total change.

7.0 REEVALUATION OF RISK-INFORMED SELECTIONS

7.1 General. Examination selections made in accordance with a risk-informed inspection program shall be reevaluated on the basis of inspection periods and inspection intervals that coincide with the inspection program requirements of IWA-2431. The third inspection period reevaluation will serve as the subsequent inspection interval reevaluation. The performance of each inspection period or inspection interval reevaluation may be accelerated or delayed by as much as 1 yr. The reevaluation shall determine if any changes to the risk-informed Inspection Program examination selections need to be made, by evaluation of the following:

(a) Plant design changes (e.g., physical: new piping or equipment installation; programmatic: power uprating/ 18- to 24-month fuel cycle; procedural; pump test frequency changes, operating procedure changes)

(b) Changes in postulated conditions or assumptions (e.g., check valve seat leakage greater than previously assumed)

(c) Examination results (e.g., discovery of leakage or flaws)

(d) Piping failures (e.g., plant specific or industry occurrences of through-wall or through-weld leakage, failure due to a new degradation mechanism, or a nonpostulated mechanism)

(e) PRA updates (e.g., new initiating events, new system functions, more detailed model used, initiating event and failure data changes)

7.2 Periodic Updates.

(a) If the periodic reevaluations of 7.1 indicate that piping structural elements, systems, or portions of systems may now be HSS and the risk-informed Inspection Program needs to be updated, the Owner shall update the program by adding examination selections in accordance with the requirements for Risk Category 1, 2, 3, 4, or 5 element selections in 4.0, or by using the applicable portions of the same risk-informed selection process previously used to establish the risk-informed Inspection Program. This reevaluation of the selections shall be performed by inserting the new information at the appropriate level of the analysis. It may not be necessary to reperform the entire risk-informed selection process, but the evaluation for the changes to the selections that occur shall be documented.

(b) If the reevaluations indicate that piping structural elements, systems, or portions of systems may now be LSS, Risk Category 6 or 7, the risk-informed Inspection Program may remain unchanged, or examination selections may be deleted by using the applicable portions of the same risk-informed selection process that previously established the risk-informed Inspection Program. This reevaluation of the selections shall be performed by inserting the new information at the appropriate level of the analysis. It may not be necessary to reperform the entire risk-informed selection process, but the evaluation for the changes to the piping selections that occur shall be documented.

(c) If any portion of the risk-informed inspection process is reperformed, a change-in-risk evaluation shall be completed in accordance with 6.0.

7.3 Interval Updates. If changes occur during periodic updates, based on qualitative reevaluation results, those changes shall be cumulatively evaluated for inclusion in the subsequent inspection interval update. The subsequent inspection interval update shall include a reevaluation using the applicable portions of the same risk-informed selection process used to establish the risk-informed Inspection Program. This reevaluation of the selections shall be performed by inserting the new information at the appropriate level of the analysis. It may not be necessary to reperform the entire risk-informed selection process, but the evaluation for the changes to the piping selections that occur shall be documented. The inspection interval update shall meet the requirements of IWA-2400, and a change-in-risk evaluation shall be completed in accordance with 6.0.

NONMANDATORY APPENDIX S
EVALUATING COVERAGE FOR SECTION XI NONDESTRUCTIVE EXAMINATION

ARTICLE S-1000
INTRODUCTION

S-1100 SCOPE

This Nonmandatory Appendix provides guidelines for evaluating nondestructive examination (NDE) coverage for visual, surface, and volumetric examination. This Nonmandatory Appendix provides guidance; consequently, it may be used in whole or in part.

ARTICLE S-2000
EXAMINATION COVERAGE

S-2100 APPLICABILITY

This Appendix is applicable for the examinations required by IWA-2200, excluding VT-2 and VT-3 visual examination, General Visual examination (Article IWE-2000), and eddy current examination.

S-2200 DEFINITIONS

examination coverage: percentage of the examination surface or volume obtained during the performance of the examination.

examination surface: surface area of the weld or base material required to be examined.

examination volume: volume of the weld or base material required to be examined.

scan limitation: inability to manipulate an ultrasonic search unit on the surface because of interference, obstruction, or geometrical configuration.

surface limitation: inability to perform an examination of the required surface, because of interference, obstruction, or geometrical configuration

volumetric limitation: inability to examine the required volume because of interference, obstruction, geometrical configuration, or metallurgical condition of material being examined.

S-2300 GENERAL REQUIREMENTS

(a) During performance of a preservice or inservice examination, essentially 100% coverage is required of the examination surface for surface and visual examination and of the examination volume for volumetric examination.

(b) Examination coverage requirements are contained in Tables IWB/IWC/IWD/IWE/IWF-2500, the associated figures, and Article I-3000. These requirements may be further augmented by 10 CFR 50.55a, Code Cases, risk-informed programs, or the applicable examination procedure.

(c) Data supporting the coverage evaluation (e.g., required examination surface or volume and any associated limitations) should be documented.

(d) The method used to evaluate coverage should be documented for each examination procedure, including all applicable qualification limitations.

ARTICLE S-3000 EXAMINATION COVERAGE EVALUATIONS

S-3100 EXAMINATION COVERAGE EVALUATIONS FOR VISUAL OR SURFACE EXAMINATION OF WELDS

(a) Determine the area of the required weld examination surface using the design, as-built, measured, or nominal weld dimensions and any required adjacent base material.

(b) Determine the area of the weld examination surface affected by surface limitations. The actual dimensions of inaccessible weld surfaces should be documented.

(c) Calculate the examination coverage.

S-3200 EXAMINATION COVERAGE EVALUATIONS FOR VISUAL OR SURFACE EXAMINATION OF COMPONENTS

(a) Determine the area of the required component examination surface using manufacturer's drawings or actual dimensions.

(b) Determine the area of the component examination surface affected by surface limitations. The actual dimensions of inaccessible component surfaces should be documented. Note that bolting may be VT-1 visual examined in place. In such instances, only those surfaces that are accessible for examination are required to be examined.

(c) Calculate the examination coverage.

S-3300 EXAMINATION COVERAGE EVALUATIONS FOR RADIOGRAPHIC EXAMINATION OF WELDS

(a) Determine the required weld examination volume using the design, as-built, measured, or nominal weld dimensions and any required adjacent base material.

(b) Determine the weld examination volume affected by volumetric limitations. The volume unable to be examined should be documented, using the radiographic image or actual dimensions and supplemented by manufacturer's drawings if necessary.

(c) Calculate the examination coverage.

S-3400 EXAMINATION COVERAGE EVALUATIONS FOR RADIOGRAPHIC EXAMINATION OF COMPONENTS

(a) Determine the required component examination volume using manufacturer's drawings or actual dimensions.

(b) Determine the component examination volume affected by volumetric limitations. The volume unable to be examined should be documented, using the radiographic image or actual dimensions and supplemented by manufacturer's drawings if necessary.

(c) Calculate the examination coverage.

S-3500 EXAMINATION COVERAGE EVALUATIONS FOR ULTRASONIC EXAMINATION OF WELDS

(a) Determine the required weld examination volume using the design, as-built, measured, or nominal weld dimensions and any required adjacent base material.

(b) Determine the weld examination volume affected by volumetric or scan limitations. The volume unable to be examined should be documented, using actual dimensions and supplemented by manufacturer's drawings if necessary. Each scan direction (e.g., CW, CCW, parallel, or perpendicular) should be weighted equally. When multiple search units (e.g., 0 deg, 45 deg, or 60 deg) are used for examination, each search unit should be weighted equally unless the search unit has limited applicability for examination of the required volume (e.g., qualification is limited to the base material of austenitic welds) or the coverage requirements are specified in a demonstrated procedure.

(c) Calculate the examination coverage, taking into consideration the coverage achieved when different search units are used for different portions of the examination volume.

S-3600 EXAMINATION COVERAGE EVALUATIONS FOR ULTRASONIC EXAMINATION OF COMPONENTS

(a) Determine the required component examination volume using manufacturer's drawings or actual dimensions.

(b) Determine the component examination volume affected by volumetric or scan limitations. The volume unable to be examined should be documented, using actual dimensions and supplemented by manufacturer's drawings if necessary. Each scan direction (e.g., CW, CCW, parallel, or perpendicular) should be weighted equally. When multiple search units (e.g., 0 deg, 45 deg, or 60 deg) are used for examination, each search unit should be weighted equally unless the search unit has limited applicability for examination of the required volume (e.g., qualification is limited to the base material of austenitic welds) or the coverage requirements are specified in a demonstrated procedure.

(c) Calculate the examination coverage, taking into consideration the coverage achieved when different search units are used for different portions of the examination volume.

NONMANDATORY APPENDIX T
REPORTING OF CONTRACTED REPAIR/REPLACEMENT ACTIVITIES

ARTICLE T-1000
INTRODUCTION

T-1100 SCOPE

This Nonmandatory Appendix provides a report form that may be used to meet the requirements of IWA-6211(f) and IWA-6212 for documenting repair/replacement activities within the jurisdiction of this Division (IWA-1200) when performed by a Repair/Replacement Organization under contract with the Owner. This Nonmandatory Appendix may be used in whole or in part as specified in the contract between the Owner and the Repair/Replacement Organization.

If the Owner requires repair/replacement activities to be documented in accordance with the provisions of this Nonmandatory Appendix, Form RRA-1 shall be completed.

This Nonmandatory Appendix is intended for use if there is no other certification program imposed on a contracted Repair/Replacement Organization for the repair/replacement activities being performed.

T-1200 RESPONSIBILITIES

T-1210 OWNER'S RESPONSIBILITY

The Owner is responsible for establishing requirements for the Repair/Replacement Organization to provide a document certifying the repair/replacement activities it performs in accordance with its Quality Assurance Program that has been reviewed and accepted in accordance with IWA-4142(a)(2). If this Appendix is specified for use by the Owner, the Repair/Replacement Organization shall document its repair/replacement activities on Form RRA-1.

T-1220 CONTRACTED REPAIR/REPLACEMENT ORGANIZATION'S RESPONSIBILITY

The contracted Repair/Replacement Organization shall complete Form RRA-1 if the Owner requires repair/replacement activities to be documented in accordance with the provisions of this Nonmandatory Appendix.

FORM RRA-1 REPORT OF CONTRACTED REPAIR/REPLACEMENT ACTIVITY
(Use of Properly Identified Additional Sheets or Sketches Is Acceptable)

1. Work Performed by ______ (1) ______ ______ (2) ______
(Name of Repair/Replacement Organization Performing Repair/Replacement Activity) (PO No., Job No., etc.)

____
(Address)

2. Owner ______ (3) ______
(Name)

____
(Address)

3. Name, Address, and Identification Number of Nuclear Power Plant ______ (4) ______

____

4. Owner Repair/Replacement Plan No. ______ (9) ______

5.	Items Affected by the Contracted Repair/Replacement Activities		
Description of Item	Item Identification No. Assigned by Owner	Name of Manufacturer	Manufacturer's Model/Serial No.
(a)			
(b) (5)	(6)	(7)	(8)
(c)			
(d)			
(e)			
(f)			
(g)			
(h)			
(i)			
(j)			

6.	Items Installed During Contracted Repair/Replacement Activities						
Identification			Construction Code for Fabrication of Installed Item				
Description of Item installed	Name of Manufacturer	Manufacturer's Model/Serial No. and Unique Traceability No.	Const Code/ Sect/Div.	Edition/ Addenda	Code Cases	Code Class	Installed into (Line No. from Section 5)
(10)	(11)	(12)	(13)	(14)	(14)	(14)	(15)

7. Section XI Applicable for the Owner's Repair/Replacement Program ______ (16) ______ (16) ______ (16) ______
(Edition) [Addenda (if applicable)] (Code Cases)

8. Section XI Used for Repair/Replacement Activities ______ (17) ______ (17) ______ (17) ______
(Edition) [Addenda (if applicable)] (Code Cases)

(07/10)

FORM RRA-1 REPORT OF CONTRACTED REPAIR/REPLACEMENT ACTIVITY (Cont'd)

9. Construction Code Used for Repair/Replacement Activities ___(13)___ ___(18)___ ___(18)___ ___(18)___
Const Code/Sect/Div. (Edition) [Addenda (if applicable)] (Code Cases)

10. Design Responsibilities ___(19)___ Reconciliation Performed ☐ No ☐ Yes (Identify Under "Description of Work" and Attach or Reference Documentation)

11. Tests Conducted ☐ Hydrostatic ☐ Pneumatic ☐ System Leakage Test ☐ N/A (Not Applicable or Test to Be Conducted by Owner) ___(20)___

12. Description of Work ___(21)___
(Use of Properly Identified Additional Sheets or Sketches Is Acceptable)

13. Remarks ___(22)___
(Use of Properly Identified Additional Sheets or Sketches Is Acceptable)

CERTIFICATE OF COMPLIANCE

I, ___(23)___ , certify that to the best of my knowledge and belief, the statements made in this report are correct, and the repair/replacement activities described above conform to Section XI of the ASME Code and the identified Repair/Replacement Plan(s).

Date ___(24)___ , 20 ___ ___(25)___ Signed ___(26)___ ___(27)___
(Name of Repair/Replacement Organization Performing Repair/Replacement Activities) (Authorized Representative) (Title)

CERTIFICATE OF INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and employed by ___(28)___
of ___(29)___
have inspected the repair/replacement activities described in this report on ___(30)___ , 20 ___ and state that to the best of my knowledge and belief, the repair/replacement activities have been completed in accordance with the requirements of Section XI of the ASME Code and the identified Repair/Replacement Plan(s).

By signing this report, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the work described in this report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury, property damage, or a loss of any kind arising from or connected with this inspection.

Date ___(24)___ , 20 ___ Signed ___(31)___ Commissions ___(32)___
(Inspector) (National Board Number and Endorsement)

(07/13)

Table T-1
Guide for Completing Form RRA-1

Reference to Circled Numbers in the Form	Description
(1)	Name and address of the Repair/Replacement Organization that performed the repair/replacement activity.
(2)	Indicate the purchase order number, job number, etc., as applicable, assigned by the organization that performed the repair/replacement activity.
(3)	Name and address of the Owner of the nuclear power plant.
(4)	Name and address of the nuclear power plant and, if applicable, identification of the unit.
(5)	Indicate the type of item affected by the repair/replacement activities (e.g., vessel, line valve, pump, piping system).
(6)	Indicate Owner's plant tag or plant identification number, if applicable, assigned to the item affected by the repair/replacement activities.
(7)	Name of the Manufacturer of the item affected by the repair/replacement activities.
(8)	Manufacturer's model/serial number for the item affected by the repair/replacement activities.
(9)	Identify the Repair/Replacement Plan number for the repair/replacement activities performed.
(10)	Indicate the type of item installed (e.g., vessel, vessel part, valve, valve part, pump, pump part, piping system, piping spool, material).
(11)	Name of the Manufacturer of the item that was installed during repair/replacement activities.
(12)	Manufacturer's model/serial number and unique traceability number for the item that was installed during repair/replacement activities. Attach the Manufacturer's Data Report for the installed item, as applicable.
(13)	Identify the name, section, and division of the Construction Code that was used (e.g., ASME Section III, Division 1; ASME B31.1).
(14)	Identify the Edition and, as applicable, Addenda, Code Cases, and Code Class of the Construction Code for the item that was installed during repair/replacement activities.
(15)	Identify the plant item that the installed item is associated with by entering the line number from Section 5.
(16)	Identify the Edition and any applicable Addenda and Code Cases of Section XI used for the Owner's Repair/Replacement Program.
(17)	Identify the Edition and any applicable Addenda and Code Cases of the ASME Section XI Code used by the Repair/Replacement Organization for the repair/replacement activity. Identify in the Remarks block of the form any portions of later Section XI used in the repair/replacement activity.
(18)	Identify the Edition and any applicable Addenda and Code Cases of the Construction Code used for the repair/replacement activity.
(19)	Identify the organization responsible for design or design reconciliation, if applicable, and attach or reference any design reconciliation documentation.
(20)	Identify the type of pressure test (e.g., hydrostatic, pneumatic, system leakage test, or N/A — test to be conducted by Owner).
(21)	Provide a description of the work performed.
(22)	Indicate any additional information pertaining to the work.
(23)	Type or print the name of the authorized representative from the organization that performed the repair/replacement activities.
(24)	Enter date certified.
(25)	Name of the organization that performed the repair/replacement activities.
(26)	Signature of the authorized representative from the organization that performed the repair/replacement activities.
(27)	Title of authorized representative.
(28)	Name of the Authorized Nuclear Inservice Inspector's employer.
(29)	Address of the Authorized Nuclear Inservice Inspector's employer (city and state or province).
(30)	Indicate month, day, and year of inspection by the Authorized Nuclear Inservice Inspector.
(31)	Signature of Authorized Nuclear Inservice Inspector.
(32)	The Inspector's National Board Commission Number and Endorsement must be shown.

NONMANDATORY APPENDIX U
EVALUATION CRITERIA FOR TEMPORARY ACCEPTANCE OF FLAWS IN MODERATE ENERGY PIPING AND CLASS 2 OR 3 VESSELS AND TANKS

ARTICLE U-1000
INTRODUCTION

U-1100 SCOPE

This Nonmandatory Appendix is comprised of two Supplements. Supplement U-S1 addresses moderate energy piping, and Supplement U-S2 addresses Class 2 or 3 vessels and tanks. If implementing either supplement, all requirements of that supplement shall be met.

NONMANDATORY APPENDIX U-S SUPPLEMENTS

SUPPLEMENT U-S1 EVALUATION CRITERIA FOR TEMPORARY ACCEPTANCE OF FLAWS IN MODERATE ENERGY PIPING

U-S1-1 SCOPE

This Supplement provides the general scope and application of the evaluation methodology for temporary acceptance of flaws in moderate energy Class 2 or 3 piping.

(a) These requirements apply to Section III, ANSI B31.1, and ANSI B31.7 piping, classified by the Owner as Class 2 or 3. The provisions of this Supplement do not apply to the following:

(1) pumps, valves, expansion joints, and heat exchangers

(2) weld metal of socket welded joints

(3) leakage through a flange joint

(4) threaded connections employing nonstructural seal welds for leakage protection

(b) The provisions of this Supplement apply to Class 2 or 3 piping whose maximum operating temperature does not exceed 200°F (93°C) and whose maximum operating pressure does not exceed 275 psig (1.9 MPa).

(c) The following flaw evaluation criteria are permitted for pipe and tube. The flaw evaluation criteria are permitted for adjoining fittings and flanges to a distance of $(R_o t)^{1/2}$ from the weld centerline.

(d) The provisions of this Supplement demonstrate the integrity of the item and not the consequences of leakage. It is the responsibility of the Owner to demonstrate system operability considering effects of leakage.

(e) The evaluation period, τ_{allow}, is the operational time for which the temporary acceptance criteria are satisfied but not exceeding 26 months from the initial discovery of the condition.

U-S1-2 PROCEDURE OVERVIEW

(a) The flaw geometry shall be characterized by volumetric inspection methods or by physical measurement. The full pipe circumference at the flaw location shall be inspected to characterize the length and depth of all flaws in the pipe section.

(b) Flaw shall be classified as planar or nonplanar.

(c) When multiple flaws, including irregular (compound) shape flaws, are detected, the interaction and combined area loss of flaws in a given pipe section shall be accounted for in the flaw evaluation.

(d) A flaw evaluation shall be performed to determine the conditions for flaw acceptance. U-S1-4.2 provides accepted methods for conducting the required analysis.

(e) Frequent periodic inspections of no more than 30-day intervals shall be used to determine if flaws are growing and to establish the time, τ_{allow}, at which the detected flaw will reach the allowable size. Alternatively, a flaw growth evaluation may be performed to predict the time, τ_{allow}, at which the detected flaw will grow to the allowable size. The flaw growth analysis shall consider the relevant growth mechanisms, such as general corrosion or wastage, fatigue, or stress corrosion cracking. When a flaw growth analysis is used to establish the allowable time for temporary operation, periodic examinations of no more than 90-day intervals shall be conducted to verify the flaw growth analysis predictions.

(f) For through-wall leaking flaws, leakage shall be observed by daily walkdowns to confirm the analysis conditions used in the evaluation remain valid.

(g) If examinations reveal flaw growth rate to be unacceptable, a repair/replacement activity shall be performed.

(h) Repair/replacement activity shall be performed no later than when the predicted flaw size from either periodic inspection or by flaw growth analysis exceeds the acceptance criteria of U-S1-4, or the next scheduled outage, whichever occurs first. Repair/replacement activity shall be in accordance with Article IWA-4000.

U-S1-3 NOMENCLATURE

ℓ = total crack length = $2c$, in. (mm)
ℓ_{all} = allowable axial through-wall flaw length, in. (mm)
a = flaw depth, in. (mm)
C = coefficient in the crack growth relationship, $\left(\text{in./hr}\right)\left(\text{ksi}\sqrt{\text{in.}}\right)^{-n}\left(\left(\text{mm/s}\right)\left(\text{MPa}\sqrt{\text{m}}\right)^{-n}\right)$
c = half crack length, in. (mm)
d_{adj} = diameter equivalent circular hole at t_{adj}, in. (mm)
d_{min} = diameter of equivalent circular hole at t_{min}, in. (mm)
D_o = outside pipe diameter, in. (mm)

da/dt = flaw growth rate for stress corrosion cracking, in./hr (mm/s)
F = nondimensional stress intensity factor for through-wall axial flaw under hoop stress
F_b = nondimensional stress intensity factor for through-wall circumferential flaw under pipe bending stress
F_m = nondimensional stress intensity factor for through-wall circumferential flaw under membrane stress
K_{max} = maximum stress intensity factor under long-term, steady-state conditions, ksi$\sqrt{\text{in.}}$ $\left(\text{MPa}\sqrt{\text{m}}\right)$
L = maximum extent of a local thinned area with $t < t_{nom}$, in. (mm)
L_{axial} = length of idealized through-wall planar flaw opening in the axial direction of the pipe, as illustrated in Figure U-S1-4.2.2-4, in. (mm)
L_{circ} = length of idealized through-wall planar flaw opening in the circumferential direction of the pipe, as illustrated in Figure U-S1-4.2.2-4, in. (mm)
L_m = maximum extent of a local thinned area with $t < t_{min}$, in. (mm)
$L_{m(a)}$ = axial extent of wall thinning below t_{min}, in. (mm)
$L_{m(t)}$ = circumferential extent of wall thinning below t_{min}, in. (mm)
$L_{m,avg}$ = average of the extent of L_m below t_{min} for adjacent thinned areas, in. (mm)
$L_{m,i}$ = maximum extent of thinned area, i, in. (mm)
M_2 = bulging factor for axial flaw
n = exponent in the crack growth relationship
p = maximum operating pressure at flaw location, ksi (MPa)
R = mean pipe radius, in. (mm)
R_o = outside pipe radius, in. (mm)
S = allowable stress at operating temperature, ksi (MPa)
S_T = coefficient for temperature dependence in the crack growth relationship
S_u = Code-specified ultimate tensile strength, ksi (MPa)
S_y = Code-specified yield strength, ksi (MPa)
SF_m = structural factor on primary membrane stress
T = metal temperature, °F (°C)
t = wall thickness, in. (mm)
t_{adj} = adjusted wall thickness that is varied for evaluation purposes in the evaluation of a through-wall nonplanar flaw, in. (mm)
t_{aloc} = allowable local thickness for a nonplanar flaw, in. (mm)
$t_{c,avg}$ = average remaining wall thickness covering degraded area with through-wall leak bounded by d_{adj}, in. (mm)
t_{min} = minimum wall thickness required for pressure loading, in. (mm)
t_{nom} = nominal wall thickness, in. (mm)
t_p = minimum remaining wall thickness, in. (mm)
W_m = maximum extent of a local thinned area perpendicular to L_m with $t < t_{min}$, in. (mm)
$X_{i,j}$ = minimum distance between thinned areas i and j, in. (mm)
θ = half crack angle for through-wall circumferential flaw, radians
λ = nondimensional half crack length for through-wall axial flaw
σ_b = nominal longitudinal bending stress for primary loading without stress intensification factor, ksi (MPa)
σ_f = material flow stress, ksi (MPa)
σ_h = pipe hoop stress due to pressure, ksi (MPa)
σ_l = reference limit load hoop stress, ksi (MPa)
σ_y = material yield strength at temperature, as defined in C-8200, ksi (MPa)
τ_{allow} = time required for the detected flaw to grow to the allowable flaw size, but not exceeding 26 months from the initial discovery of the condition, sec

U-S1-4 FLAW EVALUATION

U-S1-4.1 Scope

This section provides temporary acceptance procedures for evaluating flaws in moderate energy Class 2 or 3 piping.

U-S1-4.2 Method

Planar flaws shall be evaluated in accordance with the requirements in U-S1-4.2.1. Nonplanar flaws shall be evaluated in accordance with the requirements in U-S1-4.2.2.

Flaw growth evaluation shall be performed in accordance with the requirements in U-S1-4.2.3. Nonferrous materials shall be evaluated in accordance with the requirements in U-S1-4.2.4.

U-S1-4.2.1 Planar Flaws

(a) For planar flaws, the flaw shall be bounded by a rectangular or circumferential planar area in accordance with the methods described in Nonmandatory Appendix C. IWA-3300 shall be used to determine when multiple proximate flaws are to be evaluated as a single flaw. The geometry of a through-wall planar flaw is shown in Figure U-S1-4.2.1-1.

(b) For planar flaws in austenitic piping, the evaluation procedure in Nonmandatory Appendix C shall be used. Flaw depths up to 100% of wall thickness may be evaluated. When through-wall circumferential flaws are evaluated, the formulas for evaluation given in C-5320 may be used, with the flaw depth to thickness ratio, a/t, equal to unity.

When through-wall axial flaws are evaluated, the allowable flaw length is

$$\ell_{\text{all}} = 1.58\sqrt{Rt}\left[\left(\frac{\sigma_f}{(SF_m)\sigma_h}\right)^2 - 1\right]^{1/2} \quad (1)$$

$$\sigma_h = pD_o/2t \quad (2)$$

$$\sigma_f = \left(S_y + S_u\right)/2 \quad (3)$$

where

D_o = pipe outside diameter, in. (mm)
p = pressure for the loading condition, ksi (MPa)
S_u = Code-specified ultimate tensile strength, ksi (MPa)
S_y = Code-specified yield strength, ksi (MPa)
SF_m = structural factor on primary membrane stress as specified in C-2622
σ_f = flow stress, ksi (MPa)

Material properties at the temperature of interest shall be used.

(c) For planar flaws in ferritic piping, the evaluation procedure of Nonmandatory Appendix C shall be used. Flaw depths up to 100% of wall thickness may be evaluated. When through-wall circumferential flaws are evaluated in accordance with C-5300 or C-6300, the flaw depth to thickness ratio, a/t, shall be set to unity. When applying the Nonmandatory Appendix C screening criteria for through-wall axial flaws, a/t shall be set to unity, and the reference limit load hoop stress, σ_l, shall be defined as σ_y/M_2. When through-wall axial flaws are evaluated in accordance with C-5400, the allowable length is defined by eqs. (b)(1) through (b)(3), with the appropriate structural factors from C-2622. When through-wall flaws are evaluated in accordance with C-7300 or C-7400, the formulas for evaluation given in C-4300 may be used but with values for F_m, F_b, and F applicable to through-wall flaws. Relations for F_m, F_b, and F that take into account flaw shape and pipe geometry (R/t ratio) shall be used. The appendix to this Nonmandatory Appendix provides equations for F_m, F_b, and F for a selected range of R/t. Geometry of a through-wall crack is shown in Figure U-S1-4.2.2-1.

U-S1-4.2.2 Nonplanar Flaws

(a) The evaluation shall consider the depth and extent of the affected area and require that the wall thickness exceed $t_{\min}$ for a distance that is the greater of $2.5\sqrt{Rt_{\text{nom}}}$ or $2L_{m,\text{avg}}$ between adjacent thinned regions, where R is the mean radius of the piping item based on nominal wall thickness, and $L_{m,\text{avg}}$ is the average of the extent of L_m below $t_{\min}$ for adjacent areas (see Figure U-S1-4.2.2-1). Alternatively, the adjacent thinned regions shall be considered a single thinned region in the evaluation.

(b) For nonplanar flaws, the pipe is acceptable when the remaining pipe thickness, t_p, is greater than or equal to the minimum wall thickness $t_{\min}$:

$$t_{\min} = \frac{pD_o}{2(S + 0.4p)} \quad (4)$$

where

p = maximum operating pressure at flaw location, ksi (MPa)
S = allowable stress at operating temperature, ksi (MPa)

Alternatively, an evaluation may be performed as given below. The evaluation procedure is a function of the depth and the extent of the affected area as illustrated in Figure U-S1-4.2.2-2.

(1) When Wm is less than or equal to 0.5 $(R_o t)^{1/2}$, where R_o is the outside radius and W_m is defined in Figure U-S1-4.2.2-2, the flaw can be classified as a planar flaw and evaluated in accordance with U-S1-4.2.1(a) through U-S1-4.2.1(c), above. When the above requirement is not satisfied, (2) shall be met.

(2) When $L_{m(t)}$ is not greater than $(R_o t_{\min})^{1/2}$, t_{aloc} is determined from Curve 1 of Figure U-S1-4.2.2-3, where $L_{m(t)}$ is defined in Figure U-S1-4.2.2-2. When the above requirement is not satisfied, (3) shall be met.

(3) When L_m is less than or equal to 2.65 $(R_o t_{\min})^{1/2}$ and t_{nom} is greater than 1.13 $t_{\min}$, t_{aloc} is determined by satisfying both of the following equations:

$$\frac{t_{aloc}}{t_{\min}} \geq \frac{1.5\sqrt{R_o t_{\min}}}{L}\left[1 - \frac{t_{\text{nom}}}{t_{\min}}\right] + 1.0 \quad (5)$$

$$\frac{t_{aloc}}{t_{\min}} \geq \frac{0.353L_m}{\sqrt{R_o t_{\min}}} \quad (6)$$

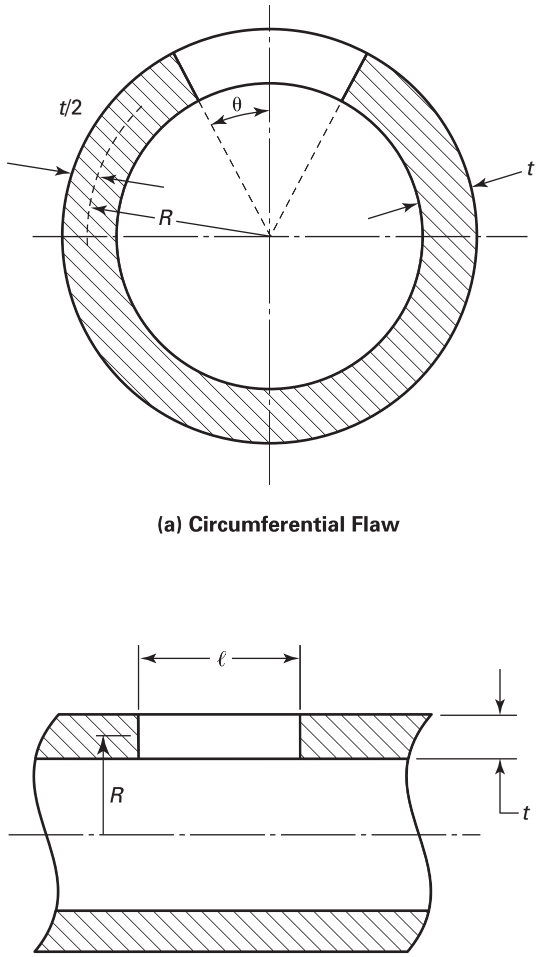
When the above requirements are not satisfied, (4) shall be met.

(4) When the requirements of (1), (2), and (3) above are not satisfied, t_{aloc} is determined from Curve 2 of Figure U-S1-4.2.2-3. In addition, t_{aloc} shall satisfy the following equation:

$$\frac{t_{aloc}}{t_{\min}} \geq \frac{\left[0.5\left(\frac{t_{\text{nom}}}{t_{\min}}\right)\left(\frac{\sigma_b}{S}\right)\right]}{1.8} \quad (7)$$

(c) When there is through-wall leakage along a portion of the thinned wall, as illustrated in Figure U-S1-4.2.2-4, the flaw may be evaluated by the branch reinforcement method. The thinned area including the through-wall opening shall be represented by a circular penetration at the flaw location. Only the portion of the flaw lying within t_{adj} need be considered as illustrated in Figure

Figure U-S1-4.2.1-1
Through-Wall Flaw Geometry



(a) Circumferential Flaw

(b) Axial Flaw

U-S1-4.2.2-5. When evaluating multiple flaws in accordance with U-S1-4.2.2, only the portions of the flaws contained within t_{adj} need be considered.

The minimum wall thickness, t_{min}, shall be determined by eq. (b)(4). For evaluation purposes, the adjusted wall thickness, t_{adj}, is a postulated thickness, as shown in Figure U-S1-4.2.2-5. The pipe wall thickness is defined as the thickness of the pipe in the nondegraded region as shown in Figure U-S1-4.2.2-5(a). The diameter of the opening is equal to d_{adj} as defined by t_{adj}, as shown in Figure U-S1-4.2.2-5(a). The postulated value for t_{adj} shall be greater than t_{min} and shall not exceed the pipe wall thickness. The t_{adj} value may be varied between t_{min} and the pipe wall thickness to determine whether there is a combination of t_{adj} and d_{adj} that satisfies the branch reinforcement requirements.

The values of t_{adj} and d_{adj} of Figure U-S1-4.2.2-5(b) shall satisfy:

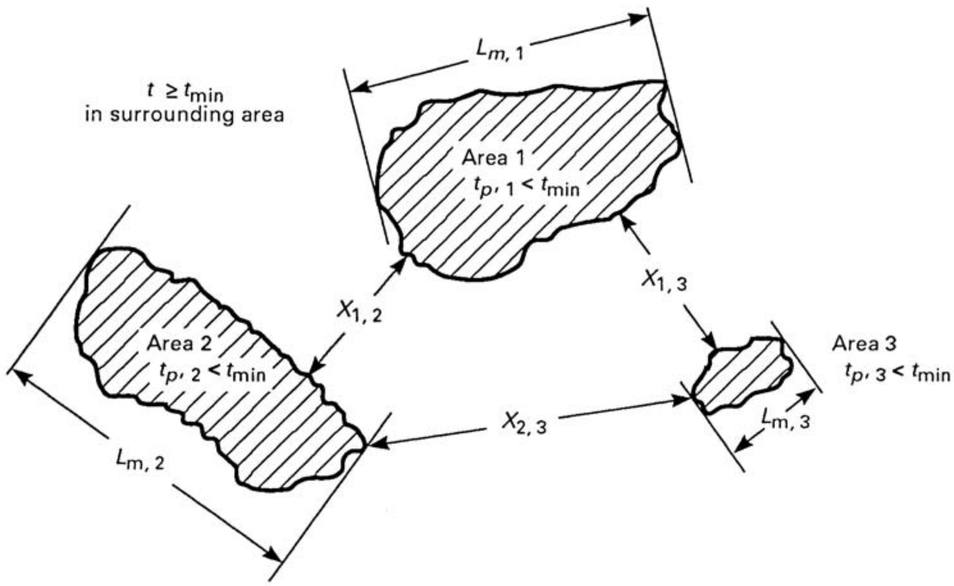
$$d_{adj} \le \frac{1.5\sqrt{Rt_{adj}}\left(t_{adj} - t_{min}\right)}{t_{min}} \tag{8}$$

The remaining ligament average thickness, $t_{c,avg}$, over the degraded area bounded by d_{adj} shall satisfy

$$t_{c,adj} \ge 0.353 d_{adj}\sqrt{\frac{p}{S}} \tag{9}$$

If a flaw growth analysis is performed, the growth in flaw dimensions shall consider the degradation mechanisms as relevant to the application. The flaw is acceptable when there is sufficient thickness in the degraded area to provide the required area reinforcement.

Figure U-S1-4.2.2-1
Separation Requirements for Adjacent Thinned Areas



$L_{m,avg}$ = 0.5 ($L_{m,i}$ + $L_{m,j}$)
$L_{m,i}$ = maximum extent of thinned area, i
$X_{i,j}$ = minimum distance between thinned areas I and j, in. (mm)

GENERAL NOTE: Combination of adjacent areas into an equivalent single area shall be based on dimensions and extents prior to combination.

(d) Alternatively, if there is a through-wall opening along a portion of the thinned wall as illustrated in Figure U-S1-4.2.2-4 the flaw may be evaluated as two independent planar through-wall flaws, one oriented in the axial direction and the other oriented in the circumferential direction. The minimum wall thickness, t_{min}, shall be determined by eq. (b)(4). The allowable through-wall lengths in the axial and circumferential directions shall be determined by varying t_{adj} shown in Figure U-S1-4.2.2-4 from t_{nom} to t_{min}. The allowable through-wall flaw lengths based on t_{adj} shall be greater than or equal to the corresponding L_{axial} and L_{circ} (see Figure U-S1-4.2.2-4) as determined from U-S1-4.2.1(a) and U-S1-4.2.1(b) or U-S1-4.2.1(c), as appropriate. The remaining ligament average thickness, $t_{c,avg}$, over the degraded area bounded by L_{axial} and L_{circ} shall satisfy eq. (c)(9).

U-S1-4.2.3 Flaw Growth Evaluation

If a flaw growth analysis is performed, the growth analysis shall consider both corrosion and crack growth mechanisms as relevant to the application.

In performing a flaw growth analysis, the procedures in Article C-3000 may be used as guidance. Relevant growth rate mechanisms shall be considered. When stress corrosion cracking (SCC) is active in systems not containing reactor coolant, the following growth rate equation shall be used:

$$da/dt = S_T C K_{max}^n \quad (10)$$

where,

C = material constant
da/dt = flaw growth rate, in./hr (mm/s)
K_{max} = maximum stress intensity factor under long-term, steady-state conditions, $\text{ksi}\sqrt{\text{in.}}$ $(\text{MPa}\sqrt{\text{m}})$
n = material constant
ST = coefficient for temperature dependence
T = metal temperature, °F (°C)

For intergranular SCC in austenitic steels, where $T \leq$ 200°F (93°C)

(U.S. Customary Units)

C = $1.79 \times 10^{-8}(\text{in./hr})(\text{ksi}\sqrt{\text{in.}})^{-n}$
n = 2.161
S_T = 1

(SI Units)

C = $1.03 \times 10^{-10}(\text{mm/s})(\text{MPa}\sqrt{\text{m}})^{-n}$

n = 2.161
S_T = 1

For transgranular SCC in austenitic steels, where $T \leq$ 200°F (93°C)

(U.S. Customary Units)

$$C = 1.79 \times 10^{-7} (\text{in./hr}) (\text{ksi}\sqrt{\text{in.}})^{-n}$$
$$n = 2.161$$
$$S_T = 3.71 \times 10^8 \left[10^{(0.01842T - 12.25)} \right]$$

(SI Units)

$$C = 1.03 \times 10^{-9} (\text{mm/s}) (\text{MPa}\sqrt{\text{m}})^{-n}$$
$$n = 2.161$$
$$S_T = 3.71 \times 10^8 \left[10^{(0.03316T - 11.66)} \right]$$

The flaw growth rate curves for the above SCC growth mechanisms are shown in Figures U-S1-4.2.3-1 and U-S1-4.2.3-2. Other growth rate parameters in eq. (10) may be used, provided they are supported by appropriate data.

U-S1-4.2.4 Nonferrous Materials

For nonferrous materials, nonplanar and planar flaws may be evaluated following the general approach of U-S1-4.2.1 through U-S1-4.2.3. For planar flaws in ductile materials, the approach given in U-S1-4.2.1(b) and U-S1-4.2.3 may be used; otherwise, the approach given in U-S1-4.2.1(c) and U-S1-4.2.3 should be applied.

Structural factors provided in U-S1-5 shall be used. It is the responsibility of the evaluator to establish conservative estimates of strength and fracture toughness for the piping material.

U-S1-5 ACCEPTANCE CRITERIA

Piping containing a circumferential planar flaw is acceptable for temporary service when flaw evaluation provides a margin using the structural factors in C-2621. For axial planar flaws, the structural factors for temporary acceptance are as specified in C-2622. Piping containing a nonplanar part through-wall flaw is acceptable for temporary service if $t_p \geq t_{aloc}$, where t_{aloc} is determined from U-S1-4.2.2(b). Piping containing a nonplanar through-wall flaw is acceptable for temporary service when the flaw conditions of U-S1-4.2.2(c) or U-S1-4.2.2(d) are satisfied.

U-S1-6 AUGMENTED EXAMINATION

An augmented volumetric examination or physical measurement to assess degradation of the affected system shall be performed as follows:

(a) From the engineering evaluation, the most susceptible locations shall be identified. A sample size of at least five of the most susceptible and accessible locations or, if fewer than five, all susceptible and accessible locations shall be examined within 30 days of detecting the flaw.

(b) When a flaw is detected, an additional sample of the same size as defined in (a) shall be examined.

(c) This process shall be repeated within 15 days for each successive sample, until no significant flaw is detected or until 100% of susceptible and accessible locations have been examined.

SUPPLEMENT U-S2 EVALUATION CRITERIA FOR TEMPORARY ACCEPTANCE OF FLAWS IN MODERATE ENERGY CLASS 2 OR CLASS 3 VESSELS AND TANKS

U-S2-1 SCOPE

(a) The provisions of this Supplement apply to vessels and tanks, including heat exchangers, classified by the Owner as Class 2 or 3, and whose maximum operating temperature does not exceed 200°F (93°C) and whose maximum operating pressure does not exceed 275 psig (1.9 MPa).

(b) The provisions of this Supplement define the requirements to demonstrate the structural integrity of the vessel or tank but not the consequences of leakage. The Owner shall determine what constitutes acceptable leakage, evaluate the consequences of leakage, and determine system operability.

(c) The provisions of this Supplement provide procedures and criteria for evaluating failure conditions for fracture and overpressure (blowout). The Owner shall verify that other potential failure modes are not relevant for the observed degradation (e.g., buckling).

(d) The evaluation period is the operational time for which the temporary acceptance criteria are satisfied (i.e., evaluation period τ_{allow}), but not greater than 26 months from the initial discovery of the condition.

U-S2-2 PROCEDURE

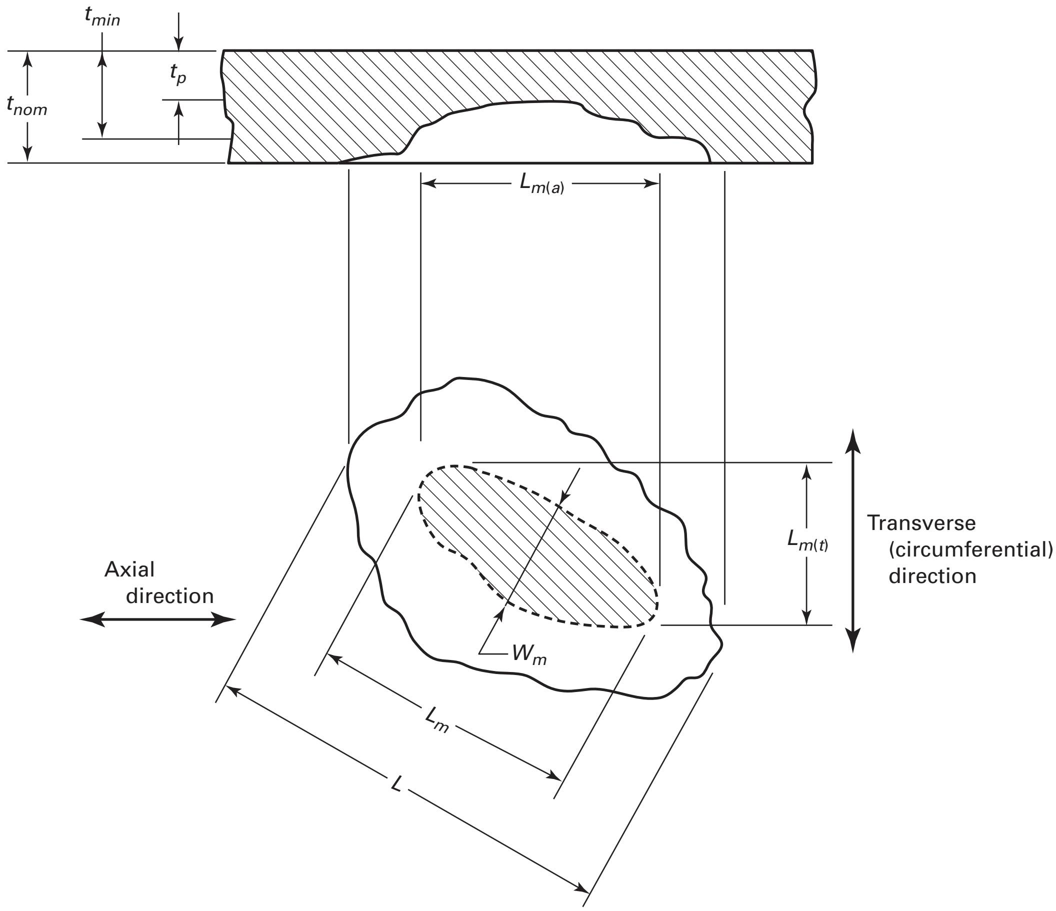
The procedures for use of this Supplement are provided in this Section, and a flowchart of the overall methodology is provided as Figure U-S2-2.1.

U-S2-2.1 Discovery of Degradation or Leakage

(a) Evaluations and examination results shall be documented in accordance with IWA-6300.

(b) Leakage shall meet the applicable leakage limits for the vessel or tank. The Owner shall determine acceptable leakage limits and evaluate the consequences of leakage and system operability.

Figure U-S1-4.2.2-2
Illustration of Nonplanar Flaw Due to Wall Thinning



U-S2-2.2 Degradation Characterization

(a) The vessel or tank shall be examined to characterize degradation in the affected section in accordance with IWA-3300, unless the alternative methods of (e) or U-S2-2.4(a) are implemented. The Owner shall develop the scope and methods of examination to characterize the degradation for the structural evaluation procedures of this Supplement.

(b) If multiple degradation locations, including irregular (compound) shapes are detected, their interaction in a given cross section shall be accounted for in. the structural integrity evaluation in accordance with IWA-3330.

(c) For degradation that intersects openings in the vessel or tank (e.g., nozzle penetrations), the effect of the opening discontinuity shall be included in the fracture evaluation.

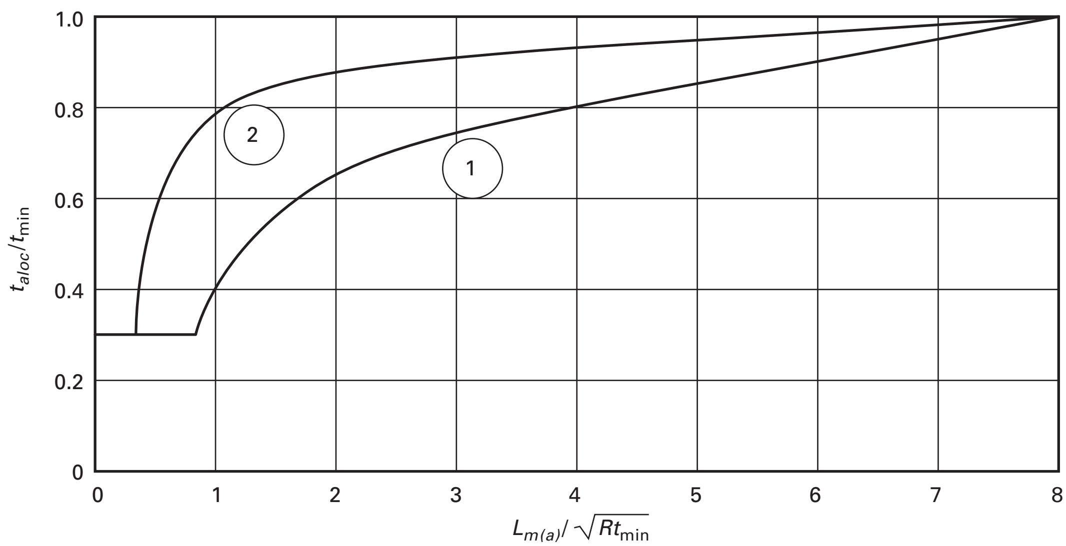
(d) Nonplanar degradation shall be projected into equivalent planar flaws in accordance with IWA-3340 for fracture evaluation purposes and characterized in terms of extent of degradation in accordance with Figure U-S2-2.2-1 or Figure U-S2-2.2-2 for part-through-wall or through-wall degradation, respectively.

(e) The Owner shall determine methods for estimating the geometry of degradation in inaccessible or uninspectable regions, e.g., size correlated to leakage rate. If using this approach to determine a maximum flaw size, such as a size correlated to an observed leak rate, a factor of 2 shall be applied to the flaw dimensions.

U-S2-2.3 Evaluation Methodology

Degradation shall be evaluated as planar in accordance with the requirements of U-S2-2.4 or U-S2-2.5. To prevent bursting, nonplanar part-through-wall degradation shall also be evaluated in accordance with the requirements of U-S2-2.6.

Figure U-S1-4.2.2-3
Allowable Wall Thickness and Length of Locally Thinned Area



U-S2-2.4 Bounding Flaw Evaluation

(a) A bounding flaw length shall be assumed for structural evaluation purposes, based on one or more of the following limiting factors:

(1) geometric limitations (e.g., overlapping welded plates in tanks that could limit degradation propagation or the ability to detect the degradation beyond a specified length)

(2) stress limitations (e.g., degradation growing into a decreasing stress field such that growth is terminated)

(3) environmental limitations (e.g., degradation growing into a nonaggressive environment)

(b) The bounding flaw shall be assumed to be a planar through-wall flaw over its entire length.

(c) A structural integrity evaluation shall be performed to determine acceptance of the bounding flaw. Acceptable methods for the required evaluation are provided in U-S2-4.1, and acceptance criteria are provided in U-S2-6. For bounding flaws that do not meet the acceptance criteria, the provisions of U-S2-2.5 shall be met.

(d) Bounding flaws that meet the acceptance criteria of U-S2-6 shall be monitored daily to ensure that leakage does not exceed leakage limits in accordance with U-S2-2.1(b) and for trending purposes. If leakage limits are exceeded within the evaluation period, structural integrity shall be reconfirmed and leakage limiting measures applied, or repair/replacement activities shall be performed.

(e) Repair/replacement activities shall be performed no later than the end of the evaluation period. Repair/replacement activities shall be in accordance with Article IWA-4000.

U-S2-2.5 Evaluation of Measured Flaws

(a) For degradation that cannot be bounded or for bounding flaws that do not meet the acceptance criteria of U-S2-6, the size and extent of degradation shall be determined by methods of U-S2-2.2.

(b) An evaluation shall be performed to determine the cause of the degradation (e.g., stress corrosion, fatigue, fabrication defects, etc.).

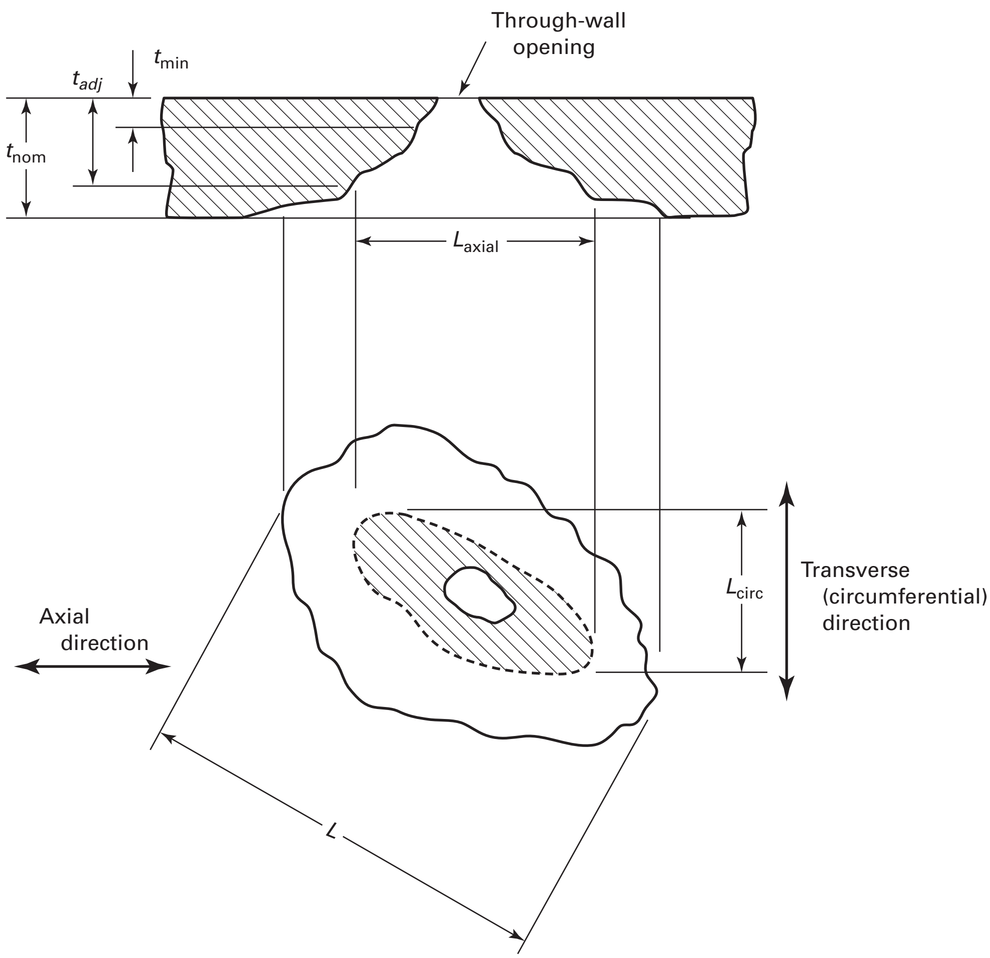
(c) A degradation-growth evaluation shall be performed to predict the time, τ_{allow}, at which the detected degradation will grow to the maximum structurally allowable size in accordance with the acceptance criteria of U-S2-6. The growth evaluation shall account for the results of the evaluation, in accordance with (b) and the relevant growth mechanisms, in accordance with U-S2-5.

(d) For degradation evaluated to be structurally acceptable for the evaluation period in accordance with U-S2-4, examination at $0.5\tau_{allow}$ shall be performed to verify the predicted growth. If τ_{allow} exceeds twice the time to the end of the evaluation period, examination is not required.

(e) Daily leakage monitoring (e.g., vessel or tank level indications, sump measurements, etc.) shall be performed to ensure that leakage, if any, does not exceed the acceptance limits, in accordance with U-S2-2.1(b), and for trending purposes. If acceptance limits are exceeded, repair/replacement activities shall be performed.

(f) The degradation growth evaluation of (c) shall be updated when new leakage monitoring or examination results become available, considering all previous examination and leakage monitoring results. If the updated flaw size from examination or the predicted flaw size from the

Figure U-S1-4.2.2-4
Illustration of Through-wall Nonplanar Flaw Due to Wall Thinning



flaw growth analysis exceeds the acceptance criteria of U-S2-6, repair/replacement activities shall be performed no later than the end of the updated evaluation period.

(g) Repair/replacement activities shall be performed no later than the end of the evaluation period. Repair/replacement activities shall be in accordance with Article IWA-4000.

U-S2-2.6 Nonplanar Part-Through-Wall Degradation Considering Degradation Growth

In addition to the requirements of U-S2-2.4 or U-S2-2.5 above, nonplanar part-through-wall degradation shall be evaluated in accordance with the requirements of U-S2-4.3.

U-S2-3 NOMENCLATURE

C = material constant in austenitic steel stress corrosion cracking equation, $(\text{in./hr})(\text{ksi}\sqrt{\text{in.}})^{-n}$ $\left[(\text{mm/s})(\text{MPa}\sqrt{\text{m}})^{-n}\right]$

D_o = vessel or tank outer diameter (for cylindrical portions of vessels and tanks), in. (mm)

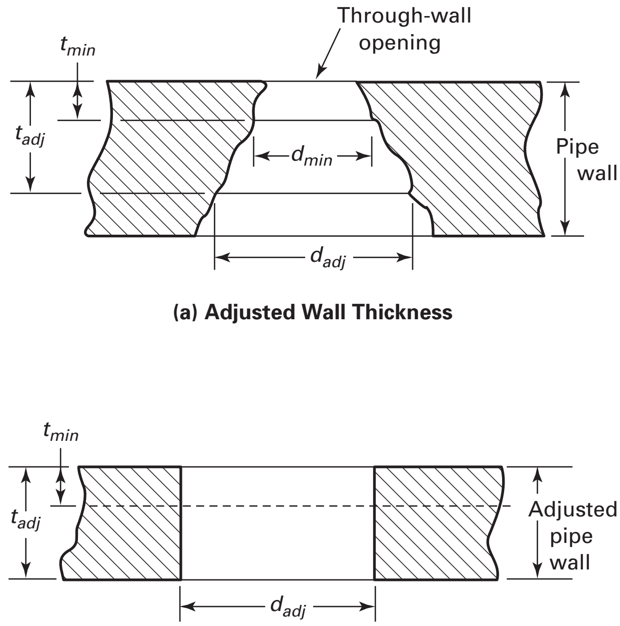
da/dt = flaw growth rate for stress corrosion cracking in austenitic steel, in./hr (mm/s)

K_I = applied stress intensity factor, $\text{ksi}\sqrt{\text{in.}}$ $(\text{MPa}\sqrt{\text{m}})$

K_{Ic} = fracture toughness, $\text{ksi}\sqrt{\text{in.}}$ $(\text{MPa}\sqrt{\text{m}})$

K_{max} = maximum stress intensity factor under long-term, steady-state conditions used in the stress corrosion cracking equation for austenitic steel, $\text{ksi}\sqrt{\text{in.}}$ $(\text{MPa}\sqrt{\text{m}})$

Figure U-S1-4.2.2-5
Illustration of Adjusted Wall Thickness and Equivalent Hole Diameters



(a) Adjusted Wall Thickness

(b) Equivalent Hole Representation

L = maximum extent of a local thinned area with $t < t_{\mathrm{nom}}$, in. (mm)

L_{axial} = crack length for through-wall nonplanar degradation in axial direction, in. (mm)

L_{circ} = crack length for through-wall nonplanar degradation in circumferential direction, in. (mm)

L_m = maximum extent of a local thinned area with $t < t_{\min}$, in. (mm)

$L_{m(a)}$ = axial extent of wall thinning below $t_{\min}$, in. (mm)

$L_{m(t)}$ = circumferential extent of wall thinning below $t_{\min}$, in. (mm)

n = material constant in austenitic steel stress corrosion cracking equation

p = maximum operating pressure at the degradation location, ksi (MPa)

R = vessel or tank mean radius (for cylindrical portions of vessels and tanks), in. (mm)

R_o = vessel or tank outer radius (for cylindrical portions of vessels and tanks), in. (mm)

S = allowable stress at the operating temperature, ksi (MPa)

S_T = temperature correction factor in austenitic steel stress corrosion cracking equation

T = metal temperature at the degradation location, °F (°C)

t = wall thickness, in. (mm)

t_{aloc} = allowable local thickness for a nonplanar flaw that exceeds $t_{\min}$, in. (mm)

$t_{\min}$ = minimum wall thickness required for pressure loading, in. (mm)

t_{nom} = nominal wall thickness, in. (mm)

t_p = minimum remaining wall thickness, in. (mm)

W_m = maximum extent of a local thinned area perpendicular to L_m with $t < t_{\min}$, in. (mm)

τ = operational time after first discovery of degradation, sec

τ_{allow} = operational time required for the detected degradation to grow to the maximum structurally allowable size, based on the acceptance criteria of U-S2-6, sec

U-S2-4 STRUCTURAL INTEGRITY EVALUATION

The structural integrity of the degraded vessel or tank shall be evaluated as specified below. The Owner shall also verify that other potential failure modes are not relevant for the observed degradation.

U-S2-4.1 Bounding and Measured Flaw Evaluations

(a) The stresses at the degradation location shall include the appropriate combination of applied loadings for Levels A, B, C, and D and test conditions from the Design Specification for the vessel or tank being evaluated. These shall include, as appropriate, deadweight, pressure, hydrostatic, thermal, and safe shutdown earthquake (SSE), including seismic sloshing. Stresses from external

Figure U-S1-4.2.3-1
Flaw Growth Rate for IGSCC in Austenitic Piping

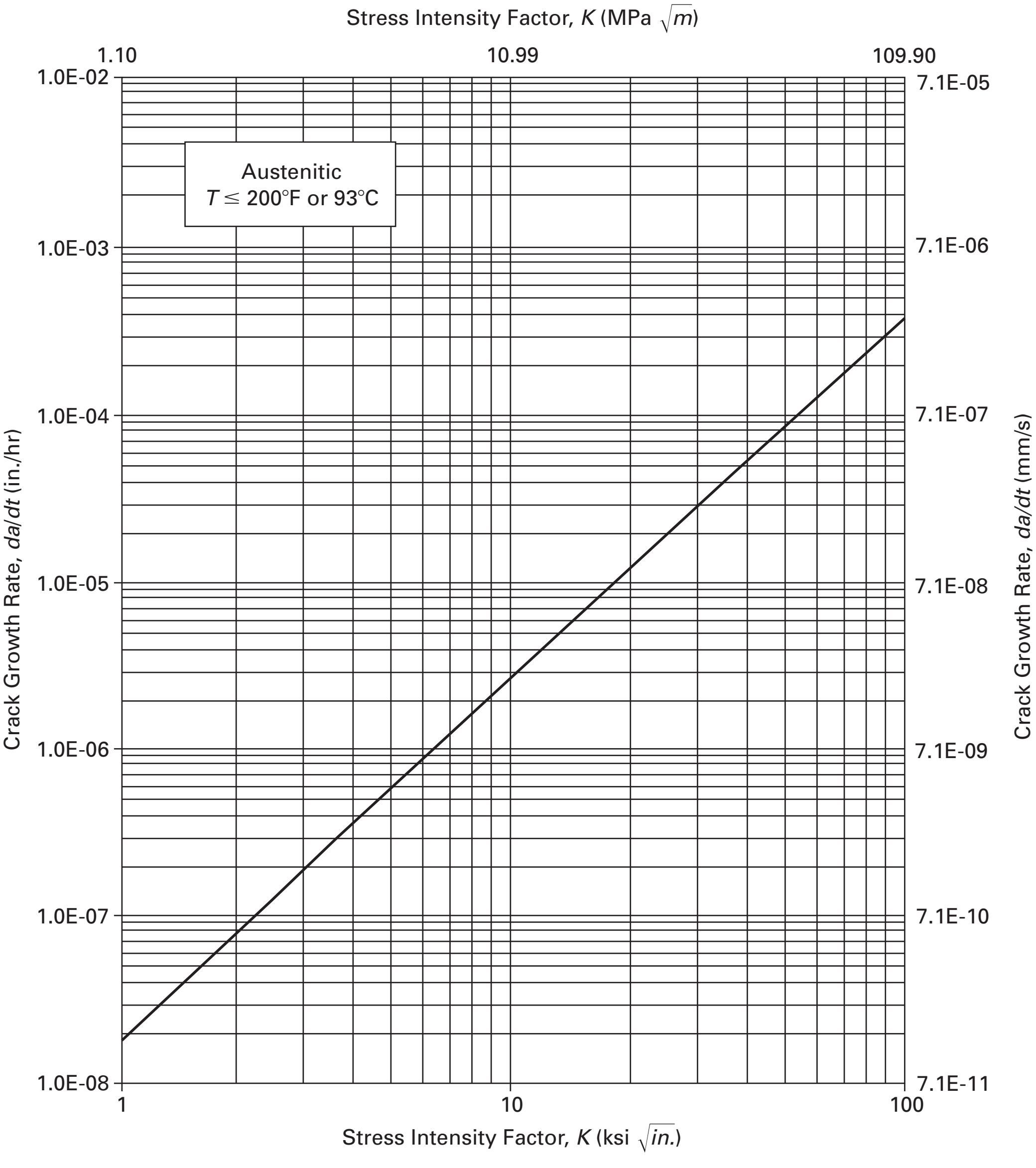
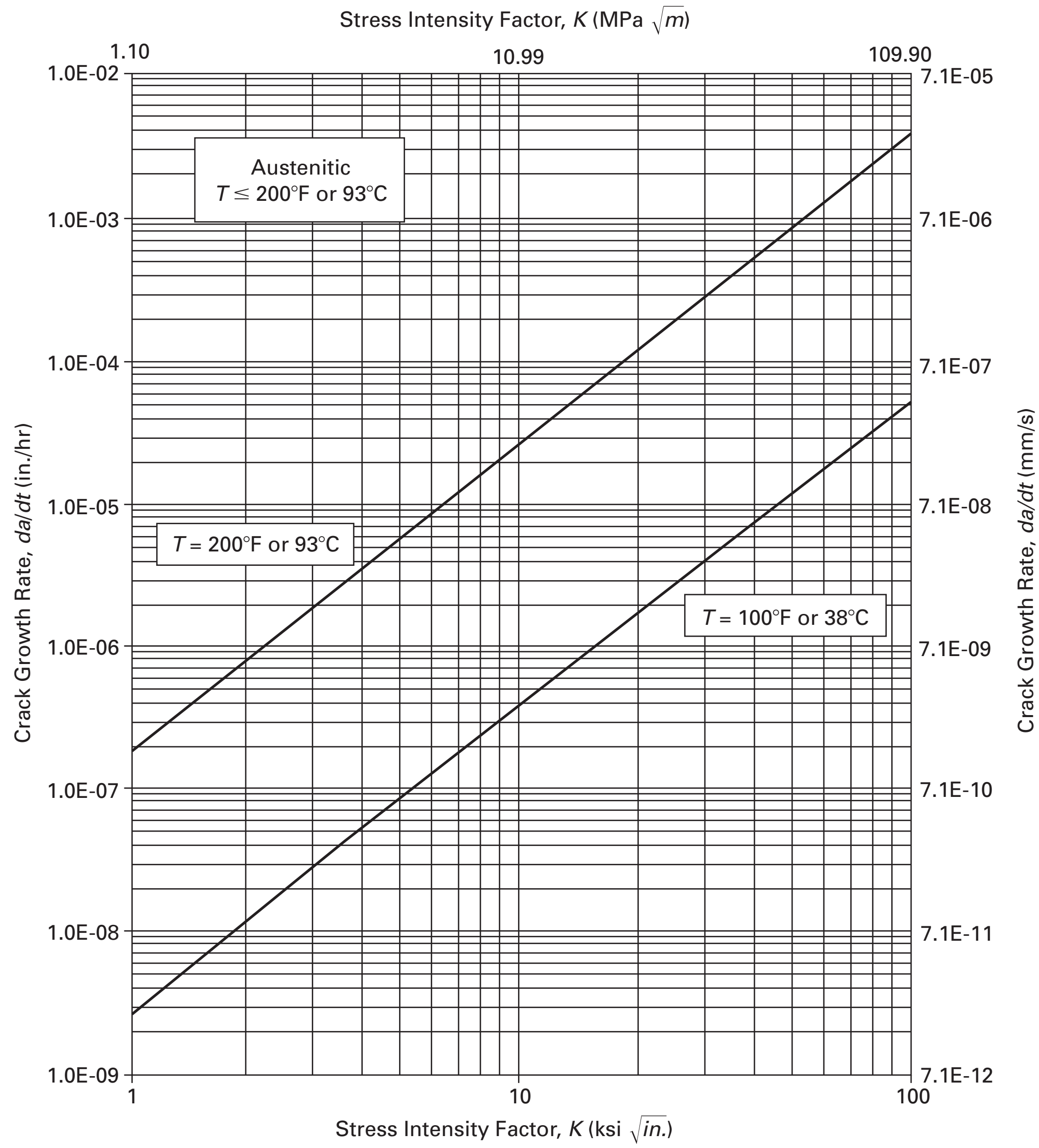


Figure U-S1-4.2.3-2
Flaw Growth Rate for TGSCC in Austenitic Piping



loadings, such as piping reactions for degradation near nozzle penetrations and wind loading, shall also be included.

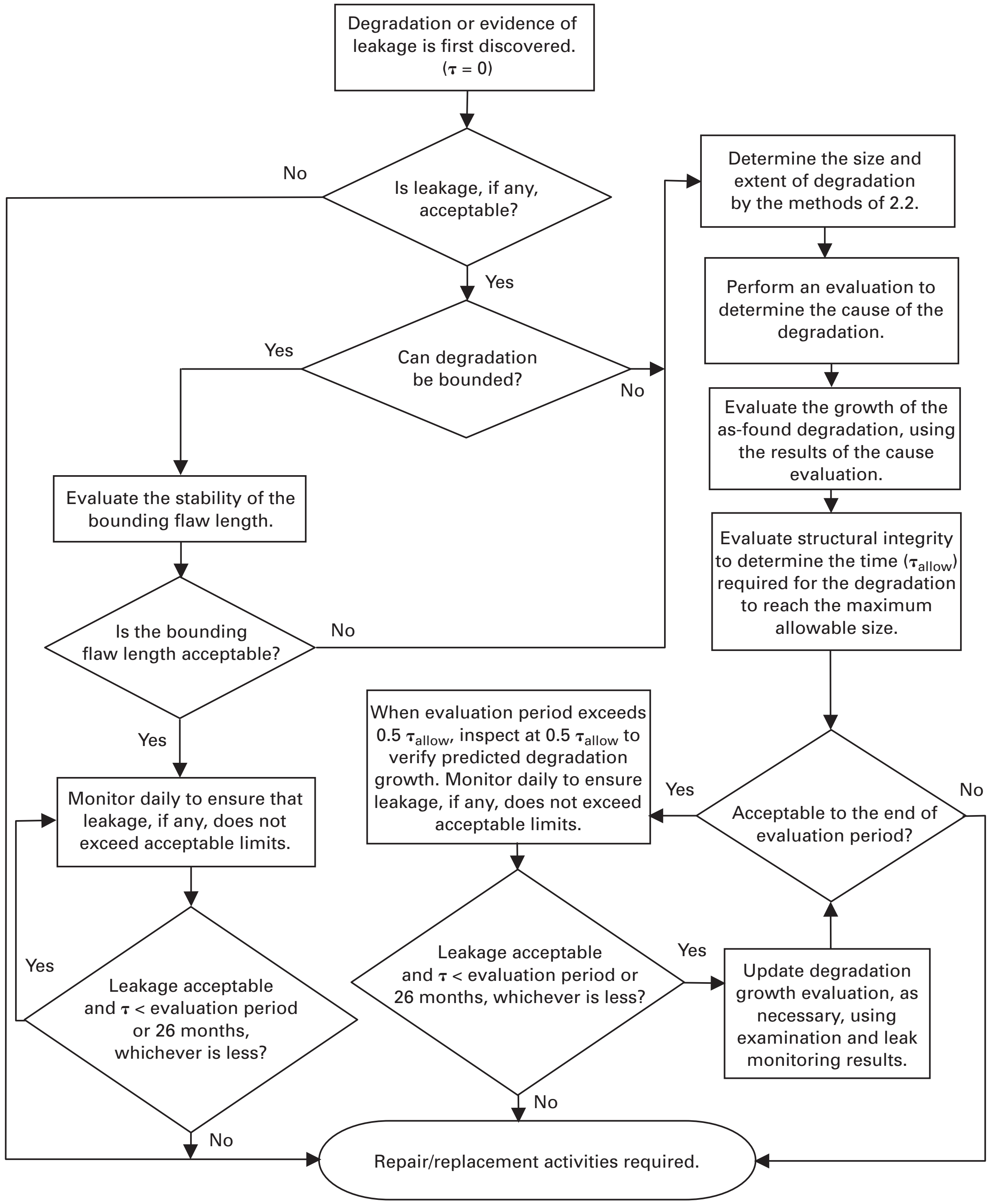
(b) Residual stresses resulting from original welding and any rework, bolt-up stresses, and cladding-induced stresses shall be evaluated in accordance with the methods of A-3200.

(c) If there is no stress analysis for the degradation location, the applied stress shall be assumed to be the yield stress.

(d) Inaccessible degradation shall be assumed to be located in the region of highest principal tensile stress within that portion of the vessel or tank. If it can be determined that the degradation is confined to a specific region, other regions may be disregarded.

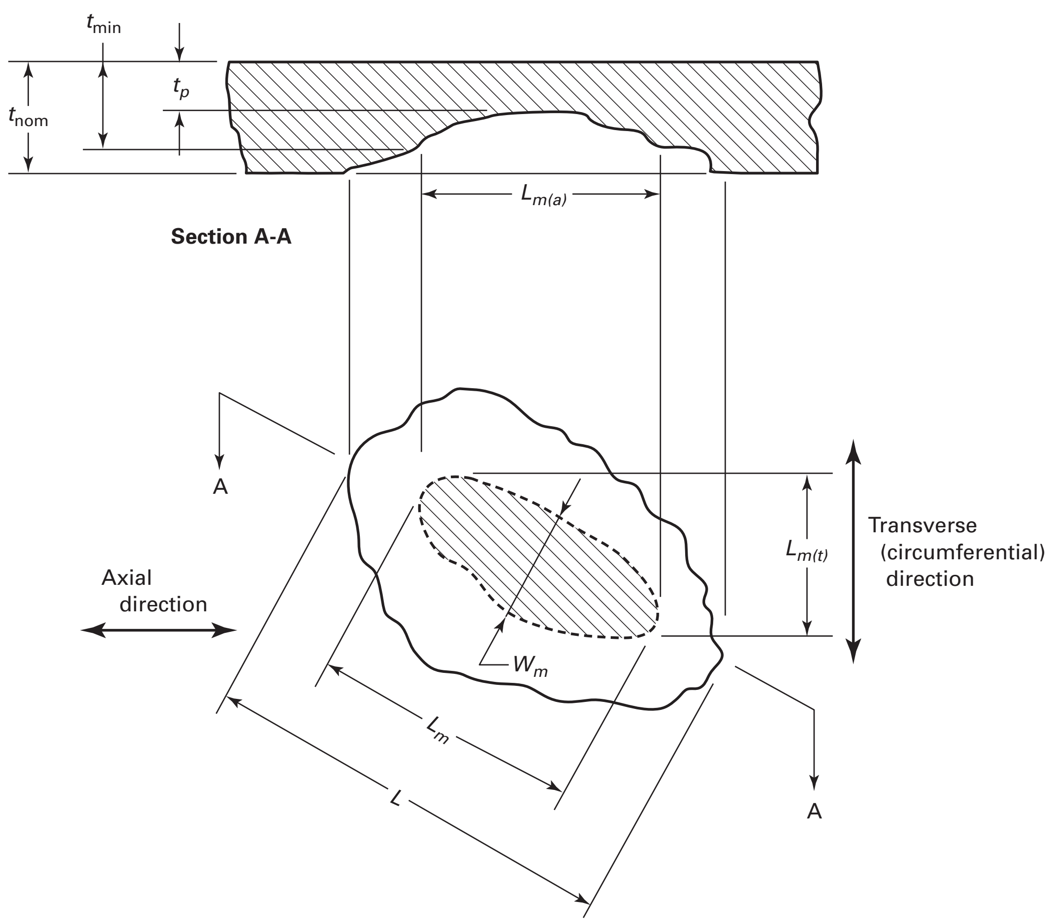
(e) The stress intensity factor for the stresses determined in (a) through (d) shall be calculated using the methods of Article A-3000 and meet the acceptance criteria of U-S2-6.

Figure U-S2-2.1
Overall Methodology



(15)

Figure U-S2-2.2-1
Illustration of Nonplanar Part-Through-Wall Degradation Due to Wall Thinning



U-S2-4.2 Flaw Evaluations Considering Degradation Growth

(a) For degradation considering growth in accordance with U-S2-2.5, the time for growth to the allowable size, τ_{allow}, shall be calculated in accordance with the acceptance criteria of U-S2-6 based on the stress intensity factor determined in U-S2-4.1(e) for planar flaws.

(b) For nonplanar through-wall degradation along a portion of the thinned wall, as illustrated in Figure U-S2-2.2-2, the degradation, including growth through the end of the evaluation period, shall be evaluated as two independent planar through-wall flaws: one oriented in the axial direction and the other oriented in the circumferential direction. The minimum wall thickness, t_{min}, shall be determined using eq. U-S2-4.3(a)(1). The through-wall lengths for each flaw are the lengths, L_{axial} and L_{circ}, where the local wall thickness is equal to t_{min} as projected along the axial and circumferential planes, as shown in Figure U-S2-2.2-2.

U-S2-4.3 Nonplanar Part-Through-Wall Degradation Considering Degradation Growth

(a) For nonplanar part-through-wall degradation (Figure U-S2-2.2-1) in cylindrical portions of vessels or tanks, including degradation growth through the evaluation period, the vessel or tank is acceptable when the remaining wall thickness, t_p, is greater than or equal to the minimum wall thickness, t_{min},

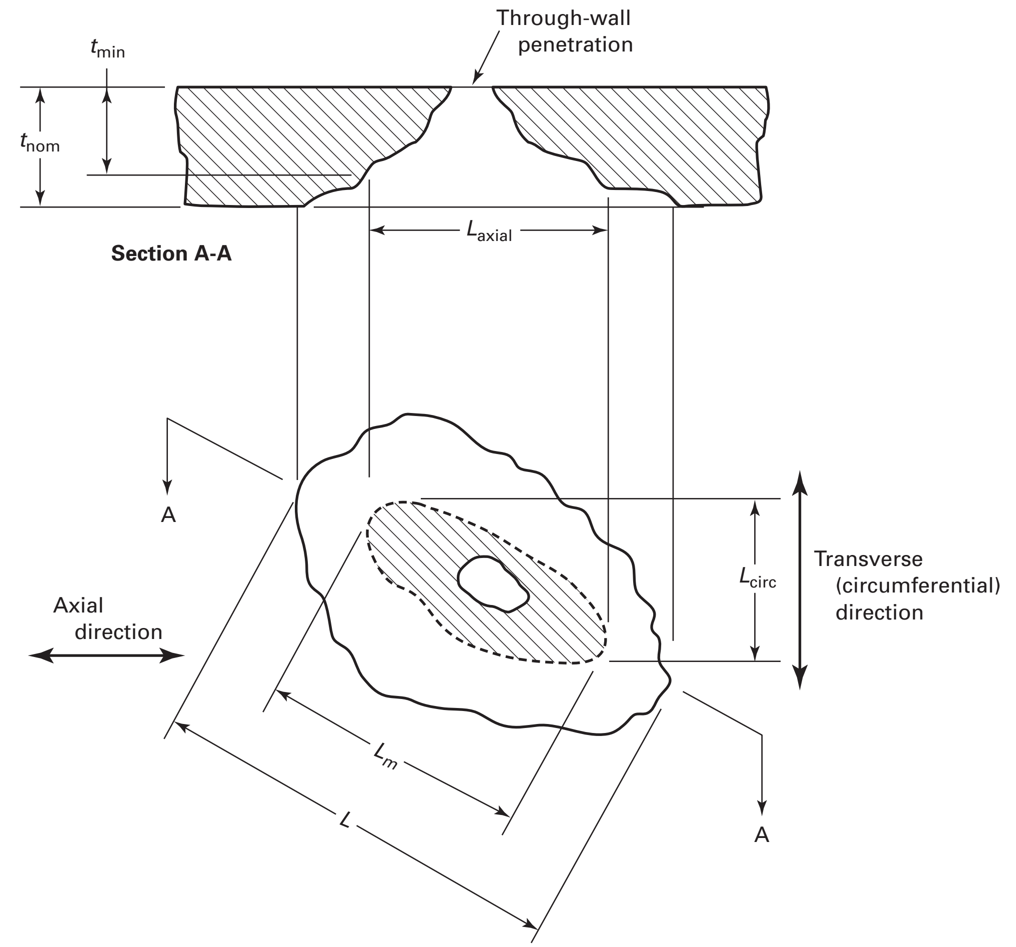
where

$$t_{min} = \frac{pD_o}{2(S + 0.5p)} \quad (1)$$

D_o = vessel or tank outside diameter, in. (mm)
p = maximum operating pressure at the degradation location, ksi (MPa)
S = allowable stress at operating temperature, ksi (MPa)

(15)

Figure U-S2-2.2-2
Illustration of Nonplanar Through-Wall Degradation Due to Wall Thinning



(b) Alternatively, an evaluation for nonplanar partthrough-wall degradation in cylindrical portions of vessels or tanks may be performed as specified below. The evaluation procedure used is dependent upon the depth and extent of the affected area, as illustrated in Figure U-S2-2.2-1, and includes degradation growth through the end of the evaluation period.

(1) When the width of the wall thinning that exceeds t_{min}, W_m, is less than or equal to $0.5\sqrt{R_o t}$, where R_o is the outside radius, and W_m is defined in Figure U-S2-2.2-1, the degradation can be classified as a planar flaw, and further analysis as a nonplanar flaw is not required. When the above requirement is not satisfied, the requirement in (2) shall be met.

(2) When the length of the wall thinning that exceeds t_{min}, $L_{m(t)}$, is not greater than $\sqrt{R_o t_{min}}$ t_{aloc} is determined from Figure U-S2-4.3-1, where $L_{m(t)}$ is defined in Figure U-S2-2.2-1. When the above requirement is not satisfied, the requirement in (3) shall be met.

(3) When the maximum extent of wall thinning that exceeds t_{min}, L_m, is less than or equal to $2.65\sqrt{R_o t_{min}}$ and t_{nom} is greater than $1.13t_{min}$, t_{aloc} is determined by satisfying both of the following equations:

$$\frac{t_{aloc}}{t_{min}} \geq \frac{1.5\sqrt{R_o t_{min}}}{L}\left[1 - \frac{t_{nom}}{t_{min}}\right] + 1.0 \qquad (2)$$

$$\frac{t_{aloc}}{t_{min}} \geq \frac{0.3353L_m}{\sqrt{R_o t_{min}}} \qquad (3)$$

(4) When the requirements of (1) through (3) are not satisfied, repair/replacement activities shall be performed.

(c) The Owner shall determine evaluation methods for nonplanar part-through-wall degradation in noncylindrical portions of vessels or tanks. The evaluation shall include analysis conditions specified in U-S2-4.1 and U-S2-4.2. Degradation is acceptable when the criteria of

U-S2-6(d) are satisfied. The Owner shall also verify that other potential failure modes (e.g., buckling) are not relevant for the observed degradation.

U-S2-5 DEGRADATION GROWTH EVALUATION

If degradation growth is evaluated, the analysis shall include the relevant growth mechanisms determined in the cause evaluation. Predicted degradation growth shall be updated based on examination and leakage monitoring results, when new results become available. The following describes some of the potential degradation growth mechanisms:

(a) Fatigue Crack Growth. Fatigue crack growth shall be calculated. Methods of Nonmandatory Appendix C shall be used for austenitic steels, and those of Nonmandatory Appendix A shall be used for ferritic steels.

(b) Stress Corrosion Cracking in Austenitic Steels. If stress corrosion cracking (SCC) is active in austenitic steels in systems not containing reactor coolant, the following growth rate equation shall be used:

$$da/dt = S_T C K_{max}{}^n \tag{4}$$

where

C = material constant
da/dt = flaw growth rate, in./hr (mm/s)
K_{max} = maximum stress intensity factor under long-term, steady-state conditions, $\text{ksi}\sqrt{\text{in.}}$ $(\text{MPa}\sqrt{\text{m}})$
n = material constant
S_T = coefficient for temperature dependence
T = metal temperature, °F (°C)

For intergranular stress corrosion cracking (IGSCC) in austenitic steels, $T \leq 200$°F (93°C)

(U.S. Customary Units)

$$C = 1.79 \times 10^{-8}(\text{in./hr})(\text{ksi}\sqrt{\text{in.}})^{-n}$$
$$n = 2.161$$
$$S_T = 1$$

(SI Units)

$$C = 1.03 \times 10^{-10}(\text{mm/s})(\text{MPa}\sqrt{\text{m}})^{-n}$$
$$n = 2.161$$
$$S_T = 1$$

See Figure U-S1-4.2.3-1 for flaw growth rate versus stress intensity factor for IGSCC in austenitic steels.

For transgranular stress corrosion cracking (TGSCC) in austenitic steels, $T \leq 200$°F (93°C),

(U.S. Customary Units)

$$C = 1.79 \times 10^{-7}(\text{in./hr})(\text{ksi}\sqrt{\text{in.}})^{-n}$$
$$n = 2.161$$
$$S_T = 3.71 \times 10^{8}\left[10^{(0.01842T - 12.25)}\right]$$

(SI Units)

$$C = 1.03 \times 10^{-9}(\text{mm/s})(\text{MPa}\sqrt{\text{m}})^{-n}$$
$$n = 2.161$$
$$S_T = 3.71 \times 10^{8}\left[10^{(0.03316T - 11.66)}\right]$$

See Figure U-S1-4.2.3-2 for flaw growth rate versus stress intensity factor for TGSCC in austenitic steels.

(c) Other Degradation Growth Mechanisms. When other degradation growth mechanisms, such as microbiologically induced corrosion (MIC), are present, as determined by the cause evaluation, the contribution to degradation growth shall be included in the degradation growth evaluation.

U-S2-6 ACCEPTANCE CRITERIA

(a) For bounding flaws or for end-of-evaluation-period flaw sizes based on flaw growth analysis, the applied stress intensity factor, K_I, shall satisfy the following limits:

$$K_I < K_{Ic}/3.0 \;(\text{Levels A and B and test conditions})$$
$$K_I < K_{Ic}/1.4 \;(\text{Levels C and D})$$

(b) If the applicable material fracture toughness values are not known, the following fracture toughness values shall be used:

(1) for austenitic stainless steels, $135\ \text{ksi}\sqrt{\text{in.}}$ $(148\ \text{MPa}\sqrt{\text{m}})$

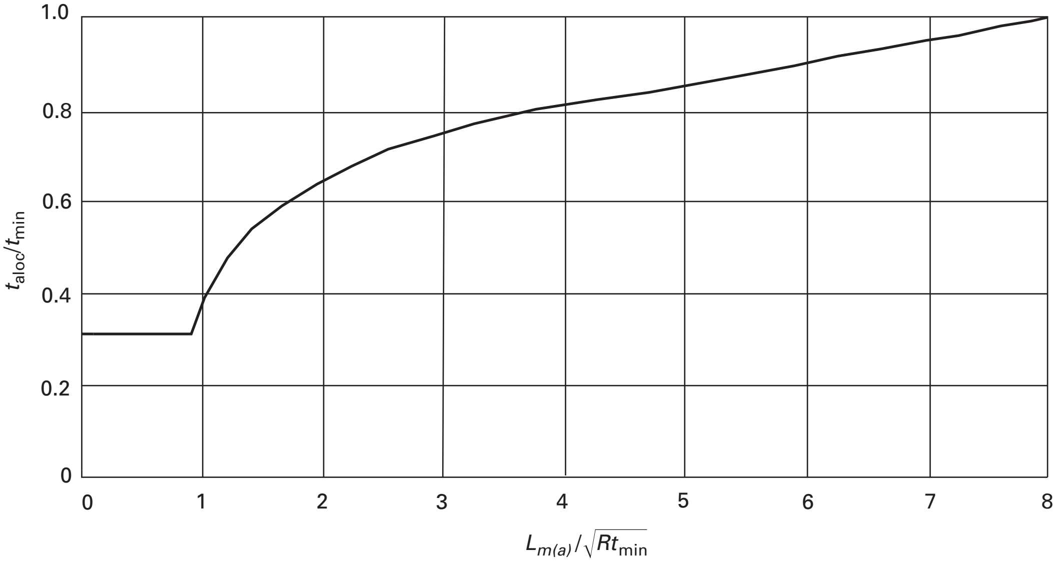
(2) for ferritic steels, $35\ \text{ksi}\sqrt{\text{in.}}$ $(38\ \text{MPa}\sqrt{\text{m}})$

(c) For nonplanar part-through-wall degradation in cylindrical portions of vessels or tanks, including degradation growth through the end of the evaluation period, the vessel or tank is acceptable when the minimum remaining wall thickness, t_p, is greater than or equal to the minimum wall thickness required for pressure loading, t_{min}, where t_{min} is determined in accordance with U-S2-4.3(a). Alternatively, the degradation is acceptable if $t_p \geq t_{aloc}$, where t_{aloc} is determined in accordance with U-S2-4.3(b).

(d) For nonplanar part-through-wall degradation in noncylindrical portions of vessels or tanks, including degradation growth through the evaluation period, the vessel or tank is acceptable if the following structural factors (SF) based on load are maintained:

$$SF \geq 3.0 \;(\text{Levels A and B and test conditions})$$

Figure U-S2-4.3-1
Allowable Wall Thickness and Length of Locally Thinned Area



$$SF \geq 1.4 \left(\text{Levels C and D}\right)$$

(e) For through-wall penetration, the potential leakage flow area of the degradation, or the total of the potential leakage flow areas of multiple degradation locations that are combined into a single, degradation location for the purpose of evaluation, shall not exceed 20 in.^{2} (130 cm^2).

U-S2-7 SUBSEQUENT EXAMINATIONS AND SURVEILLANCE

The following actions shall be implemented for degradation determined to be structurally acceptable at the end of the evaluation period:.

(a) Daily leakage monitoring (e.g., vessel or tank level indications, sump measurements, etc.) shall be performed to ensure that leakage, if any, does not exceed acceptable limits.

(b) Degradation, including growth, that meets the acceptance criteria of this Nonmandatory Appendix shall be determined by examination at one-half of the allowable operating time (i.e., $0.5\tau_{allow}$) to verify the growth predictions, unless τ_{allow} exceeds twice the time to the end of the evaluation period, as allowed by U-S2-2.5(d).

NONMANDATORY APPENDIX W MECHANICAL CLAMPING DEVICES FOR CLASS 2 AND 3 PIPING PRESSURE BOUNDARY

ARTICLE W-1000 GENERAL

(a) If an Owner chooses to use this Nonmandatory Appendix, all of the provisions of this Appendix shall be met for the mechanical clamping device being installed.

(b) Mechanical clamping devices used as piping pressure boundary may remain in service only until the next refueling outage, at which time the defect shall be removed or reduced to an acceptable size.

(c) These clamping devices may be used on piping and tubing, and their associated fittings and flanges, and the welding ends of pumps, valves, and pressure vessels, except as prohibited by (d) below.

(d) Clamping devices shall not be used on the following:

(1) Class 1 piping;

(2) portions of a piping system that forms the containment boundary;

(3) piping larger than NPS 2 (DN 50) when the nominal operating temperature or pressure exceeds 200°F (95°C) or 275 psig (1 900 kPa);

(4) piping larger than NPS 6 (DN 150).

(e) A Repair/Replacement plan shall be developed in accordance with IWA-4150, and shall identify the defect characterization method, design requirements, and monitoring requirements.

(f) Welding performed as part of the fabrication and installation of the clamping device shall be in accordance with the requirements of IWA-4400.

(g) The records required by IWA-4180 and the records required by Article IWA-6000 shall be prepared and maintained by the Owner until the clamping device is removed.

ARTICLE W-2000
DEFECT CHARACTERIZATION

The size, location, and apparent cause of the defect shall be determined. The defect size shall be bounded to account for nondestructive examination limitations. If the defect size cannot be directly determined, a conservative bound of the defect size shall be determined and documented.

ARTICLE W-3000
DESIGN REQUIREMENTS

W-3100 GENERAL DESIGN REQUIREMENTS

The following design requirements shall be included in a Repair/Replacement plan and the analyses of the clamping device (W-3200) and piping (W-3300), as applicable.

(a) Requirements to address environmental and corrosive effects of seal composition, seal installation, and system fluid on piping, clamping device, and bolting.

(b) The defect size used in the design of the clamping device shall include any projected growth.

(c) If additional supports are required to satisfy W-3200 or W-3300, they shall be considered nonpressure-retaining items and shall be designed in accordance with the requirements of the Construction Code for the system or as permitted by IWA-4220.

W-3200 CLAMPING DEVICE

The following additional requirements apply to the design of the clamping device.

(a) No credit shall be taken for structural capability of the seal.

(b) Pressure-retaining clamping device items shall be designed based on a stress analysis using the stress limits identified in Table W-3200-1 for the loading conditions specified in the Owner's Requirements for the system.

(c) The clamping device shall be mechanically connected to the piping. Seal welds may be added to prevent leakage. Serrated contact surfaces of the clamping device are acceptable, provided they do not affect the structural integrity of the piping.

(d) If the clamping device is designed to carry, by friction, longitudinal loads normally transmitted by the piping, including postulated full circumferential severance of the piping at the defect location, it shall be designed to produce clamping friction of at least five times the friction load required to prevent slippage. If a coefficient of friction greater than 0.3 is used for friction-type connections, the coefficient of friction for each interface design (e.g., serrated or nonserrated), and each combination of interface material P-Numbers, shall be experimentally determined.

W-3300 PIPING SYSTEM

The following additional requirements apply to the evaluation of the piping system.

(a) Piping system vibration shall be included when vibration is the apparent cause of the defect or the defect can be propagated by vibration.

(b) The piping system configuration with the clamping device shall be evaluated in accordance with the Owner's Requirements, and either the Construction Code or Section III.

(c) Effects of the stiffness and weight of the clamping device shall be included in the evaluation of the piping systems. When the defect is caused by erosion or corrosion, the base material thickness at the load transfer area shall be determined and projected to the time of removal of the clamping device. The projected wall thickness shall be used when evaluating the piping system.

(d) When evaluating the effects of thermal expansion of the piping system, the constraining effects of the clamping device shall be included.

(e) The Owner shall include the effect of the defect and its expected growth, in the piping system evaluation.

Table W-3200-1
Stress Limits for Design and Service Loadings

Service Limits	Stress Limits [Note (1)]
Design and Level A (Normal)	$\sigma_m < 1.0\ S$ $\sigma_m + \sigma_b < 1.5\ S$
Level B (Upset)	$\sigma_m < 1.10\ S$ $\sigma_m + \sigma_b < 1.65\ S$
Level C (Emergency)	$\sigma_m < 1.5\ S$ $\sigma_m + \sigma_b < 1.8\ S$
Level D (Faulted)	$\sigma_m < 2.0\ S$ $\sigma_m + \sigma_b < 2.4\ S$

NOTE:
(1) The symbols used in Table W-3200-1 are defined as follows:
σ_m = general membrane stress, psi (kPa). Average stress across the solid cross section produced by mechanical loads; excludes effects of discontinuities and concentrations.
σ_b = bending stress, psi (kPa). Linearly varying portion of stress produced by mechanical loads; excludes effects of discontinuities and concentrations.
S = allowable stress value, psi (kPa), at temperature, provided in the Construction Code.

ARTICLE W-4000
MATERIAL REQUIREMENTS

Material shall meet the technical requirements of IWA-4220 and shall be furnished with certified material test reports.

ARTICLE W-5000
PRESSURE TESTING REQUIREMENTS

A system leakage test in accordance with Article IWA-5000 shall be performed on the portion of the piping system containing the clamping device.

ARTICLE W-6000
MONITORING REQUIREMENTS

The Owner shall prepare a plan for monitoring defect growth in the area immediately adjacent to the clamping device. The plan shall include the following activities and requirements.

(a) Except as permitted by (b) below, or where precluded by the clamping device configuration, the area immediately adjacent to the clamping device shall be examined using a volumetric method. The examination frequency shall not exceed 3 months, and shall be specified in the Repair/Replacement Plan. When the examination reveals defect growth to a size that exceeds the projected size determined by W-3100(b), the defect shall be removed or reduced to an acceptable size.

(b) Monitoring of the defect size need not be performed for a circumferential crack.

(c) The clamping device shall be monitored for leakage at least weekly. Any leakage at any time shall be dispositioned.

DIVISION 2
RULES FOR INSPECTION AND TESTING OF COMPONENTS OF GAS-COOLED PLANTS

FOREWORD

HISTORICAL BACKGROUND

Section XI, Division 2, Rules for Inspection and Testing of Components of Gas-Cooled Plants, of the ASME Boiler and Pressure Vessel Code is addressed to the examination, inspection, and testing requirements for the components in gas-cooled nuclear power plants. This Section of the Code was developed under sponsorship of the American Society of Mechanical Engineers.

This Division of the Code is unique in that recognition was given to the problems of examining radioactive areas where access by personnel is impracticable; provisions are incorporated in the rules for the examination of such areas by remote means, employing equipment which may require development. Examination of these areas is dependent upon providing the access and space requirements as dictated by the latest development programs to mechanize and automate existing nondestructive examination techniques; but where the equipment has not been developed, no requirement is stipulated for the performance of the remote examinations until near the end of the inspection interval, or about 10 yr from the time this Division of the Code was adopted. The rationale is that the equipment development can be completed or alternative examinations devised within that time period.

INSERVICE INSPECTION PHILOSOPHY

The object of inservice inspection of components in nuclear power plants is to provide a continuing assurance that they are safe. To provide this assurance for those components that are subject to the requirements of the ASME Boiler and Pressure Vessel Code, a set of rules has been formulated to provide assurance that the safety-related functions of the components are available when required. The rules have been arranged to provide appropriate levels of assurance according to the importance of the component in its relationship to plant safety. The classifications that are established during design and manufacturing have been adopted to provide the levels of importance for the components. The types of components typically found in the various classifications have then been identified and rules formulated for each type. For each type of component in each classification, the typical safety functions have been considered and methods of inspecting, testing, or monitoring each component specified. Rules have also been formulated for establishing the methods of determining the limits of acceptance of the results. Should it be necessary to take corrective actions to repair various components, rules have been provided to establish acceptable methods of repair.

The basis on which the rules were developed assumes that a component has initially been accepted as being safe. To establish an indication of its condition for a later comparison, a preservice (baseline) examination is required. Subsequent examinations are compared to this preservice examination to determine if there has been a change in the component.

A further assumption presumes that similar components, which are subjected to essentially identical service conditions, will behave in a like manner. For this reason, representative sampling, which is rotated through the similar components, is presumed to provide adequate assurance that all the components are safe. The percentage of like components or portions of components examined and the frequency of examination are adjusted in accordance with the level of assurance judged to be appropriate.

The purpose of establishing rules, in the form of a Code, is to provide a uniform standard to which all gas-cooled nuclear power plants are subjected. By providing such a standard, important areas are not overlooked and unimportant areas do not distract attention from significant ones. Unlike water-cooled nuclear power plants, the integrity of the primary coolant pressure boundary is not the primary concern of the inspection rules. Rather, the inservice inspection rules for each component are based on the safety function of the component which has been determined by its role in plant operations.

REACTOR SYSTEM CONSIDERED IN CODE RULES

These rules are presently addressed to only a single concept of a gas-cooled nuclear power plant, that commonly known as the High Temperature Gas-Cooled Reactor (HTGR). The primary reason is that a need for these rules exists only for those plants which are expected to be built and operated in the United States and Canada during the next 5 to 10 yr. Other concepts, such as the direct-cycle, the fast reactor, and the pebble bed, are not expected to reach such early development. Probably at least one full-size, full-function demonstration plant would be required before any newer concept would become available to an Owner within the meaning of the ASME Boiler and Pressure Vessel Code. This demonstration period would provide ample time for the drafting of Code provisions applicable to the specific concept. A secondary reason is that, although it might be desirable to attempt to write rules of sufficient generality to serve as precedents, the characteristic design features and equipment may differ so much among concepts that adequate rules could not be formulated at this time.

The limitation of the rules to the single concept of the HTGR establishes a context in which they should be understood. Although a specific reference design is not described, there are several design features characteristic of the HTGR. These include: helium cooling; carbon-encapsulated fuel particles in a graphite matrix; graphite-moderated, prismatic core and reflector elements; pressure enclosure by a prestressed concrete reactor vessel, and steam power cycle. These characteristics inherently affect the way in which safety-related functions are performed and, thus, the way in which these rules are formulated and interpreted.

For the rules for inspection and testing of components of gas-cooled plants, refer to the 1992 Edition with the 1993 Addenda, pages 485 through 653.

DIVISION 3
RULES FOR INSPECTION AND TESTING OF COMPONENTS OF LIQUID-METAL-COOLED PLANTS

FOREWORD

INTRODUCTION

Section XI, Division 3, Rules for Inspection and Testing of Components of Liquid-Metal-Cooled Plants, of the ASME Boiler and Pressure Vessel Code provides rules for the examination, testing, inspection, repair, and replacement of components and systems in a liquid-metal-cooled nuclear power plant. The rules and requirements for components and systems containing liquid metal or cover gas are detailed in this Division. The rules and requirements for those components and systems of this plant type that contain other fluids are provided by references to Articles or portions thereof in Division 1, on the basis that these Division 1 rules are appropriate and applicable to Liquid-Metal-Cooled Nuclear Power Plants; otherwise such rules and requirements are provided in this Division.

GENERAL REQUIREMENTS

RATIONALE FOR DIVISION 3 RULES

(a) The rules in this Division of Section XI are based upon anticipated service environments peculiar to systems which contain liquid metals (sodium or sodium alloys) as coolants and upon the comprehensive protection against failure of the liquid-metal coolant boundary that is characteristic of this type of plant.

(b) The liquid-metal system service environments derive from the physical and chemical properties of these coolants (typically sodium or sodium–potassium alloy), which vary considerably from water. Examples:

(1) Sodium freezes at about 208°F (98°C). It is therefore necessary to provide heaters and insulation on all sodium lines and components.

(2) Sodium and sodium alloys react with oxygen and water vapor in air and an inert cover gas is thus required within all of the plant components containing free liquid-metal surfaces. Generally, primary system components are located in cells or vaults containing an inert gas atmosphere to minimize possible coolant reaction should a boundary leak develop.

(3) Sodium and sodium alloys have very low vapor pressure over a wide range of operating temperatures. As a result, systems are operated at relatively low pressures and stored energy is minimal compared to systems cooled with water.

(c) Characteristic features of these plants that offer protection against liquid-metal coolant boundary failures include the following.

(1) The liquid metal containing primary system boundary is typically constructed of an austenitic stainless steel. All materials in the liquid-metal system boundary operate in a temperature range where high fracture toughness is inherent.

(2) The characteristics of the coolant and the coolant boundary material ensure that a boundary failure is not accompanied by a large release of energy.

(3) Design features are typically provided that offer protection against loss of core cooling, burning of spilled sodium, and sodium-concrete reactions in the event of a coolant boundary failure.

(4) External sodium leakage is readily and reliably detectable by several diverse and practicable methods on a continuous basis during plant operation.

(5) Internal coolant leakage between portions of the primary system, or leakage between primary and intermediate coolant systems, characteristically does not compromise the ability to cool the core adequately and does not constitute release of radioactivity.

APPLICABILITY OF DIVISION 3 RULES

These rules are intended to be generally applicable to either the loop type or pool type of LMR primary coolant system. For the requirements for inspection and testing of components of liquid-metal-cooled plants, refer to the 2001 Edition with the 2003 Addenda, pages 482–716.

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ENDNOTES

1 Classification criteria are specified in the facility's current licensing basis.

2 Design considerations other than access provisions may be needed for specific system components to render inservice inspections practical (such as surface finish of components subject to crud or corrosion product buildup, material selection to minimize activation in service, and shielding from irradiation effects).

3 The flaw depth dimensions a_s and a_e are the allowable flaw standards for surface and subsurface flaws, respectively.

4 The term *repair/replacement activity* includes those activities previously known as *repair, replacement, modification*, or, *alteration*. Those previous terms no longer have a unique meaning or significance and are combined in the term *repair/replacement activity*. Reasons for repair/replacement activities may include the following:
(a) discrepancies detected during inservice inspection, maintenance, or service
(b) regulatory requirements change
(c) design changes to improve equipment service
(d) changes to improve reliability
(e) damage
(f) failure during service
(g) personnel exposure
(h) economics
(i) end of service life
(j) addition of new items or systems

5 Limitations on fabrication by a Repair/Replacement Organization are provided in IWA-4143.

6 Examination and testing requirements for snubbers and testing requirements for pumps and valves are provided in the ASME Code for Operation and Maintenance of Nuclear Power Plants (OM Code).

7 NPS (*Nominal Pipe Size*) and DN (used with SI) — designations assigned for the purpose of convenient specification of pipe size. The actual inside and outside dimensions are listed in ASME B36.10M.

8 This provision does not negate the requirement to implement the Owner's QA Program, nor does it affect Owner commitments to regulatory and enforcement authorities.

9 Mechanical processing refers to metal removal by mechanical means, e.g., grinding, machining, chipping.

10 Welders and brazers include welding and brazing operators.

11 Chemical composition meeting the requirements of the original material specification.

12 Same phase and similar grain shape as produced by the heat treatment required by the applicable material specification.

13 P-Nos. 12A, 12B, and 12C designations refer to specific material classifications originally identified in Section III and subsequently reclassified in a later Edition of Section IX.

14 ANSI/AWS D3.6M, "Underwater Welding Code," contains additional technical information that the Owner or user may find useful. Additional variables or controls may be considered for specific applications.

15 APPM = atomic parts per million.

16 Background gas is gas that displaces water and is not necessarily intended to shield the arc. The gas may or may not be breathable.

17 The boundary limits are generally defined by the location of the safety class interface valves within the system.

18 Nonmandatory Appendix T does not apply to organizations fabricating parts or constructing components within the jurisdiction of the Construction Code and certifying such activities in accordance with the Construction Code. Such organizations are not Repair/Replacement Organizations.

19 The exemptions from examination in IWC-1220 may be applied to those components permitted to be Class 2 in lieu of Class 1 by the regulatory authority having jurisdiction at the plant site.

20 For heat exchangers, the shell side and tube side may be considered separate components.

21 Welds, areas, or parts are those described or intended in a particular inspection item of Tables IWB-2500-1 (B-A) through IWB-2500-1 (B-O) and Table IWB-2500-1 (B-Q).

22 An inspection item, as listed in Tables IWB-2500-1 (B-A) through IWB-2500-1 (B-O) and Table IWB-2500-1 (B-Q), may comprise a number of welds, areas, or parts of a component required to be examined in accordance with the inspection plan and schedule (IWA-2420).

23 For structural factors included in the acceptance standards, refer to report listed under 8(f)(1) of the Organization of Section XI.

24 The standards apply to accessible surfaces of bolting when examined in place, and to all surfaces when bolting is removed for examination.

25 Relevant conditions are defined in Article IWA-9000; they do not include fabrication marks, scratches, surface abrasion, material roughness, and any other conditions acceptable by material, design, and manufacturing specifications.

26 Relevant conditions are defined in Article IWA-9000; they do not include fabrication marks, material roughness, casting irregularities, and other conditions acceptable by material, design, and manufacturing specifications of the component.

27 Wall thickness is determined either from design information, construction drawings, or by measurement on the component.

28 Relevant conditions are defined in Article IWA-9000; they do not include fabrication marks, material roughness, and other conditions acceptable by material, design, and manufacturing specifications of the component.

29 Cross-sectional area is determined either from design information, construction drawings, or by measurement on the weld.

30 RHR, ECC, and CHR systems are the Residual Heat Removal, Emergency Core Cooling, and Containment Heat Removal Systems, respectively.

31 Statically pressurized, passive safety injection systems of pressurized water reactor plants are typically called:
(a) accumulator tank and associated system
(b) safety injection tank and associated system
(c) core flooding tank and associated system

32 Welds, areas, or parts are those described or intended in a particular inspection item of Tables IWC-2500-1 (C-A) through IWC-2500-1 (C-F-2).

33 An inspection item, as listed in Tables IWC-2500-1 (C-A) through IWC-2500-1 (C-F-2), may comprise a number of welds, areas, or parts of a component required to be examined in accordance with the inspection plan and schedule (IWA-2420).

34 Relevant conditions are defined in Article IWA-9000; they do not include conditions that result in condensation on components, normal collection of fluid in sumps, and drips from open drains.

35 Welds, areas, or parts are those described or intended in a particular inspection item of Table IWD-2500-1 (D-A).

36 An inspection item, as listed in Table IWD-2500-1 (D-A), may comprise a number of welds, areas, or parts of a component required to be examined in accordance with the inspection plan and schedule (IWA-2420).

37 Discharge lines to structural compartments (e.g., service water pump intake structures) and collection tanks, sumps, and basins that are open (or may become open) to the atmosphere are considered open ended.

38 The standards apply to accessible surfaces of bolting and the bolted connection when examined in place, and to all surfaces when the bolting or bolted connection is disassembled for examination.

39 Examination and test requirements for snubbers can be found in the ASME Code for Operation and Maintenance of Nuclear Power Plants (OM Code).

40 Attachment portion includes welds, bolting, pins, clamps, etc.

41 For pipe-clamp-type supports, the mechanical connection to the pressure boundary includes the bolting, pins, and their interface to the clamp, but does not include the component-to-clamp interface.

42 An aggressive below-grade environment is defined as having a pH of less than 5.5, chlorides in excess of 500 ppm, or sulfates in excess of 1,500 ppm.

43 Corrosion protection medium is exempt from the requirements of Article IWL-4000. However, corrosion protection medium shall be restored in accordance with IWL-2526 following concrete containment post-tensioning system repair/replacement activities.

44 Refer to report listed under 8(f)(2) of the Organization of Section XI for example problems that apply the evaluation procedures with various assumptions using the Summer 1976 Addenda to the 1974 Edition of the Code.

45 Low ΔK_I values are those below the knee of the curves in Figure A-4300-2. High ΔK_I values are those above the knee of the curves in Figure A-4300-2.

46 A plane containing the pipe axis.

47 A plane perpendicular to the pipe axis.

48 Alloys 600, 82, 182, and 132 are common abbreviations for UNS N06600, N06082, W86182, and W86132, respectively.

49 T_c is the bulk reactor coolant temperature, and $\Delta T_c/\Delta t$ is the maximum variation of temperature T_c in any 1 hr period.

50 RT_{NDT} is the highest adjusted reference temperature (for weld or base material) at the inside surface of the reactor vessel as determined by Regulatory Guide 1.99 Rev. 2.

51 The *stress intensity factor* as used in fracture mechanics has no relation to and must not be confused with the *stress intensity* used in Section III, Division 1. Furthermore, stresses referred to in this Appendix are calculated normal tensile stresses not stress intensities in a defect-free stress model at the surface nearest the location of the assumed defect.

52 WRCB 175 (Welding Research Council Bulletin 175) "PVRC Recommendations on Toughness Requirements for Ferritic Materials" provides procedures in Paragraph 5(c)(2) for considering maximum postulated defects smaller than those described.

53 The coolant temperature is the reactor coolant inlet temperature.

54 The vessel metal temperature is the temperature at a distance one fourth of the vessel section thickness from the inside wetted surface in the vessel beltline region. RT_{NDT} is the highest adjusted reference temperature (for weld or base metal in the beltline region) at a distance one fourth of the vessel section thickness from the vessel wetted inner surface as determined by Regulatory Guide 1.99, Rev. 2.

55 Use of eq. G-2223(c)(4) or eq. G-2223(d)(6) is only a recommendation for determination of K_I . Other techniques may be used, provided the methods and analyses are documented.

56 A plane parallel to the nozzle axis.

57 A plane parallel, within 10 deg of the plane of the attachment weld, as illustrated in Figure IWB-3662-1.

58 Systems fabricated to nuclear power standards, while resistant to degradation mechanisms addressed in the design process, have experienced damage from phenomena unknown at the time of installation.

59 Boiling Water Reactor Vessel and Internals Project (BWRVIP)-75 "Technical Basis for Revision to Generic Letter 88-01 Inspection Schedules," October 1999.

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ASME BOILER AND PRESSURE VESSEL CODE SECTION XI

INTERPRETATIONS Volume 63

Interpretations of the Code have historically been posted in January and July at http://cstools.asme.org/interpretations.cfm. Interpretations issued during the previous two calendar years are included with the publication of the applicable Section of the Code in the 2015 Edition. Interpretations of Section III, Divisions 1 and 2 and Section III Appendices are included with Subsection NCA.

Following the 2015 Edition, interpretations will not be included in the edition; they will be issued in real time in ASME's Interpretations Database at http://go.asme.org/Interpretations. Historical BPVC interpretations may also be found in the Database.

Volume 63 is the interpretations volume included with the update service to the 2015 Edition.

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INTERPRETATIONS VOLUME 63 — SECTION XI

Replies to Technical Inquiries January 1, 2013 through December 31, 2014

FOREWORD

GENERAL INFORMATION

This publication includes all written interpretations issued between the indicated dates by the ASME Staff on behalf of the ASME Boiler and Pressure Vessel Committee in response to inquiries concerning interpretations of the ASME Boiler and Pressure Vessel Code. A contents is also included that lists subjects specific to the interpretations covered in the individual volume.

These interpretations are taken verbatim from the original letters, except for a few typographical and editorial corrections made for the purpose of improved clarity. In some instances, a review of the interpretation revealed a need for corrections of a technical nature. In these cases, a revised interpretation is presented bearing the original interpretation number with the suffix R and the original file number with an asterisk. Following these revised interpretations, new interpretations and revisions to them issued during the indicated dates are assigned interpretation numbers in chronological order. Interpretations applying to more than one Code Section appear with the interpretations for each affected Section.

ASME procedures provide for reconsideration of these interpretations when or if additional information is available that the inquirer believes might affect the interpretation. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. As stated in the Statement of Policy in the Code documents, ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

An interpretation applies either to the Edition and Addenda in effect on the date of issuance of the interpretation or the Edition and Addenda stated in the interpretation. Subsequent revisions to the Code may supersede the interpretation.

For detailed instructions, see "Submittal of Technical Inquiries to the ASME Boiler and Pressure Vessel Standards Committees" in the front matter.

SUBJECT AND NUMERICAL INDEXES

Subject and numerical indexes (if applicable) have been prepared to assist the user in locating interpretations by subject matter or by location in the Code. They cover interpretations issued from Volume 12 up to and including the present volume.

Subject	Interpretation	File No.
IWA-4712.2(a) (2013 Edition)	XI-1-15-07	14-1560
Case N-661-1, Para. 5(b)	XI-1-13-26	14-168
Cases N-770-1 Through N-770-3, Paras. -1100 and -1210	XI-1-13-27	14-382
Code Case N-606-1	XI-1-13-19	13-56
Code Cases N-716 and N-716-1, Table 1	XI-1-15-01	14-916
Code Cases N-729 Through N-729-3	XI-1-13-16	12-2059
Code Cases N-770, N-770-1, N-770-2, and N-770-3	XI-1-13-21	13-1912
IWA-2210 (2013 Edition) and Case N-823	XI-1-13-24	13-1241
IWA-2323; Mandatory Appendix VI, VI-4300; and Mandatory Appendix VII, VII-4340 (2001 Edition With the 2003 Addenda Through the 2010 Edition With the 2011 Addenda)	XI-1-13-12	12-1905
IWA-4132 and IWA-4540 (2004 Edition)	XI-1-13-14	12-827
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Interpretation: XI-1-13-08R

Subject: Table IWB-2500-1, Examination Category B-A, Item Numbers B1.30 and B1.40, Notes (4) and (5) (1992 Edition With the 1994 Addenda Through the 2013 Edition)
Date Issued: October 2, 2013
File: 12-1353*

Question (1): Is it a requirement of Table IWB-2500-1, Examination Category B-A, Note (4) that a minimum of 50% of the examination volume is to be examined from the flange face?

Reply (1): No.

Question (2): Is it the intent of Table IWB-2500-1, Examination Category B-A, Item Numbers B1.30 and B1.40 that Note (5) requirements must be met prior to using Note (3) or Note (4), as applicable?

Reply (2): No.

Interpretation: XI-1-13-10R

Subject: Table IWE-2500-1, Examination Category E-D, Item E5.30 (1992 Edition With the 1992 Addenda Through the 1995 Edition With the 1997 Addenda) and Examination Category E-A, Item E1.30 (1998 Edition Through the 2013 Edition)
Date Issued: October 31, 2013
File: 12-1950*

Question: Do Table IWE-2500-1, Examination Category E-D, Item E5.30 (1992 Edition with the 1992 Addenda through the 1995 Edition with the 1997 Addenda) and Examination Category E-A, Item E1.30 (1998 Edition through the 2013 Edition) require examination of leak chase channel threaded plugs, caps, seals, or covers?

Reply: No.

Interpretation: XI-1-13-12

Subject: IWA-2323; Mandatory Appendix VI, VI-4300; and Mandatory Appendix VII, VII-4340 (2001 Edition With the 2003 Addenda Through the 2010 Edition With the 2011 Addenda)
Date Issued: January 16, 2013
File: 12-1905

Question: When administering multiple-choice written examinations in accordance with IWA-2323, VI-4300, or VII-4340, is it the intent that the certified Level III may delegate a noncertified proctor to administer and monitor the testing process of the Level III candidate?

Reply: Yes, as long as the certified Level III has a valid certification in the applicable test method.

Interpretation: XI-1-13-13

Subject: Table IWD-2500-1, Category D-A (2004 Edition Through the 2010 Edition With the 2011 Addenda)
Date Issued: January 22, 2013
File: 11-1126

Question: Is it the intent of Table IWD-2500-1, Category D-A, Note (3) [Note (4) in the 2007 Edition with the 2009 Addenda through the 2010 Edition with the 2011 Addenda] to select only one welded attachment of only one of the multiple vessels for examination?

Reply: Yes.

Interpretation: XI-1-13-14

Subject: IWA-4132 and IWA-4540 (2004 Edition)
Date Issued: February 13, 2013
File: 12-827

Question (1): If new bolting is installed as part of rotating an item from stock in accordance with IWA-4132, are an R/R plan and NIS-2 data report required for the replacement bolting?

Reply (1): Yes.

Question (2): Is it a requirement of IWA-4540 for the replacement bolting included in Question (1) to be pressure tested?

Reply (2): No.

Interpretation: XI-1-13-15

Subject: IWA-4132 and IWA-4540(c) (1998 Edition)
Date Issued: February 13, 2013
File: 12-1585

Question (1): Is it a requirement of the 1998 Edition of IWA-4540(c) to perform a pressure test following installation of a pressure relief valve rotated from stock in accordance with IWA-4132 that does not include replacement of pressure-retaining bolting?

Reply (1): Yes, from the 1996 Addenda to the 1998 Edition, IWA-4132(e) and IWA-4540(c) required pressure testing of mechanical connections made during the rotation of pressure relief valves from stock whether or not bolting was replaced.

Question (2): Is it a requirement of the 1998 Edition of IWA-4540(c) to perform a pressure test following installation of a pressure relief valve rotated from stock in accordance with IWA-4132 that includes replacement of pressure-retaining bolting?

Reply (2): Yes, from the 1996 Addenda to the 1998 Edition, IWA-4132(e) and IWA-4540(c) required pressure testing of mechanical connections made during the rotation of pressure relief valves from stock whether or not bolting was replaced.

Interpretation: XI-1-13-16

Subject: Code Cases N-729 Through N-729-3
Date Issued: February 13, 2013
File: 12-2059

Question: Is it a requirement of -3132.1(b) that a rounded indication of any size be subject to the provisions of -3232.2 if there are no relevant conditions indicating nozzle leakage?

Reply: No.

Interpretation: XI-1-13-17

Subject: IWB-3522.1 (1998 Edition With the 2000 Addenda Through the 2007 Edition) and IWA-5300 (1998 Edition With the 2000 Addenda Through the 2013 Edition)
Date Issued: May 15, 2013
File: 12-2273

Question (1): Is it a requirement of IWB-3522.1 to consider as relevant any identified leakage from mechanical connections?

Reply (1): Yes.

Question (2): Is it a requirement of IWA-5300 to record all leakage?

Reply (2): Yes.

Interpretation: XI-1-13-18

Subject: Mandatory Appendix VII, VII-4310(a) (1998 Edition Through the 2013 Edition)
Date Issued: May 15, 2013
File: 13-888

Question (1): Do the requirements of VII-4310(a) requiring a question bank containing at least twice the minimum number of questions and examinations assembled using a random selection process apply only to the ultrasonic examination method?

Reply (1): Yes.

Question (2): Is it a requirement of VII-4310(a) that examinations be assembled from a question bank using a “random selection process” without consideration to the requirements of VII-4321 and VII-4322?

Reply (2): No. All applicable paragraphs of VII-4300 are required.

Interpretation: XI-1-13-19

Subject: Code Case N-606-1
Date Issued: June 21, 2013
File: 13-56

Question: Is it the intent that the application of peening to the initial or final weld layer for the purpose of surface stress mitigation be prohibited by Code Case N-606-1, 1(f)?

Reply: No. The prohibition against peening was intended to prevent the use of high-impact peening methods used to control distortion. It was not intended to prohibit peening methods used only for the purpose of surface stress mitigation, such as rotary peening.

Interpretation: XI-1-13-20

Subject: IWF-1300(e) (2004 Edition)
Date Issued: June 21, 2013
File: 13-114

Question (1): Is it the intent of IWF-1300(e) to allow insulation to remain in place during examination of those supports under continuous compression or tension load, regardless of orientation (i.e., horizontal, vertical, or anywhere in between) when examination is required in accordance with Table IWF-2500-1?

Reply (1): Yes.

Question (2): Is it the intent of IWF-1300(e) to remove insulation during examination of those supports that normally carry no load (such as snubbers) when examination is required in accordance with Table IWF-2500-1?

Reply (2): Yes.

Interpretation: XI-1-13-21

Subject: Code Cases N-770, N-770-1, N-770-2, and N-770-3
Date Issued: October 31, 2013
File: 13-1912

Question: Do Cases N-770, N-770-1, N-770-2, and N-770-3 require a visual examination be performed on unmitigated butt welds at cold leg operating temperature ≥ 525°F (274°C) and < 580°F (304°C) if an ultrasonic examination described in Table 1, Notes (3) and (4), is performed within the same interval the visual examination is scheduled to be performed?

Reply: No.

Interpretation: XI-1-13-22

Subject: IWA-4530(a) and IWF-2220 (1998 Edition With the 2000 Addenda)
Date Issued: October 31, 2013
File: 13-1916

Question: In accordance with IWA-4530(a) and IWF-2220, is it a requirement to perform a preservice inspection on a component support subjected to a Repair/Replacement Activity if the support is exempted from examination by IWF-1230?

Reply: No.

Interpretation: XI-1-13-23

Subject: IWA-4530(a) (1998 Edition With the 2000 Addenda Through the 2004 Edition With the 2005 Addenda)
Date Issued: November 5, 2013
File: 13-1537

Question: Does IWA-4530(a) apply to a Repair/Replacement Activity to install a new replacement snubber assembly (pin-to-pin) in an existing support?

Reply: No. IWA-4530(b) shall be used.

Interpretation: XI-1-13-24

Subject: IWA-2210 (2013 Edition) and Case N-823
Date Issued: January 23, 2014
File: 13-1241

Question (1): Is it the intent of IWA-2210 or Case N-823 that there are no illumination, distance, angle-of-view, and resolution demonstration requirements for VT-2 visual examinations?

Reply (1): Yes.

Question (2): Is it the intent of IWA-2210 or Case N-823 that there are no angle-of-view requirements for VT-3 visual examinations?

Reply (2): Yes.

Interpretation: XI-1-13-25

Subject: IWE-1230 (1992 Edition With the 1992 Addenda Through the 2013 Edition)
Date Issued: March 7, 2014
File: 13-2137

Question (1): Is it a requirement of IWE-1230 that the containment surface covered by thermal insulation be considered accessible for general visual examination in accordance with Table IWE-2500-1, Examination Category E-A?

Reply (1): No.

Question (2): Is it a requirement of IWE-1230 that the containment surface covered by thermal insulation be considered accessible for augmented examination in accordance with Table IWE-2500-1, Examination Category E-C, if these surfaces are subject to accelerated degradation and aging?

Reply (2): Yes.

Interpretation: XI-1-13-26

Subject: Case N-661-1, Para. 5(b)
Date Issued: March 7, 2014
File: 14-168

Question: Does Case N-661-1, para. 5(b), prohibit repairing through-wall leaks by installing a metal plug into the through-wall opening and seal welding?

Reply: No.

Interpretation: XI-1-13-27

Subject: Cases N-770-1 Through N-770-3, Paras. -1100 and -1210
Date Issued: March 10, 2014
File: 14-382

Question: Is it a requirement of paras. -1100 and -1210 of Cases N-770-1 through N-770-3 that the Case applies to Examination Category B-J branch connection welds in piping?

Reply: No. Cases N-770-1 through N-770-3 only apply to circumferential butt welds, as shown in Figure 1 of the Case.

Interpretation: XI-1-13-28

Subject: Table IWB-2500-1, Examination Category B-K, Item B10.10 (1995 Edition With the 1996 Addenda Through the 2013 Edition)
Date Issued: April 1, 2014
File: 14-167

Question: Is it a requirement of Table IWB-2500-1, Examination Category B-K, Item B10.10, to perform a surface examination of the weld buildup on a nozzle associated with the vessel support if the weld buildup does not weld any attachment to the nozzle?

Reply: No.

Interpretation: XI-1-15-01

Subject: Code Cases N-716 and N-716-1, Table 1
Date Issued: August 5, 2014
File: 14-916

Question: For welds with full structural or optimized weld overlays that are required to be examined in accordance with Table 1 of Code Cases N-716 and N-716-1, are the required examination volumes those specified in the figures in IWB-2500?

Reply: No. Code Cases N-716 and N-716-1 do not address examination volumes.

Interpretation: XI-1-15-02

Subject: IWL-2520 (1995 Edition With the 1997 Addenda Through the 2015 Edition)
Date Issued: August 26, 2014
File: 14-126

Question: Is it a requirement of IWL-2520 that protruding wires documented in accordance with IWL-2524.1 be evaluated for acceptability in accordance with IWL-3220 and IWL-2330(c)?

Reply: Yes.

Interpretation: XI-1-15-03

Subject: Mandatory Appendix VIII, Supplement 14, Para. 3.3(b) (2004 Edition Through the 2015 Edition)
Date Issued: August 26, 2014
File: 14-1463

Question: Is it a requirement of Mandatory Appendix VIII, Supplement 14, para. 3.3(b) that axial flaws shall be included in depth sizing tests?

Reply: No.

Interpretation: XI-1-15-04

Subject: IWA-4520(a)(1) (2001 Edition Through the 2015 Edition)
Date Issued: August 26, 2014
File: 14-1472

Question: May the exemption of IWA-4520(a)(1) be used to exempt from RT a pipe or fitting base material repair in a portion of a Class 3 piping system in which none of the full penetration butt welds require Construction Code volumetric examination?

Reply: Yes.

Interpretation: XI-1-15-05

Subject: IWC-1221(d) and IWC-1222(d) (1995 Edition With the 1996 Addenda Through the 2013 Edition)
Date Issued: October 1, 2014
File: 14-132 (associated Code revision 14-1159)

Question: Is it the intent of IWC-1221(d) and IWC-1222(d) to exempt from examination piping and other components of any size in open-ended portions of suction or discharge lines that do not contain water during normal plant operating conditions?

Reply: Yes.

Interpretation: XI-1-15-06

Subject: IWF-1230 (1995 Edition Through the 2015 Edition)
Date Issued: November 5, 2014
File: 13-2071

Question: Is it the intent of IWF-1230 that only those portions of supports that are inaccessible by being encased in concrete, buried underground, or encapsulated by guard pipe are exempt from examination if the supports are attached to piping with welds that are exempt from examination in accordance with IWC-1223?

Reply: Yes.

Interpretation: XI-1-15-07

Subject: IWA-4712.2(a) (2013 Edition)
Date Issued: December 2, 2014
File: 14-1560

Question (1): When performing tube plugging by fusion welding, shall the test assembly simulate the conditions to be used in production with respect to position, tube hole pattern, and the essential variables listed in IWA-4712.2(a)?

Reply (1): No. The procedure qualification essential variables are only those provided in IWA-4712.2(a).

Question (2): When performing tube plugging by fusion welding, may the five required consecutive welds be made in a straight line on the tubesheet test assembly, rather than the actual tubesheet hole pattern, provided the ligament dimensions are correct?

Reply (2): Yes.

Interpretation: XI-1-15-08

Subject: IWA-4540 (1995 Edition With the 1995 Addenda Through the 2015 Edition)
Date Issued: December 2, 2014
File: 14-2038

Question (1): In the 1998 Edition with the 1999 Addenda through the 2013 Edition, does IWA-4540 require a hydrostatic or system leakage test of a replacement manway cover with lifting lugs (nonstructural attachments) attached by welding?

Reply (1): No.

Question (2): In the 1995 Edition with the 1995 Addenda through the 1998 Edition, does IWA-4540 require pressure testing of the mechanical joint between a replacement manway cover and the vessel?

Reply (2): Yes. IWA-4540(c) requires a system leakage test of the mechanical joint.

Interpretation: XI-1-15-09

Subject: IWA-4723.4 (1998 Edition)
Date Issued: December 2, 2014
File: 14-2121

Question: IWA-4723.4 states, "The welded sleeve attachment shall be examined to confirm that the attachment is in the correct location and conforms to the Construction Code and Owner's Requirements." Does IWA-4723.4 require the application of Construction Code tube-to-tubesheet examination requirements for sleeve attachment welds?

Reply: No.

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