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SECTION III

Rules for Construction of Nuclear Facility Components

2015 ASME Boiler and Pressure Vessel Code

An International Code

Division 1 — Subsection NG

Core Support Structures

ASME

SETTING THE STANDARD

AN INTERNATIONAL CODE

2015 ASME Boiler & Pressure Vessel Code

2015 Edition

July 1, 2015

III

RULES FOR CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS

Division 1 - Subsection NG

Core Support Structures

ASME Boiler and Pressure Vessel Committee on Nuclear Power

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.

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

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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ORGANIZATION OF SECTION III

1 GENERAL

Section III consists of Division 1, Division 2, Division 3, and Division 5. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, by the letter "W" for Division 3, and by the letter "H" for Division 5. Each Subsection is published separately, with the exception of those listed for Divisions 2, 3, and 5.

- Subsection NCA — General Requirements for Division 1 and Division 2
- Appendices
- Division 1
  - Subsection NB — Class 1 Components
  - Subsection NC — Class 2 Components
  - Subsection ND — Class 3 Components
  - Subsection NE — Class MC Components
  - Subsection NF — Supports
  - Subsection NG — Core Support Structures
  - Subsection NH — Class 1 Components in Elevated Temperature Service[*]
- Division 2 — Code for Concrete Containments
  - Subsection CC — Concrete Containments
- Division 3 — Containments for Transportation and Storage of Spent Nuclear Fuel and High Level Radioactive Material and Waste
  - Subsection WA — General Requirements for Division 3
  - Subsection WB — Class TC Transportation Containments
  - Subsection WC — Class SC Storage Containments
- Division 5 — High Temperature Reactors
  - Subsection HA — General Requirements
    - Subpart A — Metallic Materials
    - Subpart B — Graphite Materials
    - Subpart C — Composite Materials
  - Subsection HB — Class A Metallic Pressure Boundary Components
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HC — Class B Metallic Pressure Boundary Components
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HF — Class A and B Metallic Supports
    - Subpart A — Low Temperature Service
  - Subsection HG — Class A Metallic Core Support Structures
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HH — Class A Nonmetallic Core Support Structures
    - Subpart A — Graphite Materials
    - Subpart B — Composite Materials

2 SUBSECTIONS

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

[*] 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.

3 ARTICLES

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

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping With Certification Mark, and Reports

The numbering of Articles and the 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 rules have been prepared with some gaps in the numbering.

4 SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5 SUBSUBARTICLES

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

6 PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

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 NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8 SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

9 REFERENCES

References used within Section III generally fall into one of the following four categories:

(a) References to Other Portions of Section III. When a reference is made to another Article, subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in subarticle NB-3200; reference to NB-3230 includes all paragraphs, NB-3231 through NB-3236.

(b) References to Other Sections. Other Sections referred to in Section III are the following:

(1) Section II, Materials. 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."

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

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

(4) Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

(c) Reference 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 (ASTM). At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E94 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by The American Society of Mechanical Engineers and approved by the American National Standards Institute.[**] When a product is to conform to such a standard, for example ASME B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NCA-7100-1, for example ASME B16.5-2003. Standards published by The American Society of Mechanical Engineers are available from ASME (https://www.asme.org/).

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-100, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, Inc. (MSS), 127 Park Street, NE, Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NCA-7100-1, for example MSS SP-89-2003.

(4) Specifications for welding and brazing materials are published by the American Welding Society (AWS), 8669 Doral Boulevard, Suite 130, Doral, FL 33166. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-605. When documents so designated are referred to in Section III, for example API-605–1988, they are standards published by the American Petroleum Institute and are listed in Table NCA-7100-1.

(d) References to Appendices. Section III uses two types of appendices that are designated as either Section III Appendices or Subsection Appendices. Either of these appendices is further designated as either Mandatory or Nonmandatory for use. Mandatory Appendices are referred to in the Section III rules and contain requirements that must be followed in construction. Nonmandatory Appendices provide additional information or guidance when using Section III.

(1) Section III Appendices are contained in a separate book titled "Appendices." These appendices have the potential for multiple subsection applicability. Mandatory Appendices are designated by a Roman numeral followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as II-1500 or XIII-2131. Nonmandatory Appendices are designated by a capital letter followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as D-1200 or Y-1440.

(2) Subsection Appendices are specifically applicable to just one subsection and are contained within that subsection. Subsection-specific mandatory and nonmandatory appendices are numbered in the same manner as Section III Appendices, but with a subsection identifier (e.g., NF, NH, D2, etc.) preceding either the Roman numeral or the capital letter for a unique designation. For example, NF-II-1100 or NF-A-1200 would be part of a Subsection NF mandatory or nonmandatory appendix, respectively. For Subsection CC, D2-IV-1120 or D2-D-1330 would be part of a Subsection CC mandatory or nonmandatory appendix, respectively.

(3) It is the intent of this Section that the information provided in both Mandatory and Nonmandatory Appendices may be used to meet the rules of any Division or Subsection. In case of conflict between Appendix rules and Division/Subsection rules, the requirements contained in the Division/Subsection shall govern. Additional guidance on Appendix usage is provided in the front matter of Section III Appendices.

[**] The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

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)*
vi	List of Sections	Revised
viii	Foreword	*(1)* Revised *(2)* New footnote added by errata *(13–860)*
xi	Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees	In last line of 6(a), URL revised
xiii	Personnel	Updated
xxx	Organization of Section III	*(1)* New footnote added *(2)* 9(d)(3) added *(13–1032)*
11	NG-2420	For first paragraph, reference in first sentence revised *(14-2229)*
13	NG-2432.1	For subpara. (d), reference in last sentence revised *(14-2229)*
24	NG-3112.2	For subpara. (a), "Subsection" changed to "Article" *(11-1074)*
33	NG-3222	NCA reference in first sentence revised *(14-45)*
43	Figure NG-3232-1	Editorially revised
51	NG-4212	Second reference in first sentence deleted *(14-2229)*
53	NG-4324	Section IX QW references deleted *(14-2229)*
58	Figure NG-4427-1	Editorially revised
65	Table NG-5111-1	Fifth, seventh, and ninth columns centered by errata *(13-1944)*
64	NG-5130	Subparagraph (a) corrected by errata *(13-1944)*
68	NG-5521	Subparagraphs (a), (a)(3), and (a)(4) revised *(12-454)*

NOTE: Volume 63 of the Interpretations to Section III, Divisions 1 and 2, of the ASME Boiler and Pressure Vessel Code follows the last page of Subsection NCA.

LIST OF CHANGES IN RECORD NUMBER ORDER

Record Number	Change
11-1074	Revised NG-3112.2(a) to change "Subsection" to "Article."
12-454	Incorporated acceptance of the ASNT SNT-TC-1A 2011 Standard into subarticle 5500 of Division 1, Subsections NB, NC, ND, NE, NF, and NG; subsubarticle CC-5120; subarticle WB-5500; subarticle WC-5500; and Tables NCA-7100-2, NCA-7100-3, and WA-7100-2. The requirement for the near-vision acuity examination was clarified.
13-860	Errata correction. See Summary of Changes for details.
13-1032	Added a paragraph to the introduction of Section III, Division 1, Organization of Section III, Article 9(d) References to Appendices to add guidance on the use of Nonmandatory Appendices for Section III.
13-1944	Errata correction. See Summary of Changes for details.
14-45	Corrected reference from NCA-2142.2(a) to NCA-2142.4(b)(1) in NG-3222.
14-2229	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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ARTICLE NG-1000 INTRODUCTION

NG-1100 SCOPE

NG-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

Subsection NG establishes rules for materials, design, fabrication, examination, and preparation of reports required in the manufacture and installation of core support structures.[1, 2]

NG-1120 DEFINITION OF STRUCTURES AND APPLICATION OF THESE RULES TO THEM

NG-1121 Core Support Structures

Core support structures shall be constructed to the rules of this Subsection. Core support structures are those structures or parts of structures which are designed to provide direct support or restraint of the core (fuel and blanket assemblies) within the reactor pressure vessel. Structures which support or restrain the core only after the postulated failure of core support structures are considered to be internal structures (NG-1122).

NG-1122 Internal Structures

(a) Internal structures are *all* structures within the reactor pressure vessel other than core support structures, fuel[3] and blanket assemblies, control assemblies, and instrumentation.

(b) The rules of this Subsection apply to internal structures as defined in (a) above, only when so stipulated by the Certificate Holder manufacturing core supports, hereafter referred to in this Subsection as Certificate Holder.

(c) The Certificate Holder shall certify[2] that the construction of all internal structures is such as not to affect adversely the integrity of the core support structure.

NG-1123 Temporary Attachments

A temporary attachment is an element in contact with or connected to the core support structure, which is removed prior to operation. Temporary attachments include items such as alignment lug tie straps and braces.

NG-1130 BOUNDARIES OF JURISDICTION APPLICABLE TO THIS SUBSECTION

NG-1131 Boundary Between Core Support Structure and Reactor Pressure Vessel

The jurisdictional boundary between a core support structure and the reactor pressure vessel shall be the surface of the core support structure. The first connecting weld of a core support structure to the reactor pressure vessel shall be considered part of the reactor pressure vessel unless the weld is more than $2t$ from the pressure-retaining portion of the reactor pressure vessel, where t is the nominal thickness of the pressure-retaining material. Beyond the first connecting weld to the reactor pressure vessel, or beyond $2t$ from the pressure-retaining portion of the reactor pressure vessel, the first weld shall be considered part of the core support structure, unless otherwise specified in the Design Specification. Mechanical fasteners used to connect a core support structure to the reactor pressure vessel shall meet the requirements of this Subsection. Figure NG-1131-1 is provided as an aid in defining the boundary and construction requirements of this Subsection.

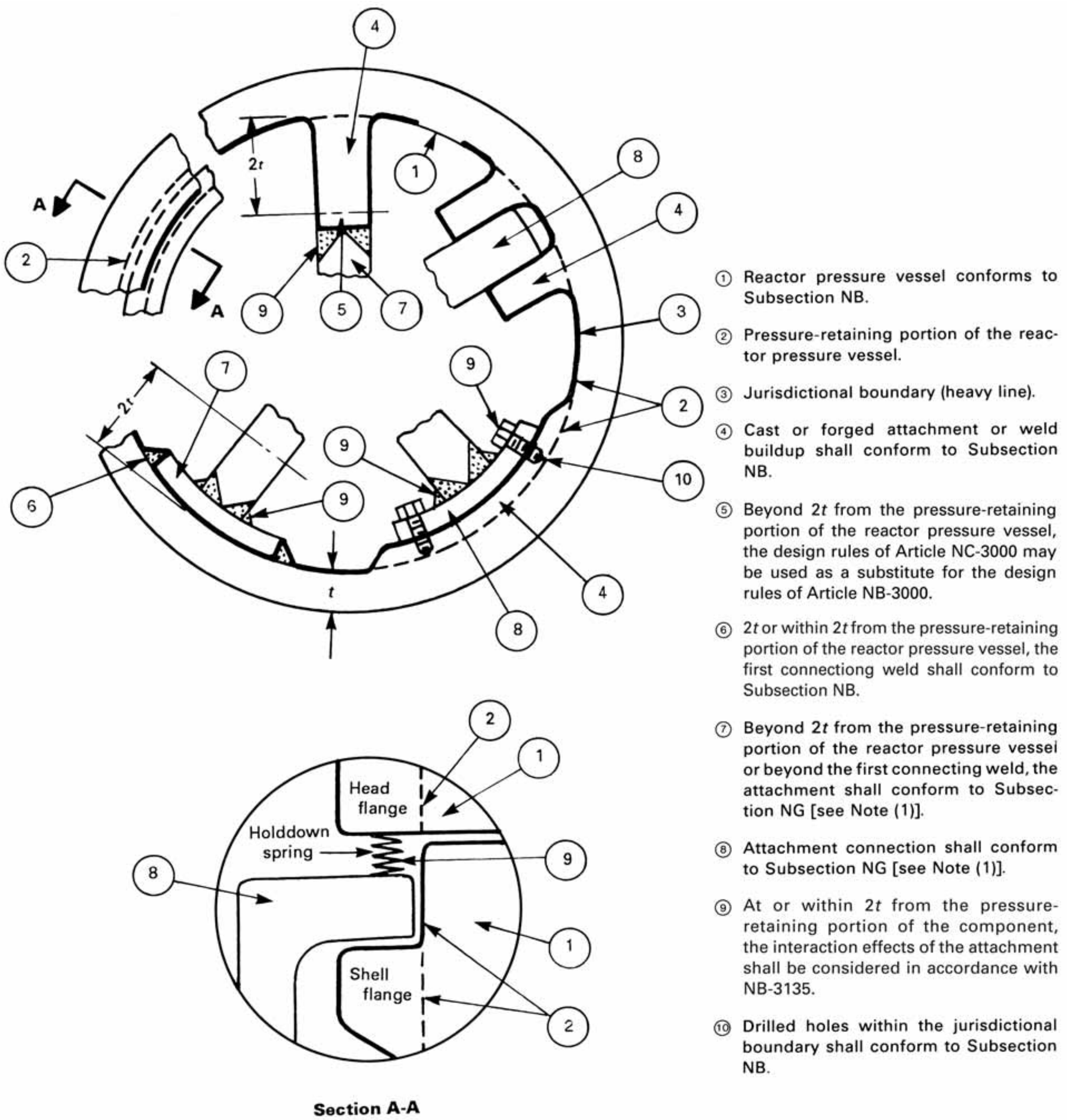
NG-1132 Boundary Between Core Support Structure and Internal Structure

(a) Internal structures may bear on or may be welded, cast, or fastened to core support structures.

(b) The jurisdictional boundary between a core support structure and an internal structure is the surface of the core support structure. The means by which the internal structure is connected to the core support structure shall fall within the jurisdiction of this Subsection.

(c) One or more portions of a casting may be classified as core support structures and different portions of the same casting may be classified as internal structures. The portions of the casting so classified shall be defined by the Design Specification or on the drawing. The entire casting (core support and internal structural portions) shall meet the material property requirements of Article NG-2000 with the additional nondestructive examinations of the internal structure portion sufficient to meet the requirement of NG-1122(c).

Figure NG-1131-1
Jurisdictional Boundary Between Core Support Structure and Reactor Pressure Vessel



GENERAL NOTE: These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

NOTE:

(1) If the attachment is an internal structure (NG-1122), material, design, and connections, as appropriate, are outside Code jurisdiction except when the Certificate Holder stipulates they shall conform to Subsection NG.

NG-1133 Boundary Between Core Support Structure and Temporary Attachment

The jurisdictional boundary between a core support structure and a temporary attachment shall be the surface of the core support structure.

ARTICLE NG-2000
MATERIAL

NG-2100 GENERAL REQUIREMENTS FOR MATERIAL

NG-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in NCA-1220. The term *Material Organization* is defined in Article NCA-9000.

(b) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply:

(1) plate: the thickness is the dimension of the short transverse direction.

(2) forgings: the thickness is the dimension defined as follows:

(-a) hollow forgings: the nominal thickness is measured between the inside and outside surfaces (radial thickness).

(-b) disk forgings (axial length less than the outside diameter): the nominal thickness is the axial length.

(-c) flat ring forgings (axial length less than the radial thickness): for axial length ≤ 2 in. (50 mm), the axial length is the nominal thickness; for axial length > 2 in. (50 mm), the radial thickness is the nominal thickness.

(-d) rectangular solid forgings: the least rectangular dimension is the nominal thickness.

(3) castings: thickness, t, is defined as the largest nominal thickness of the load carrying portion of the casting.

NG-2120 MATERIAL FOR CORE SUPPORT STRUCTURES

NG-2121 Permitted Material Specifications

(a) Core support structural material, and material welded thereto, and threaded structural fasteners, with the exception of welding material (NG-2430), hard surfacing material (Section IX, QW-251.4), cladding which is 10% or less of the thickness of the base material (NG-3122), or the material excluded by NG-4430, shall conform to the requirements of the specifications for material given in Section II, Part D, Subpart 1, Tables 2A and 2B, including all applicable notes in the table, and to all of the special requirements of this Article which apply to the product form in which the material is used.

(b) The requirements of this Article apply to the internal structures (NG-1122) only as specifically stipulated by the Certificate Holder; however, the Certificate Holder shall certify that the material used for the internal structures shall not adversely affect the integrity of the core support structure.

(c) Welding material used in manufacture of items shall comply with an SFA Specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to materials used as backing rings or backing strips in welded joints.

NG-2122 Special Requirements Conflicting With Permitted Material Specifications

Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specification wherever the special requirements conflict with the material specification requirements (NCA-3856). Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination, test, or treatment need be performed only once. Required nondestructive examinations shall be performed as specified for each product form in NG-2500. Any examination, repair, test, or treatment required by the material specification or this Article may be performed by the Material Organization or the Certificate Holder as provided in NG-4121.1. Any hydrostatic or pneumatic pressure test required by a material specification need not be performed provided the material is not used in a pressure-retaining function.

(a) The stress rupture test of SA-453 and SA-638 for Grade 660 (UNS S66286) is not required for design temperatures of 800°F (427°C) and below.

NG-2124 Size Ranges

Material outside the limits of size or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in the rules for construction. In those specifications in which chemical composition, mechanical properties, or both are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range (NCA-3856).

NG-2130 CERTIFICATION OF MATERIAL

All material used in the construction or installation of core support structures shall be certified as required in NCA-3862 and NCA-3861. Certified Material Test Reports are required for core support material except as provided by NCA-3862. A Certificate of Compliance may be provided in lieu of Certified Material Test Reports for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a core support structure shall be furnished with the material.

NG-2140 WELDING MATERIAL

For the requirements governing the material to be used for welding, see NG-2400.

NG-2150 MATERIAL IDENTIFICATION

The identification of material for core support structures shall meet the requirements of NCA-3856. Material for small items shall be controlled during manufacture of the core support structures so that they are identifiable as acceptable material at all times. Welding material shall be controlled during the repair of material and the manufacture and installation of core support structures so that they are identifiable as acceptable material until the material is actually consumed in the process (NG-4122).

NG-2160 DETERIORATION OF MATERIAL IN SERVICE

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (NCA-3250), with specific attention being given to the effects of service conditions upon the properties of the material.

NG-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES

Carbon steels, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat-treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the component at a temperature of not less than 1100°F (595°C) may be considered to be the tempering phase of the heat treatment.

NG-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and -calibrated furnaces or the heat treating shall be controlled by measurement of material temperature by thermocouples in contact with the material or attached to blocks in contact with the material or by calibrated pyrometric instruments. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

NG-2190 TEMPORARY ATTACHMENT MATERIAL

Material used for temporary attachments need not comply with Article NG-2000 and may be welded to the core support structure provided the requirements of NG-4430 are met.

NG-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL

NG-2210 HEAT TREATMENT REQUIREMENTS

NG-2211 Test Coupon Heat Treatment for Ferritic Material[4]

Where ferritic steel material is subjected to heat treatment during construction, the material used for the tensile and impact test specimens shall be heat-treated in the same manner as the core support structures, except that test coupons and specimens for P-No. 1 Groups Nos. 1 and 2 material with a nominal thickness of 2 in. (50 mm) or less are not required to be so heat-treated. The Certificate Holder shall provide the Material Organization with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle.

NG-2212 Test Coupon Heat Treatment for Quenched and Tempered Material

NG-2212.1 Cooling Rates. Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing those materials shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings and castings (NG-2223.3 and NG-2226.4). This rule shall apply for coupons taken directly from the material as well as for separate test coupons representing the material, and one of the general procedures described in NG-2212.2 or one of the specific procedures described in NG-2220 shall be used for each product form.

NG-2212.2 General Procedures. One of the general procedures stipulated in (a) through (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with NG-2220. Further specific details of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used which can be demonstrated to produce a cooling rate in the test material that matches the cooling rate of the main body of the product at the region midway between midthickness and the

surface ($^1/_4t$) and no nearer any heat-treated edge than a distance equal to the nominal thickness t being quenched within 25°F (14°C) and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat-treated in the device to represent the material provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in NG-2220 are used, faster cooling rates at the edges may be compensated for by

(1) taking the test specimens at least t from a quenched edge where t equals the material thickness

(2) attaching a steel pad at least t wide by a partial penetration weld, which completely seals the buffered surface, to the edge where specimens are to be removed

(3) using thermal barriers or insulation at the edge where specimens are to be removed

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

NG-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL

NG-2221 General Requirements

The procedure for obtaining test coupons and specimens for quenched and tempered material is related to the product form. Coupon and specimen location and the number of tension test specimens shall be in accordance with the material specifications, except as required by this subarticle. References to dimensions signify nominal values.

NG-2222 Plates

NG-2222.1 Number of Tension Test Coupons. The number of tension test coupons required shall be in accordance with the material specification and SA-20, except that from carbon steel plates weighing 42,000 lb (19 000 kg) and over and alloy steel plates weighing 40,000 lb (18 000 kg) and over, two tension test coupons shall be taken, one representing the top end of the plate and one representing the bottom end of the plate.

NG-2222.2 Orientation and Location of Coupons. Coupons shall be taken so that specimens shall have their longitudinal axes at least $^1/_4t$ from a rolled surface and with the midlength of the specimen at least t from any heat-treated edge, where t is the nominal thickness of the material.

NG-2222.3 Requirements for Separate Test Coupons. Where a separate test coupon is used to represent the core support structure material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least $^1/_4t$ deep and t from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with NG-2212.2(b), the dimensions of the coupon shall be not less than $3t \times 3t \times t$, where t is the nominal material thickness.

NG-2223 Forgings

NG-2223.1 Location of Coupons. Coupons shall be taken so that specimens shall have their longitudinal axes at least $^1/_4t$ from any surface and with the midlength of the specimens at least t from any second surface, where t is the maximum heat-treated thickness. A thermal buffer as described in NG-2212.2(c) may be used to achieve these conditions, unless cooling rates applicable to the bulk forgings are simulated as otherwise provided in NG-2212.2.

NG-2223.2 Very Thick and Complex Forgings. Test coupons for forgings which are both very thick and complex, such as contour nozzles, flanges, nozzles, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, may be removed from prolongations or other stock provided on the product. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat-treated surface, equivalent at least to the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat-treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than $^3/_4$ in. (19 mm) to any heat-treated surface and the midlength of the specimens shall be at least $1^1/_2$ in. (38 mm) from any second heat-treated surface.

NG-2223.3 Coupons From Separately Produced Test Forgings. Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in the following:

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat-treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface and with the midlength of the specimens no nearer any heat-

treated edge than a distance equal to the forging thickness except when the thickness-to-length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

(e) Test coupons for complex forgings shall be taken in accordance with NG-2223.2.

NG-2224 Location of Coupons

(a) Bars. Coupons shall be taken so that specimens shall have their longitudinal axes at least $^1/_4t$ from the outside or rolled surface and with the midlength of the specimens at least t from a heat-treated end, where t is either the bar diameter or thickness.

(b) Threaded Structural Fastener Material. For threaded structural fastener material, the coupons shall be taken in conformance with the applicable material specification and with the midlength of the specimen at least one diameter or thickness from a heat-treated end. When the threaded structural fasteners, including studs and nuts, are not of sufficient length, the midlength of the specimen shall be at the midlength of the threaded structural fasteners. The threaded structural fasteners, including studs and nuts, selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented threaded structural fasteners.

NG-2225 Tubular Products and Fittings

NG-2225.1 Location of Coupons. Coupons shall be taken so that specimens shall have their longitudinal axes at least $^1/_4t$ from the inside or outside surface and with the midlength of the specimens at least t from a heat-treated end, where t is the nominal wall thickness of the tubular product.

NG-2225.2 Separately Produced Coupons Representing Fittings. Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of NG-2223.3 shall be met.

NG-2226 Castings

NG-2226.1 Castings With 2 in. (50 mm) Maximum Thickness and Less. For castings with a maximum thickness of 2 in. (50 mm) and less, the specimens shall be taken from either the standard separately cast coupons or the casting, in accordance with the material specification.

NG-2226.2 Castings With Thicknesses Exceeding 2 in. (50 mm) Maximum Thickness. For castings exceeding a thickness of 2 in. (50 mm), the coupons shall be taken from the casting (or an extension of it) so that specimens shall have their longitudinal axes at least $^1/_4t$ of the maximum heat-treated thickness from any surface and with the midlength of the specimens at least t from any second surface. A thermal buffer may be used [NG-2212.2(c)].

NG-2226.3 Separately Cast Test Coupons for Castings With Thicknesses Exceeding 2 in. (50 mm). In lieu of the requirements of NG-2226.2, separately cast test coupons may be used under the following conditions:

(a) The separate test coupon representing castings from one heat and one heat treatment lot shall be of the same heat of material and shall be subjected to substantially the same foundry practices as the production casting it represents.

(b) The separate test coupon shall be heat-treated in the same furnace charge and under the same conditions as the production casting, unless cooling rates applicable to the bulk castings are simulated in accordance with NG-2212.2.

(c) The separate test coupon shall be not less than $3t \times 3t \times t$, where t equals the nominal thickness of the casting. Test specimens shall be taken with their longitudinal axes at the region midway between midthickness and the surface and with the midlength of the specimens no nearer any heat-treated edge than a distance equal to the casting thickness.

NG-2226.4 Castings Machined or Cast to Finished Configuration Before Heat Treatment. In lieu of the requirements of NG-2226.1, NG-2226.2, or NG-2226.3, test coupons may be removed from prolongations or other stock provided on the product. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat-treated surface equivalent at least to the greatest distance that the indicated high tensile stress surface will be from the nearest outside surface during heat treatment and with the midlength of the specimens a minimum of twice this distance from a second heat-treated surface. In any case, the longitudinal axes of the specimens shall be at least $^3/_4$ in. (19 mm) from any heat-treated surface and the midlength of the specimens shall be at least $1^1/_2$ in. (38 mm) from any second heat-treated surface. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service.

NG-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

NG-2310 MATERIAL TO BE IMPACT TESTED

NG-2311 Components for Which Impact Testing of Material Is Required

(a) When the Design Specifications for core support structures require impact testing[5] they shall be impact tested in accordance with the requirements of NG-2300, except that the following materials are not to be impact tested as a requirement of this Subsection:

(1) material with a nominal section thickness of $^5/_8$ in. (16 mm) and less

(2) threaded structural fasteners, including studs and nuts, with a nominal size of 1 in. (25 mm) and less

(3) bars with a nominal cross-sectional area of 1 in.^{2} (650 mm^2) and less

(4) all thicknesses of materials for pipe, tube, and fittings with an NPS 6 (DN 150) diameter and smaller

(5) austenitic stainless steels, including precipitation-hardened austenitic Grade 660 (UNS S66286)

(6) nonferrous material

(b) Drop weight tests are not required for martensitic high alloy chromium (Series 4XX) steels and precipitation-hardening steels listed in Section II, Part D, Subpart 1, Tables 2A and 2B. The other requirements of NG-2331 and NG-2332 apply for these steels. For nominal wall thickness greater than $2^1/_2$ in. (64 mm), the required C_v value shall be 40 mils (1.00 mm) lateral expansion.

NG-2320 IMPACT TEST PROCEDURES

NG-2321 Types of Tests

NG-2321.1 Drop Weight Tests. The drop weight test, when required, shall be performed in accordance with ASTM E208. Specimen types P-1, P-2, or P-3 may be used. The orientations and locations of all test specimens and the results of all tests performed to meet the requirements of NG-2330 shall be reported in the Certified Material Test Report.

NG-2321.2 Charpy V-Notch Tests. The Charpy V-notch test (C_v), when required, 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 lateral expansion and absorbed energy, as applicable, and the test temperature, as well as the orientation and location of all tests performed to meet the requirements of NG-2330 shall be reported in the Certified Material Test Report.

NG-2322 Test Specimens

NG-2322.1 Location of Test Specimens. Impact test specimens for quenched and tempered material shall be removed from the locations in each product form specified in NG-2220 for tensile test specimens. For material in other heat-treated conditions, impact test specimens shall be removed from the locations specified for tensile specimens in the material specification. For all other material, the number of tests shall be in accordance with NG-2340. For threaded structural fasteners, the C_v impact test specimens shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimens shall be at least one diameter or thickness from the heat-treated end. When the threaded structural fasteners, including studs and nuts, are not of sufficient length, the midlength of the specimen shall be at the midlength of the threaded structural fasteners. The threaded structural fasteners, including studs and nuts, selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented threaded structural fasteners.

NG-2322.2 Orientation of Impact Test Specimens.

(a) Specimens for Charpy V-notch tests shall be oriented as follows:

(1) Specimens for forgings, other than threaded structural fasteners and bars, shall be oriented in a direction normal to the principal direction in which the material was worked. Specimens are neither required nor prohibited from the thickness direction.

(2) Specimens from material for pipe, tube, and fittings, except for those made from plate, shall be oriented in the axial direction.

(3) Specimens from threaded structural fastener material and bars shall be oriented in the axial direction.

(4) Specimens for all plate material, including those used for pipe, tube, and fittings, shall be oriented in a direction normal to the principal rolling direction, other than thickness direction.

(5) Specimens for cast material shall have their axes oriented the same as the axes of the tensile specimens (NG-2226).

(6) In cases (1) through (5) above, the length of the notch of the C_v specimen shall be normal to the surface of the material.

(b) Specimens for drop weight tests may have their axes oriented in any direction. The orientation used shall be reported in the Certified Material Test Report.

NG-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS[6]

NG-2331 Material for Core Support Structures Not Exceeding 2 in. (50 mm) Maximum Thickness

Material for core support structures (other than threaded structural fasteners) with nominal thickness 2 in. (50 mm) and less shall be tested as required in the following:

(a) Test three C_v specimens at a temperature lower than or equal to the lowest service temperature.[7] All three specimens shall meet the requirements of Table NG-2331(a)-1.

(b) Apply the procedures of (a) above to

(1) base material,[8]

(2) the base material, the heat-affected zone, and weld metal from the weld procedure qualification tests in accordance with NG-4330, and

(3) the weld metal of NG-2431.

Table NG-2331(a)-1
Required C_v Values for Core Structure Material With 2 in. (50 mm) Maximum Thickness (Other than Threaded Structural Fasteners)

Nominal Wall Thickness, in. (mm)	Lateral Expansion, mils (mm)
$^5/_8$ (16) or less	No test required
Over $^5/_8$ to $^3/_4$ (16 to 19), incl.	20 (0.50)
Over $^3/_4$ to $1^1/_2$ (19 to 38), incl.	25 (0.64)
Over $1^1/_2$ to $2^1/_2$ (38 to 64), incl.	40 (1.00)

NG-2332 Material With Thickness Exceeding 2 in. (50 mm)

Material for core support structures (other than threaded structural fasteners) with nominal wall thickness over 2 in. (50 mm) shall meet the following requirements:

(a) Establish a reference temperature RT_{NDT}; this shall be done as required in (1) through (5) below.

(1) Determine a temperature T_{NDT} which is at or above the nil-ductility transition temperature by drop weight tests.

(2) At a temperature not greater than [T_{NDT} + 60°F (33°C)], each specimen of the C_v test (NG-2321.2) shall exhibit at least 35 mils (0.89 mm) lateral expansion and not less than 50 ft-lb (68 J) absorbed energy. Retesting in accordance with NG-2350 is permitted. When these requirements are met, T_{NDT} is the reference temperature RT_{NDT}.

(3) In the event that the requirements of (2) are not met, conduct additional C_v tests in groups of three specimens (NG-2321.2) to determine the temperature T_{C_v} at which they are met. In this case, the reference temperature $RT_{NDT} = T_{C_v}$ − 60°F (33°C). Thus, the reference temperature RT_{NDT} is the higher of T_{NDT} or [T_{C_v} − 60°F (33°C)].

(4) When a C_v test has not been performed at [T_{NDT} + 60°F (33°C)] or when the C_v test at [T_{NDT} + 60°F (33°C)] does not exhibit a minimum of 50 ft-lb (68 J) energy absorption and 35 mils (0.89 mm) lateral expansion, a temperature representing a minimum of 50 ft-lb (68 J) energy absorption and 35 mils (0.89 mm) lateral expansion may be obtained from a full C_v impact curve developed from the minimum data points of all the C_v tests performed.

(5) The lowest service temperature shall be not lower than RT_{NDT} + 100°F (55°C) unless a lower temperature is justified by using methods similar to those contained in Section III Appendices, Nonmandatory Appendix G, Article G-2000.

(b) Apply the procedures of (a) above to

(1) the base material

(2) the base material, the heat-affected zone, and weld metal from the weld procedure qualification tests in accordance with NG-4330

(3) the weld metal of NG-2431

(c) Product forms having dimensions which prohibit obtaining drop weight test specimens shall be tested in accordance with NG-2331.

(d) Consideration shall be given to the effects of irradiation on material toughness properties (such as core beltline region of reactor). The Design Specifications shall include additional requirements, as necessary, to assure adequate fracture toughness for the service lifetime of the core support structures. The toughness properties may be verified in service periodically by a material surveillance program using the methods of ASTM E185 and the material conditions monitored by the in-service inspection requirements of Section XI.

NG-2333 Threaded Structural Fasteners

For threaded structural fastener material, including studs and nuts, test three C_v specimens at a temperature no higher than the preload temperature or the lowest service temperature, whichever is the lesser. All three specimens shall meet the requirements of Table NG-2333-1.

NG-2340 NUMBER OF IMPACT TESTS REQUIRED

NG-2341 Plates

One test shall be made from each plate as heat-treated. Where plates are furnished in the nonheat-treated condition and qualified by heat-treated test specimens, one test shall be made for each plate as-rolled. The term *as-rolled* refers to the plate rolled from a slab or directly from an ingot, not to its heat-treated condition.

NG-2342 Forgings and Castings

(a) Where the weight of an individual forging or casting is less than 1,000 lb (450 kg), one test shall be made to represent each heat in each heat treatment lot.

(b) When heat treatment is performed in a continuous type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment

Table NG-2333-1
Required C_v Values for Threaded Structural Fastener Material

Nominal Diameter, in. (mm)	Lateral Expansion, mils (mm)	Absorbed Energy, ft-lb (J)
1 (25) or less	No test required	No test required
1 (25) through 4 (100)	25 (0.64)	No requirements
Over 4 (100)	25 (0.64)	45 (61)

charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2,000 lb (900 kg).

(c) One test shall be made for each forging or casting of 1,000 lb to 10,000 lb (450 kg to 4 500 kg) in weight.

(d) As an alternative to (c) above, a separate test forging or casting may be used to represent forgings or castings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

(e) Forgings or castings larger than 10,000 lb (4 500 kg) shall have two tests per part for Charpy V-notch and one test for drop weights. The location of drop weight or C_v impact test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging or casting 180 deg apart.

(f) As an alternative to (e) for static castings, a separately cast test coupon (NG-2226.3) may be used; one test shall be made for Charpy V-notch and one test for drop weight.

NG-2343 Bars

One test shall be made for each diameter or size having a nominal cross-sectional area greater than 1 in.^{2} in each lot, where a lot is defined as one heat of material heat-treated in one charge or as one continuous operation, not to exceed 6,000 lb (2 700 kg).

NG-2344 Tubular Products and Fittings

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than $^1/_4$ in. (6 mm); such a lot shall be in a single heat treatment load or in the same continuous run in a continuous furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

NG-2345 Threaded Structural Fastener Material

One test shall be made for each lot of material where a lot is defined as one heat of material heat-treated in one charge or as one continuous operation, not to exceed in weight the following:

Diameter	Weight
$1^3/_4$ in. (45 mm) and less	1,500 lb (700 kg)
Over $1^3/_4$ in. to $2^1/_2$ in. (45 mm to 64 mm)	3,000 lb (1 350 kg)
Over $2^1/_2$ in. to 5 in. (64 mm to 125 mm)	6,000 lb (2 700 kg)
Over 5 in. (125 mm)	10,000 lb (4 500 kg)

NG-2346 Test Definition

Unless otherwise stated in NG-2341 through NG-2345, the term *one test* is defined to include the combination of the drop weight test and the C_v test when RT_{NDT} is required (NG-2332) and only the C_v test when determination of RT_{NDT} is not required (NG-2331).

NG-2350 RETESTS

(a) For C_v tests required by NG-2330, one retest at the same temperature may be conducted, provided

(1) the average value of the test results meets the minimum requirements

(2) not more than one specimen per test is below the minimum requirements

(3) the specimen not meeting the minimum requirements is not lower than 10 ft-lb (13.6 J) or 5 mils (0.13 mm) below the specified requirements

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retest, both specimens shall meet the minimum requirements.

NG-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and C_v impact test machines used in impact testing shall be performed at the frequency specified in the following:

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-3858.2 at least once in each 3-month interval.

(b) C_v test machines shall be calibrated and the results recorded to meet the requirements of NCA-3858.2. The calibrations shall be performed using the frequency and methods outlined in ASTM E23 and employing standard specimens obtained from the National Institute of Standards and Technology, or any supplier of subcontracted calibration services accredited in accordance with the requirements of NCA-3126 and NCA-3855.3(c).

NG-2400 WELDING MATERIAL

NG-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of components or material, except welding material used for hard surfacing, shall conform to the requirements of the material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this subarticle and to the rules covering identification in NG-2150.

(b) The Certificate Holder shall provide the organization performing the testing with the following information, as applicable:

(1) welding process

(2) SFA Specification and classification

(3) other identification if no SFA Specification applies

(4) minimum tensile strength [NG-2431.1(e)] in either the as-welded or heat-treated condition or both [NG-2431.1(c)]

(5) drop weight test for material as-welded or heat-treated or both (NG-2332)

(6) Charpy V-notch test for material as-welded or heat-treated or both (NG-2331); the test temperature, and the lateral expansion or the absorbed energy, shall be provided

(7) the preheat and interpass temperatures to be used during welding of the test coupon [NG-2431.1(c)]

(8) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat-treated [NG-2431.1(c)]

(9) elements for which chemical analysis is required per the SFA Specification or WPS, and NG-2432

(10) minimum delta ferrite (NG-2433)

(15) NG-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electro-gas welding) processes (Section IX, QG-109); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux; for each combination of lot of fabricated electrodes and lot of submerged arc flux; for each combination of heat of bare electrodes or lot of fabricated electrodes and dry blend of supplementary powdered filler metal and lot of submerged arc flux; or for each combination of heat of bare electrodes and lot of electroslag flux. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by Article NG-4000 and this subarticle are made and the results conform to the requirements of this Article. The following definitions apply:

(a) dry batch of covering mixture: the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes [see (c)].

(b) dry blend: one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) wet mix: the combination of a dry batch or dry blend [(a) and (b), respectively] and liquid binder ingredients at one time in one mixing vessel.

(d) lot of covered, flux cored, or fabricated electrodes: the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45 000 kg), from chemically controlled tube, wire, or strip and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding materials is coded for identification and traceable to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrodes.

(1) chemically controlled tube, wire, or strip: consumable tube, wire, or strip material supplied on coils with a maximum of one splice per coil that has been chemically analyzed to ensure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed, except those coils which are splice free need only be analyzed on one end of the coil.

(2) chemically controlled mixes of flux: flux material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) heat of bare electrode, rod, wire, or consumable insert: the material produced from the same melt of metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with SAW, OFW, GMAW, GTAW, PAW, and EGW processes, a *heat* may be defined as either the material produced from the same melt of metal, or the material produced from one type and size of wire when produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45 000 kg), from chemically controlled wire, subject to the following requirements:

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(2) Carbon, manganese, silicon, and other intentionally added elements shall be determined to identify the material to ensure that it conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) lot of submerged arc or electroslag flux: the quantity of flux produced from the same combination of raw materials under one production schedule.

(h) dry blend of supplementary powdered filler metal: one or more mixes of material produced in a continuous period, not to exceed 24 hr and not to exceed 20,000 lb

(9 000 kg), from chemically controlled mixes of powdered filler metal, provided each container of powdered metal is coded for identification and traceable to the production period, the shift, and the mixing vessel.

(i) chemically controlled mix of powdered filler metal: powdered filler metal material that has been chemically analyzed to ensure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

NG-2430 WELD METAL TESTS

NG-2431 Mechanical Properties Test

Tensile and impact tests shall be made, in accordance with this paragraph, of welding material used to join P-Nos. 1, 3 through 7, 9, and 11 base materials in any combination, with the following exceptions:

(a) austenitic stainless steel and nonferrous welding material used to join the listed P-Numbers

(b) consumable inserts (backing filler material)

(c) welding material used for GTAW root deposits with a maximum of two layers

(d) welding material to be used for the welding of base material exempted from impact testing by NG-2300 shall likewise be exempted from the impact testing required by this paragraph

NG-2431.1 General Test Requirements. The welding test coupon shall be made in accordance with (a) through (f) below using each process with which the weld material will be used in production welding.

(a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.

(b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to eliminate substantially the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding. The base material shall conform with the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.

(c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures which will be used in production welding. Coupons shall be tested in the as-welded condition or they shall be tested in the applicable postweld heat-treated condition when the production welds are to be postweld heat-treated. The postweld heat treatment holding time[4] shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process that are tested in the as-welded condition, or following a postweld heat treatment within the holding temperature ranges of Table NG-4622.1-1 or Table NG-4622.4(c)-1, shall have a thickness within the range of 0.5 to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment which will include heating the coupon to a temperature above the "Holding Temperature Range" of Table NG-4622.1-1 for the type of material being tested shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.

(d) The tensile specimens, and the C_v impact specimens where required, shall be located and prepared in accordance with the requirements of SFA-5.1, or the applicable SFA Specification. Drop weight impact test specimens, where required, shall be oriented so that the longitudinal axis is transverse to the weld with the notch in the weld face or in a plane parallel to the weld face. For impact specimen preparation and testing, the applicable parts of NG-2321.1 and NG-2321.2 shall apply. The longitudinal axis of the specimen shall be at a minimum depth of $^1/_4t$ from a surface, where t is the thickness of the test weld.

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. When base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirements of either of the base material specifications.

(f) Impact specimens of the weld metal shall be tested where impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the requirements of NG-2330 applicable to the base material. Where different requirements exist for the two base materials, the weld metal may conform to either of the two requirements.

NG-2431.2 Standard Test Requirements. In lieu of the use of the General Test Requirements specified in NG-2431.1, tensile and impact tests may be made in accordance with this subparagraph where they are required for mild and low alloy steel covered electrodes. The material combinations to require weld material testing, as listed in NG-2431, shall apply for this Standard Test Requirements option. The limitations and testing under this Standard Test option shall be in accordance with the following:

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in Specification SFA-5.1 or SFA-5.5.

(b) The test assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of C_v specimens and the drop weight test specimens required by NG-2330, where applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA Specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also in the postweld heat-treated condition. The postweld heat treatment temperatures shall be in accordance with Table NG-4622.1-1 for the applicable P-Number equivalent. The time at postweld heat treatment temperature shall be 8 hr (this qualifies postweld heat treatments of 10 hr or less). Where the postweld heat treatment of the production weld exceeds 10 hr or the PWHT temperature is other than that required above, the general test of NG-2431.1 shall be used.

(d) The tensile and C_v specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable. Drop weight impact test specimens, where required, shall be located and oriented as specified in NG-2431.1(d).

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA Specification for the applicable electrode classification.

(f) The requirements of NG-2431.1(f) shall be applicable to the impact testing of this option.

NG-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with NG-2420 and as required by the following subparagraphs.

(15) **NG-2432.1 Test Method.** The chemical analysis test shall be performed in accordance with this subparagraph and Table NG-2432.1-1, and the results shall conform to NG-2432.2.

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for either the filler metal analysis or the undiluted weld deposit analysis or for *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA Specification. Where a weld deposit method is not provided by the SFA Specification, the sample shall be removed from a weld pad, groove, or other test weld[9] made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specifications that will be followed when the material is consumed. The test sample for ESW shall be removed from the weld metal of the Mechanical Properties Test coupon. Where a chemical analysis is required for a welding material which does not have a Mechanical Properties Test requirement, a chemical analysis test coupon shall be prepared as required by NG-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of NG-2431.1(c) do not apply.

(d) The alternative method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion-resistant overlay cladding shall require a test weld made in accordance with the essential variables of the Welding Procedure Specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis samples shall conform with QW-453 for the minimum thickness for which the Welding Procedure Specification is qualified.

NG-2432.2 Requirements for Chemical Analysis. The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with the following:

Table NG-2432.1-1
Sampling of Welding Materials for Chemical Analysis

	GTAW/PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

(a) All welding material shall be analyzed for the elements listed in Table NG-2432.2-1 and for other elements specified either in the welding material specification referenced by the Welding Procedure Specification or in the Welding Procedure Specification.

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the Welding Procedure Specification shall apply for acceptability.

(c) The results of the chemical analysis shall be reported in accordance with NCA-3862.1. Elements listed in Table NG-2432.2-1 but not specified in the welding material specification shall be reported for information only.

NG-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, Table QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.4, Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

NG-2433.1 Method. Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of NG-2432 in conjunction with Figure NG-2433.1-1.

(a) Calibration of magnetic instruments shall conform to AWS A4.2.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with NG-2432.1(c).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number (FN).

Table NG-2432.2-1
Welding Material Chemical Analysis

Materials	Elements
Carbon and low alloy materials	C, Cr, Mo, Ni, Mn, Si, P, S, V, Cu
Chromium and Cr-Ni stainless material	C, Cr, Mo, Ni, Mn, Si, P, S, V, Cb + Ta, Ti, Cu
Nickel and Ni-alloy materials	C, Cr, Mo, Ni, Mn, Si, S, Cb + Ta, Cu, Fe, Co

NG-2433.2 Acceptance Standards. The minimum acceptable delta ferrite shall be 5FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of NG-2130 or NG-4120.

NG-2440 STORAGE AND HANDLING OF WELDING MATERIAL

Suitable storage and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

NG-2500 EXAMINATION AND REPAIR OF CORE SUPPORT STRUCTURE MATERIAL

NG-2510 EXAMINATION OF CORE SUPPORT STRUCTURE MATERIAL

Material for core support structures shall be examined by nondestructive methods applicable to the material and product form as required by the rules of this subarticle.

NG-2520 EXAMINATION AFTER QUENCHING AND TEMPERING

Ferritic steel products that have their properties enhanced by quenching and tempering shall be examined by the methods specified in this subarticle for each product form after the quenching and tempering phase of the heat treatment.

NG-2530 EXAMINATION AND REPAIR OF PLATE

NG-2531 Required Examination

All plates for core support structures greater than $^3/_4$ in. (19 mm) thickness shall be examined by the straight beam ultrasonic method in accordance with NG-2532.1.

NG-2532 Examination Procedures

NG-2532.1 Straight Beam Examination. The requirements for straight beam examination shall be in accordance with SA-578, as shown in Section V, except that the extent of examination and the acceptance standards to be applied are given in the following:

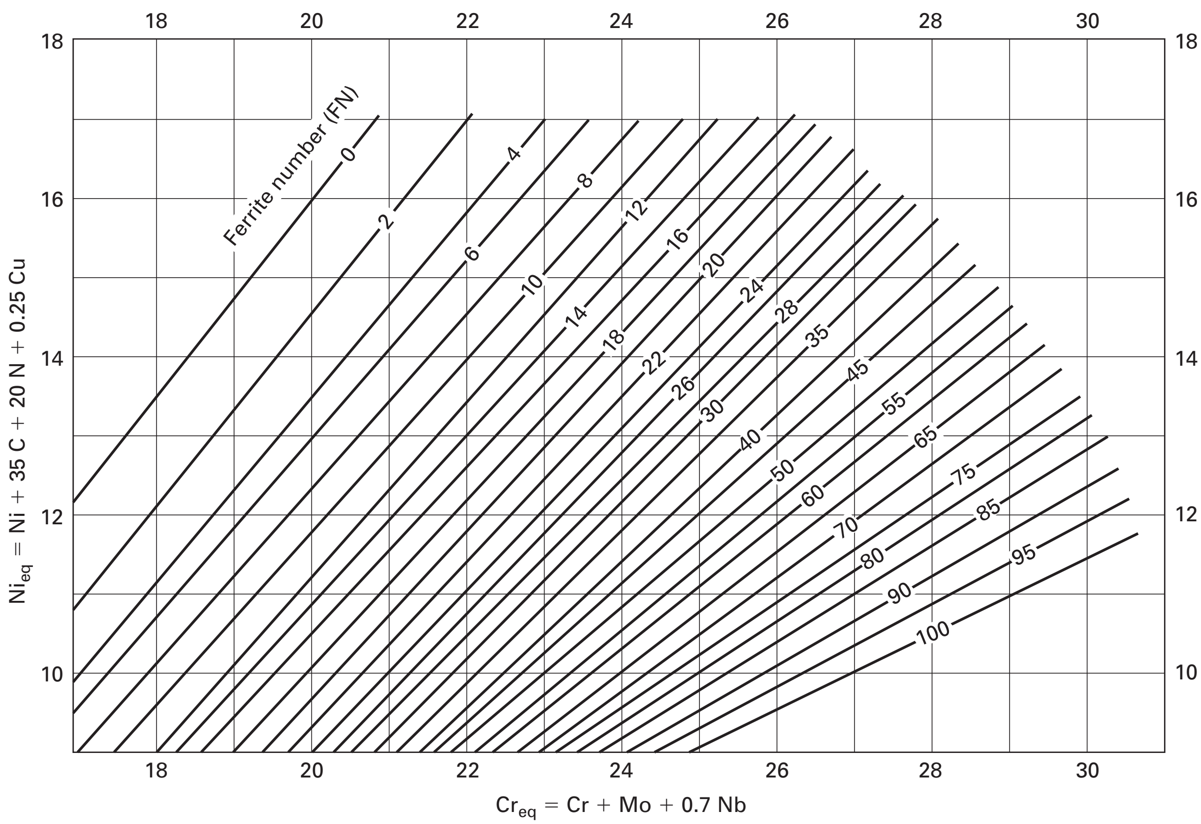
(a) Extent of Examination. 100% of one major plate surface shall be covered by moving the search unit in parallel paths with not less than a 10% overlap.

(b) Acceptance Standards

(1) Any area where one or more imperfections produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. (75 mm) or one-half of the plate thickness, whichever is greater, is unacceptable.

(2) In addition, two or more imperfections smaller than described in (1) above shall be unacceptable unless separated by a minimum distance equal to the greatest

Figure NG-2433.1-1
Weld Metal Delta Ferrite Content



GENERAL NOTES:

(a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:

(1) GMAW welds, 0.08%, except that when self-shielding, flux-cored electrodes are used, 0.12%

(2) Welds made using other processes, 0.06%.

(b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

diameter of the larger imperfection, or unless they may be collectively encompassed by the circle described in (1) above.

NG-2532.2 Angle Beam Examination. The requirements for angle beam examination shall be in accordance with SA-577, Specification for Ultrasonic Shear Wave Inspection of Steel Plates, as shown in Section V, as supplemented by this subparagraph. The calibration notch, extent of examination, and the acceptance standards to be applied are given in the following:

(a) Calibration. Angle beam examination shall be calibrated from a notch.

(b) Extent of Examination. 100% of one major plate surface shall be covered by moving the search unit in parallel paths with not less than 10% overlap.

(c) Acceptance Standards. Material which shows one or more imperfections which produce indications exceeding in amplitude the indication from the calibration notch is unacceptable.

NG-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in the following:

(a) Ultrasonic examination shall be performed after rolling to size and after heat treatment, except postweld heat treatment.

(b) Radiographic examination of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination of repair welds in ferritic material shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment of P-No. 1 material 2 in. (50 mm) and less nominal thickness. All repair welds in austenitic and nonferrous material may be liquid penetrant examined prior to any required postweld heat treatment.

NG-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the following requirements are met:

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface with not less than a 3:1 taper.

(b) After defect elimination, the area is examined by the magnetic particle method in accordance with NG-2545 or the liquid penetrant method in accordance with NG-2546 to assure that the defect has been removed or reduced to an imperfection of an acceptable size.

(c) Areas ground to remove oxide scale or other mechanically caused impressions for appearance or to facilitate proper ultrasonic testing need not be examined by the magnetic particle or liquid penetrant test method.

(d) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of Article NG-3000, the product shall be repaired in accordance with NG-2539.

NG-2539 Repair by Welding

Material from which defects have been removed may be repaired by welding, provided the requirements of the following subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for any repair of plates to be used in the manufacture of core support structures.

NG-2539.1 Defect Removal. The defect shall be removed or reduced to an imperfection of an acceptable size by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair (NG-4211.1).

NG-2539.2 Qualification of Welding Procedures and Welders. The welding procedure and welders or welding operators shall be qualified in accordance with Article NG-4000 and Section IX.

NG-2539.3 Blending of Repaired Areas. After repair, the surface shall be blended uniformly into the surrounding surface.

NG-2539.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method (NG-2545) or by the liquid penetrant method (NG-2546). In addition, when the depth of the repair cavity exceeds the lesser of $^3/_8$ in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed in accordance with Article NG-5000 and to the acceptance standards of NG-5320 or shall be ultrasonically examined after repair in accordance with NG-2532.2 or NG-2532.1.

NG-2539.5 Heat Treatment After Repairs. The product shall be heat-treated after repair in accordance with the heat treatment requirements of NG-4620.

NG-2539.6 Material Report Describing Defects and Repairs. Each defect repair exceeding in depth the lesser of $^3/_8$ in. (10 mm) or 10% of the section thickness and, in addition, all repair welds exceeding an accumulated area of 20% of the area of the part or 15 in.^{2} (9 700 mm^2), whichever is less, shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographs.

NG-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS

NG-2541 Required Examinations

(a) Forgings and bars except as noted in NG-2551 shall be examined by the ultrasonic method in accordance with NG-2542, except that forgings or sections of forgings which have coarse grains or configurations which do not yield meaningful examination results by ultrasonic methods shall be examined by radiographic methods in accordance with Section V, Article 2, and the acceptance standards of NG-5320. In addition, selected surfaces, as designated by the Certificate Holder, shall be liquid penetrant examined in accordance with NG-2546 or magnetic particle examined in accordance with NG-2545.

(b) Forged flanges and fittings, such as elbows, tees, and couplings, shall be examined in accordance with the requirements of NG-2550.

(c) Bar material used for threaded structural fasteners shall be examined in accordance with NG-2580.

NG-2542 Ultrasonic Examination

NG-2542.1 Examination Procedure. All forgings in the rough forged or finished condition, and bars, shall be examined in accordance with one of the following specifications: SA-745, Standard Practice for Ultrasonic Examination of Austenitic Steel Forgings; or SA-388, Recommended Practice for Ultrasonic Testing and Inspection of Heavy Steel Forgings, as shown in Section V, Article 23. Contact, immersion, or water column coupling is permissible. The following techniques are required, as applicable:

(a) All forgings and bars shall be examined by the ultrasonic method using the straight beam technique.

(b) Ring forgings and other hollow forgings shall, in addition, be examined using the angle beam technique in two circumferential directions, unless wall thickness or geometric configuration makes angle beam examination impractical.

(c) Forgings may be examined by the use of alternative ultrasonic methods which utilize distance amplitude corrections provided the acceptance standards are shown to be equivalent to those listed in NG-2542.2.

NG-2542.2 Acceptance Standards.

(a) Straight Beam General Rule. A forging shall be unacceptable if the results of straight beam examinations show one or more reflectors which produce indications accompanied by a complete loss of back reflection not associated with or attributable to geometric configurations.

Complete loss of back reflection is assumed when the back reflection falls below 5% of full calibration screen height.

(b) Angle Beam Rule. A forging shall be unacceptable if the results of angle beam examinations show one or more reflectors which produce indications exceeding in amplitude the indication from the appropriate calibration notches.

NG-2545 Magnetic Particle Examination

NG-2545.1 Examination Procedure. The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7.

NG-2545.2 Evaluation of Indications.

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication in excess of the NG-2545.3 acceptance standards which is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NG-2545.3 Acceptance Standards.

(a) Only imperfections producing indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $^1/_{16}$ in. (1.5 mm) long for material less than $^5/_8$ in. (16 mm) thick, greater than $^1/_8$ in. (3 mm) long for material from $^5/_8$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $^3/_{16}$ in. (5 mm) long for material 2 in. (50 mm) thick and greater

(2) rounded indications with dimensions greater than $^1/_8$ in. (3 mm) for thicknesses less than $^5/_8$ in. (16 mm) and greater than $^3/_{16}$ in. (5 mm) for thicknesses $^5/_8$ in. (16 mm) and greater

(3) four or more relevant indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge

(4) ten or more relevant indications in any 6 in.^{2} (4 000 mm^2) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated

NG-2546 Liquid Penetrant Examination

NG-2546.1 Examination Procedure. The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

NG-2546.2 Evaluation of Indications.

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks or surface conditions may produce similar indications which are not relevant.

(b) Any indication in excess of the NG-2546.3 acceptance standards that is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NG-2546.3 Acceptance Standards.

(a) Only imperfections producing indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $^1/_{16}$ in. (1.5 mm) long for material less than $^5/_8$ in. (16 mm) thick, greater than $^1/_8$ in. (3 mm) long for material from $^5/_8$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $^3/_{16}$ in. (5 mm) long for materials 2 in. (50 mm) thick and greater

(2) rounded indications with dimensions greater than $^1/_8$ in. (3 mm) for thicknesses less than $^5/_8$ in. (16 mm) and greater than $^3/_{16}$ in. (5 mm) for thicknesses $^5/_8$ in. (16 mm) and greater

(3) four or more relevant indications in a line separated by $^1/_{16}$ in. (1.6 mm) or less edge to edge

(4) ten or more relevant indications in any 6 in.^{2} (4 000 mm^2) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated

NG-2547 Time of Examination

Acceptance examinations, including those for repair welds, shall be performed at the time of manufacture as required in the following:

(a) Ultrasonic examination may be performed at any time after forging, and the maximum practical volume shall be examined after final heat treatment, excluding postweld heat treatment.

(b) Radiographic examination of repair welds, if required, may be performed prior to any required postweld heat treatment.

NG-2548 Elimination of Surface Defects

Elimination of surface defects shall be made in accordance with NG-2538.

NG-2549 Repair by Welding

Repair by welding shall be in accordance with NG-2539, except that

(a) the depth of repair that is permitted is not limited, and

(b) for ferritic steel forgings, the completed repair may be examined by the ultrasonic methods in accordance with the requirements of NG-2542 in lieu of radiography.

NG-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED TUBULAR PRODUCTS AND FITTINGS

NG-2551 Required Examination

(a) The examination performed shall be practical and yield meaningful pertinent information for the product form being examined. Certain examination methods are ineffective for some material conditions and product configuration. Some examples are

(1) it may not be practical or meaningful to examine irregular shapes such as welding flanges and fittings by ultrasonic methods

(2) ultrasonic examination employing special techniques is required on coarse-grained austenitic stainless steel or coarse-grained, nickel-base alloy materials

(b) Welded tubular products and fittings, including flanges and fittings, made from plate material greater than $^3/_4$ in. (19 mm) in thickness shall be ultrasonically or radiographically examined in accordance with NG-2552 or NG-2553.

(c) All welds in welded tubular products and fittings, including flanges and fittings, shall be ultrasonically or radiographically examined in accordance with NG-2552 or NG-2553. In addition, all welds shall be magnetic particle or liquid penetrant examined on all accessible surfaces in accordance with NG-2555 or NG-2556.

(d) Wrought seamless tubular products and fittings, including flanges and fittings machined from forgings and bars, greater than $^3/_8$ in. (10 mm) thickness shall be ultrasonically or radiographically examined in accordance with NG-2552 or NG-2553.

NG-2552 Ultrasonic Examination

NG-2552.1 Examination Procedure. The procedure for ultrasonic examination shall provide a sensitivity which will consistently detect defects that produce indications equal to and greater than the indication produced by standard defects included in the reference specimen specified in NG-2552.2. Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimens are unacceptable unless the defects are eliminated or repaired in accordance with NG-2558 or NG-2559, as applicable.

NG-2552.2 Reference Specimens.

(a) The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat-treated condition as the product which is being examined. The standard defects shall be axial notches or grooves on the outside and the inside surfaces of the reference specimen and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $^1/_{16}$ in. (1.5 mm), and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness. The reference specimen may be the product being examined.

(b) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification.

NG-2552.3 Checking and Calibration of Equipment. The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the reference specimens, as a minimum

(a) at the beginning of each production run of a given size and thickness of a given material

(b) after each 4 hr or less during the production run

(c) at the end of the production run

(d) at any time that malfunctioning is suspected

If during any check it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

NG-2553 Radiographic Examination

The radiographic examination shall be performed in accordance with Section V, Article 2, as modified by NG-5111, using the acceptance requirements of NG-5320.

NG-2555 Magnetic Particle Examination

The magnetic particle examination shall be performed in accordance with the requirements of NG-2545.

NG-2556 Liquid Penetrant Examination

The liquid penetrant examination shall be performed in accordance with the requirements of NG-2546.

NG-2557 Time of Examination

Time of acceptance examination, including that of repair welds, shall be in accordance with NG-2537.

NG-2558 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining provided the following requirements are met:

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is reexamined by the method which originally disclosed the defect to assure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of Article NG-3000, the product shall be repaired in accordance with NG-2559.

NG-2559 Repair by Welding

Repair welding of base material defects shall be in accordance with NG-2539. Repair welding of seam defects shall be made in accordance with NG-4450.

NG-2570 EXAMINATION AND REPAIR OF STATICALLY AND CENTRIFUGALLY CAST PRODUCTS

NG-2571 Required Examinations

NG-2571.1 General Requirements. The portion of castings, as specified by the Design Specifications or drawings, used for core support structures shall be examined over the maximum feasible volume by radiographic methods, or ultrasonic methods, or a combination of both methods. Castings or sections of castings which have coarse grains or configurations which do not yield meaningful examination results by ultrasonic methods shall be examined by radiographic methods. In addition, the portion of castings used for core support structures shall be examined on accessible surfaces by either magnetic particle or liquid penetrant methods. Accessible machined surfaces, except threaded surfaces, of a cast product shall be examined by either liquid penetrant or magnetic particle methods after machining.

NG-2571.2 Alternative General Requirements. The portion of castings 2 in. (50 mm) thick and less, which are specified by the Design Specifications or drawings to be used for core support structures, may be utilized when the following requirements are met:

(a) The design stress intensity values in Section II, Part D, Subpart 1, Tables 2A and 2B are reduced by applying a quality factor of 0.75.

(b) A fatigue strength reduction factor of 2.0 is applied to the allowable S_a values when peak stresses are considered.

(c) The portions of castings used as core support structures are magnetic particle or liquid penetrant examined per NG-2575 or NG-2576 on all accessible as-cast or, if machined, machine-finished surfaces. The acceptance criteria of NG-2575 or NG-2576 shall be utilized except that no linear indications greater than $^1/_{16}$ in. (1.5 mm) are permitted.

(d) Five pilot castings[10] made from a new or altered design of a production run[11] shall be radiographically examined over the maximum feasible volume to the requirements of NG-2573.1. If all five pilot castings meet the radiographic acceptance criteria, a production run may be poured. The production run shall be examined using either of the sampling plans specified in (1) or (2) below. The five pilot castings, having passed examination, are not to be included in the following sampling examination programs:

(1) The production run shall be considered a single lot. Twenty castings shall be randomly selected from the production run and examined to the requirements of the pilot castings. The production run is accepted if all 20 castings meet the examination requirements and it is rejected if any one of the 20 castings does not meet the examination requirements. Acceptable castings may be retrieved from a rejected production run by examining all castings from that production run.

(2) The production run castings shall, in order of manufacture, be grouped into sublots with a maximum of 25 castings each. Five castings shall be randomly selected from each sublot and examined to the requirements of the pilot castings. The sublot is accepted if all five castings meet the examination requirements and it is rejected if any one of the five castings does not meet the examination requirements. In the event two sublots are rejected by the sampling examination, succeeding sublots shall have eight castings randomly selected for examination to the requirements of the pilot castings. In any event, acceptable castings may be retrieved from a rejected sublot by examining all castings from that sublot.

NG-2572 Ultrasonic Examination of Castings

The requirements for ultrasonic examination of statically and centrifugally cast products are given in the following subparagraphs.

NG-2572.1 Straight Beam Method. When castings are to be examined ultrasonically, all sections, regardless of thickness, shall be examined in accordance with SA-609, Standard Method and Specification for Longitudinal Beam Ultrasonic Inspection of Carbon and Low Alloy Castings, as shown in Section V; however, supplementary angle beam examination in accordance with NG-2572.2 or radiographic examination in accordance with NG-2573 shall be performed in areas where a back reflection cannot be maintained during the straight beam examination, or where the angle between the two surfaces of the casting is more than 15 deg.

NG-2572.2 Angle Beam Method. Examination shall be conducted in accordance with Section V, Article 5, T-571.4, except that the acceptance standards in Section V do not apply.

NG-2572.3 Acceptance Standards.

(a) The Quality Levels of SA-609 as shown in Section V shall apply for the casting thicknesses indicated.

(1) Quality Level 1 for thicknesses up to 2 in. (50 mm)

(2) Quality Level 3 for thicknesses 2 to 4 in. (50 mm to 100 mm)

(3) Quality Level 4 for thicknesses greater than 4 in. (100 mm)

(b) In addition to the Quality Level requirements stated in (a), the requirements in (1) through (5) shall apply for both straight beam and angle beam examination.

(1) Area imperfections producing indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation are unacceptable:

UT Quality Level	Longest Dimension of Area [Note (1)], [Note (2)], [Note (3)]
1	1.5 in. (38 mm)
2	2.0 in. (50 mm)
3	2.5 in. (64 mm)
4	3.0 in. (75 mm)

NOTES:
(1) The areas for the Ultrasonic Quality Levels in SA-609 as shown in Section V refer to the surface area on the casting over which a continuous indication exceeding the transfer-corrected distance–amplitude curve is maintained.
(2) Areas are to be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.
(3) In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria which incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. (25 mm) of the surface regardless of the overall thickness.

(3) Imperfections indicated to have a change in depth equal to or greater than one-half the wall thickness or 1 in., whichever is less, are unacceptable.

(4) Two or more imperfections in the same plane with indication amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent imperfections are unacceptable if they cannot be encompassed within an area less than that of the Quality Level specified in (1) above.

(5) Two or more imperfections greater than permitted for Quality Level 1 for castings less than 2 in. (50 mm) in thickness, greater than permitted for Quality Level 2 for thickness 2 in. through 4 in. (50 mm to 100 mm), and greater than permitted for Quality Level 3 for thickness greater than 4 in. (100 mm), separated by a distance less than the longest dimension of the larger of the adjacent imperfections, are unacceptable if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (a) above.

NG-2573 Radiographic Examination

NG-2573.1 Extent, Methods, and Acceptance Standards. Radiographic examination, where required, shall be performed on castings used for core support structures. The radiographic methods shall be in accordance with ASTM E94, Recommended Practice for Radiographic Testing, and ASTM E142, Controlling Quality of Radiographic Testing, and shall meet the acceptance requirements of Severity Level 3 for Category A and B defects and Severity Level 2 for Category C defects of ASTM E446,[12] Reference Radiographs for Steel Castings Up To 2 in. (50 mm) In Thickness, ASTM E186,[12] Reference Radiographs for Heavy-Walled [2 to $4^1/_2$ in. (50 mm to 114 mm)] Steel Castings, or ASTM E280,[12] Reference Radiographs for Heavy-Walled [$4^1/_2$ to 12 in. (114 mm to 300 mm)] Steel Castings, as applicable for the thickness being radiographed, except that Category D, E, F, or G defects are not acceptable. ASTM E280[12] shall also apply for castings over 12 in. (300 mm) in thickness.

NG-2573.2 Examination Requirements. Radiographic examination shall be performed in accordance with Section V, Article 2, Mandatory Appendix VII Radiographic Examination of Metallic Castings, with the following modifications:

(a) The geometric unsharpness limitations of Section V, Article 2, T-274.2 need not be met.

(b) The examination procedure or report shall also address the following:

(1) type and thickness of filters, if used

(2) for multiple film technique, whether viewing is to be single or superimposed, if used

(3) blocking or masking technique, if used

(4) orientation of location markers

(5) description of how internal markers, when used, locate the area of interest

(c) The location of location markers (e.g., lead numbers or letters) shall be permanently stamped on the surface of the casting in a manner permitting the area of interest on a radiograph to be accurately located on the casting and providing evidence on the radiograph that the extent of coverage required by NG-2573.1 has been obtained. For castings or sections of castings where stamping is not feasible, the radiographic procedure shall so state and a radiographic exposure map shall be provided.

NG-2575 Magnetic Particle Examination

The magnetic particle examination, when required, shall be performed in accordance with the requirements of NG-2545.

NG-2576 Liquid Penetrant Examination

The liquid penetrant examination, when required, shall be performed in accordance with the requirements of NG-2546.

NG-2577 Time of Examination

Acceptance examinations, including those for weld repairs, shall be performed as stipulated in the following subparagraphs.

NG-2577.1 Ultrasonic Examination. Ultrasonic examination, if required, shall be performed at the stage of manufacture as required for radiography.

NG-2577.2 Radiographic Examination.
(a) Radiography shall be performed after final heat treatment as required by the material specification, except radiography may be performed prior to postweld heat treatment. The examination shall be performed at the stage of manufacture defined in this subparagraph.

(b) Castings prior to finish machining shall be radiographed at the limiting thicknesses stipulated in the following:

(1) For thicknesses less than 2 in. (50 mm), castings shall be radiographed within 50% of the finished thickness. The image quality indicator (IQI) shall be based on the final thickness.

(2) For thicknesses less than 6 in. (150 mm) but greater than 2 in. (50 mm), castings shall be radiographed within 20% of the finished thickness. The IQI shall be based on the final thickness.

(3) For thicknesses 6 in. (150 mm) and greater, castings shall be radiographed within 10% of the finished thickness. The IQI shall be based on the final thickness.

(4) Where casting practices for core support structure sections require thickness to exceed the finished machined thickness limits of (2) and (3) above, radiography of the as-cast thickness is acceptable provided the acceptance reference radiographs of the next lesser thickness are met in those areas; e.g., if the section being radiographed exceeds $4\frac{1}{2}$ in. (114 mm), use ASTM E186[12] reference radiographs. The IQI shall be based on the thickness of the section being radiographed.

NG-2577.3 Magnetic Particle or Liquid Penetrant Examination. Magnetic particle or liquid penetrant examination shall be performed after the final heat treatment required by the material specification. Repair weld areas shall be examined after postweld heat treatment when a postweld heat treatment is performed, except that repair welds in P-No. 1 material, 2 in. (50 mm) nominal thickness and less, may be examined prior to postweld heat treatment. For cast products with machined surfaces, all accessible finished machined surfaces, except threaded surfaces, shall also be examined by magnetic particle or liquid penetrant methods.

NG-2578 Elimination of Surface Defects

Elimination of surface defects shall be in accordance with NG-2538.

NG-2579 Repair by Welding

The Material Organization may repair castings by welding after removing the material containing defects. The depth of the repair is not limited. A cored hole or access hole may be closed by the Material Organization by welding in accordance with the requirements of this paragraph, provided the hole is closed by filler metal only. If the hole is closed by welding in a metal insert, the welding shall be in accordance with the requirements of Article NG-4000 by a Certificate of Authorization Holder.

NG-2579.1 Defect Removal. The defect shall be removed or reduced to an imperfection of an acceptable size by suitable mechanical or thermal cutting or gouging methods, and the cavity prepared for repair. When thermal cutting is performed, consideration shall be given to preheating the material.

NG-2579.2 Qualification of Welding Procedures and Welders. The welding procedure and welders or welding operators shall be qualified in accordance with Article NG-4000 and Section IX.

NG-2579.3 Blending of Repaired Areas. After welding, the surface shall be blended uniformly into the surrounding surface.

NG-2579.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method (NG-2545) or by the liquid penetrant method (NG-2546). In addition, repair welds in cavities the depth of which exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness shall be radiographed in accordance with NG-2573. The radiographic method and acceptance standards of NG-2573 shall apply except that weld slag, including elongated slag, shall be considered as inclusions under Category B of the applicable reference radiographs. The total area of all inclusions, including slag inclusions, shall not exceed the limits of the applicable severity level of Category B of the reference radiographs.

NG-2579.5 Heat Treatment After Weld Repair. After repair, the casting shall be heat-treated in accordance with NG-4620, except that the heating and cooling limitations of NG-4623 do not apply.

NG-2579.6 Material Report Describing Defects and Repairs. Each repair weld exceeding in depth either $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness shall be described in the Certified Material Test Report. The Certified Material Test Report shall include a chart for each repaired casting which shows the location and size of the repaired cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographs.

NG-2580 EXAMINATION OF THREADED STRUCTURAL FASTENERS

NG-2581 Required Examinations

Threaded structural fasteners shall be visually examined in accordance with NG-2582. Externally threaded structural fasteners $^3/_8$ in. (10 mm) and greater and nuts greater than 1 in. (25 mm) shall be examined by either the magnetic particle or liquid penetrant method. In addition, nominal sizes greater than $^1/_2$ in. (13 mm) but not over 4 in. (100 mm) shall be examined by ultrasonic methods in accordance with NG-2584, and nominal sizes greater than 4 in. (100 mm) shall be examined by ultrasonic methods in accordance with both NG-2584 and NG-2585.

NG-2582 Visual Examination

Externally threaded structural fasteners less than $^3/_8$ in. (10 mm) and nuts 1 in. (25 mm) and smaller shall be visually examined in the areas of threads, shanks, and heads of final machined parts prior to plating or other surface protection type treatments. Harmful discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.

NG-2583 Magnetic Particle or Liquid Penetrant Examination

Externally threaded structural fasteners $^3/_8$ in. (10 mm) and greater and nuts greater than 1 in. (25 mm) shall be examined by a magnetic particle method (NG-2545) or a liquid penetrant method (NG-2546). Such examination shall be performed on the finished threaded structural fastener after threading and prior to plating or other surface protection type treatments. On threaded surfaces no relevant indications are permitted. Relevant indications include any linear indications or rounded indications greater than $^1/_{16}$ in. (1.5 mm). Indications, caused by a particular manufacturing method, that may appear to be relevant, such as the crest of rolled threads or root of cut threads, may be shown to be nonrelevant and acceptable by prior process qualification or destructive metallographic examination. On all other accessible surfaces, no linear indications or rounded indications greater than $^1/_{16}$ in. (1.5 mm) are permitted, except that linear axial indications less than one diameter or 1 in. (25 mm) in length are permitted.

NG-2584 Ultrasonic Examination for Sizes Greater Than $^1/_2$ in. (13 mm)

All threaded structural fasteners greater than $^1/_2$ in. (13 mm) nominal bolt size shall be ultrasonically examined over the entire cylindrical surface prior to threading, in accordance with the requirements of the following subparagraphs.

NG-2584.1 Ultrasonic Method. Examination shall be carried out by the straight beam, radial scan method.

NG-2584.2 Examination Procedure. Examination shall be performed at a nominal frequency of 2.25 MHz unless variables such as production material grain structure necessitate the use of a 1 MHz frequency in order to assure adequate penetration, with a search unit not to exceed 1 in.^{2} (650 mm^2) area.

NG-2584.3 Calibration of Equipment. Calibration sensitivity shall be established by adjustment of the instrument so that the first back reflection is 75% to 90% of full screen height.

NG-2584.4 Acceptance Standards. Any imperfection which causes an indication in excess of 20% of the height of the first back reflection or any imperfection which prevents the production of a first back reflection of 50% of the calibration amplitude is not acceptable.

NG-2585 Ultrasonic Examination for Sizes Over 4 in. (100 mm)

In addition to the requirements of NG-2584, all threaded structural fasteners over 4 in. (100 mm) shall be ultrasonically examined over the entire surface of each end before or after threading in accordance with the requirements of the following subparagraphs.

NG-2585.1 Ultrasonic Method. Examination shall be carried out by the straight beam, longitudinal mode scan method.

NG-2585.2 Examination Procedure. Examination shall be performed at a nominal frequency of 2.25 MHz unless variables such as production material grain structure necessitate the use of a 1 MHz frequency in order to assure adequate penetration with a search unit having a circular cross section with a diameter not less than $^1/_2$ in. (13 mm) nor more than $1^1/_8$ in. (29 mm).

NG-2585.3 Calibration of Equipment. Calibration shall be established on a test bar of the same nominal composition and diameter as the production part and a minimum of one-half of the length. A $^3/_8$ in. (10 mm) diameter × 3 in. (75 mm) deep flat bottom hole shall be drilled in one end of the bar and plugged to full depth. A distance–amplitude correction curve shall be established by scanning from both ends of the test bar.

NG-2585.4 Acceptance Standards. Any imperfection which causes an indication in excess of 50% of that produced by the calibration hole in the reference specimen, as corrected by the distance–amplitude correction curve, is not acceptable.

NG-2586 Elimination of Surface Defects

Surface defects may be eliminated by grinding or machining, provided the final dimension of the affected portion meets the requirements of the design and the area is reexamined by the magnetic particle or liquid penetrant method in accordance with NG-2583.

NG-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS

NG-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program that meets the requirements of NCA-3800.

(b) The requirements of NCA-3862 shall be met as required by NG-2130. The other requirements of NCA-3800 need not be used by Material Organizations for small products, as defined in (c), and for material which is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (Article NCA-4000) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable special requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in the following:

(1) pipe, tube (except heat exchanger tube), pipe fittings, and flanges 2 in. nominal pipe size (DN 50) and less

(2) threaded structural fastener material, including studs and nuts of 1 in. (25 mm) nominal diameter and less

(3) bars with a nominal cross-sectional area of 1 in.^{2} (650 mm^2) and less

ARTICLE NG-3000
DESIGN

NG-3100 GENERAL DESIGN

NG-3110 LOADING CRITERIA

NG-3111 Loading Conditions

The loadings that shall be taken into account in designing core support structures include, but are not limited to, those in the following:

(a) pressure differences due to coolant flow

(b) weight of the core support structure

(c) superimposed loads such as those due to other structures, the reactor core, steam separating equipment, flow distributors and baffles, thermal shields, and safety equipment

(d) earthquake loads or other loads which result from motion of the reactor vessel

(e) reactions from supports, restraints, or both

(f) loads due to temperature effects, thermal gradients and differential expansion, or both

(g) loads resulting from the impingement or flow of reactor coolant, or other contained or surrounding fluids

(h) transient pressure difference loads, such as those which result from rupture of the main coolant pipe

(i) vibratory loads

(j) loads resulting from the operation of machinery, such as snubbing of control rods

(k) handling loads experienced in preparation for or during refueling or in-service inspection

NG-3112 Design Loadings

The Design Loadings are the pressure differences, temperatures, and various forces applicable to the design of core support structures as defined in the following subparagraphs.

NG-3112.1 Design Pressure Difference.

(a) The specified internal and external Design Pressure Difference shall not be less than the maximum difference in pressure between the inside and outside of the core support structure which exists under the specified normal service conditions. It shall be used in the computations made to show compliance with the stress intensity limits of NG-3221, NG-3227.1, NG-3227.2, NG-3227.4, NG-3228.1, NG-3228.2, and NG-3231. The actual service pressure difference at the appropriate time shall be used in the computations made to show compliance with the stress intensity limits of NG-3222, NG-3228.3, and NG-3232. When the occurrence of different pressure differences during service can be predicted for different zones of a structure, the Design Pressure Difference of the different zones may be based on their predicted pressure difference.

(b) The Design Pressure Difference shall include allowances for pressure difference surges.

NG-3112.2 Design Temperature. The Design Temperature shall be established in accordance with NCA-2142.1(b). It shall be used in computations involving the Design Pressure Difference and coincidental Design Mechanical Loads. The actual metal temperature at the point under consideration shall be used in all computations where the use of the actual service pressure difference is required. (**15**)

(a) All temperatures referred to in this Article are the metal temperatures expressed in degrees Fahrenheit (°F) [degrees Celsius (°C)].

(b) Where a core support structure is heated by tracing, induction coils, jacketing, or internal heat generation, the effect of such heating shall be incorporated in the establishment of the Design Temperature.

NG-3112.3 Design Mechanical Loads. The specific combinations and values of mechanical loadings which must be considered in conjunction with the Design Pressure Difference and Design Temperature in evaluating the requirements of NG-3221.1 and NG-3221.2 shall be those identified in the Design Specifications (NCA-3250) and designated as the Design Mechanical Loads in accordance with NCA-2142.1(c). The actual mechanical loads at the appropriate time shall be used in the computations made to show compliance with the stress intensity limits of NG-3222.2 and NG-3222.4. The following requirements shall also apply:

(a) Impact forces caused by either external or internal conditions shall be considered.

(b) The effects of earthquake shall be considered in the design of core support structures. The loadings, movements, and number of cycles to be used in the analysis shall be part of the Design Specifications. The stresses resulting from these earthquake effects shall be included with pressure differences or other applied loads.

(c) Core support structures shall be arranged and supported so that vibration will be minimized.

NG-3112.4 Design Stress Intensity Values. Design stress intensity values for materials are listed in Section II, Part D, Subpart 1, Tables 2A and 2B. The material shall not be used at metal temperatures and Design Temperatures that exceed the temperature limit in the applicability column for which stress intensity values are listed. The values in the Table may be interpolated for intermediate temperatures.

NG-3113 Service Loadings

Each loading to which the structure may be subjected shall be classified in accordance with NCA-2142 and Service Limits [NCA-2142.4(b)] designated in the Design Specifications in such detail as will provide a complete basis for design, construction, and inspection in accordance with these rules.

NG-3120 SPECIAL CONSIDERATIONS

NG-3121 Corrosion

Material subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made for these effects during the design or specified life of the structure by a suitable increase in or addition to the thickness of the base metal over that determined by the design equations. Material added or included for these purposes need not be of the same thickness for all areas of the structure if different rates of attack are expected for the various areas. It should be noted that the tests on which the design fatigue curves (Section III Appendices, Mandatory Appendix I) are based did not include tests in the presence of corrosive environments which might accelerate fatigue failure.

NG-3122 Cladding

The rules of this paragraph apply to the design analysis of clad structures constructed of material permitted in Section II, Part D, Subpart 1, Tables 2A and 2B.

NG-3122.1 Primary Stresses. No structural strength shall be attributed to the cladding in satisfying NG-3221.1 and NG-3221.3.

NG-3122.2 Design Dimensions. The dimensions given in (a) and (b) shall be used in the design of the component.

(a) For structures subjected to internal pressure difference, the inside diameter shall be taken at the nominal inner face of the cladding.

(b) For structures subjected to external pressure difference, the outside diameter shall be taken at the outer face of the base metal.

NG-3122.3 Secondary and Peak Stresses. In satisfying NG-3222.2 and NG-3222.4(b), the presence of the cladding shall be considered with respect to both the thermal analysis and the stress analysis. The stresses in both materials shall be limited to the values specified in NG-3222.2 and NG-3222.4(b). However, when the cladding is of the integrally bonded type and the nominal thickness of the cladding is 10% or less of the total thickness of the structure, the presence of the cladding may be neglected.

NG-3122.4 Bearing Stresses. In satisfying NG-3227.1, the presence of cladding shall be included.

NG-3123 Welds Between Dissimilar Metals

In satisfying the requirements of this subarticle, caution should be exercised in design and construction involving dissimilar metals having different coefficients of thermal expansion in order to avoid difficulties in service.

NG-3124 Environmental Effects

Changes in material properties may occur due to environmental effects. In particular, fast (>1 MeV) neutron irradiation above a certain level may result in significant increase in the brittle fracture transition temperature and deterioration in the resistance to fracture at temperatures above the transition range (upper shelf energy). Therefore, structural discontinuities in ferritic structures should preferably not be placed in regions of high neutron flux.

NG-3130 GENERAL DESIGN RULES

NG-3131 Scope

Design rules generally applicable to core support structures are provided in the following paragraphs.

NG-3132 Reinforcement for Openings

The rules for reinforcing applicable to Class 1 vessels and piping may be used in the design of core support structures if stipulated in the Design Specifications.

NG-3133 External Pressure Difference

NG-3133.1 General. Rules are given in this paragraph for determining the stresses under external pressure difference loading in spherical shells, cylindrical shells with or without stiffening rings, and tubular products consisting of pipes, tubes, and fittings. Charts for determining the stresses in shells, hemispherical heads, and tubular products are given in Section II, Part D, Subpart 3.

NG-3133.2 Nomenclature. The symbols used in this paragraph are defined as follows:

A = factor determined from Section II, Part D, Subpart 3, Figure G and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having D_o/T values less than 10, see NG-3133.3(b). Also, factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a stiffening ring, corresponding to the factor B and the design metal temperature for the shell under consideration.

A_s = cross-sectional area of a stiffening ring

B = factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a shell or stiffening ring at the design metal temperature

D_o = outside diameter of the cylindrical shell course or tube under consideration

E = modulus of elasticity of material at Design Temperature (for this value, see Section II, Part D, Subpart 2, Table TM). Use the curve with this value on the material/temperature line of the applicable chart in Section II, Part D, Subpart 3.

I = available moment of inertia of the combined ring–shell section about its neutral axis, parallel to the axis of the shell, in.^{4} (mm^4). The width of the shell which is taken as contributing to the combined moment of inertia shall not be greater than $1.10\sqrt{D_o/T_n}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing area to more than one stiffening ring.

I_s = required moment of inertia of the combined ring–shell section about its neutral axis parallel to the axis of the shell

L = total length of a tube between tubesheets, or the design length of a cylindrical section, taken as the largest of the following:

(a) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings

(b) the greatest center-to-center distance between any two adjacent stiffening rings or

(c) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head, all measured parallel to the axis of the cylinder, in. (mm)

L_s = one-half of the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the component. A line of support is

(a) a stiffening ring that meets the requirements of this paragraph

(b) a circumferential line on a head at one-third the depth of the head from the head tangent line or

(c) a circumferential connection to a jacket for a jacketed section of a cylindrical shell

P = external design pressure (gage or absolute, as required)

P_a = allowable external pressure (gage or absolute, as required)

R = inside radius of spherical shell

S = the lesser of 1.5 times the stress intensity at design metal temperature from Section II, Part D, Subpart 1, Tables 2A and 2B or 0.9 times the tabulated yield strength at design metal temperature from Section II, Part D, Subpart 1, Table Y-1

T = minimum required thickness of cylindrical shell or tube, or spherical shell

T_n = nominal thickness used, less corrosion allowance, of a cylindrical shell or tube

NG-3133.3 Cylindrical Shells and Tubular Products.

(a) The minimum thickness of cylindrical shells or tubular products under external pressure difference having D_o/T values equal to or greater than 10 shall be determined by the procedure given in Steps 1 through 8.

Step 1. Assume a value for T. Determine the ratios L/D_o and D_o/T.

Step 2. Enter Section II, Part D, Subpart 3, Figure G at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of L/D_o of 50. For values of L/D_o less than 0.05, enter the chart at a value of L/D_o of 0.05.

Step 3. Move horizontally to the line for the value of D_o/T determined in Step 1. Interpolation may be made for intermediate values of D_o/T. From this intersection move vertically downwards and read the value of factor A.

Step 4. Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material/temperature under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material line, see Step 7.

Step 5. From the intersection obtained in Step 4 move horizontally to the right and read the value of B.

Step 6. Using this value of B, calculate the maximum allowable pressure difference P_a by the following equation:

$$P_a = \frac{4B}{3(D_o/T)}$$

Step 7. For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following equation:

$$P_a = \frac{2AE}{3(D_o/T)}$$

Step 8. Compare P_a with P. If P_a is smaller than P, select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

(b) The minimum thickness of cylindrical shells or tubular products under external pressure difference having D_o/T values less than 10 shall be determined by the procedure given in Steps 1 through 4.

Step 1. Using the same procedure as given in (a) above, obtain the value of B. For values of D_o/T less than 4, the value of factor A can be calculated using the following equation:

$$A = \frac{1.1}{(D_o/T)^2}$$

For values of A greater than 0.10 use a value of 0.10.

Step 2. Using the value of B obtained in Step 1, calculate a value P_{a1} using the following equation:

$$P_{a1} = \left[\frac{2.167}{(D_o/T)} - 0.0833\right]B$$

Step 3. Calculate a value P_{a2} using the following equation:

$$P_{a2} = \frac{2S}{(D_o/T)}\left[1 - \frac{1}{(D_o/T)}\right]$$

Step 4. The smaller of the values of P_{a1} calculated in Step 2 or P_{a2} calculated in Step 3 shall be used for the maximum allowable external pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

NG-3133.4 Spherical Shells. The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the procedure given in Steps 1 through 6.

Step 1. Assume a value for T and calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R/T)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values at A falling to the left of the material/temperature line, see Step 5.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B.

Step 4. Using the value of B obtained in Step 3, calculate the value of the maximum allowable external pressure P_a using the following equation:

$$P_a = \frac{B}{(R/T)}$$

Step 5. For values of A falling to the left of the applicable material/temperature line for the Design Temperature, the value of P_a can be calculated using the following equation:

$$P_a = \frac{0.0625E}{(R/T)^2}$$

Step 6. Compare P_a obtained in Steps 4 or 5 with P. If P_a is smaller than P, select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

NG-3133.5 Stiffening Rings for Cylindrical Shells.

(a) The required moment of inertia of the combined ring–shell section is given by the following equation:

$$I_s = \frac{D_o^2 L_s (T + A_s/L_s)A}{10.9}$$

The available moment of inertia I for a stiffening ring shall be determined by the procedure given in Steps 1 through 6.

Step 1. Assuming that the shell has been designed and D_o, L_s, and T_n are known, select a member to be used for the stiffening ring and determine its area A_s and the value of I defined in NG-3133.2. Then calculate B by the following equation:

$$B = \frac{3}{4}\left[\frac{PD_o}{T_n + A_s/L_s}\right]$$

Step 2. Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined in Step 1. If different materials are used for the shell and stiffening ring, then use the material chart resulting in the larger value for factor A in Step 4 or 5.

Step 3. Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4. Move vertically to the bottom of the chart and read the value of A.

Step 5. For values of B falling below the left end of the material/temperature line for the Design Temperature, the value of A can be calculated using the following equation:

$$A = 2B/E$$

Step 6. If the required I_s is greater than the computed moment of inertia I for the combined ring– shell section selected in Step 1, a new section with a larger moment of inertia must be selected and a new I_s determined. If the required I_s is smaller than the computed I for the section selected in Step 1, that section should be satisfactory.

(b) Stiffening rings may be attached to either the outside or the inside of the component by continuous welding.

NG-3133.6 Cylinders Under Axial Compression. The maximum allowable compressive stress to be used in the design of cylindrical shells and tubular products subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in (a) or (b).

(a) the S_m value for the applicable material at Design Temperature given in Section II, Part D, Subpart 1, Tables 2A and 2B

(b) the value of the factor B determined from the applicable chart contained in Section II, Part D, Subpart 3, using the following definitions for the symbols on the charts:

R = inside radius of the cylindrical shell or tubular product, in. (mm)
T = minimum required thickness of the shell or tubular product, exclusive of the corrosion allowance, in. (mm)

The value of B shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 in the manner given in Steps 1 through 5.

Step 1. Using the selected values of T and R, calculate the value of factor A using the following equation:

$$A = 0.125/(R/T)$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 4.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B. This is the maximum allowable compressive stress for the values of T and R used in Step 1.

Step 4. For values of A falling to the left of the applicable material/temperature line, the value of B shall be calculated using the following equation:

$$B = AE/2$$

Step 5. Compare the value of B determined in Step 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of T and R. If the value of B is smaller than the computed compressive stress, a greater value of T must be selected and the design procedure repeated until a value of B is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

NG-3200 DESIGN BY ANALYSIS

NG-3210 DESIGN CRITERIA

NG-3211 Requirements for Acceptability

The requirements for the acceptability of a design by analysis are those set forth in (a) through (d).

(a) The design shall be such that stress intensities will not exceed the limits of NG-3200 using the design stress intensity values S_m as tabulated in Section II, Part D, Subpart 1, Tables 2A and 2B.

(b) The design details shall conform to the rules given in NG-3100 and NG-3350.

(c) For configurations where compressive stresses occur, in addition to the requirements in (a) and (b), the critical buckling stress shall be taken into account; see NG-3133. (For the special case of external pressure difference, see NG-3133.1. Where dynamic pressure differences are involved, the permissible external pressure difference shall satisfy the requirements of NG-3133 or be limited to 25% of the dynamic instability pressure difference for normal service conditions.)

(d) Protection against nonductile fracture shall be provided. An acceptable procedure for nonductile failure prevention is given in Section III Appendices, Nonmandatory Appendix G.

NG-3212 Basis for Determining Stresses

The theory of failure used in the rules of this Subsection for combining stresses is the maximum shear stress theory. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

NG-3213 Terms Relating to Stress Analysis

Terms used in this Subsection relating to stress analysis are defined in the following subparagraphs.

NG-3213.1 Stress Intensity.[13] Stress intensity is defined as twice the maximum shear stress, which is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive and compressive stresses are considered negative.

NG-3213.2 Gross Structural Discontinuity. Gross structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through the entire wall thickness. Gross discontinuity-type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the wall thickness. Examples of a gross structural discontinuity are head-to-shell junctions, flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

NG-3213.3 Local Structural Discontinuity. Local structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized deformation or strain and has no significant effect on the shell-type discontinuity deformations. Examples are small fillet radii, small attachments, and partial penetration welds.

NG-3213.4 Normal Stress. Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to have two components — one uniformly distributed and equal to the average stress across the thickness under consideration, and the other varying from this average value across the thickness.

NG-3213.5 Shear Stress. Shear stress is the component of stress tangent to the plane of reference.

NG-3213.6 Membrane Stress. Membrane stress is the component of normal stress that is uniformly distributed and equal to the average stress across the thickness of the section under consideration.

NG-3213.7 Bending Stress. Bending stress is the component of normal stress that varies across the thickness. The variation may or may not be linear.

NG-3213.8 Primary Stress. Primary stress is 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. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure or, at least, in gross distortion. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one that is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stress are

(a) general membrane stress in a circular cylindrical shell or a spherical shell due to internal pressure or to distributed loads

(b) bending stress in the central portion of a flat head due to pressure

Refer to Table NG-3217-1 for examples of primary stress.

NG-3213.9 Secondary Stress. Secondary stress is a normal stress or a 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. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stress are

(a) general thermal stress [NG-3213.12(a)]

(b) bending stress at a gross structural discontinuity

Refer to Table NG-3217-1 for examples of secondary stress.

NG-3213.10 Peak Stress. Peak stress is that increment of stress that is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress [NG-3213.12(b)] including the effects, if any, of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress that is not highly localized falls into this category if it is of a type that cannot cause noticeable distortion. Examples of peak stress are

(a) the thermal stress in the austenitic steel cladding of a carbon steel part

(b) certain thermal stresses that may cause fatigue but not distortion

(c) the stress at a local structural discontinuity

(d) surface stresses produced by thermal shock

NG-3213.11 Load Controlled Stress. Load controlled stress is the stress resulting from application of a loading, such as pressure difference, inertial loads, or gravity, whose magnitude is not reduced as a result of displacement.

NG-3213.12 Thermal Stress. Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally would under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in (a) and (b) below.

(a) General thermal stress is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. Therefore this type is classified as secondary stress in Table NG-3217-1. Examples of general thermal stress are

(1) stress produced by an axial temperature distribution in a cylindrical shell

(2) stress produced by the temperature difference between a nozzle and the shell to which it is attached

(3) the equivalent linear stress[14] produced by the radial temperature distribution in a cylindrical shell

(b) Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as peak stresses in Table

NG-3217-1. In evaluating local thermal stresses the procedures of NG-3227.6(b) shall be used. Examples of local thermal stress are

(1) the stress in a small hot spot in a vessel wall

(2) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell

(3) the thermal stress in a cladding material that has a coefficient of expansion different from that of the base metal

NG-3213.13 Total Stress. Total stress is the sum of the primary, secondary, and peak stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate stress limitations.

NG-3213.14 Service Cycle. Service cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle. The types of service conditions that may occur are further defined in NG-3113.

NG-3213.15 Stress Cycle. Stress cycle is a condition in which the alternating stress difference [NG-3222.4(e)] goes from an initial value through an algebraic maximum value and an algebraic minimum value, then returns to the initial value. A single service cycle may result in one or more stress cycles. Dynamic effects shall also be considered as stress cycles.

NG-3213.16 Fatigue Strength Reduction Factor. Fatigue strength reduction factor is a stress intensification factor which accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. In the absence of experimental data, the theoretical stress concentration factor may be used.

NG-3213.17 Shakedown. Shakedown is the absence of a continuing cycle of plastic deformation. A structure shakes down if after a few cycles of load application, the deformation stabilizes and subsequent structural response is elastic, excluding creep effects.

NG-3213.18 Free End Displacement. Free end displacement consists of the relative motions that would occur between an attachment and connected structure or equipment if the two members were separated. Examples of such motions are those that would occur because of relative thermal expansion of piping, equipment, and equipment supports or because of rotations imposed upon the equipment by sources other than the piping.

NG-3213.19 Expansion Stresses. Expansion stresses are those stresses resulting from restraint of free end displacement of piping which may act as a core support structure.

NG-3213.20 Limit Analysis — Collapse Load. The methods of limit analysis are used to compute the maximum load or combination of loads a structure made of ideally plastic (nonstrain-hardening) material can carry. The deformations of an ideally plastic structure increase without bound at this load, which is termed the *collapse load*. Among the methods used in limit analysis is a technique which assumes elastic, perfectly plastic, material behavior and a constant level of moment or force in those redundant structural elements in which membrane yield, plastic hinge, or critical buckling load has been reached. Any increase in load must be accompanied by a stable primary structure until a failure mechanism defined by the lower bound theorem of limit analysis is reached in the primary structure.

NG-3213.21 Collapse Load — Lower Bound. If, for a given load, any system of stresses can be found which everywhere satisfies equilibrium and nowhere exceeds the material yield strength, the load is at or below the collapse load. This is the lower bound theorem of limit analysis which permits calculations of a lower bound to the collapse load.

NG-3213.22 Stress Ratio Method. The methods of plastic analysis which utilize the stress ratio combinations are used to compute the maximum load a strain-hardened material can carry (Section III Appendices, Nonmandatory Appendix A, Article A-9000). Stress ratio combinations are useful since the actual shape factor (function of cross section) and the type and magnitude of different stress fields may be considered in determining the load.

NG-3214 Stress Analysis

A detailed stress analysis of all major structural components shall be prepared in sufficient detail to show that each of the stress limitations of NG-3220 and NG-3230 is satisfied when the core support structure is subjected to the loadings of NG-3110. As an aid to the evaluation of these stresses, equations and methods for the solution of certain recurring problems have been placed in Section III Appendices, Nonmandatory Appendix A.

NG-3215 Derivation of Stress Intensities

One requirement for the acceptability of a design (NG-3210) is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities which are subject to the specified limits. The steps in the procedure are stipulated in (a) through (e).

(a) At the point on the component which is being investigated, choose an orthogonal set of coordinates, such as tangential, longitudinal, and radial, and designate them by the subscripts t, l, and r. The stress components in these directions are then designated σ_t, σ_l, and σ_r for direct stresses and τ_{lt}, τ_{lr}, and τ_{rt} for shear stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected and assign each set of stress values to one or a group of the following categories:[15]

(1) general primary membrane stress P_m (NG-3213.8)

(2) primary bending stress P_b (NG-3213.7 and NG-3213.8)

(3) expansion stress P_e (NG-3213.19)

(4) secondary stress Q (NG-3213.9)

(5) peak stress F (NG-3213.10)

(c) For each category, calculate the algebraic sum of the values of σ_t which result from the different types of loadings, and similarly for the other five stress components. Certain combinations of the categories must also be considered.

(d) Translate the stress components for the t, l, and r directions into principal stresses σ_1, σ_2, and σ_3. In many pressure component calculations, the t, l, and r directions may be so chosen that the shear stress components are zero and σ_1, σ_2, and σ_3 are identical to σ_t, σ_l, and σ_r.

(e) Calculate the stress differences S_{12}, S_{23}, and S_{31} from the relations

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

The stress intensity S is the largest absolute value of S_{12}, S_{23}, and S_{31}.

NOTE: Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component level in (b) or (c) above.

NG-3216 Derivation of Stress Differences and Alternating Stress Intensities

If the specified operation of the structure does not meet the conditions of NG-3222.4(d), the ability of the structure to withstand the specified cyclic service without fatigue failure shall be determined as provided in NG-3222.4(e). The determination shall be made on the basis of the stresses at a point of the structure, and the allowable stress cycles shall be adequate for the specified service at every point. Only the stress differences due to cyclic service loadings as specified in the Design Specifications need be considered.

NG-3216.1 Constant Principal Stress Direction. For any case in which the directions of the principal stresses at the point being considered do not change during the cycle, the steps stipulated in (a) through (c) shall be taken to determine the alternating stress intensity.

(a) Principal Stresses. Consider the values of the three principal stresses at the point versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects which vary during the cycle. These are designated as σ_1, σ_2, and σ_3 for later identification.

(b) Stress Differences. Determine the stress differences $S_{12} = \sigma_1 - \sigma_2$; $S_{23} = \sigma_2 - \sigma_3$; $S_{31} = \sigma_3 - \sigma_1$ versus time for the complete cycle. In what follows, the symbol S_{ij} is used to represent any one of these three stress differences.

(c) Alternating Stress Intensity. Determine the extremes of the range through which each stress difference S_{ij} fluctuates and find the absolute magnitude of this range for each S_{ij}. Call this magnitude S_{rij} and let $S_{\text{alt } ij} = 0.5S_{rij}$. The alternating stress intensity S_{alt} is the largest of the $S_{\text{alt } ij}$ values.

NG-3216.2 Varying Principal Stress Direction. For any case in which the directions of the principal stresses at the point being considered do change during the stress cycle, it is necessary to use the more general procedure of (a) through (e).

(a) Consider the values of the six stress components σ_t, σ_l, σ_r, τ_{lt}, τ_{lr}, τ_{rt} versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects which vary during the cycle.

(b) Choose a point in time when the conditions are one of the extremes for the cycle (either maximum or minimum, algebraically) and identify the stress components at this time by the subscript i. In most cases it will be possible to choose at least one time during the cycle when the conditions are known to be extreme. In some cases it may be necessary to try different points in time to find the one which results in the largest value of alternating stress intensity.

(c) Subtract each of the six stress components σ_{ti}, σ_{li}, etc., from the corresponding stress components σ_t, σ_l, etc., at each point in time during the cycle and call the resulting components σ'_t, σ'_l, etc.

(d) At each point in time during the cycle, calculate the principal stresses σ'_1, σ'_2, σ'_3 derived from the six stress components σ'_t, σ'_l, etc. Note that the directions of the principal stresses may change during the cycle but each principal stress retains its identity as it rotates.

(e) Determine the stress differences $S'_{12} = \sigma'_1 - \sigma'_2$, $S'_{23} = \sigma'_2 - \sigma'_3$, $S'_{31} = \sigma'_3 - \sigma'_1$ versus time for the complete cycle and find the largest absolute magnitude of any stress difference at any time. The alternating stress intensity S_{alt} is one-half of this magnitude.

NG-3217 Classification of Stress

Table NG-3217-1 provides assistance in the determination of the category to which a stress should be assigned.

Table NG-3217-1
Classification of Stress Intensities for Some Typical Cases

Core Support Structure	Location	Origin of Stress	Type of Stress	Classification	Discontinuity Gross	Discontinuity Local
Cylindrical or spherical shell	Shell plate remote from discontinuities	Pressure difference	General membrane	P_m	No	No
			Gradient through plate thickness	Q	Yes	No
		Axial thermal gradient	Membrane	Q	Yes	No
			Bending	Q	Yes	No
	Junction with head or flange	Pressure difference	Membrane	Q	Yes	No
			Bending	Q	Yes	No
Any shell or head	Any section across entire shell	External load or moment, or pressure difference	General membrane averaged across full section. Stress component perpendicular to cross section.	P_m	No	No
		External load or moment	Bending across full section. Stress component perpendicular to cross section.	P_m	No	No
	Near nozzle or other opening	External load or moment, or pressure difference	Membrane	Q	Yes	No
			Bending	Q	Yes	No
			Peak (fillet or corner)	F	Yes	Yes
	Any location	Temp. difference between shell and head	Membrane	Q	Yes	No
			Bending	Q	Yes	No
Dished head or conical	Crown	Pressure difference	General membrane	P_m	No	No
			Bending	P_b	No	No
	Knuckle of junction to shell	Pressure difference	Membrane	Q [Note (1)]	Yes	No
			Bending	Q	Yes	No
Flat head	Center region	Pressure difference	General membrane	P_m	No	No
			Bending	P_b	No	No
	Junction to shell	Pressure difference	Membrane	Q	Yes	No
			Bending	Q	Yes	No
Perforated head or shell	Typical ligament in a uniform pattern	Pressure difference or external load	General membrane (avg. through cross section)	P_m	No	No
			Bending (avg. through width of ligament, but gradient through plate)	P_b	No	No
			Peak	F	No	Yes
	Isolated or atypical ligament	Pressure difference	Membrane	Q	Yes	No
			Bending	F	Yes	Yes
			Peak	F	Yes	Yes
Nozzle	Cross section perpendicular to nozzle axis	Pressure difference or external load or moment	General membrane avg. across full section. Stress component perpendicular to section.	P_m	No	No
		External load or moment	Bending across nozzle section	P_m	No	No
	Nozzle wall	Pressure difference	General membrane	P_m	No	No
			Membrane	Q	Yes	No
			Bending	Q	Yes	No
			Peak	F	Yes	Yes
		Differential expansion	Membrane	Q	Yes	No
			Bending	Q	Yes	No
			Peak	F	Yes	Yes
Cladding	Any	Differential expansion	Membrane	F	Yes	Yes
			Bending	F	Yes	Yes
Any	Any	Radial thermal gradient through plate thickness [Note (2)]	Stress due to equivalent bending portion	Q [Note (3)]	Yes	No
			Stress due to nonlinear portion	F	Yes	Yes
Any	Any	Any	Stress concentration (notch effect)	F	Yes	Yes

Table NG-3217-1
Classification of Stress Intensities for Some Typical Cases (Cont'd)

NOTES:
(1) Consideration must also be given to the possibility of wrinkling and excessive deformation in shells with large diameter-to-thickness ratio.
(2) Consider the possibility of thermal stress ratchet.
(3) Equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

NG-3220 STRESS LIMITS FOR OTHER THAN THREADED STRUCTURAL FASTENERS

NG-3221 Design Loadings

The stress intensity limits which must be satisfied for the Design Loadings (NG-3112) stated in the Design Specifications are the three limits of this paragraph and the special stress limits of NG-3227. The provisions of NG-3228 may provide relief from certain of these stress limits if plastic analysis techniques or tests are applied. The design stress intensity values S_m are given by NG-3229. The limits are summarized by Figure NG-3221-1.

NG-3221.1 General Primary Membrane Stress Intensity. This stress intensity (derived from P_m in Figure NG-3221-1) is derived from the average value across the thickness of a section of the general primary stresses (see NG-3213.8) produced by design internal pressure difference and other specified Design Mechanical Loads, but excluding all secondary and peak stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable value of the stress intensity is S_m at the Design Temperature.

NG-3221.2 Primary Membrane Plus Primary Bending Stress Intensity. This stress intensity (derived from $P_m + P_b$ in Figure NG-3221-1) is derived from the highest value across the thickness of a section of the general primary membrane stresses plus primary bending stresses produced by Design Pressure Difference and other specified Design Mechanical Loads, but excluding all secondary and peak stresses. The allowable value of this stress intensity is $1.5S_m$.

NG-3221.3 External Pressure Difference. The provisions of NG-3133 apply.

(15) NG-3222 Level A Service Limits

The Level A Service Limits must be satisfied for the Service Conditions [NCA-2142.4(b)(1)] for which these limits are designated in the Design Specifications and are the four limits of this paragraph and NG-3227. The provisions of NG-3228 may provide relief from certain of these stress limits if plastic analysis techniques are applied. The design stress intensity values S_m are given by NG-3229. The limits are summarized by Figure NG-3221-1.

NG-3222.1 Primary Membrane and Bending Stress Intensities. The stresses due to primary loads presented during normal service must be computed and satisfy the limits of NG-3221.

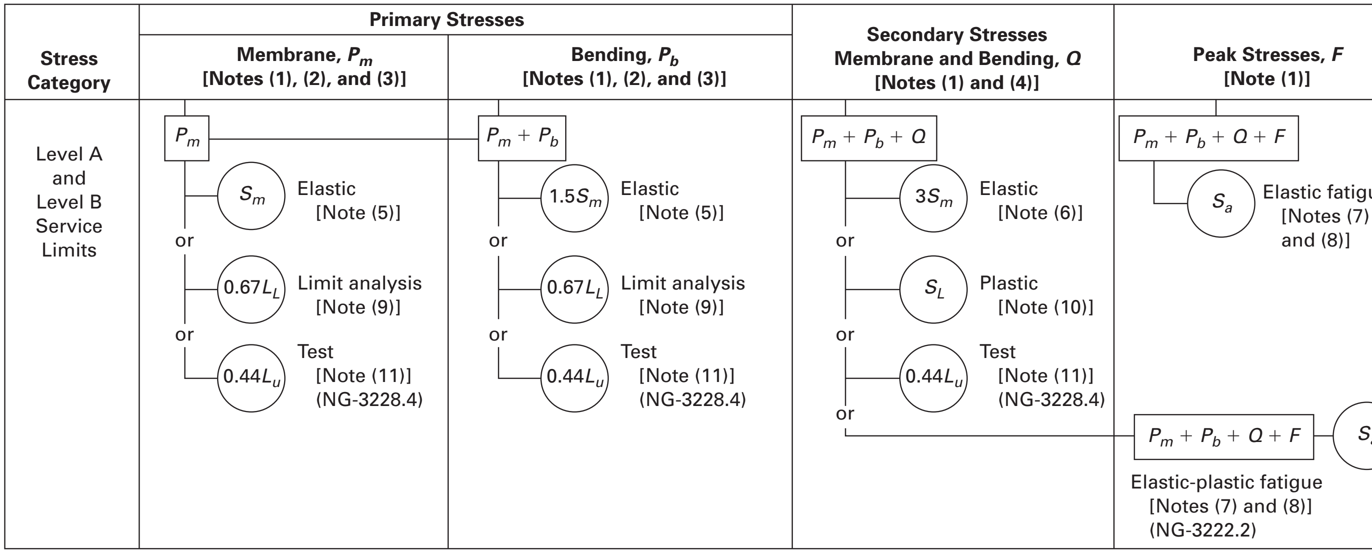
NG-3222.2 Primary Plus Secondary Stress Intensity.[16] This stress intensity is derived from the highest value at any point across the thickness of a section of the general or local primary membrane stresses, plus primary bending stresses, plus secondary stresses, produced by the specified service pressure differences and other specified mechanical loads and by general thermal effects associated with normal service loadings. The effects of gross structural discontinuities but not of local structural discontinuities (stress concentrations) shall be included. The allowable value for the maximum range of this stress intensity is $3S_m$ [Figure NG-3221-1, Note (1)], except for certain cyclic events which may exceed the $3S_m$ limit during the design life of the plant. For this exception, in lieu of meeting the $3S_m$ limit, an elastic–plastic fatigue analysis in accordance with NG-3228.3 may be performed to demonstrate that the cumulative fatigue usage attributable to the combination of these low cycle events plus all other cyclic events does not exceed a value of 1.0 when calculated in accordance with NG-3222.4.

NG-3222.3 Expansion Stress Intensity.[16] This stress intensity is the highest value of stress, neglecting local structural discontinuities, produced at any point across the thickness of a section by the loadings which result from restraint of free end displacement and the effect of anchor point motions. The allowable value of the maximum range of this stress intensity when combined with all other primary and secondary stress intensities is $3S_m$.

NG-3222.4 Analysis for Cyclic Operation.

(a) Suitability for Cyclic Condition. The suitability of a structure for specified Service Loadings involving cyclic application of loads and thermal conditions shall be determined by the methods described herein, except that the suitability of high strength threaded structural fasteners shall be determined by the methods of NG-3232.3(b) and the possibility of thermal stress ratchet shall be investigated in accordance with NG-3222.5. If the specified Service Loadings of the structure meet all of the conditions of (d) below, no analysis for cyclic service is required, and it may be assumed that the limits on peak stress intensities as governed by fatigue have been

Figure NG-3221-1
Stress Categories and Limits of Stress Intensities for Service Levels A and B



NOTES:

(1) The symbols P_m, P_b, Q, and F do not represent single quantities, but rather sets of six quantities representing the six stress components σ_t, σ_l, σ_r, τ_{lt}, τ_{lr}, and τ_{rt}.

(2) For configurations where compressive stresses occur, the stress limits shall be reviewed to take into account critical buckling stresses [NG-3211(c)].

(3) When loads are transiently applied, consideration should be given to the use of dynamic load amplification.

(4) The stresses in Category Q are those parts of the total stress which are produced by thermal gradients, structural discontinuities, etc., and do not include primary stresses which may also exist at the same point. It should be noted, however, that a detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, this calculated value represents the total of $P_m + P_b + Q$, and not Q alone. Similarly, if the stress in Category F is produced by a stress concentration, the quantity F is the additional stress produced by the notch, over and above the nominal stress. For example, if a plate has a nominal stress intensity, $P_m = S$, $P_b = 0$, $Q = 0$, and a notch with a stress concentration K is introduced, then $F = P_m(K - 1)$ and the peak stress intensity equals $P_m + P_m(K - 1) = KP_m$.

(5) The triaxial stresses represent the algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) for the combination of stress components. Where uniform tension loading is present, triaxial stresses are limited to $4S_m$.

(6) This limitation applies to the range of stress intensity. When the secondary stress is due to a temperature excursion at the point at which the stresses are being analyzed, the value of S_m shall be taken as the average of the S_m values tabulated in Section II, Part D, Subpart 1, Tables 2A and 2B for the highest and the lowest temperature of the metal during the transient. When part or all of the secondary stress is due to mechanical load, the value of S_m shall be taken as the S_m value for the highest temperature of the metal during the transient.

(7) S_a is obtained from the fatigue curves of Section III Appendices, Mandatory Appendix I. The allowable stress intensity for the full range of fluctuation is $2S_a$.

(8) Values of S_{alt}, calculated on an elastic basis, shall not exceed the S_a value associated with 10 cycles when using the fatigue curves of Section III Appendices, Mandatory Appendix I.

(9) L_L = lower bound limit load with yield point equal to $1.5S_m$ (where S_m is the value of allowable stress intensity at temperature as contained in Section II, Part D, Subpart 1, Tables 2A and 2B. The *lower bound limit load* is here defined as that produced from the analysis of an ideally plastic (nonstrain-hardening) material where deformations increase with no further increase in applied load. The lower bound load is one in which the material everywhere satisfies equilibrium and nowhere exceeds the defined material yield strength using either a shear theory or a strain energy of distortion theory to relate multiaxial yielding to the uniaxial case.

(10) S_L denotes the structural action of shakedown load as defined in NG-3213.17, calculated on a plastic basis as applied to a specific location on the structure.

(11) L_u is defined in NG-3228.4.

satisfied by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Subsection. If the Service Loadings do not meet all the conditions of (d) below, a fatigue analysis shall be made in accordance with (e) below or a fatigue test shall be made in accordance with Section III Appendices, Mandatory Appendix II, II-1500.

(b) Peak Stress Intensity. This stress intensity is derived from the highest value at any point across the thickness of a section of all primary, secondary, and peak stresses produced by specified service pressure differences and other mechanical loads, and by general and local thermal effects associated with normal Service Conditions and including the effects of gross and local structural discontinuities.

(c) Conditions and Procedures. The conditions and procedures of NG-3222.4 are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength curves of Section III Appendices, Mandatory Appendix I. These curves show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles. This stress intensity amplitude is calculated on the assumption of elastic behavior and, hence, has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The design fatigue curves in Section III Appendices, Mandatory Appendix I are derived from both strain-controlled test data and load-controlled fatigue data. When strain-controlled test data is used, the fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. The curves have been adjusted, where necessary, to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value which is different from zero. As a consequence of this procedure, it is essential that the requirements of NG-3222.2 be satisfied at all times with transient stresses included, and that the calculated value of the alternating stress intensity be proportional to the actual strain amplitude. To evaluate the effect of alternating stresses of varying amplitudes, a linear damage relation is assumed in (e)(5) below.

(d) Components Not Requiring Analysis for Cyclic Service. An analysis for cyclic service is not required, and it may be assumed that the limits on peak stress intensities as governed by fatigue have been satisfied for a structure by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Subsection, provided the specified Service[17] Loadings of the structure or portion thereof meets all the conditions stipulated in (1) through (4) below.

(1) Temperature Difference — Startup and Shutdown. The temperature difference in °F (°C) between any two adjacent points[18] of the structure during normal service does not exceed $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curves for the specified number of startup–shutdown cycles, α is the value of the instantaneous coefficient of thermal expansion at the mean value of the temperatures at the two points as given by Section II, Part D, Subpart 2, Table TE, and E is taken from Section II, Part D, Subpart 2, Table TM at the mean value of the temperature at the two points.

(2) Temperature Difference — Normal Service. The temperature difference in °F (°C) between any two adjacent points[18] does not change[19] during normal service by more than the quantity $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I for the total specified number of significant temperature difference fluctuations. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/2E\alpha$, where S is defined as follows:

(-a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(-b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(3) Temperature Difference — Dissimilar Materials. For structures fabricated from materials of differing moduli of elasticity and coefficients of thermal expansion or both, the total algebraic range of temperature fluctuation in °F (°C) experienced by the component during normal service does not exceed the magnitude $S_a/2(E_1\alpha_1 - E_2\alpha_2)$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the values of the instantaneous coefficients of thermal expansion at the mean temperature value involved for the two materials of construction (Section II, Part D, Subpart 2, Tables TE and TM). A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity $S/2(E_1\alpha_1 - E_2\alpha_2)$, where S is defined as follows:

(-a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(-b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve. If the two materials used have different applicable design fatigue curves, the lower value of S_a shall be used in applying the rules of this paragraph.

(4) Mechanical Loads. The specified full range of mechanical loads, including pipe reactions and pressure differences, does not result in load stresses whose range exceeds the S_a value obtained from the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuations exceeds 10^6, the S_a value at $N = 10^6$ may be used. A load fluctuation shall be considered to be significant if the total excursion of load stress exceeds the value of S_a, where S is defined as follows:

(-a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(-b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(e) Procedure for Analysis for Cyclic Loading. If the specified service loadings for the structure do not meet the conditions of (d) above, the ability of the structure to withstand the specified cyclic service without fatigue failure shall be determined as provided herein. The determination shall be made on the basis of the stresses at a point and the allowable stress cycles shall be adequate for the specified Service Loadings at every point. Only the stresses due to service cycles as specified in the Design Specifications need be considered. Compliance with these requirements means only that the structure is suitable from the standpoint of possible fatigue failure; complete suitability for the specified Service Loadings is also dependent on meeting the general stress limits of NG-3222 and any applicable special stress limits of NG-3227.

(1) Stress Differences. For each condition of normal service, determine the stress differences and the alternating stress intensity S_a in accordance with NG-3216.

(2) Local Structural Discontinuities. These effects shall be evaluated by the use of theoretical stress concentration factors for all conditions, except that experimentally determined fatigue strength reduction factors may be used when stated herein or when determined in accordance with the procedures of Section III Appendices, Mandatory Appendix II, II-1600. Except for the case of cracklike defects and specific piping geometries for which specific values are given in NB-3680, no fatigue strength reduction factor greater than 5 need be used.

(3) Design Fatigue Curves. Section III Appendices, Mandatory Appendix I contains the applicable fatigue design curves for the materials permitted by this Subsection. When more than one curve is presented for a given material, the applicability of each curve to material of various strength levels is identified. Linear interpolation may be used for intermediate strength levels of these materials. As used herein the strength level is the specified minimum room temperature value.

(4) Effect of Elastic Modulus. Multiply S_{alt} (NG-3216.1 or NG-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(5) Cumulative Damage. If there are two or more types of stress cycle which produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps 1 through 6 below.

Step 1. Designate the specified number of times each type of stress cycle of types 1, 2, 3, etc., will be repeated during the life of the component as $n_1, n_2, n_3, \ldots, n_n$, respectively.

NOTE: In determining $n_1, n_2, n_3, \ldots, n_n$, consideration shall be given to the superposition of cycles of various origins which produce a total stress difference range greater than the stress difference ranges of the individual cycles. For example, if one type of stress cycle produces 1000 cycles of a stress difference variation from zero to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to −50,000 psi, the two types of cycle to be considered are defined by the following parameters:

$$\text{Type 1 cycle: } n_1 = 1000,$$
$$S_{alt1} = (60,000 + 50,000)/2 = 55,000 \text{ psi}$$

$$\text{Type 2 cycle: } n_2 = 9000,$$
$$S_{alt2} = (50,000 + 0)/2 = 25,000 \text{ psi}$$

Step 2. For each type of stress cycle, determine the alternating stress intensity S_{alt} by the procedures of NG-3216.1 or NG-3216.2 above. Call these quantities $S_{alt1}, S_{alt2}, S_{alt3}, \ldots, S_{alt\,n}$.

Step 3. For each value $S_{alt1}, S_{alt2}, S_{alt3}, \ldots, S_{alt\,n}$, use the applicable design fatigue curve to determine the maximum number of repetitions which would be allowable if this type of cycle were the only one acting. Call these values $N_1, N_2, N_3, \ldots, N_n$.

Step 4. For each type of stress cycle, calculate the usage factors $U_1, U_2, U_3, \ldots, U_n$, from $U_1 = n_1/N_1$, $U_2 = n_2/N_2$, $U_3 = n_3/N_3, \ldots, U_n = n_n/N_n$.

Step 5. Calculate the cumulative usage factor U from $U = U_1 + U_2 + U_3 + \ldots + U_n$.

Step 6. The cumulative usage factor U shall not exceed 1.0.

NG-3222.5 Thermal Stress Ratchet. It should be noted that under certain combinations of steady state and cyclic loadings there is a possibility of large distortions developing as the result of ratchet action; that is, the deformation increases by a nearly equal amount for each cycle. Examples of this phenomenon are treated in this subparagraph and in NG-3227.3.

(a) The limiting value of the maximum cyclic thermal stress permitted in a portion of an axisymmetric shell loaded by steady-state internal pressure difference in order to prevent cyclic growth in diameter is as follows:

Let y' = maximum allowable range of thermal stress computed on an elastic basis divided by the yield strength S_y[20]

x = maximum general membrane stress due to pressure difference divided by the yield strength S_y[20]

(1) Case 1 — linear variation of temperature through the wall

$$y' = \frac{1}{x} \text{ for } 0 < x < 0.5$$

$$y' = 4(1 - x) \text{ for } 0.5 < x < 1.0$$

(2) Case 2 — parabolic constantly increasing or constantly decreasing variation of temperature through the wall

y' = 5.2(1 − x) for 0.615 < x < 1.0 and approximately for x < 0.615 as follows:
for x = 0.3, 0.4, 0.5
y' = 4.65, 3.55, 2.70

(b) Use of yield strength S_y in the above relations instead of the proportional limit allows a small amount of growth during each cycle until strain hardening raises the proportional limit to S_y. If the yield strength of the material is higher than two times the S_a value for the maximum number of cycles on the applicable fatigue curve of Figs. I-9.0 for the material, the latter value shall be used if there is to be a large number of cycles because strain softening may occur.

NG-3222.6 Deformation Limits. Any deformation limits prescribed by the Design Specifications shall be satisfied.

NG-3223 Level B Service Limits

For components operating within the temperature limits of this Section the requirements of (a) and (b) apply.

(a) The Level A Service Limits in NG-3222 shall apply to Service Level B, except that the primary stress intensity limits shall be increased by 10%.

(b) The Design Specifications shall be satisfied.

NG-3224 Level C Service Limits

Level C Service Limits must be satisfied for Service Loadings for which they are designated by the Design Specifications and are those of one of the five methods permitted in NG-3224.1. These stress intensity limits are summarized by Figure NG-3224-1. Dynamic instability shall be considered in meeting the load, stress, and deformation limits. The requirements of NG-3224.2 through NG-3224.6 shall also be met.

NG-3224.1 Stress Intensity Limits.

(a) Elastic Analysis Method

(1) The general primary membrane stress intensity (NG-3213.6, NG-3213.8, and NG-3221.1) shall not exceed 1.5 times the allowable stress intensity S_m as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(2) The primary membrane plus primary bending stress intensity (NG-3213.7, NG-3213.8, and NG-3221.3) shall not exceed 2.25 times the allowable stress intensity S_m as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(b) Limit Load Analysis. Instead of the elastic analysis of (a), a limit load analysis may be performed as set forth below.

(1) The lower bound limit load L_L is determined with material yield point equal to 1.5 times the allowable stress intensity S_m at temperatures where S_m is given in Section II, Part D, Subpart 1, Tables 2A and 2B. The lower bound limit load (NG-3213.21) is that load, determined from the analysis (NG-3213.20) of an ideally plastic (nonstrain-hardening) material, which produces increasing deformations with no further increase in applied load. The lower bound load is one in which the material everywhere satisfies equilibrium and nowhere exceeds the defined material yield strength, using either the maximum shear stress theory or a strain energy of distortion theory to relate multiaxial yielding to the uniaxial case.

(2) For Service Loadings for which Level C Limits are designated, the general primary membrane stress intensity shall not exceed the lower bound limit load L_L.

(3) For Service Loadings for which Level C Limits are designated, the general primary membrane plus primary bending stress intensities shall not exceed the lower bound limit load L_L.

(c) Plastic Analysis. Instead of the elastic analysis of (a), a plastic analysis may be performed as set forth in (1) and (2) below.

(1) For Service Loadings for which Level C Limits are designated, general primary membrane stress intensity values shall not exceed 1.5 times the allowable stress intensity S_m at temperatures where S_m is given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(2) For Service Loadings for which Level C Limits are designated, the general primary membrane plus primary bending stress intensities shall not exceed the greater of either one-half of the ultimate strength values at temperature or 2.25 times the allowable stress intensity values S_m at temperature as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(d) Stress Ratio Analysis. Instead of the elastic analysis of (a), a stress ratio analysis (NG-3213.22) may be performed, in which event the limits of (1) and (2) below shall be met.

Figure NG-3224-1
Stress Categories and Limits of Stress Intensities for Service Level C

Stress Category	Primary Stresses: Membrane, P_m [Notes (1), (2), and (3)]	Primary Stresses: Bending, P_b [Notes (1), (2), and (3)]	Secondary Stresses Membrane and Bending, Q [Notes (1) and (4)]	Peak Stresses, F [Note (1)]
Level C [Note (4)]	P_m	$P_m + P_b$	Evaluation not required	Evaluation not required
	$1.5S_m$ Elastic analysis [Note (5)]	$2.25S_m$ Elastic analysis [Note (5)]		
	or	or		
	L_L Limit analysis [Note (6)]	L_L Limit analysis [Note (6)]		
	or	or		
	$1.5S_m$ Plastic analysis [Note (7)]	$2.25S_m$ or $0.5S_u$ Plastic analysis [Notes (7) and (8)]		
	or	or		
	$0.6L_e$ Test [Note (9)]	$0.6L_e$ Test [Note (9)]		
	or	or		
	S_E Stress-ratio analysis [Note (10)]	KS_E Stress-ratio analysis [Note (10)]		

NOTES:

(1) The symbols P_m, P_b, Q, and F do not represent single quantities, but rather sets of six quantities representing the six stress components σ_t, σ_l, σ_r, τ_{lt}, τ_{lr}, τ_{rt}.

(2) For configurations where compressive stresses occur, the stress limits shall be revised to take into account critical buckling stresses [NG-3211(c)].

(3) When loads are transiently applied, consideration should be given to the use of dynamic load amplification and possible change in modulus of elasticity.

(4) Where deformation is of concern in a structure, the deformation shall be limited to two-thirds the value given in Design Specifications for Level C Service Limits.

(5) The triaxial stresses represent the algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) for the combination of stress components. Where uniform tension loading is present, triaxial stresses should be limited to $6S_m$.

(6) L_L = lower bound limit load with yield point equal to $1.5S_m$ (where S_m is the value of allowable stress intensity at temperature as contained in Section II, Part D, Subpart 1, Tables 2A and 2B. The *lower bound limit load* is here defined as that produced from the analysis of an ideally plastic (nonstrain-hardening) material where deformations increase with no further increase in applied load. The lower bound load is one in which the material everywhere satisfies equilibrium and nowhere exceeds the defined material yield strength using either a shear theory or a strain energy of distortion theory to relate multiaxial yielding to the uniaxial case.

(7) Elastic–plastic evaluated nominal primary stress. Strain hardening of the material may be used for the actual monotonic stress–strain curve at the temperature of loading or any approximation to the actual stress–strain curve that everywhere has a lower stress for the same strain as the actual monotonic curve may be used. Either the shear or strain energy of distortion flow rule shall be used to account for multiaxial effects.

(8) S_u = ultimate strength at temperature. Multiaxiality effect on the ultimate strength shall be considered.

(9) L_e is defined in NG-3224.1(e).

(10) Stress ratio is a method of plastic analysis that uses the stress ratio combinations [combination of stresses that consider the ratio of the actual stress to the allowable plastic or elastic stress, NG-3224.1(d)] to compute the maximum load strain-hardening material can carry.

(1) Service loads producing primary membrane stresses shall not result in stress intensities exceeding S_E where $S_E \leq 2.0S_m$.

(2) The stress intensity limits for other stress fields shall be as specified in Section III Appendices, Nonmandatory Appendix A, Article A-9000. For example, for bending

$$P_B \leq S_E\left[1 - \left(\frac{P_m}{S_E}\right)^2\right]$$

for rectangular sections, where

$$n = 2 \quad \text{or} \quad P_B \leq \sqrt{K^2 S_E (S_E - P_m)}$$

where K is the Section Factor for n = 1 as determined by the method of Section III Appendices, Nonmandatory Appendix A, Article A-9000.

(e) Prototype or Model Tests. For Service Loadings for which Level C Limits are designated, the limits of (a) need not be satisfied if it can be shown from the test of a prototype or model that the specified loads (dynamic or static equivalent) do not exceed 60% of L_e, where L_e is the ultimate load or the maximum load or load combination used in the test. In using this method, account shall be taken of the size effect and dimensional tolerances which exist between the actual part and the test part or parts, as well as differences which may exist in the ultimate strength or other governing material properties of the actual part and the tested parts, to assure that the loads obtained from the test are a conservative representation of the load carrying capability of the actual structure under postulated Service Loadings for which Level C Limits are designated.

NG-3224.2 External Pressure. The permissible equivalent static external pressure shall be taken as 150% of that permitted by the rules of NG-3133. Where dynamic pressures are involved, the permissible external pressure shall satisfy the preceding requirements or be limited to one-half the dynamic instability pressure.

NG-3224.3 Special Stress Limits. The permissible values for special stress limits shall be taken as 150% of the values given in NG-3227 and NG-3228.1.

NG-3224.4 Secondary and Peak Stresses. The requirements of NG-3222.2, NG-3222.4(b), NG-3222.5, and NG-3227.3 need not be satisfied.

NG-3224.5 Fatigue Requirements. Service Loadings for which Level C Limits are designated need not be considered when applying the procedures of NG-3222.4(a) to determine whether or not a fatigue analysis is required.

NG-3224.6 Deformation Limits. Any deformation limits prescribed by the Design Specifications shall be considered [Figure NG-3224-1, Note (4)].

NG-3225 Level D Service Limits

If the Design Specifications specify any Service Loadings for which Level D Limits are designated [NCA-2142.4(b)(4)], the rules contained in Section III Appendices, Nonmandatory Appendix F may be used in evaluating these loadings, independently of all other Design and Service Loadings. In addition, when the special stress limits of NG-3227 are applicable for Level D Limits, the calculated stresses shall not exceed twice the stress limits given in NG-3227 as applied for Level A and Level B Service Limits.

NG-3227 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special Service Loadings or configurations. Some of these deviations are more restrictive and some are less restrictive than the basic stress limits. Rules governing application of these special stress limits for Level C and Level D Service Limit applications are contained in NG-3224.3 and NG-3225, respectively. In cases of conflict between these requirements and the basic stress limits, the rules of NG-3227 take precedence for the particular situations to which they apply. NG-3227 does not apply to threaded structural fasteners (NG-3230).

NG-3227.1 Bearing Loads.

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of Design Loadings or of Service Loadings for which Level A Limits are designated, shall be limited to S_y at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted. For clad surfaces the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(b) When bearing loads are applied near free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. In the case of load stress only, the average shear stress shall be limited to $0.6S_m$. In the case of load stress plus secondary stress, the average shear stress shall not exceed the following:

(1) for material of Section II, Part D, Subpart 1, Table 2A to which Note G7 is applicable and Section II, Part D, Subpart 1, Table 2B to which Note G1 is applicable, the lower of $0.5S_y$ at 100°F (38°C) and 0.675 S_y at temperature;

(2) for all other material, $0.5S_y$ at temperature.

(c) For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base

metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(d) When considering bearing stresses in pins and similar members, the S_y at temperature value is applicable, except that a value of $1.5S_y$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

NG-3227.2 Pure Shear.

(a) The average primary shear stress across a section loaded in pure shear, experienced as a result of Design Loadings or Service Loadings for which Level A Limits are designated (e.g., keys, shear rings), shall be limited to $0.6S_m$.

(b) The maximum primary shear, experienced as a result of Design Loadings or Service Loadings for which Level A Limits are designated exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_m$. Primary plus secondary and peak shear stresses shall be converted to stress intensities (equal to two times pure shear stress) and as such shall not exceed the basic stress limits of NG-3222.2 and NG-3222.4(b).

NG-3227.3 Progressive Distortion of Nonintegral Connections. Screwed on caps, screwed in plugs, shear ring closures, and breechlock closures are examples of nonintegral connections which are subject to failure by bell mouthing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (NG-3222.2) which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion shall be limited to the value S_y (Section II, Part D, Subpart 1, Table Y-1).

NG-3227.4 Triaxial Stresses. The algebraic sum of the three primary principal stresses $(\sigma_1 + \sigma_2 + \sigma_3)$ shall not exceed four times the tabulated value of S_m.

NG-3227.5 Nozzle Piping Transition. The P_m classification of stresses in nozzle resulting from pressure difference, external loads, and moments is applicable for that length of nozzle which lies within the limits or reinforcement given by NG-3132, whether or not nozzle reinforcement is provided. Beyond the limits of reinforcement, a P_m classification shall be applied to the general primary membrane stress intensity averaged across the section (not thickness) resulting from combined pressure difference and external mechanical loads; $P_m + P_b$ classification shall be applied to primary membrane plus primary bending stress intensities that result from Design Pressure Difference and external mechanical loads; and a $P_m + P_b + Q$ classification shall be applied to primary plus secondary stress intensities resulting from all loads including external load or moment attributable to restrained free end displacement of the attached pipe. Beyond the limits of reinforcement, the $3S_m$ limit on the range of primary plus secondary stress intensity may be exceeded as provided in NG-3228.3 except that in the evaluation of NG-3228.3(a), stresses from attached pipe thermal expansion loads and moments may also be excluded. The range of membrane plus bending stress intensity attributable solely to thermal expansion of the attached piping shall be ≤ $3S_m$. The nozzle, outside the reinforcement limit, shall not be thinner than the larger of the pipe thickness or the quantity $t_p\ (S_{mp}/S_{mn})$ where t_p is the nominal thickness of the mating pipe, S_{mp} is the allowable stress intensity value for the pipe material, and S_{mn} is the allowable stress intensity value for the nozzle material.

NG-3227.6 Applications of Elastic Analysis for Stresses Beyond the Yield Strength. Certain of the allowable stresses permitted in the design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary plus secondary stress intensity of $3S_m$ (NG-3222.2) has been placed at a level which assures shakedown to elastic action after a few repetitions of the stress cycle except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation. Therefore

(a) in evaluating stresses for comparison with the stress limits on other than fatigue allowables, stresses shall be calculated on an elastic basis

(b) in evaluating stresses for comparison with fatigue allowables, all stresses except those which result from local thermal stresses [NG-3213.12(b)] shall be evaluated on an elastic basis. In evaluating local thermal stresses, the elastic equations shall be used except that the numerical value substituted for Poisson's ratio shall be determined from the expression

$$\nu = 0.5 - 0.2\frac{S_y}{S_a} \text{ but not less than } 0.3$$

where

S_a = alternating stress intensity determined in NG-3222.4(e) prior to the elastic modulus adjustment in NG-3222.4(e)(4)

S_y = the yield strength of the material at the mean value of the temperature of the cycle

NG-3228 Applications of Plastic Analysis

The following subparagraphs provide guidance in the application of plastic analysis and some relaxation of the basic stress limits which are allowed if plastic analysis is used.

NG-3228.1 Plastic Analysis. The limits on primary plus secondary stress intensity (NG-3222.2), thermal stress ratchet in shell (NG-3222.5), and progressive distortion of nonintegral connections (NG-3227.3) need not be satisfied at a specific location if, at the location, the procedures of (a) through (c) are used.

(a) In evaluating stresses for comparison with the remaining stress limits, the stresses are calculated on an elastic basis.

(b) In lieu of satisfying the specific requirements of NG-3222.2, NG-3222.5, and NG-3227.3 at a specific location, the structural action is calculated on a plastic basis, and the design shall be considered to be acceptable if shakedown occurs (as opposed to continuing deformation) and if the deformations which occur prior to shakedown do not exceed specified limits. However, this shakedown requirement need not be satisfied provided the following conditions are met:

(1) The requirements on primary plus secondary stress intensity (NG-3222.2), thermal stress ratchet in shell (NG-3222.5), and progressive distortion of nonintegral connections (NG-3227.3) need not be satisfied at a specific location, provided that at the location the evaluation of stresses for comparison with all the other design, service, testing, and special limits specified in NG-3220 is calculated on an elastic basis.

(2) The maximum accumulated strain at any point, as a result of cyclic operations to which plastic analysis is applied, does not exceed 5.0%.

(3) The maximum deformations do not exceed specified limits.

(4) In evaluating stresses for comparison with fatigue allowables, the numerically maximum principal total strain range shall be multiplied by one-half the modulus of elasticity of the material (Section II, Part D, Subpart 2, Table TM) at the mean value of temperature of the cycle.

(5) The material shall have a minimum specified yield strength to specified minimum ultimate strength ratio of less than 0.80.

(c) In evaluating stresses for comparison with fatigue allowables, the numerically maximum principal total strain range which occurs after shakedown shall be multiplied by one-half of the modulus of elasticity of the material (Section II, Part D, Subpart 2, Table TM) at the mean value of the temperature of the cycle.

NG-3228.2 Limit Analysis. The limits on primary membrane stress intensity (NG-3221.1) and primary membrane plus primary bending stress intensity (NG-3221.2) need not be satisfied at a specific location if it can be shown by means of limit analysis or by tests that the specified loadings do not exceed two-thirds of the lower bound collapse load, except for those materials of Section II, Part D, Subpart 1, Table 2A to which Note G7 is applicable and Section II, Part D, Subpart 1, Table 2B to which Note G1 is applicable. For these latter materials, the specified loading shall not exceed the product of the applicable permanent strain limiting factor of Section II, Part D, Subpart 1, Table Y-2 times the lower bound collapse load.

NG-3228.3 Simplified Elastic–Plastic Analysis. The $3S_m$ limit on the range of primary plus secondary stress intensity (NG-3222.2) may be exceeded, provided that the requirements of (a) through (f) below are met

(a) The range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be $\leq 3S_m$.

(b) The value of S_a used for entering the design fatigue curve is multiplied by the factor K_e where

$$K_e = 1.0 \text{ for } S_n \leq 3S_m$$

$$= 1.0 + \frac{(1-n)}{n(m-1)}\left(\frac{S_n}{3S_m} - 1\right) \text{ for}$$

$$3S_m < S_n < 3mS_m$$

$$= 1/n \text{ for } S_n \geq 3mS_m$$

S_n = range of primary plus secondary stress intensity

The values of the material parameters m and n for the various classes of permitted materials are as follows:

Material	m	n	T_{max}, °F (°C)
Low alloy steel	2.0	0.2	700 (370)
Martensitic stainless steel	2.0	0.2	700 (370)
Carbon steel	3.0	0.2	700 (370)
Austenitic stainless steel	1.7	0.3	800 (425)
Nickel–chromium–iron	1.7	0.3	800 (425)
Nickel–copper	1.7	0.3	800 (425)

(c) The rest of the fatigue evaluation stays the same as required in NG-3222.4, except that the procedure of NG-3227.6 need not be used.

(d) The structure meets the thermal ratcheting requirement of NG-3222.5.

(e) The temperature does not exceed those listed in the above table for the various classes of materials.

(f) The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.

NG-3228.4 Tests for Level A and B Service Limits. For Level A and B Service Limits, the limits on primary membrane plus primary bending need not be satisfied in a structure if it can be shown from the test of a prototype or model that the specified loads (dynamic or static equivalent) do not exceed 44% of L_u, where L_u is the ultimate load or the maximum load or load combination used in the test. In using this method, account shall be taken of the size effect and dimensional tolerances which may exist between the actual part and test part or parts, as well as differences which may exist in the ultimate strength or other governing material properties of the actual part and the tested parts to assure that the loads obtained from the test are a conservative representation of the load-carrying capability of the actual structure under the postulated Service Loading.

NG-3229 Design Stress Values

The design stress intensity values S_m are given in Section II, Part D, Subpart 1, Tables 2A and 2B for core support structure material. Values for intermediate temperatures may be found by interpolation. These form the basis for the various stress limits. Values of yield strength are given in Section II, Part D, Subpart 1, Table Y-1. Values of the coefficient of thermal expansion are in Section II, Part D, Subpart 2, Table TE, and values of the modulus of elasticity are in Section II, Part D, Subpart 2, Table TM. The basis for establishing stress values is given in Section III Appendices, Mandatory Appendix III. The design fatigue curves used in conjunction with NG-3222.4 are those of Section III Appendices, Mandatory Appendix I.

NG-3230 STRESS LIMITS FOR THREADED STRUCTURAL FASTENERS

NG-3231 Design Conditions

(a) The rules of this paragraph apply to mechanical connections joining parts in core support structures located within a pressure-retaining boundary. Devices which are used to assemble structural elements of core support structures are referred to as threaded structural fasteners. The design stress intensity values S_m and yield strength values S_y for threaded structural fasteners shall be the values given in Section II, Part D, Subpart 1, Tables 2A and 2B and in Section II, Part D, Subpart 1, Table Y-1, respectively.

(b) The special stress limits of NG-3227 do not apply to threaded structural fasteners. For connections joining parts of pressure-retaining boundaries see NB-3230.

NG-3232 Level A Service Limits

The number and cross-sectional area of threaded structural fasteners shall be such that the stress intensity limits of this paragraph are satisfied for the Service Loadings for which Level A Limits are designated in the Design Specifications. The stress intensity limits are summarized in Figure NG-3232-1. Any deformation limit prescribed in the Design Specifications shall be considered. The total axial load transferred through the fastener threads shall not go to or through zero during the specified Service Loadings.

NG-3232.1 Average Stress. Elastic analysis of specified conditions shall show that the average primary plus secondary membrane stress including stress from preload meets the following requirements:

(a) The maximum value of the membrane stress intensity averaged across either the area of the fastener shank or the tensile stress area of the threads shall be no greater than the lesser of either $0.9S_y$ or $^2/_3 S_u$, where S_y and S_u are determined at service temperature.

(b) The average shear stress across the threads when loaded in pure shear shall be no greater than $0.6S_y$, where S_y is determined at service temperature.

(c) The average value of bearing stress under the fastener head shall be no greater than $2.7S_y$, where S_y is determined at service temperature.

(d) The primary membrane stress intensity P_m due only to Design Mechanical Loads applied to the fastener shall be no greater than S_m, where S_m is determined at service temperature.

(e) If a tight joint is required, the stress due to preload shall be greater than that due to primary and secondary membrane stress excluding preload.

(f) The primary shear stress across the threads when loaded in pure shear due only to Design Mechanical Loads applied to the fastener shall be no greater than $0.6S_m$, where S_m is determined at service temperature.

NG-3232.2 Maximum Stress.

(a) The maximum primary membrane and bending plus secondary membrane and bending stress intensities, produced by the combination of all primary loads and secondary loads but excluding effects of stress concentrations, shall be no greater than 1.33 times the limits of NG-3232.1(a).

(b) For torquing during installation of fasteners, the maximum value of membrane stress intensity shall be no greater than 1.2 times the limits of NG-3232.1(a), and the maximum value of membrane plus bending stress intensity shall be no greater than 1.2 times the limits of (a) at installation temperature.

NG-3232.3 Fatigue Analysis of Threaded Structural Fasteners. Unless threaded structural fasteners meet the conditions of NG-3222.4(d) and thus require no fatigue analysis, the suitability of threaded structural fasteners for cyclic service shall be determined in accordance with the procedures of (a) through (e) below.

(a) Threaded Structural Fasteners Having Less Than 100 ksi (690 MPa) Tensile Strength. Fasteners made of material which has specified minimum tensile strength of less than 100 ksi (690 MPa) shall be evaluated for cyclic service by the methods of NG-3222.4(e), using the applicable design fatigue curves of Section III Appendices, Mandatory Appendix I and an appropriate fatigue strength reduction factor [see (c)].

(15)

NG-3232-1
Stress Intensity Limits for Design of Threaded Structural Fasteners

Stress Categories	Average Primary Membrane Plus Secondary Membrane Including Stress From Preload [Notes (1) and (2)]	Primary Membrane and Bending Plus Secondary Membrane and Bending [Notes (2) and (3)]	Peak Stresses
For Level A and Level B Service Limits [Notes (9) and (10)]	$P_m + Q_m$: $0.9S_y$ Shank or threads [Note (4)] (NG-3232.1) or $2/3S_u$ [Note (5)] or $0.67L_L$ Limit analysis [Note (7)] or $0.44L_u$ Test [Note (8)] $0.6S_y$ Thread shear (NG-3232.1) $2.7S_y$ Bearing under head P_m: S_m Shank or threads	$P_m + Q_m + P_b + Q_B$: $1.2S_y$ Shank or threads [Note (4)] or $8/9S_u$ (NG-3232.2) [Note (5)] or $0.67L_L$ Limit analysis [Note (7)] or $0.44L_u$ Test [Note (8)]	$P_m + Q_m + P_b + Q_B + F$: S_a (NG-3232.3) [Note (6)]

NOTES:
(1) If a tight joint is required, the stress due to preload should exceed that due to primary plus secondary membrane other than preload.
(2) Q_m are secondary membrane stresses.
(3) Q_B are secondary bending stresses.

NG-3232-1
Stress Intensity Limits for Design of Threaded Structural Fasteners (Cont'd)

NOTES (CONT'D):

(4) For torquing during installation, the maximum membrane stress intensity shall not exceed 1.2 times these values at installation temperature.

(5) Figure NG-3224-1, Note (5).

(6) Figure NG-3221-1, Note (7) and Note (8).

(7) Figure NG-3221-1, Note (9).

(8) L_u is defined in NG-3228.4.

(9) For Level C Service Limits, comply with NG-3234.

(10) For Level D Service Limits, comply with NG-3235.

(b) High-Strength Threaded Structural Fasteners. High-strength fasteners may be evaluated for cyclic service by the methods of NG-3222.4(e) using the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I, provided

(1) the maximum value of primary and secondary stresses, including preload, at the periphery of the fastener cross section (resulting from direct tension plus bending and neglecting stress concentrations) shall not exceed $0.9S_y$, where S_y is determined at service temperature

(2) threads shall have a minimum thread root radius no smaller than 3 mils (0.08 mm)

(3) fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.06

(c) Fatigue Strength Reduction Factor (NG-3213.16). Unless it can be shown by analysis or tests that a lower value is appropriate, the fatigue strength reduction factor used in the fatigue evaluation of threaded members shall not be less than 4. However, when applying the rules of (b) for high-strength fasteners, the value used shall not be less than 4.

(d) Effect of Elastic Modulus. Multiply S_{alt} (NG-3216.1 or NG-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(e) Cumulative Damage. The fasteners shall be acceptable for the specified cyclic application of loads and thermal stress provided the cumulative usage factor U as determined in NG-3222.4(e)(5) does not exceed 1.

NG-3233 Level B Service Limits

Level A Service Limits (NG-3232) apply.

NG-3234 Level C Service Limits for Threaded Structural Fasteners

The number and cross-sectional area of threaded structural fasteners shall be such that the requirements of NG-3224 are satisfied for the Service Loadings for which Level C Limits are designated in the Design Specifications. For high-strength structural fasteners [specified minimum tensile strength $S_u \geq 100$ ksi (690 MPa)], the limits of NG-3232.1 and NG-3232.2(a) also apply for these Service Loadings. Any deformation limit prescribed in the Design Specifications shall be considered.

NG-3235 Level D Service Limits for Threaded Structural Fasteners

The number and cross-sectional area of threaded structural fasteners shall be such that the requirements of NG-3225 are satisfied for the Service Loadings for which Level D Limits are designated [NCA-2142.4(b)(4)] in the Design Specifications. Any deformation limit prescribed in the Design Specifications shall be considered.

NG-3300 CORE SUPPORT STRUCTURE DESIGN

NG-3310 GENERAL REQUIREMENTS

NG-3311 Acceptability

The requirements for acceptability of a core support structure design are given in (a) through (c).

(a) The design shall be such that the requirements of NG-3100 and NG-3200 are satisfied.

(b) The requirements of NG-3300 are satisfied. In case of conflict between NG-3200 and NG-3300, the requirements of NG-3300 shall govern.

(c) The requirements of this subarticle apply to internal structures, NG-1122, only as specifically stipulated by the Certificate Holder; however, the Certificate Holder shall certify that the design used for the internal structures shall not adversely affect the integrity of the core support structure.

NG-3320 DESIGN CONSIDERATIONS

NG-3321 Design and Service Loadings

The provisions of NG-3110 apply.

NG-3322 Special Considerations

The provisions of NG-3120 apply.

NG-3323 General Design Rules

The provisions of NG-3130 apply, except when they conflict with rules of this subarticle. In case of conflict, this subarticle governs in the design of core support structures.

NG-3350 DESIGN FOR WELDED CONSTRUCTION

NG-3351 Welded Joint Categories

(a) The term *category* as used herein defines the location of a joint. The categories established by this paragraph are for use elsewhere in this Subsection to identify special restrictions regarding type of joint permitted for the location. Figures NG-3351(a)-1 and NG-3351(a)-2 illustrate locations of some typical welded joints in each category. Joints whose design functions are neither to restrain nor support the core do not fall into any category.

(b) The *types* of joints that may be used at the various locations are defined in NG-3352.

NG-3351.1 Joints of Category A. Joints of Category A are longitudinal joints in cylindrical members. Category A joints may be of Type I, II, or, with the following

Figure NG-3351(a)-1
Typical Locations of Joints of Several Categories

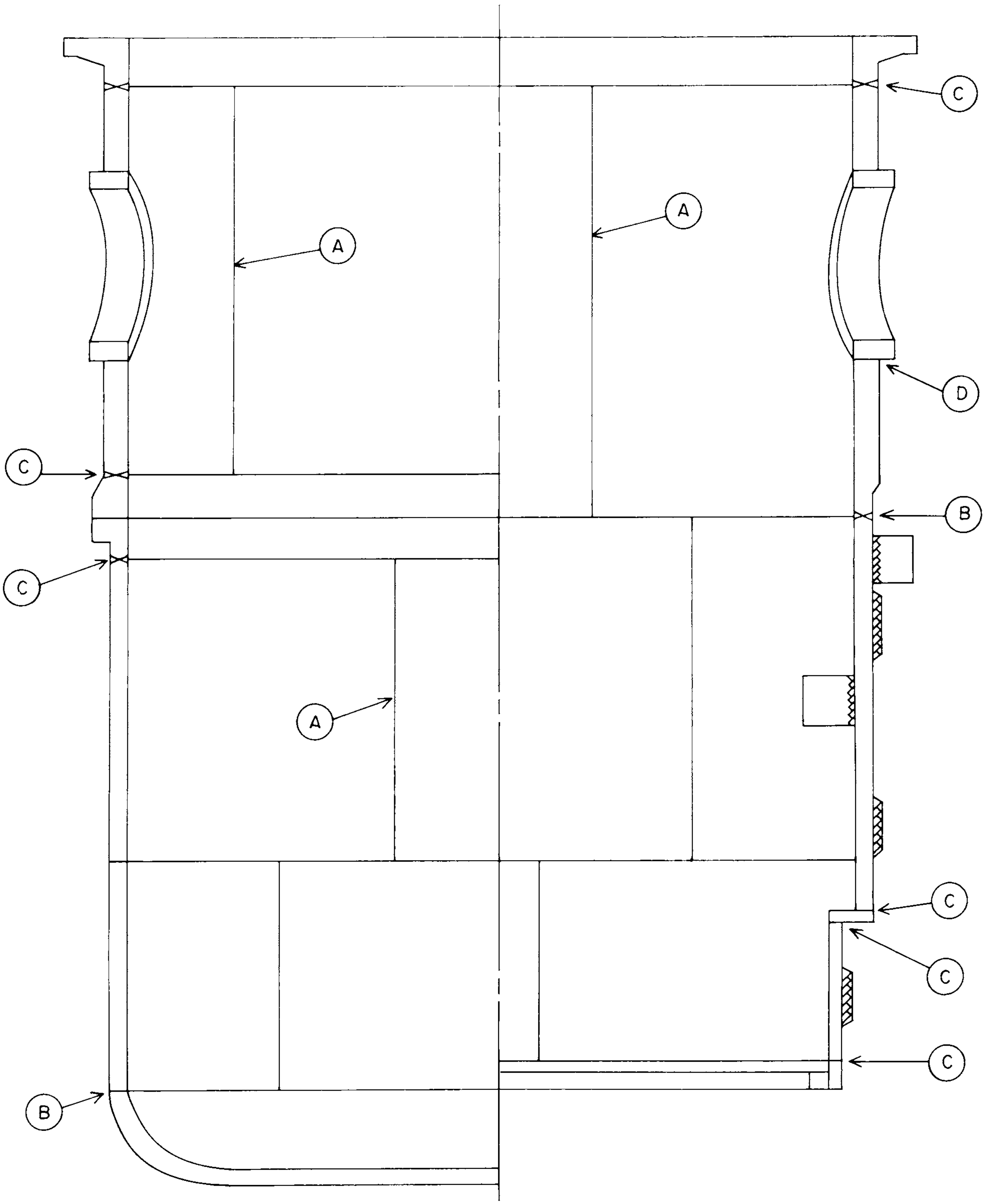
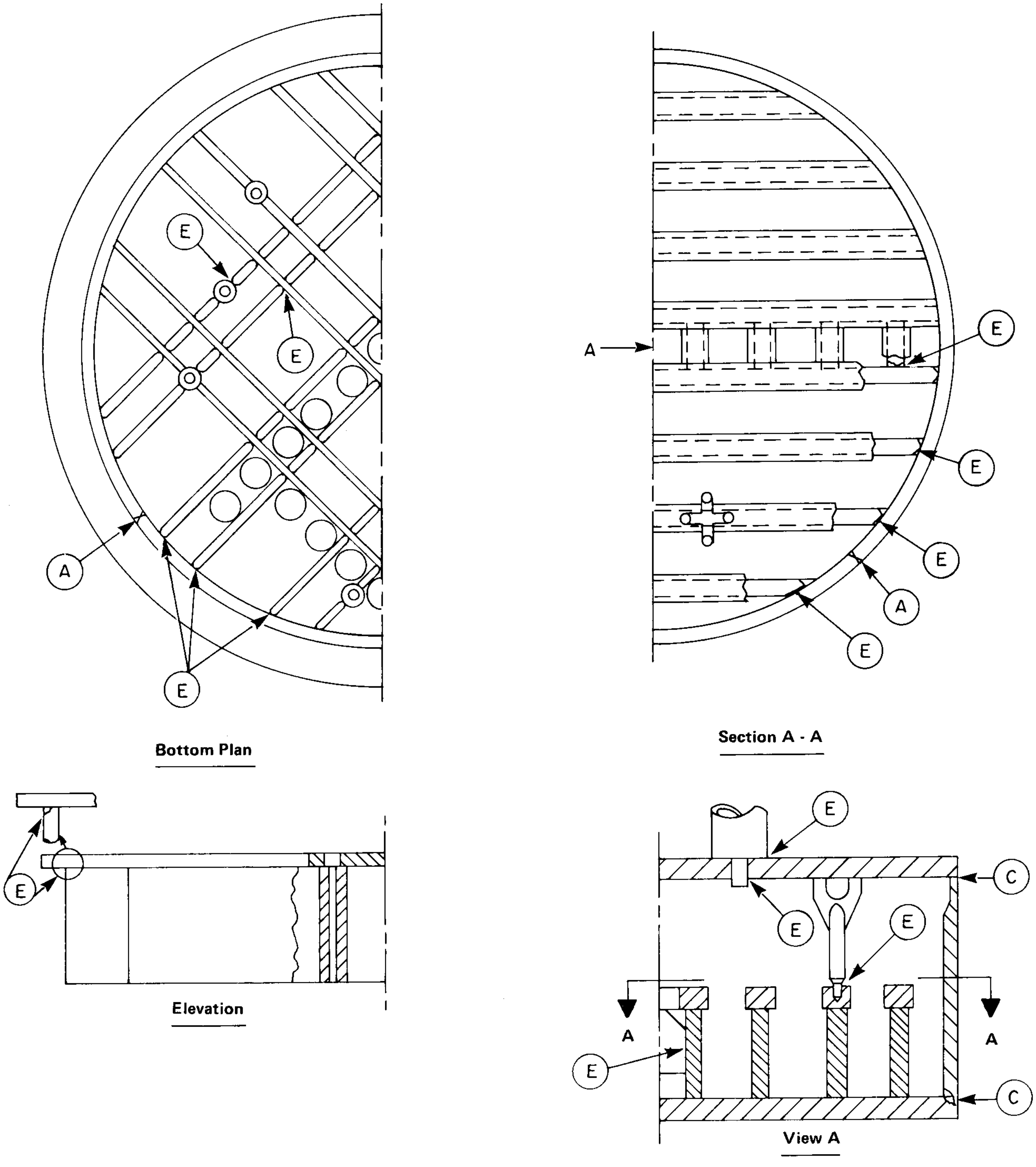


Figure NG-3351(a)-2
Typical Welded Joint Category Locations



restriction, Type IV. When a Type IV joint is used in Category A, the quality factor shall be one-half that permitted for Type I or II by Table NG-3352-1 for the examination used.

NG-3351.2 Joints of Category B. Joints of Category B are girth welds in cylindrical members. Category B joints may be of Type I, II, or, with the following restriction, Type IV or V. When Type IV or V joints are used in Category B, the quality factor shall be one-half that permitted for Type I or II by Table NG-3352-1 for the examination used.

NG-3351.3 Joints of Category C. Joints of Category C are primarily for joining flanges to cylinders. Category C joints may be of Type I, II, III, or, with the following restriction, Type IV or V. When Type IV or V joints are used in Category C, the quality factor shall be one-half that permitted for Type I or II by Table NG-3352-1 for the examination used.

NG-3351.4 Joints of Category D. Joints of Category D are primarily for attaching nozzles to other members. Category D joints may be of Type I, II, III, IV, V, VI, or VII.

NG-3351.5 Joints of Category E. Joints of Category E are for joints at the ends of webs of beams. Category E joints may be of Type I, II, III, IV, V, VI, VII, or VIII.

NG-3352 Permissible Types of Welded Joints

Subject to the limitations given in NG-3351, core support structures may use any of the types of joints described in the following subparagraphs, providing the quality factor n and fatigue factor f used in the analysis meet the requirements of Table NG-3352-1 for the method of examination employed. The quality factor is used by multiplying the allowable stress limit for primary and secondary categories times the quality factor in evaluating the design. The use of weld quality factor n is for static, not fatigue applications. In performing a fatigue analysis, use the fatigue factor f, designated in Table NG-3352-1, and the applicable fatigue curve in Section III Appendices, Mandatory Appendix I.

NG-3352.1 Type I Joints. Full penetration welds between plates or other elements that lie approximately in the same plane or have an offset angle not greater than 30 deg meet the intent of this subparagraph when made either as double welded butt joints, or with consumable inserts or gas backup, or with metal backing strips that are later removed, provided the backface of such joints meets the requirements of NG-4424.

NG-3352.2 Type II Joints. Full penetration welds between plates or other elements meet the intent of this subparagraph when made either according to NG-3352.1 or with edges of the joint prepared with opposing lips to form an integral backing strip, or with metal backing strips which are not later removed, except that the suitability for cyclic operation shall be analyzed by the method of NG-3222.4 (when used, backing strips shall be continuous and any splices shall be full penetration welded).

NG-3352.3 Type III Joints. Full penetration welds between plates or other elements that may have an offset angle up to 90 deg meet the intent of this subparagraph when either made according to NG-3352.2 or are corner welds. Attachment of connections using deposited weld metal as reinforcement and oblique connections meet the intent of this subparagraph.

NG-3352.4 Type IV Joints. Partial penetration welds of double groove design (minimum depth of each groove equals one-eighth times the thickness of the thinnest element) meet the intent of this subparagraph when the area of the connection is determined by the product of the throat thickness times the length of welds.

NG-3352.5 Type V Joints. Double fillet welds meet the intent of this subparagraph when the area of the connection is determined by the product of the theoretical throat thickness times the length of the welds (). Joints made having one side a single fillet and the other side a single groove meet the intent of this subparagraph.

NG-3352.6 Type VI Joints. Partial penetration welds of single groove design meet the intent of this subparagraph when the area of the connection is determined as the product of the weld throat thickness times the length of weld.

NG-3352.7 Type VII Joints. Single fillet welds meet the intent of this subparagraph when the area of the connection is determined as the product of the theoretical throat thickness of the fillet welds times the length of weld ().

NG-3352.8 Type VIII Joints. Intermittent fillet or plug welds meet the intent of this subparagraph when the area of the intermittent fillet weld connection is determined as the product of the theoretical throat thickness times the sum of weld lengths and the area of plug weld connection is determined as the product of the number of plug welds times the area of the minimum cross section.

NG-3352.9 Limitations on Types of Joints. The type of joint used for service shall be one of those permitted for the Category of the joint (NG-3351). Reduced quality factors must be used for certain types of joints when used in Categories A, B, and C (Table NG-3352-1).

Table NG-3352-1
Permissible Welded Joints and Design Factors

Type of Welded Joint	Permissible for Category Shown Below	Quality Factor and Fatigue Factor [Note (1)]: RT or UT [Note (2)] and PT or MT Examination NG-5220	Progressive PT or MT Examination NG-5231	Root and Final PT or MT Examination NG-5232	Surface PT or MT Examination NG-5233	Surface Visual Examination NG-5260
I. Full penetration	A, B, C, D, E	n = 1.0 f = 1	n = 0.9 f = 1	n = 0.75 f = 1	n = 0.65 f = 1	n = 0.5 f = 1
II. Full penetration	A, B, C, D, E	n = 1.0 f = 2	n = 0.9 f = 2	n = 0.75 f = 2	n = 0.65 f = 2	n = 0.5 f = 2
III. Full penetration	C, D, E	n = 1.0 f = 1	n = 0.9 f = 1 [Note (3)]	n = 0.75 f = 1 [Note (3)]	n = 0.65 f = 1 [Note (3)]	n = 0.5 f = 1 [Note (3)]
IV. Double groove (RT not applicable)	A, B, C	n = 0.5 f = 4	n = 0.45 f = 4	n = 0.4 f = 4	n = 0.35 f = 4	n = 0.25 f = 4
	D, E	n = 0.9 f = 4	n = 0.8 f = 4	n = 0.7 f = 4	n = 0.6 f = 4	n = 0.4 f = 4
V. Double fillet (RT not applicable)	B, C	n = 0.5 f = 4	n = 0.45 f = 4	n = 0.4 f = 4	n = 0.35 f = 4	n = 0.25 f = 4
	D, E	n = 0.9 f = 4	n = 0.8 f = 4	n = 0.7 f = 4	n = 0.6 f = 4	n = 0.4 f = 4
VI. Single groove (RT not applicable)	D, E	n = 0.6 f = 4	n = 0.55 f = 4	n = 0.45 f = 4	n = 0.4 f = 4	n = 0.35 f = 4
VII. Single fillet (RT not applicable)	D, E	n = 0.6 f = 4	n = 0.55 f = 4	n = 0.45 f = 4	n = 0.4 f = 4	n = 0.35 f = 4
VIII. Intermittent fillet or plug	E	Not applicable	n = 0.45 f = 4	n = 0.4 f = 4	n = 0.35 f = 4	n = 0.3 f = 4

NOTES:
(1) See NG-3352 for definitions.
(2) Electroslag butt welds shall be examined by radiography. Electroslag welds in ferritic material shall also be examined for their full length by the ultrasonic method after a grain refining heat treatment, when performed, or after a postweld heat treatment.
(3) A minimum fatigue strength reduction factor of 1.0 is permitted when both sides of weld are examined; otherwise a factor of 2.0 must be used in analysis for cyclic operation.

ARTICLE NG-4000 FABRICATION AND INSTALLATION

NG-4100 GENERAL REQUIREMENTS

NG-4110 INTRODUCTION

(a) Core support structures (NG-1121) shall be manufactured and installed in accordance with the requirements of this Article and shall be manufactured from materials which meet the requirements of Article NG-2000.

(b) The rules of this Article apply to the internal structures (NG-1122) only as specifically implemented by the Certificate Holder; however, the Certificate Holder shall certify that each internal structure has been fabricated so as to avoid creating an adverse effect on the integrity of the core support structure.

NG-4120 CERTIFICATION OF MATERIAL AND FABRICATION BY CERTIFICATE HOLDER

NG-4121 Means of Certification

The Certificate Holder for an item shall certify, by application of the appropriate Certification Mark and completion of the appropriate data report in accordance with NCA-8000, that the materials used comply with the requirements of Article NG-2000 and that the fabrication and installation comply with the requirements of this Article.

NG-4121.1 Certification of Treatments, Tests, and Examinations. If the Certificate Holder performs treatments, tests, repairs, or examinations required by other Articles, he shall certify that he has fulfilled such requirements. Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

NG-4121.2 Repetition of Tensile or Impact Tests. If during the fabrication or installation of the item the material is subjected to heat treatment that has not been covered by treatment of the test coupons (NG-2200), and that may reduce either tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons which have been taken and treated in accordance with the requirements of Article NG-2000.

NG-4122 Material Identification

Material for core support structures shall carry identification markings which will remain distinguishable until the core support structure is fabricated or installed. If the original identification markings are cut off or the material is divided, the marks shall be accurately transferred to the parts or a coded marking shall be used to assure identification of each piece of material during subsequent fabrication or installation, unless otherwise provided by NG-2150. Material supplied with a Certificate of Compliance and welding and brazing material shall be identified and controlled so that they can be traced to the core support structure, or else a control procedure shall be employed which ensures that the specified material is used.

NG-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with requirements of Article NG-4000, may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to NG-5500 and NG-5100, respectively, unless so specified.

NG-4125 Testing of Welding Material

All welding material shall meet the requirements of NG-2400.

NG-4130 REPAIR OF MATERIAL

NG-4131 Elimination and Repair of Defects

Material originally accepted on delivery in which defects exceeding the limits of NG-2500 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used provided the condition is corrected in accordance with the requirements of NG-2500 for the applicable product form, except

(a) the limitation on the depth of the weld repair does not apply

(b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with NG-5130

NG-4132 Documentation of Repair Welds of Base Material

The Certificate Holder who makes a repair weld, exceeding in depth the lesser of $^3/_8$ in. (10 mm) or 10% of the section thickness, shall prepare a report which shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results of repair welds. In addition, all repair welds exceeding an accumulated area of 20% of the area of the part or 15 in.[2] (9 700 mm^2), whichever is less, shall require the same documentation as welds exceeding the minimum depth.

NG-4200 FORMING, FITTING, AND ALIGNING

NG-4210 CUTTING, FORMING, AND BENDING

NG-4211 Cutting

Materials may be cut to shape and size by mechanical means, such as machining, shearing, chipping, or grinding, or by thermal cutting.

NG-4211.1 Preheating Before Thermal Cutting. When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material, using preheat schedules, such as suggested in Section III Appendices, Nonmandatory Appendix D.

NG-4211.2 Material Preparation After Thermal Cutting for P-No. 8 Material. When metal is to be removed by thermal cutting methods, additional material shall be removed by mechanical means to the extent required in the Design Specifications.

(15) NG-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend core support structure material, including weld metal, provided the required dimensions are attained (see NG-4214), and provided the specified impact properties of the material, when required, are not reduced below the minimum specified values or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (56°C) below the lower transformation temperature of the material. When required, the process shall be qualified for impact properties as outlined in NG-4213.

NG-4213 Qualification of Forming Processes for Impact Property Requirements

A procedure qualification test shall be conducted using specimens taken from material of the same specification, grade or class, heat treatment, and with similar impact properties as required for the material in the structure. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the structure. Applicable tests shall be conducted to determine that the required impact properties of NG-2300 are met after straining.

NG-4213.1 Exemptions. Procedure qualification tests are not required for materials listed in (a) through (f)

(a) hot formed material, such as forgings, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens

(b) hot formed material represented by test coupons required in either NG-2211 or NG-4121.2 which has been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts

(c) material which does not require impact tests in accordance with NG-2300

(d) material which has a final strain less than 0.5%

(e) material where the final strain is less than that of a previously qualified procedure for that material

(f) material from which the impact testing required by NG-2300 is performed on each heat and lot, as applicable, after forming

NG-4213.2 Procedure Qualification Test. The procedure qualification test shall be performed in the manner stipulated in (a) through (f).

(a) The tests shall be performed on three different heats of material both before and after straining to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of Article NG-2000 and from the tension side of the strained material.

(c) The percent strain shall be established by the following equations:

For cylinders

$$\%\ \text{strain} = 50t/R_f\left[1 - \left(R_f/R_o\right)\right]$$

For spherical or dished surfaces

$$\%\ \text{strain} = 75t/R_f\left[1 - \left(R_f/R_o\right)\right]$$

For pipe

$$\%\ \text{strain} = 100r/R$$

where

R = nominal bending radius to the center line of the pipe
r = nominal radius of the pipe
R_f = final radius to center line of shell
R_o = original radius (equal to infinity for a flat part)
t = nominal thickness

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient C_v specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different

temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen each. Depending on the product form, it may be necessary to plot the transition curves using both lateral expansion and energy level data (NG-2300). In addition, drop weight tests shall be made when required by NG-2300.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either

(1) the maximum change in NDT temperature along with

(-a) the maximum change of lateral expansion and energy at the temperature under consideration or

(-b) the maximum change in temperature at the lateral expansion or energy levels under consideration or

(2) where lateral expansion is the acceptance criterion (NG-2300), either the maximum change in temperature or the maximum change in lateral expansion

NG-4213.3 Acceptance Criteria for Formed Material. To be acceptable, the formed material used in the component shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qualified forming procedure used.

NG-4213.4 Requalification. A new procedure qualification test is required when any of the following changes are made:

(a) the actual postweld heat treatment time at temperature is greater than previously qualified considering NG-2211. If the material is not postweld heat-treated, the procedure must be qualified without postweld heat treatment.

(b) the maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%.

(c) preheat over 250°F (120°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

NG-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of Article NG-3000, the material may be repaired in accordance with NG-4130.

NG-4230 FITTING AND ALIGNING

NG-4231 Fitting and Aligning Methods

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

NG-4231.1 Tack Welds. Tack welds used to secure alignment shall either be removed completely, when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined in accordance with NG-5261 and defective tack welds removed.

NG-4232 Maximum Offset of Aligned Sections

Alignment of sections shall be such that the maximum offset of the finished welded joint will not be greater than $\frac{1}{2}t$, where t is the nominal thickness of the thinner section at the joint. Alternatively, smaller alignment tolerances may be specified by the Design Specifications.

NG-4232.1 Fairing of Offsets. Any offset within the allowable limit provided shall be faired to at least a 3:1 taper, length to offset, over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld. In addition, offsets greater than those stated in NG-4232 are acceptable provided the requirements of NG-3200 are met.

NG-4240 REQUIREMENTS FOR WELD JOINTS IN COMPONENTS

NG-4245 Complete Joint Penetration Welds

Complete joint penetration is considered to be achieved when the acceptance criteria for the examinations specified by this Subsection have been met. No other examination is required to assess that complete penetration has been achieved.

NG-4300 WELDING QUALIFICATIONS

NG-4310 GENERAL REQUIREMENTS

NG-4311 Types of Processes Permitted

Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection may be used for welding core support structure material or attachments thereto. Any process used shall be such that the records required by NG-4320 can be prepared. Stud welds are not permitted.

NG-4311.2 Capacitor Discharge Welding. Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided that

(a) temporary attachments are removed in accordance with the provisions of NG-4430(b),

(b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.3 mm), and

(c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

NG-4311.3 Inertia and Continuous Drive Friction Welding. Inertia and continuous drive friction welding shall not be used for the fabrication of core support structures.

NG-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS

NG-4321 Required Qualifications

(a) Each Certificate Holder is responsible for the welding done by his organization, and he shall establish the procedure and conduct the tests required by this Article and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to core support structure parts and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (550 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

NG-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of their qualified welding procedures and of the welders and welding operators qualified by them, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and certified by the Certificate Holder by signature or some other method of control in accordance with the Certificate Holder's Quality Assurance Program and shall be available to the Authorized Nuclear Inspector.

NG-4322.1 Identification of Joints by Welder or Welding Operator.

(a) Each welder or welding operator shall apply the identification mark assigned to him by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which he welds. The marking shall be at intervals of 3 ft (1 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.

(b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, welds of specially designed seals, weld metal cladding, hard surfacing, and tube-to-tubesheet welds are made on an item, the Certificate Holder need not identify the welder or welding operator who welded each individual joint, provided

(1) the Certificate Holder maintains a system that will identify the welders or welding operators that made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification

(c) The identification of welder or welding operator is not required for tack welds.

NG-4323 Welding Prior to Qualification

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with NG-4320 and Section IX shall be used.

NG-4324 Transferring Qualifications (15)

The welding procedure qualifications and the performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures and shall not qualify welders or welding operators to weld for any other Certificate Holder except as provided in Section IX.

NG-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

NG-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented by the requirements of this Article.

NG-4333 Heat Treatment of Qualification Welds for Ferritic Material

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of NG-4600 and Section IX. The postweld heat treatment time at temperature shall be at least 80% of the maximum time to be applied to the weld material. The postweld heat treatment total time may be applied in one heating cycle.

NG-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b).

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the $^1/_4t$ location required by this Section, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

NG-4334.1 Coupons Representing the Weld Deposits. Impact test specimens and testing methods shall conform to NG-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $^1/_4t$ and, where the thickness of the test assembly permits, not less than $^3/_8$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in NG-4620 and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test assembly.

NG-4334.2 Coupons Representing the Heat-Affected Zone. Where impact tests of the heat-affected zone are required by NG-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c).

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

(b) The heat-affected zone impact test specimens and testing methods shall conform to the requirements of NG-2321.2. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat-affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat-affected zone. 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 heat-affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain-refining heat treatment is not performed on welds made by the electroslag or electrogas welding process, the notch for the impact specimens shall be located in the grain-coarsened region.

(c) For the comparison of heat-affected zone values with base material values [NG-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat-affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat-affected zone specimens, and the axis of the notch shall be normal to the surface of the base material. When required by NG-4335.2(b), drop weight specimens shall be removed from a depth as near as practical to midway between the surface and center thickness of the unaffected base material and shall be tested in accordance with the requirements of NG-2321.1.

NG-4335 Impact Test Requirements

When materials are required to be impact tested per NG-2300, impact tests of the weld metal and heat-affected zone shall be performed in accordance with the following subparagraphs. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of NG-2330 and NG-4334. Retests in accordance with the provisions of NG-2350 are permitted.

NG-4335.1 Impact Tests of Weld Metal.

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $^5/_8$ in. (16 mm) in thickness when the weld will be made on the surface or will penetrate the base material that requires impact testing in accordance with NG-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with NG-2310, regardless of the depth of the repair.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in NG-2330 for the base material to be welded or repaired. Where two materials are to be joined by welding and have different fracture toughness requirements, the test requirements and acceptance standards of either material may be used for the weld metal except where otherwise specified by NCA-1280 or other parts of this Section.

NG-4335.2 Impact Tests of Heat-Affected Zone.

(a) Charpy V-notch tests of the heat-affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $^5/_8$ in. (16 mm) and either of the base materials requires

impact testing in accordance with the rules of NG-2310. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat-treated and are made by any process other than electroslag, electrogas, or thermit

(2) the qualification for weld deposit cladding or hard-facing on any base material

(3) that portion of the heat-affected zone associated with GTAW root deposits with a maximum of two layers or $^3/_{16}$ in. (5 mm) thickness, whichever is less

(b) The required testing shall be in accordance with (c) for base material tested under NG-2332 and in accordance with (d) for base material tested under NG-2331.

(c) For heat-affected zones associated with base material tested under NG-2332, the required testing shall be in accordance with (1) through (7).

(1) Determine the T_{NDT} of the unaffected base material to be used in the welding procedure qualification test assembly.

(2) Charpy V-notch test specimens representing both the heat-affected zone and the unaffected base material shall be tested at the [T_{NDT} + 60°F (33°C)] temperature.

(3) The Charpy V-notch tests of the unaffected base material shall meet the applicable requirements of NG-2332 or additional testing shall be performed at higher temperatures until the requirements of NG-2332 are met.

(4) The heat-affected zone specimens shall be tested at the test temperature determined in (3). If the average lateral expansion value of the specimens equals or exceeds the average lateral expansion value of the unaffected base material the qualification test is acceptable for the essential and supplemental essential variables recorded on the Welding Procedure Qualification Record. If the heat-affected zone average lateral expansion value is less than the unaffected base material average lateral expansion value, the adjustment given in (5) through (7) shall be determined and applied as provided in (e). Alternatively, another test coupon may be welded and tested.

(5) Additional Charpy V-notch tests shall be performed on either the heat-affected zone or the unaffected base material, or both, at temperatures where the lateral expansion value of all three specimens tested is not less than 35 mils (0.89 mm). The average lateral expansion value for each test meeting this requirement shall be plotted on a lateral expansion versus temperature graph. The difference in temperature T_{HAZ} and T_{UBM} where the heat-affected zone and the unaffected base material average lateral expansion values are the same and not less than 35 mils (0.89 mm) shall be used to determine the adjustment temperature T_{ADJ} where

$$T_{ADJ} = T_{HAZ} - T_{UBM}$$

If $T_{ADJ} \leq 0$, then $T_{ADJ} = 0$.

(6) As an alternative to (5), if the average lateral expansion value of the heat-affected zone specimens is no less than 35 mils (0.89 mm) and the average of the heat-affected zone specimens is not less than 5 mils (0.13 mm) below the average lateral expansion value of the unaffected base material specimens, T_{ADJ} may be taken as 15°F (8°C).

(7) As a second alternative to (5), if the average lateral expansion value of the heat-affected zone specimens is no less than 35 mils (0.89 mm), the difference between the average lateral expansion of the heat-affected zone and the unaffected base material specimens shall be calculated and used as described in (e)(3).

(d) For heat-affected zones associated with base materials tested under NG-2331, the required testing shall be in accordance with (1) through (5).

(1) Three Charpy V-notch specimens shall be removed from both the unaffected base material and the heat-affected zone. The unaffected base material specimens shall be tested at the lowest service temperature established in the Design Specification or additional testing shall be performed at higher temperatures until the applicable requirements of Table NG-2331(a)-1 are met for the thickness of material to be welded in production.

(2) The heat-affected zone specimens shall be tested at the test temperature determined in (1). If the average lateral expansion value of the specimens equals or exceeds the average lateral expansion value of the unaffected base material the qualification test is acceptable for the essential and supplemental essential variables recorded on the Welding Procedure Qualification Record. If the heat-affected zone average lateral expansion value is less than the unaffected base material lateral expansion value, the adjustment given in (3) through (5) shall be determined and applied as provided in (e). Alternatively, another test coupon may be welded and tested.

(3) Additional Charpy V-notch tests shall be performed on either the heat-affected zone or the unaffected base material, or both, at temperatures where the lateral expansion value of all three specimens tested is not less than the values shown in Table NG-2331(a)-1 for the thickness of base material to be welded in production. The average lateral expansion value for each test meeting this requirement shall be plotted on a lateral expansion versus temperature graph. The difference in temperature T_{HAZ} and T_{UBM} where the heat-affected zone and the unaffected base material average lateral expansion values are the same shall be used to determine the adjustment temperature T_{ADJ} where

$$T_{ADJ} = T_{HAZ} - T_{UBM}$$

If $T_{ADJ} \leq 0$, then $T_{ADJ} = 0$.

(4) As an alternative to (3), if the average lateral expansion value of the heat-affected zone is no less than 35 mils (0.88 mm) and the average of the heat-affected

zone specimens is not less than 5 mils (0.13 mm) below the average lateral expansion value of the unaffected base material, T_{ADJ} may be taken as 15°F (8°C).

(5) As a second alternative to (3), if the average lateral expansion value of the heat-affected zone specimens is no less than 35 mils (0.88 mm), the difference between the average lateral expansion of the heat-affected zone and the unaffected base material specimens shall be calculated and used as described in (e)(3).

(e) At least one of the following methods shall be used to compensate for the heat-affected zone toughness decrease due to the welding procedure:

(1) The RT_{NDT} temperature established in NG-2332 or the lowest service temperature specified in NG-2331 for all of the material to be welded in production Welding Procedure Specifications supported by this Welding Procedure Qualification Record shall be increased by the adjustment temperature T_{ADJ}.

(2) The specified testing temperature for the production material may be reduced by T_{ADJ}.

(3) The materials to be welded may be welded using the Welding Procedure Specification provided they exhibit Charpy V-notch values which are no less than the minimum required lateral expansion value required by NG-2300 plus the difference in average lateral expansion values established in (c)(7) or (d)(5).

(f) The Charpy V-notch testing results shall be recorded on the Welding Procedure Qualification Record and any offsetting T_{ADJ} or increased toughness requirements shall be noted on the Welding Procedure Qualification Record and on the Welding Procedure Specification. More than one compensation method may be documented on the Welding Procedure Qualification Record.

NG-4336 Qualification Requirements for Built-Up Weld Deposits

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of NG-4331 to NG-4335, inclusive.

NG-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

NG-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING

NG-4411 Identification, Storage, and Handling of Welding Material

Each Certificate Holder is responsible for control of the welding electrodes and other material which is used in the fabrication and installation of core support structures (NG-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

NG-4412 Cleanliness and Protection of Welding Surfaces

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

NG-4420 RULES FOR MAKING WELDED JOINTS

NG-4421 Backing Rings

Backing rings shall conform to the requirements of NG-3350. The material for backing rings, when used, shall be compatible with the base metal. Permanent backing rings, when permitted by NG-3350, shall be continuous, and any splices shall be made by full penetration welds. Spacer pins shall not be incorporated into the welds.

NG-4422 Peening

Controlled peening may be performed to minimize distortion. Peening shall not be used on the initial layer, root of the weld metal, nor on the final layer unless the weld is postweld heat-treated.

NG-4423 Double Welded Joints

Before applying weld metal on the second side to be welded, the root of full penetration double welded joints shall be prepared by suitable methods such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetration are otherwise obtained and demonstrated to be satisfactory by welding procedure qualification.

NG-4424 Surfaces of Welds

As-welded surfaces are permitted. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys to meet the following requirements:

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and any other required nondestructive examinations of the welds. In those cases where there is a question regarding the surface condition on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with NG-4426.

(c) Undercuts shall not exceed $^1/_{32}$ in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single welded circumferential butt weld is permitted when the resulting thickness of the weld meets the requirements of Article NG-3000.

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

NG-4425 Welding Items of Different Diameters

When items of different diameters are welded together, there shall be a gradual transition between the two surfaces. The length of the transition may include the weld. The slope of the transition shall be such that the length–offset ratio shall not be less than 3:1, unless greater slopes are shown to be acceptable by analysis in accordance with NG-3200.

NG-4426 Reinforcement of Welds

The surface of the reinforcement of all butt-welded joints in core support structures may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the following thickness:

Nominal Thickness, in. (mm)	Maximum Reinforcement, in. (mm)
Up to 1 (25) incl.	$^3/_{32}$ (2.5)
Over 1 to 2 (25 to 50), incl.	$^1/_8$ (3.0)
Over 2 to 3 (50 to 75), incl.	$^5/_{32}$ (4.0)
Over 3 to 4 (75 to 100), incl.	$^7/_{32}$ (5.5)
Over 4 to 5 (100 to 125), incl.	$^1/_4$ (6.5)
Over 5 (125)	$^5/_{16}$ (8.0)

NG-4427 Shape and Size of Fillet Welds

(a) Fillet welds may vary from convex to concave. The shape and size of the weld shall be in accordance with the requirements of . A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than $^1/_{16}$ in. (1.5 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (50 mm) in length. On web-to-flange welds on girders, no underrun is permitted at the ends for a length equal to twice the width of the flange. In making socket welds, a gap as shown in shall be provided prior to welding. The gap need not be present nor be verified after welding. For sleeve type joints without internal shoulder, the gap shall be between butting ends of the pipe or tube.

(b) Socket welds smaller than those specified in may be used provided the requirements of Article NG-3000 are met.

NG-4429 Welding of Clad Parts[21]

The joint types and welding procedures used for cladding shall be such as to prevent the formation of brittle weld composition. Any such weld deposited cladding shall be examined by a liquid penetrant method in accordance with the requirements of NG-5110 and meet the acceptance standards of NG-5350. Parts welded to clad items shall be welded directly to the base metal and not to the cladding, except in the case of weld overlay cladding.

NG-4430 WELDING OF TEMPORARY ATTACHMENTS AND THEIR REMOVAL

(a) Temporary attachments (NG-1123) may be noncertified material and may be welded to the core support structure or its parts with continuous or intermittent fillet or partial penetration welds, provided the following conditions are met:

(1) the welding procedure and the welders have been qualified in accordance with NG-4321.

(2) the material is identified and is suitable for welding.

(3) the material is compatible with the material to which it is attached.

(4) the welding material is identified and compatible with the materials joined, and

(5) the welds are postweld heat-treated when required by NG-4620.

(b) Removal of temporary attachments shall be accomplished as follows:

(1) The immediate area around the temporary attachment is marked in a suitable manner so that after removal the area can be identified until after it has been examined in accordance with (3) below.

(2) The temporary attachment is completely removed in accordance with the procedures of NG-4211.

(3) After the temporary attachment has been removed, the marked area is examined by the liquid penetrant or magnetic particle method in accordance with the requirements of NG-5110 and meets the acceptance standards of NG-5340 or NG-5350, whichever is applicable; this examination is not required if more than $^1/_8$ in. (3.0 mm) of material will be removed by any subsequent machining operations.

(4) As an alternative to (a)(5) above, postweld heat treatment may be deferred until after removal of the attachment.

NG-4450 REPAIR OF WELD METAL DEFECTS

NG-4451 General Requirements

Defects in weld metal detected by the examinations required by Article NG-5000 shall be eliminated and repaired when necessary.

NG-4452 Elimination of Surface Defects

Weld metal surface defects may be removed by grinding or machining and need not be repaired by welding, provided that the following requirements are met:

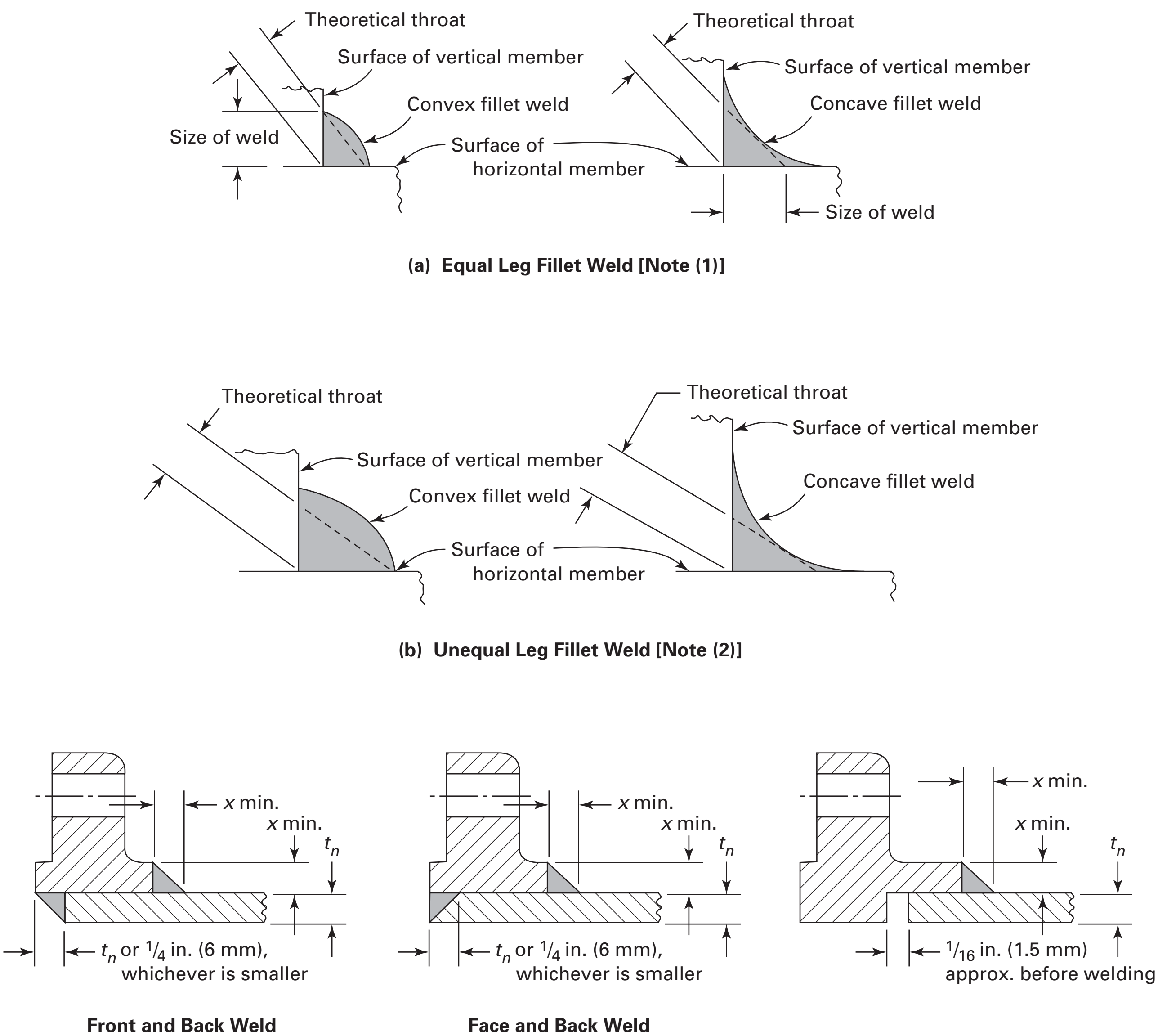
(a) The remaining thickness of the section is not reduced below that required by Article NG-3000.

(b) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(c) The area is examined by a magnetic particle or liquid penetrant method in accordance with NG-5110 after blending and meets the acceptance standards of NG-5300 to ensure that the defect has been removed or the indication reduced to an acceptable limit. Defects detected by

(15)

Figure NG-4427-1
Fillet and Socket Weld Details and Dimensions



(a) Equal Leg Fillet Weld [Note (1)]

(b) Unequal Leg Fillet Weld [Note (2)]

(c-1) Slip-On Flange

(c-2) Socket Welding Flange

(c) Minimum Welding Dimensions for Slip-On and Socket Welding Flanges [Note (3)]

NOTES:

(1) The size of an equal leg fillet weld is the leg length of the largest inscribed right isosceles triangle. Theoretical throat = 0.7 × size of weld.

(2) The size of an unequal leg fillet weld is the shorter leg length of the largest right triangle which can be inscribed within the fillet weld cross section.

(3) x min. = $1.4t_n$ or the thickness of the hub, whichever is smaller, but not less than 1/8 in. (3 mm), where t_n = nominal pipe wall thickness.

the visual or volumetric method and located on an interior surface need only be reexamined by the method which initially detected the defect when the interior surface is inaccessible for surface examination.

NG-4453 Requirements for Making Repairs of Welds

Excavations in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.

NG-4453.1 Defect Removal. Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with NG-5110 and meet the acceptance standards of NG-5340 or NG-5350. This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

NG-4453.2 Requirements for Welding Material, Procedures, and Welders. The weld repair shall be made using welding material, welders, and welding procedures qualified in accordance with NG-4125 and NG-4300.

NG-4453.3 Blending of Repaired Areas. After repair the surface shall be blended uniformly into the surrounding surface.

NG-4453.4 Examination of Repair Welds. The examination of a weld repair shall be repeated as required for the original weld, except that it need only be reexamined by the liquid penetrant or magnetic particle method when the unacceptable indication was originally detected by the liquid penetrant or magnetic particle method and when the repair cavity does not exceed the following:

(a) $^1/_3t$ for $t \leq {}^1/_2$ in. (13 mm)

(b) $^1/_4$ in. (6 mm) for $^1/_2$ in. (13 mm) $< t \leq 2^1/_2$ in. (64 mm)

(c) the lesser of $^3/_8$ in. (10 mm) or 10% t for $t > 2^1/_2$ in. (64 mm)

where t equals the thickness of the weld.

NG-4500 BRAZING

Brazing is not permitted for core support structures.

NG-4600 HEAT TREATMENT

NG-4610 WELDING PREHEAT REQUIREMENTS

NG-4611 When Preheat Is Necessary

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thickness. Some practices used for preheating are given in Section III Appendices, Nonmandatory Appendix D as a general guide for the materials listed by P-Numbers of Section IX. It is cautioned that the preheating suggested in Section III Appendices, Nonmandatory Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the requirements for individual materials within the P-Number listing may be more or less restrictive. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

NG-4612 Preheating Methods

Preheat for welding or thermal cutting, when employed, may be applied by any method which does not harm the base material or any weld metal already applied or which does not introduce deleterious material into the welding area which is harmful to the weld.

NG-4613 Interpass Temperature

Consideration shall be given to the limitations of interpass temperatures for quenched and tempered material to avoid detrimental effects on the mechanical properties.

NG-4620 POSTWELD HEAT TREATMENT

NG-4621 Heating and Cooling Methods

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

NG-4622 PWHT Time and Temperature Requirements

NG-4622.1 General Requirements.[4] Except as otherwise permitted in NG-4622.7, all welds, including repair welds, shall be postweld heat-treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature range and for the minimum holding time specified in Table NG-4622.1-1, except as otherwise permitted in NG-4622.4(c). P-Number groups in Table NG-4622.1-1 are in accordance with Section IX, QW-420. Except as provided in NG-4624.3, PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. In addition, the requirements of the following subparagraphs shall apply.

NG-4622.2 Time–Temperature Recordings. Time–temperature recordings of all postweld heat treatments shall be made available for review by the Authorized Inspector. Identification on the time–temperature recording shall be to the weld, part, or core support structure. A summary of the time–temperature recording may be provided for permanent records in accordance with NCA-4134.17.

Table NG-4622.1-1
Mandatory Requirements for Postweld Heat Treatment (PWHT) of Welds

P-No. (Sect. IX, QW-420)	Holding Temperature Range, °F (°C) [Note (1)]	Minimum Holding Time at Temperature for Weld Thickness (Nominal), in. (mm)			
		$^1/_2$ in. (13 mm) or Less	Over $^1/_2$ in. (13 mm) to 2 in. (50 mm)	Over 2 in. (50 mm) to 5 in. (125 mm)	Over 5 in. (125 mm)
1, 3	1100–1250 (595–675)	30 min	1 hr/in. (2 min/mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)
4	1100–1250 (595–675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
5A, 5B, 5C, 6 except P-No. 6 Gr. 4	1250–1400 (675–760)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
6 Gr. 4	1050–1150 (565–620)				
7	1300–1400 (705–760)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
9A Gr. 1	1100–1250 (595–675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
9B Gr. 1	1100–1175 (595–635)				
10F Gr. 1	1100–1250 (595–675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
10I Gr. 1	1300–1400 (705–760)				
11A Gr. 4	1000–1050 (540–565)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)
15E Gr. 1	1350–1425 (730–775)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
P-Nos. 8, 34, 42, 43, 45, and hard surfacing on P-No. 1 base metal whose reported carbon content is not more than 0.30%	PWHT neither required nor prohibited				

GENERAL NOTE: Exemptions to the mandatory requirements of this Table are defined in NG-4622.7.

NOTE:
(1) All temperatures are metal temperatures.

NG-4622.3 Definition of Nominal Thickness Governing PWHT. The nominal thickness in Table NG-4622.7(b)-1 is the thickness of the weld, the base material, or the thinner of the base materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed $^1/_8$ in. (3 mm). For fillet welds the nominal thickness is the throat thickness, and for partial penetration and material repair welds the nominal thickness is the depth of the weld groove or preparation.

NG-4622.4 Holding Times at Temperature.

(a) The holding time at temperature as specified in Table NG-4622.1-1 shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat treat cycles.

(b) Holding time at temperature in excess of the minimum requirements of Table NG-4622.1-1 may be used, provided that specimens so heat-treated are tested in accordance with NG-2200, NG-2400, and NG-4300.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table NG-4622.1-1, it is permissible to perform the postweld

heat treatment of certain materials at lower temperatures for longer periods of time in accordance with Table NG-4622.4(c)-1 and the following:

(1) Except for P-No. 1 materials, when welds in the materials listed in Table NG-4622.4(c)-1 are to be postweld heat-treated at these lower minimum temperatures, impact test specimens for the welding procedure qualification required by NG-4300 shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in Table NG-4622.1-1 and at the lower temperature and increased minimum holding time permitted by this subparagraph, are also qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be extrapolated from Table NG-4622.1-1 and the alternative requirements of Table NG-4622.4(c)-1.

(2) Except for P-No. 1 materials, when welds in the materials listed in Table NG-4622.4(c)-1 are to be postweld heat-treated at these lower minimum temperatures, the welding material certification required by NG-2400 shall be made using the same minimum temperature and increased minimum holding time. Welding material certified at the temperature range and minimum holding time specified in Table NG-4622.1-1 and at the lower minimum temperatures and increased minimum holding time permitted by Table NG-4622.4(c)-1 is also certified for any temperatures in between.

(3) Base material certified in accordance with NG-2200 may be postweld heat-treated at the lower minimum temperatures and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation, provided a higher tempering temperature is not required by the material specification.

NG-4622.5 PWHT Requirements When Different P-Number Materials Are Joined. When materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in Table NG-4622.1-1 for the material requiring the higher PWHT temperature range.

NG-4622.7 Exemptions to Mandatory Requirements. Postweld heat treatment in accordance with this subarticle is not required for

(a) nonferrous materials

(b) welds exempted in Table NG-4622.7(b)-1

(c) welds subjected to temperatures above the PWHT temperature range specified in Table NG-4622.1-1, provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld material have been heat-treated at the higher temperature

(d) postweld heat treatment is not required for core support structures constructed of P-No. 7 Type 405 material or of Type 410 material with carbon content not exceeding 0.08%, welded with electrodes that produce an austenitic chromium–nickel weld deposit or a nonair-hardening nickel–chromium–iron weld deposit, provided the plate thickness at the welded joint does not exceed $^3/_8$ in. (10 mm)

NG-4623 PWHT Heating and Cooling Rate Requirements

Above 800°F (425°C) the rate of heating and cooling in any hourly interval shall not exceed 400°F (220°C) divided by the maximum thickness in inches of the material being heat-treated, but shall not exceed 400°F (220°C) and need not be less than 100°F (56°C) in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F (138°C) within any 15 ft (4.6 m) interval of weld length. The following exceptions are permitted:

(a) P-No. 6 material may be cooled in air from the postweld heat treatment holding temperature specified in Table NG-4622.1-1.

(b) For P-No. 7 material the cooling rate at temperatures above 1200°F (650°C) shall not exceed 100°F/hr (56°C/hr), after which the rate of cooling shall be sufficiently rapid to prevent embrittlement.

NG-4624 Methods of Postweld Heat Treatment

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

NG-4624.1 Furnace Heating — One Heat. Heating the core support structure or item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation, and direct impingement of flame on the core support structure or item is prohibited.

NG-4624.2 Furnace Heating — More Than One Heat. The core support structure or item may be heated in more than one heat in a furnace, provided the furnace

Table NG-4622.4(c)-1
Alternative Holding Temperatures and Times

Material P-Numbers	Alternative Minimum Holding Temperatures	Alternative Minimum Holding Times [Note (1)]
1, 3, 9A Gr. 1, 9B Gr. 1	1,050°F (565°C)	2 hr/in. (4 min/mm) thickness
1, 3, 9A Gr. 1, 9B Gr. 1	1,000°F (540°C)	4 hr/in. (8 min/mm) thickness

NOTE:
(1) All other requirements of NG-4622 shall apply.

Table NG-4622.7(b)-1
Exemptions to Mandatory PWHT

P-No. (Sect. IX, QW-420)	Type of Weld [Note (1)]	Nominal Thickness (NG-4622.3)	Max. Reported Carbon, % [Note (2)]	Min. Preheat Req'd., °F (°C)
1	All welds where the materials being joined are 1½ in. (38 mm) and less	1¼ in. (32 mm) or less	0.30 or less	...
		Over 1¼ in. (32 mm) to 1½ in. (38 mm)	0.30 or less	200 (95)
		¾ in. (19 mm) or less	Over 0.30	...
		Over ¾ in. (19 mm) to 1½ in. (38 mm)	...	200 (95)
	All welds in material over 1½ in. (38 mm)	¾ in. (19 mm) or less	...	200 (95)
1 Gr. 1 or Gr. 2	Cladding or repair of cladding [Note (3)] with A-No. 8 or F-No. 43 filler metal in base material of: 1½ in. (38 mm) or less	...	0.30	100 (38)
	Over 1½ in. (38 mm) to 3 in. (75 mm)	...	0.30	200 (95) [Note (4)]
	Over 3 in. (75 mm)	...	0.30	250 (120) [Note (5)]
3 except Gr. 3	All welds	½ in. (13 mm) or less	0.25 or less	200 (95)
4	All welds in pipes NPS 4 (DN 100) and less or tubes with nominal O.D. 4.5 in. (114 mm) or less	½ in. (13 mm) or less	0.15 or less	250 (120)
5A, 5B, 5C	All welds in pipes or tubes with maximum specified chromium 3.00% or less, NPS 4 (DN 100) or less pipe, and nominal O.D. 4.5 in. (114 mm) or less tubes	½ in. (13 mm) or less	0.15 or less	300 (150)
7	Type 405 and 410S welded with A-No. 8, A-No. 9, or F-No. 43 filler metal	⅜ in. (10 mm) or less	0.08 or less	...
9A Gr. 1	All welds provided the procedure qualification is made using equal or greater thickness base material than the production weld	⅝ in. (16 mm) or less	...	200 (95)
	Attachment welds joining nonpressure-retaining material to pressure-retaining material over ⅝ in. (16 mm)	½ in. (13 mm) or less	...	200 (95)
	Circumferential butt welds or socket welds in pipe NPS 4 (DN 100) or less and tubes with nominal O.D. 4.5 in. (114 mm) or less and attachment welds	½ in. (13 mm) or less	0.15 or less	250 (120)
9B Gr. 1	All welds provided the procedure qualification is made using equal or greater thickness base material than the production weld	⅝ in. (16 mm) or less	...	200 (95)
	Attachment welds joining nonpressure-retaining material to pressure-retaining material over ⅝ in. (16 mm)	½ in. (13 mm) or less	...	200 (95)
10I Gr. 1	All welds in material ½ in. (13 mm) and less	½ in. (13 mm) or less	...	...
11A Gr. 4	All welds in material ½ in. (13 mm) and less	½ in. (13 mm) or less	...	250 (120)

GENERAL NOTE: The exemptions noted in this table do not apply to electron beam welds in ferritic materials over ⅛ in. (3 mm) in thickness.

NOTES:
(1) Where the thickness of material is identified in the Type of Weld column, it is the thickness of the base material at the welded joint.
(2) Carbon level of the pressure-retaining materials being joined.
(3) The maximum resulting hardness of the heat-affected zone in the procedure qualification test plate shall not exceed 35 Rc.
(4) Intermediate postweld soak at not less than 200°F (95°C) for 2 hr minimum.
(5) Intermediate postweld soak at not less than 300°F (150°C) for 2 hr minimum.

atmosphere control requirements of NG-4624.1 apply and overlap of the heated sections of the core support structure or item is at least 5 ft (1.5 m). When this procedure is used, the portion of the core support structure or item outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the core support structure or item projects from the furnace shall not intersect a structural discontinuity.

NG-4624.3 Local Heating. Welds may be locally postweld heat-treated when it is not practical to heat treat the entire core support structure or item. Local postweld heat treatment shall consist of heating a circumferential band around the core support structure or item at temperature within the ranges specified in this subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (50 mm), whichever is less. The temperature of the core support structure or item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

NG-4624.4 Heating Structures Internally. The core support structure or item may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the core support structure or item. Previous to this operation, the core support structure or item should be fully enclosed with insulating material.

NG-4630 HEAT TREATMENT OF WELDS OTHER THAN THE FINAL POSTWELD HEAT TREATMENT

The holding temperature, the time at temperature, the heating rate, and the cooling rate need not conform to the requirements of this Article for heat treatments other than the final postweld heat treatment.

NG-4650 HEAT TREATMENT AFTER BENDING OR FORMING

NG-4651 Ferritic Materials

Ferritic materials may be used in the as-formed or as-bent condition, heat-treated in accordance with NG-4620, fully annealed, normalized and tempered, or quenched and tempered, provided the requirements of NG-2210, NG-4212, and NG-4213 are met.

NG-4652 Austenitic and Nonferrous Materials

Heat treatment of austenitic and nonferrous materials is neither required nor prohibited after bending or forming operations.

NG-4660 HEAT TREATMENT OF ELECTROSLAG WELDS

Electroslag welds in ferritic material over $1\frac{1}{2}$ in. (38 mm) in thickness at the joints shall be given a grain refining heat treatment.

NG-4700 MECHANICAL JOINTS

NG-4710 THREADED STRUCTURAL FASTENERS

NG-4711 Thread Engagement

All threaded structural fasteners shall be engaged in accordance with the design drawings or Design Specifications.

NG-4712 Thread Lubricants

Any lubricant or compound used in threaded joints shall be suitable for the Service Conditions and shall not react unfavorably with either the service fluid or any component material in the system.

NG-4713 Removal of Thread Lubricants

All threading lubricants or compounds shall be removed from surfaces which are to be seal welded.

NG-4720 TEMPORARY FASTENERS AND THEIR REMOVAL

All fasteners used to connect temporary attachments to the core support structure shall be removed prior to operation.

ARTICLE NG-5000 EXAMINATION

NG-5100 GENERAL REQUIREMENTS FOR EXAMINATION

NG-5110 PROCEDURES, QUALIFICATIONS, AND EVALUATION

NG-5111 General Requirements

Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be performed in accordance with Section V, Article 2, except that fluorescent screens are not permitted for film radiography, the geometric unsharpness shall not exceed the limits of Section V, Article 2, T-274.2, and the image quality indicators (IQIs) of Table NG-5111-1 shall be used in lieu of those shown in Section V, Article 2, Table T-276. The requirements for the retention of electronic and digital radiographic images are the same as that for radiographic film. Ultrasonic examination shall be in accordance with Section V, Article 4; magnetic particle examination shall be in accordance with Section V, Article 7; liquid penetrant examination shall be in accordance with Section V, Article 6; and visual examination shall be in accordance with Section V, Article 9. The examinations required by this Article or by reference to this Article shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

NG-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radioscopic images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy." Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

NG-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination materials are applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

NG-5120 TIME OF EXAMINATION OF WELDS

Acceptance examinations of welds required by NG-5200 shall be performed at the time stipulated in the following subparagraphs during fabrication and installation:

(a) For welds in core support structure components, radiographic or ultrasonic examination, when required, shall be performed after an intermediate or final postweld heat treatment if heat treatment is required by NG-4622.

(b) Magnetic particle, liquid penetrant, or visual examinations shall be performed on the final surface after any required postweld heat treatment, except that welds in P-No. 1 material may be examined either before or after postweld heat treatment. Weld surfaces that are covered with weld metal cladding shall be examined before the weld metal cladding is applied. Weld surfaces which are not accessible after a postweld heat treatment shall be examined prior to the operations which caused this inaccessibility.

(c) All dissimilar metal weld joints, such as in austenitic or high nickel to ferritic material or using austenitic or high nickel alloy filler metal to join ferritic material, shall be examined on the final surface after final postweld heat treatment.

NG-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES (15)

All full penetration weld edge preparation surfaces in material 1 in. (25 mm) or more in thickness shall be examined by the magnetic particle or liquid penetrant method. Indications shall be evaluated in accordance with the acceptance standards of (a) through (c) below.

(a) Only indications with major dimensions greater than $^1/_{16}$ in. (1.6 mm) shall be considered relevant.

(b) Laminar-type discontinuities are acceptable without repair if they do not exceed $^1/_2$ in. (13 mm) in length. The extent of all laminar-type indications exceeding $^1/_2$ in. (13 mm) in length shall be determined by ultrasonic examination. Indications exceeding $^1/_2$ in. (13 mm) in length shall be repaired by welding to a depth of $^3/_8$ in. (10 mm)

(15)

Table NG-5111-1
Thickness, IQI Designations, Essential Holes, and Wire Diameters

Single Wall Material Thickness Range, in (mm)	IQI(s) — Hole or Wire Type [Note (1)]							
	Source Side				Radiograph Side			
	Designation	Hole Size, in. (mm)	Essential Hole	Required Wire Diameter — IQI, in. (mm)	Designation	Hole Size, in. (mm)	Essential Hole	Required Wire Diameter — IQI, in. (mm)
Up to $\frac{1}{4}$ (6) incl.	5	0.040 (1.02)	4T	0.006 (0.15)	5	0.040 (1.02)	4T	0.006 (0.15)
Over $\frac{1}{4}$–$\frac{3}{8}$ (6–10)	7	0.040 (1.02)	4T	0.006 (0.15)	7	0.040 (1.02)	4T	0.006 (0.15)
Over $\frac{3}{8}$–$\frac{1}{2}$ (10–13)	10	0.040 (1.02)	4T	0.010 (0.25)	10	0.040 (1.02)	4T	0.010 (0.25)
Over $\frac{1}{2}$–$\frac{5}{8}$ (13–16)	12	0.050 (1.27)	4T	0.013 (0.33)	12	0.050 (1.27)	4T	0.013 (0.33)
Over $\frac{5}{8}$–$\frac{3}{4}$ (16–19)	15	0.060 (1.52)	4T	0.016 (0.41)	12	0.050 (1.27)	4T	0.013 (0.33)
Over $\frac{3}{4}$–1 (19–25)	20	0.040 (1.02)	2T	0.016 (0.41)	17	0.035 (0.89)	2T	0.013 (0.33)
Over 1–1$\frac{1}{4}$ (25–32)	25	0.050 (1.27)	2T	0.020 (0.51)	17	0.035 (0.89)	2T	0.013 (0.33)
Over 1$\frac{1}{4}$–1$\frac{1}{2}$ (32–38)	30	0.060 (1.52)	2T	0.025 (0.64)	20	0.040 (1.02)	2T	0.016 (0.41)
Over 1$\frac{1}{2}$–2 (38–50)	35	0.070 (1.78)	2T	0.032 (0.81)	25	0.050 (1.27)	2T	0.020 (0.51)
Over 2–2$\frac{1}{2}$ (50–64)	40	0.080 (2.03)	2T	0.040 (1.02)	30	0.060 (1.52)	2T	0.025 (0.64)
Over 2$\frac{1}{2}$–3 (64–75)	45	0.090 (2.29)	2T	0.040 (1.02)	35	0.070 (1.78)	2T	0.032 (0.81)
Over 3–4 (75–100)	50	0.100 (2.54)	2T	0.050 (1.27)	40	0.080 (2.03)	2T	0.040 (1.02)
Over 4–6 (100–150)	60	0.120 (3.05)	2T	0.063 (1.60)	45	0.090 (2.29)	2T	0.040 (1.02)
Over 6–8 (150–200)	80	0.160 (4.06)	2T	0.100 (2.54)	50	0.100 (2.54)	2T	0.050 (1.27)
Over 8–10 (200–250)	100	0.200 (5.08)	2T	0.126 (3.20)	60	0.120 (3.05)	2T	0.063 (1.60)
Over 10–12 (250–300)	120	0.240 (6.10)	2T	0.160 (4.06)	80	0.160 (4.06)	2T	0.100 (2.54)
Over 12–16 (300–400)	160	0.320 (8.13)	2T	0.250 (6.35)	100	0.200 (5.08)	2T	0.126 (3.20)
Over 16–20 (400–500)	200	0.400 (10.16)	2T	0.320 (8.13)	120	0.240 (6.10)	2T	0.160 (4.06)

NOTE:
(1) Hole (plaque) type IQIs may be used on flat plates and on objects with geometries such that the IQI hole image is not distorted.

or the depth of the indication, whichever is less, unless the ultrasonic examination reveals that additional depth of repair is required to meet the ultrasonic examination requirement for the product form.

(c) The following relevant indications are unacceptable:

(1) any linear indication greater than $^1/_8$ in. (3 mm) long for materials 1 in. (25 mm) thick to under 2 in. (50 mm) thick and $^3/_{16}$ in. (5 mm) long for materials 2 in. (50 mm) thick and greater

(2) rounded indications with dimensions greater than $^3/_{16}$ in. (5 mm)

(3) four or more indications greater than $^1/_{16}$ in. (1.5 mm) long in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge

(4) ten or more indications greater than $^1/_{16}$ in. (1.5 mm) long in any 6 in.^{2} (4 000 mm^2) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated

(d) Weld repairs made to weld edge preparations for Types I, II, and III welds shall be examined by the magnetic particle or liquid penetrant method before the surfaces become inaccessible. The examination may be performed before or after postweld heat treatment.

NG-5200 REQUIRED EXAMINATION OF WELDS

NG-5210 PERMISSIBLE EXAMINATION METHODS

Welds used in core support structures shall be examined in accordance with the requirements of this subarticle for the type of examination specified by the Certificate Holder to meet the requirement of Table NG-3352-1. The Certificate Holder may upgrade the examination in Table NG-3352-1 to a level higher than originally specified.

NG-5220 REQUIREMENTS FOR RADIOGRAPHY OR ULTRASONIC AND LIQUID PENETRANT OR MAGNETIC PARTICLE EXAMINATION

When required by the Certificate Holder (Table NG-3352-1), welds shall be radiographically examined and the external and accessible internal weld surfaces and adjacent base metal for at least $^1/_2$ in. (13 mm) on each side of the weld examined by either the magnetic particle or liquid penetrant method. Ultrasonic examination may be substituted for radiography except for those materials and welds which have coarse grains or configurations which do not yield meaningful results by ultrasonic methods.

NG-5230 REQUIREMENTS FOR LIQUID PENETRANT OR MAGNETIC PARTICLE EXAMINATION

NG-5231 Requirements for Progressive Liquid Penetrant or Magnetic Particle Examination

When required by the Certificate Holder (Table NG-3352-1), welds shall be either liquid penetrant or magnetic particle examined progressively at the lesser of either one-third of the thickness of the weld joint or each $^1/_2$ in. (13 mm), and on the external and accessible internal weld surfaces and the adjacent base material for $^1/_2$ in. (13 mm) on each side of the weld. For welds $^3/_8$ in. (10 mm) thick or less, examination of the root, each subsequent layer, and the external and accessible internal weld surfaces and adjacent base material for at least $^1/_2$ in. (13 mm) on each side of the weld is permitted in lieu of the above.

NG-5232 Requirements for Root and Final Liquid Penetrant or Magnetic Particle Examination

When required by the Certificate Holder (Table NG-3352-1), welds shall be either liquid penetrant or magnetic particle examined after the root and final passes on the external and accessible internal weld surfaces and the adjacent base material for at least $^1/_2$ in. (13 mm) on each side of the weld.

NG-5233 Requirements for Surface Liquid Penetrant or Magnetic Particle Examination

When required by the Certificate Holder (Table NG-3352-1), welds shall be either liquid penetrant or magnetic particle examined on the external and accessible internal weld surfaces and the adjacent base material for at least $^1/_2$ in. (13 mm) on each side of the weld.

NG-5260 REQUIREMENTS FOR SURFACE VISUAL EXAMINATION

NG-5261 Visual Examination in Addition to Other NDT Examination

All welds shall be visually examined to the acceptance criteria of NG-5361. This visual examination shall be in addition to all other required examinations.

NG-5262 Visual Examination for Weld Surface Integrity

When required by the Certificate Holder (Table NG-3352-1), welds shall be visually examined on the final surface to the acceptance criteria of NG-5362.

NG-5270 HARD SURFACING

Hard surfacing shall be examined by the liquid penetrant method in accordance with NG-2546, and the acceptance standards applicable to materials 2 in. (50 mm) thick and greater shall apply.

NG-5300 ACCEPTANCE STANDARDS

NG-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS

NG-5321 Evaluation of Indications

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

(a) any indication characterized as a crack or zone of incomplete fusion or penetration

(b) any other elongated indication that has a length greater than

(1) $^1/_4$ in. (6 mm) for t up to $^3/_4$ in. (19 mm), inclusive

(2) $^1/_3t$ for t from $^3/_4$ in. (19 mm) to $2^1/_4$ in. (57 mm), inclusive

(3) $^3/_4$ in. (19 mm) for t over $2^1/_4$ in. (57 mm)

where t is the thickness of the thinner portion of the weld

(c) internal root weld conditions are acceptable when the density change or image brightness difference as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable as provided in (b)

(d) any group of aligned indications having an aggregate length greater than t in a length of $12t$, unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication

(e) any group of aligned indications whose aggregate length exceeds the permissible length of a single indication and with the minimum distance between these successive indications less than $3L$, L being the length of the largest indication

(f) rounded indications in excess of that shown as acceptable in Section III Appendices, Mandatory Appendix VI; four or more rounded indications shall constitute aligned rounded indications for welds covered by Section III Appendices, Mandatory Appendix VI

NG-5330 ULTRASONIC ACCEPTANCE STANDARDS

All imperfections which produce a response equal to or greater than 50% of the reference level are unacceptable, except as noted in (a).

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding

(1) $^1/_4$ in. (6 mm) for t up to $^3/_4$ in. (19 mm), inclusive

(2) $^1/_3t$ for t from $^3/_4$ in. (19 mm) to $2^1/_4$ in. (57 mm), inclusive

(3) $^3/_4$ in. (19 mm) for t over $2^1/_4$ in. (57 mm)

where t is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

NG-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS

NG-5341 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NG-5342 Acceptance Standards

(a) Only imperfections producing indications whose major dimensions are greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks and linear indications

(2) rounded indications with 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 the major dimension of this area not to exceed 6 in. (150 mm), with the area taken in the most unfavorable location relative to the indications being evaluated

NG-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS

NG-5351 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks or surface conditions may produce similar indications which are nonrelevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NG-5352 Acceptance Standards

(a) Only imperfections producing indications whose major dimensions are greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications

(2) rounded indications with 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 the major dimension of this area not to exceed 6 in. (150 mm) with the area taken in the most unfavorable location relative to the indications being evaluated

NG-5360 VISUAL EXAMINATION ACCEPTANCE STANDARDS

NG-5361 General Acceptance Standards

When visual examination is performed in accordance with NG-5261, the following acceptance standards shall be met:

(a) Weld reinforcement, underfill, undercut, and overlap shall not exceed the allowable limits of this Subsection.

(b) The examined surface shall be free of abrupt irregularities.

NG-5362 Acceptance Standards for Visual Examination for Weld Surface Integrity

(a) When visual examination is performed in accordance with NG-5262, the weld surface shall meet the acceptance criteria given in NG-5361.

(b) The following imperfections are unacceptable:

(1) any imperfection characterized as a crack, or lack of penetration

(2) rounded imperfections whose major dimension exceeds $^1/_8$ in. (3 mm)

(3) four or more rounded imperfections greater than $^1/_{32}$ in. (0.8 mm) in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge

(4) ten or more rounded imperfections greater than $^1/_{32}$ in. (0.8 mm) in any 6 in.^{2} (4 000 mm^2) of surface with the major dimension of this area not to exceed 6 in. (150 mm) with the area taken in the most unfavorable location relative to the imperfections being evaluated

NG-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

NG-5510 GENERAL REQUIREMENTS

Organizations performing Code-required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by NG-5520. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of NG-5520. All nondestructive examinations required by this Subsection shall be performed by, and the results evaluated by, qualified nondestructive examination personnel.

NG-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION

NG-5521 Qualification Procedure (**15**)

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A.[22, 23] The ACCP Level II and III provisions for qualification and certification and the ASNT administered Level II certification provision for qualification and certification of NDE Personnel shall not be used for Section III. The Employer's[24] written practice required by paragraph 5 of SNT-TC-1A shall identify Employer requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered minimum requirements except as modified in the following:

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(-a) The basic and method examinations, paragraphs 8.8.1 and 8.8.2 of SNT-TC-1A, may be prepared and administered by the Employer, ASNT, or an outside agency.

(-b) The specific examination, paragraph 8.8.3 of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall

identify the minimum grade requirement in a written program when the basic and method examinations have been administered by ASNT which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform a nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 A and Table 6.3.1 B of SNT-TC-1A. The time of training and experience shall be described in written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

The minimum classroom training times for visual examination personnel identified in Table 6.3.1 A of SNT-TC-1A for Level II certification may be reduced from 16 hr to 8 hr.

(4) For the near-vision acuity examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in para. 8.2.1 of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) An NDE Level I individual shall be qualified to properly perform specific setups, specific calibrations, specific NDE, and specific evaluations for acceptance or rejection determinations according to written instructions and to record results. The NDE Level I individual shall receive the necessary instruction and supervision from a certified NDE Level II or Level III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

NG-5522 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of the Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [see NG-5521(a)(2)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

NG-5523 Verification of Nondestructive Examination Personnel Certification

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Organizations qualified by them in accordance with NCA-3820 and subcontractors who provide nondestructive examination services to them.

NG-5530 RECORDS

Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.

ARTICLE NG-8000
NAMEPLATES, STAMPING WITH CERTIFICATION MARK, AND REPORTS

NG-8100 REQUIREMENTS

The applicable requirements given in NCA-8000 shall apply to core support structures.

ENDNOTES

1 See below.
(a) The rules of Subsection NG are not directed to sealing against coolant leakage. Further, gross hydrostatic loading may not be typical of the loads experienced by core support structures. Thus, hydrostatic testing of the structures is not required.
(b) Core support structures need not remain leak tight to perform their function. However, if leak tightness is required for a structure, the rules for pressure boundary construction may be appropriate.

2 In Subsection NG it is recognized that the design functions are frequently handled separately from the fabrication functions of the Certificate Holder manufacturing core supports. The separation of these functions is necessary because the design of core support structures cannot be performed completely independent of the nuclear or hydraulic design of the coolant system. Furthermore, portions of a set of structures may be fabricated by a specialist and assembled at the site without any one fabricator having a controlling position for fabrication of the complete structure. Therefore, provisions are made herein for separate organizations to perform the design and fabricating functions of the Certificate Holder. This Section (NCA-3510), however, requires that one organization have overall responsibility for compliance with the requirements of this Subsection NG. The use of the term *Certificate Holder* therefore must be understood to mean the design or fabricating organization assuming the overall responsibility for compliance with this Section. The term *Certificate Holder*, as used in this Subsection, applies to the Certificate Holder manufacturing core supports who shall be responsible for certifying that all core support structures and internal structures, as defined in NG-1120, comply with the requirements of this Subsection.

3 Note that some fuel and blanket positions in the core matrix may be filled with structures related to reflector or shielding functions. These structures also fall into the *fuel and blanket* category described above.

4 Any postweld heat treatment time that is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specifications. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

5 When impact testing is required, the methods of Section III Appendices, Nonmandatory Appendix G may be used as an alternative procedure for assuring protection against nonductile fracture.

6 In addition to providing a basis for acceptance standards for material, the test data are designated to be used as a basis for establishing in-service operation and for use in fracture prevention evaluation (Section III Appendices, Nonmandatory Appendix G).

7 Lowest service temperature is the minimum temperature of the fluid around the component or, alternatively, the calculated volumetric average metal temperature expected during normal operation whenever the pressure within the reactor vessel exceeds 20% of the preoperational system hydrostatic test pressure.

8 The requirements for impact-testing of the heat-affected zone (NG-4335.2) may result in reduced test temperatures or increased toughness requirements for the base material.

9 The methods given in the Appendix of SFA 5.9, Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

10 *pilot casting*: a casting poured to a production run to prove the casting process. Pilot castings shall be made from the same pattern, poured of the same type or grade of material, and use the identical foundry procedure (risering, gating, pouring, and melting) as each casting in the production run.

11 *production run*: a maximum of 100 castings made from the same pattern, poured of the same type or grade of material, and using the identical foundry procedure (risering, gating, pouring, and melting) as the pilot castings. All castings in a production run need not be made from the same heat of material.

12 The reference radiographs accompanying previous editions of ASTM E186, E280, and E446 may be used with later editions of the specification, provided the text of the specified edition is used.

13 This definition of stress intensity is not related to the definition of stress intensity applied in the field of Fracture Mechanics.

14 Equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

15 See Table NG-3217-1 and Figure NG-3221-1, Note (4).

16 The concept of stress differences discussed in NG-3216 is essential to determination of the maximum range, since algebraic signs must be retained in the computation. Note that this limitation on range is applicable to the entire history of normal Service Loadings, not just to the stresses resulting from each individual transient.

17 As stated in NG-3223, for structures operating within the temperature limits of this Subsection, Service Loadings for which Level B Limits are designated must be considered as though Level A Limits were designated in evaluating exemptions from fatigue analysis.

18 Adjacent points are defined as points which are spaced less than the distance

$$\left(2\sqrt{Rt}\right)$$

from each other, where R and t are the mean radius and thickness, respectively, of the shell of revolution. In configurations other than a shell of revolution, either the allowable distance between adjacent points must be determined in appropriate configurations or a fatigue analysis shall be accomplished.

19 The algebraic range of the difference shall be used.

20 It is permissible to use $1.5S_m$ whenever it is greater than S_y.

21 Welds that are exposed to corrosive action should have a resistance to corrosion that is not substantially less than that of the cladding. The use of filler metal that will deposit weld metal which is similar to the composition of the cladding material is recommended. If weld metal of different composition is used, it should have properties compatible with the application.

22 SNT-TC-1A is a Recommended Practice for Nondestructive Testing Personnel Qualification and Certification published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518.

23 Personnel qualified by examination and certified to previous editions of SNT-TC-1A are considered to be qualified to the edition referenced in Table NCA-7100-2 when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the edition referenced inTable NCA-7100-2.

24 Employer as used in this Article shall include: N Certificate Holders, Quality System Certificate Holders, Material Organizations who are qualified in accordance with NCA-3842, and organizations who provide subcontracted nondestructive examination services to organizations described above.

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