Prevention of Brittle Fracture of Pressure Vessels

API RECOMMENDED PRACTICE 920
FIRST EDITION, MARCH 1990

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005

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Refining Department

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FOREWORD

This recommended practice offers guidance in the selection of steels for new pressure vessels and the inspection and operation of existing pressure vessels to minimize the probability of brittle fracture. This recommended practice is aimed at preventing brittle fracture caused by low toughness at temperatures below approximately 120°F. Other mechanisms of deterioration are not addressed in this publication.

Both sections of this recommended practice are influenced by the improved toughness requirements voluntarily imposed by several companies for vessels used in refineries and by a few companies for petrochemical plants, natural gas processing plants, and transportation facilities. This recommended practice is also based on the toughness requirements included in the 1989 edition of Section VIII, Division 1, of the ASME *Boiler and Pressure Vessel Code*. The provision of API Standards 620 and 650 have also influenced the development of this recommended practice.

Little precedent exists for the specification of enhanced toughness for multiple duplicate (or mass produced) vessels, nor for those vessels used in natural resource services (see Section 6 of API 510 for a more complete definition of the latter).

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Suggested revisions are invited and should be submitted to the director of the Refining Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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SECTION 1—SELECTION OF PRESSURE VESSEL STEELS TO PREVENT BRITTLE FRACTURE

1.1 Introduction

1.1.1 Pressure vessels have failed by brittle fracture when the steel used did not have sufficient toughness for the exposure conditions. In the majority of cases, the failures occurred during the hydrostatic test (hydrotest) of the vessel and were triggered by discontinuities introduced during fabrication. Special toughness requirements have voluntarily been applied to vessels that operate at temperatures above −20°F, the temperature at which the ASME *Boiler and Pressure Vessel Code,* Section VIII, Division 1 (before the December 1987 Addenda) permitted the use of steels without restrictions on notch toughness.

Note: In 1987, the ASME Code extended its requirements for the toughness of steel in pressure vessels to temperatures above −20°F. These requirements are presented in this recommended practice as Level I (base level) protection. Reflecting the stricter toughness requirements imposed by some users, Level II protection imposes additional restrictions on the type of steel that may be used and eliminates one of the ASME Code exemptions.

1.1.2 Although many vessels have been constructed of steels that meet only the previous minimum requirements of the ASME Code, the overall performance record for these vessels has been very good. This record has undoubtedly been enhanced by the voluntary imposition of requirements that are more restrictive than the minimum requirements of the ASME Code.

1.1.3 For a brittle fracture to occur, the following three criteria must exist simultaneously:

a. A steel that is notch-brittle at the existing metal temperature.
b. A notch that causes a stress concentration, such as a crack or geometric discontinuity.
c. A stress at the notch that is equal to, or approaching, previously applied stresses (see Appendix A for comments on warm prestressing).

The absence of any one of Items a—c greatly reduces the probability of brittle fracture.

1.2 Purpose

1.2.1 The purpose of Section 1 of this recommended practice is to provide the user with the option of choosing a toughness level above that required by the ASME Code. Two levels of protection—the level required by the ASME Code and the enhanced toughness level—are outlined in this publication for convenient user reference.

1.2.2 Recognizing that a number of companies have at times found it necessary to adopt a higher level of conservatism, this recommended practice offers an additional level to provide increased assurance against brittle fractures of new pressure vessels.

1.3 General Philosophy

1.3.1 For Level I protection, the basic philosophy is to adhere to the requirements of the ASME Code.

1.3.2 For Level II protection, the basic philosophy is to improve resistance to brittle fracture by applying the additional toughness requirements employed by some users. Level II also has recommendations—more stringent than the minimum requirements of the ASME Code—that restrict the use of certain as-rolled plate steels known to have been responsible for several brittle failures.

1.4 Materials Selection

1.4.1 The steels used for Level I protection should be those permitted by Figure UCS-66 of the ASME Code, which is reproduced in this recommended practice as Figure D-1.

1.4.2 The steels used for Level II protection should be limited to those in Table UCS-23 of the ASME Code as permitted by the Code for the design temperature with the exception that the maximum thickness at welds should be limited to less than ½ inch for the following plate specifications:

a. SA 285, Grade C.
b. SA 299.
c. SA 455.
d. SA 515, Grades 65 and 70.

Note: Material specifications with the designation "SA" can be found in Section II, Part A, of the ASME Code.

Structural steel pressure parts, such as those specified in SA 36 and SA 283, are not permitted in any thickness. The exemption from impact testing for P1, Group 2, steels (less than ½ inch for Curve A and less than one inch in thickness for B, C and D materials) given in

Paragraph UG 20(f) of the ASME Code is not permitted for Level II protection. The exemption is permitted up to ½ inch in thickness for P1, Group 1, steels. All other provisions of the ASME Code apply.

1.5 Referenced Publications

The most recent editions (unless otherwise specified) of the following standards, codes, and specifications are cited in this recommended practice:

API
- 510 *Pressure Vessel Inspection Code*
- Std 620 *Design and Construction of Large, Welded, Low-Pressure Storage Tanks*
- Std 650 *Welded Steel Tanks for Oil Storage*
- Publ 959 *Characterization Study of Temper Embrittlement of Chromium-Molybdenum Steels*
- *Guide for Inspection of Refinery Equipment,* Chapter III, "Inspection Planning"; Chapter IV, "Inspection Tools"; Chapter VI, "Pressure Vessels (Towers, Drums, and Reactors)"; and Appendix, "Inspection of Welding"
- *Code for the Design, Construction, Inspection, and Repair of Unfired Pressure Vessels for Petroleum Liquids and Gases* (1934 edition)

ASME[1]
- *Boiler and Pressure Vessel Code,* Section II, "Material Specifications," Part A; Section VIII, "Pressure Vessels," Division 1

ASTM[2]
- A 283 *Low and Intermediate Tensile Strength Carbon Steel Plates, Shapes, and Bars*
- A 285 *Low and Intermediate Tensile Strength Carbon Steel Pressure Vessel Plates*
- A 515 *Carbon Steel Pressure Vessel Plates for Intermediate- and Higher-Temperature Service*
- A 516 *Carbon Steel Pressure Vessel Plates for Moderate- and Lower-Temperature Service*

SECTION 2—TOUGHNESS EVALUATION OF EXISTING PRESSURE VESSELS

2.1 Introduction

2.1. Pressure vessels have failed by brittle fracture when the steel used did not have sufficient toughness for the exposure conditions. In the majority of cases, the failures occurred during the hydrostatic test (hydrotest) of the vessel and were triggered by discontinuities introduced during fabrication. The few cases of failures that have occurred while the vessel was in service have prompted a concern that further caution should be exercised to prevent additional failures in existing vessels. The temperatures of primary concern range from very low atmospheric temperatures to approximately 120°F. The overall record of successful operation has been very good, considering how many thousands of vessels are in service; however, the consequences of a failure can be severe.

2.1.2 In spite of generally favorable experience, the severity of the failures that have occurred with vessels in service has led some companies to adopt practices for evaluating the notch toughness of their existing vessels. Other companies have made case-by-case studies of brittle failures as an alternative to a formalized review procedure. These efforts recognize that changes in service may increase the risk of failure.

2.2 Purpose

The purpose of Section 2 of this recommended practice is to furnish suggestions for classifying a degree of confidence with regard to the ability of existing equipment to resist brittle fracture. Three categories that give progressively increased assurance against catastrophic brittle fracture are outlined in this section.

2.3 Scope

2.3.1 VESSELS

The pressure vessels covered in this recommended practice are primarily the welded vessels constructed in accordance with Section VIII, Division 1, of the ASME Code or with the API *Code for Unfired Pressure Vessels,* which was discontinued in 1956.

2.3.2 MATERIALS

The pressure vessel steels of primary concern are the nonimpact tested steels (except for bolting) included in

[1]American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.
[2]American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

the ASME Code under Part UCS of Section VIII, Division 1. Before the 1987 Addenda, steels of this kind were permitted by Section VIII, Division 1, of the ASME Code for a minimum temperature of −20°F without restriction; they were also permitted for lower temperatures caused by ambient temperatures. (See Appendix B for information on obsolete specifications.)

In considering the toughness properties of welded base metals, attention should be given to possible lower toughness in the heat-affected zone (HAZ) and to the possible formation of HAZ cracks. Users may compensate for the reduction in toughness by raising base metal requirements. The chance of brittle fracture originating from cracks in the heat-affected zone can be reduced by increased inspection of the zone. (See Appendix C for guidance on the inspection of HAZ cracks.)

2.3.3 SERVICE EMBRITTLEMENT

This recommended practice does not cover embrittlement that can occur in service and result in loss of toughness. One example is temper embrittlement that may occur in 1¼Cr-½Mo, 2¼Cr-1Mo, and 3Cr-1Mo steels at elevated temperatures. Information on these steels may be obtained from published sources, such as API Publication 959.

2.3.4 PRODUCT FORMS OTHER THAN PLATE

Catastrophic brittle failures of vessel parts made from product forms other than plate (pipe, forging, shapes, and so forth) have been infrequent; however, enough failures have occurred to warrant consideration, especially when these product forms are used as primary welded components of vessels.

2.3.5 DEPOSITED WELD METAL

Deposited weld metal is not considered in detail in this recommended practice. Although cracks and notches in welds and heat-affected zones are usually the initiators of brittle fracture, such fractures rarely progress in weld metal. At most temperatures considered in this recommended practice, welds deposited with manual electrodes usually have greater notch toughness than does ordinary as-rolled carbon steel plate. Welds deposited in large beads by several automatic welding processes are more frequently inferior in toughness to the adjacent plate and often deserve individual attention. The suggestions for weld inspections presented in this recommended practice reduce the need to evaluate the toughness of weld deposits. Furthermore, postweld heat treatment (stress relief) has long been recognized as one means of reducing the risk of brittle fracture.

2.3.6 VESSEL SERVICES

2.3.6.1 The services of primary concern are those in which the pressure may exceed 0.4 times the maximum allowable working pressure or a nominal membrane stress that exceeds 6 kips per square inch at temperatures below approximately 120°F and down to low atmospheric temperatures. Particular attention should be given to transient low temperatures, including those during start-up and shutdown.

2.3.6.2 Vessels used for pressure storage of products such as liquefied petroleum gases (for example, butane, propane, and mixtures) have a pressure reduction at the lower atmospheric temperatures; however, toughness evaluation of such vessels is recommended. The effects of autorefrigeration could cause local low temperatures without reducing stress levels. Attention should also be called to potential problems caused by nonpressure loads, which would include problems due to earthquakes, uneven settlement of supports, high winds, product weight, piping connections, structural attachments, and stress introduced by repairs or alterations.

2.4 General Philosophy

2.4.1 This recommended practice covers three levels of confidence against brittle fracture—Categories IA, IB, and II—with the likelihood of fracture decreasing from Category IA to Category II. Users must decide the toughness category appropriate to the equipment being analyzed, taking into account the potential consequences of failure.

2.4.2 Vessels in Categories IA and IB may not meet the toughness requirements of the ASME Code. Vessels in Category IA offer the lowest resistance to brittle fracture and are most appropriately employed in natural resource service or in other services where the consequences of fracture are small.

2.4.3 Vessels in Category IB offer a reduced risk of brittle fracture; they have demonstrated their performance in similar service under similar stress levels in the past (grandfathering), or they have been qualified by hydrotesting or inspection. The concept of grandfathering is a well-proven and widely accepted approach to the re-use of vessels; however, it still leaves some risk of brittle fracture under more extreme service conditions or as a result of defect growth. Category 1B is acceptable for many refinery vessels in process service.

2.4.4 Vessels in Category II operate at conditions that are always above the appropriate materials curve as defined for Level II protection in Section 1, or they have been constructed from materials that were toughness tested at an appropriately low temperature. These vessels are generally anticipated to have enough toughness to resist brittle fracture. Category II is appropriate for refinery vessels, for which an increased confidence level is desired.

2.4.5 Users must identify the category into which a vessel falls in its intended service. If the category must be raised to reduce the risk of brittle fracture, remedial actions such as inspection and testing or restricting service conditions will be necessary.

2.4.6 For Category IA vessels, the basic philosophy is to recognize the continued operation of vessels under conditions that are more liberal than those permitted by Level I protection for new construction, provided that they are in noncyclic service below 650°F and were originally hydrotested to 1.5 times the maximum allowable working pressure and were then either (a) rehydrotested to 1.5 times the maximum allowable working pressure or extensively inspected after repairs or modifications by welding or (b) rehydrotested.

2.4.7 For Category IB vessels, the basic philosophy is to recognize that a multitude of pressure vessels have given satisfactory service at temperatures below those suggested by Level II protection and the ASME Code. The Category IB approach is built on the fact that after long periods of service, any given vessel has probably had adverse operating conditions equalling, or approaching, the severity of future operating conditions and has therefore demonstrated its fitness for service. Such vessels should continue to provide safe service if they are in satisfactory condition.

2.4.8 For Category II vessels (see 2.5.2), the basic philosophy is to ensure that the toughness level is the same as that required by Section VIII, Division 1, of the ASME Code when impact testing is required. To facilitate this decision, the exemption curves from the ASME Code are included in this recommended practice as Figure D-1. Vessels that have a combination of thickness and temperature above or to the left of the appropriate material curve are considered to meet Category II requirements.

2.5 Criteria for Service

2.5.1 Category IA vessels are considered satisfactory for continued service at design conditions provided that all requirements of API 510 are met for any repairs or alterations by welding.

2.5.2 Category IB vessels are considered satisfactory for continued service at nominally unchanged operating conditions provided that the conditions in 2.5.2.1 through 2.5.2.5 are considered.

2.5.2.1 The nominal operating conditions have been the same for a significant period of time (about 5–10 years). Vessels with less service time should be considered Category IA vessels.

2.5.2.2 The anticipated future operating conditions (including start-up and transients) have been evaluated and are not expected to be more severe than in the past. Consideration should be given to the possibilities of degradation by stress corrosion cracking, metal loss, and embrittlement.

2.5.2.3 The condition of the vessel is satisfactory, meaning that it is in approximately an as-built condition as determined by inspection, with particular attention given to crack detection by magnetic-particle inspection. (See 2.6, Appendix C, and API 510.)

2.5.2.4 If the vessel has been repaired or altered, appropriate welding, heat-treatment, and test requirements have been utilized. (See 2.6, Appendix A, Appendix C, and API 510.) If no hydrotest is made, consideration should be given to raising the minimum temperature for pressurization.

2.5.2.5 Corrosion loss has not reduced the average effective thickness by more than 10 percent (or the amount of the initial corrosion allowance, if less). For clarification, see A.6.

2.5.3 Category II vessels are considered to be fit for continued service, or for service at more severe conditions of pressure and temperature, if they comply (at the more severe conditions) with Level II protection in Section 1 and if the steel has not deteriorated.

2.6 Importance of Condition

The condition of existing vessels is of key importance. For existing vessels to be evaluated by the criteria given in 2.5, they should be judged to be in satisfactory condition as determined by inspection (see Appendix C). If the vessels have been repaired or altered, the steel and welding procedures should be selected to provide toughness in the weldment (including the heat-affected zone) that is at least equal to that provided by the initial construction; particular attention should be given to preheat and postweld heat-treatment requirements. See Appendixes A and C concerning hydrostatic testing after repairs or alterations.

APPENDIX A—HYDROSTATIC TESTING

A.1 General

Hydrostatic testing (hydrotesting) of pressure vessels to a significant overload has long been recognized as an important contributor to successful service at low temperatures. The function of an overload hydrotest that enhances performance at low temperatures has variously been referred to as crack blunting, mechanical stress relief, warm preloading, and notch nullification. This function has been verified by wide plate tests in England, Japan, and the United States. When vessel materials are sufficiently notch ductile at operating temperature, this function is of much less importance.

A.2 Other Functions of Hydrotesting

Other well recognized functions of the hydrotest include leak detection and structural verification. The leak detection is of most value in production-line types of pressure equipment that have a rather high frequency of leaks. The function of structural verification is primarily valuable in detecting gross errors in design, fabrication, or inspection. Proper inspection methods are much more effective in finding flaws than are hydrotests.

A.3 Pressure Level

The pressure level of the hydrotest is important, especially with respect to the crack-blunting function. While wide plate tests have generally shown that low-temperature failures do not happen at pressures (loads) less than the warm pretest pressure, extensive studies of pipeline tests and retests show that pressure reveals down to about 80 percent of the previously applied test pressures may be expected in some cases (usually with rather large defects). Any hydrotests should probably be conducted at a pressure equal to the pressure that was initially used. In any case, the pressure should be at least 1.25 times the maximum allowable working pressure, but it should not exceed a pressure that produces a shell membrane stress of 90 percent of the specified minimum yield strength of the steel. Special consideration should be given to the pressure-temperature conditions during the test, recognizing the change in allowable stress between the test temperature and the service temperature. A test to 1.5 times the maximum allowable working pressure is usually considered desirable.

A.4 Temperature Level

The temperature level at which the hydrotest is conducted has been considered by many to be of considerable importance with respect to the crack-blunting function. Several investigators have favored testing at relatively high temperature levels that correspond to upper-shelf levels as determined by the Charpy V-notch impact test for the steels used. Such high levels are considered by some to be advantageous because the improved toughness at the higher temperature permits greater plastic deformation at crack tips during the overload. Others emphasize the beneficial effect of a long time at pressure (up to 24 hours) because of data that indicate coasting strain, or creep, at crack tips. Still others have advocated that any successful overload test at a temperature higher than the service temperature improves the chance of subsequent success at the service temperature.

A.5 Minimizing Risks

The imposition of an overload hydrostatic test may in itself impose certain risks, especially if the test is conducted at too low a temperature. Moreover, the failure of any important vessel can cause operational delays. To minimize the risk of brittle fracture during hydrotesting, the test temperature should be 30°F above the minimum permissible operating temperature for vessels that are more than 2 inches thick, or 10°F above for vessels that have a thickness of 2 inches or less. It should be noted that the beneficial influence of crack-blunting is negated by elevated temperature aging; therefore, it is usually not taken into account when the vessel design temperature exceeds 650°F (see 2.4.6).

A.6 Retesting

If the original hydrotest during construction did not stress the full membrane thickness, including the corrosion allowance, to at least 125 percent of the design stress, vessels that have lost more than 10 percent of the original thickness (but not more than the corrosion allowance) should be rehydrotested. The temperature precautions in A.5 should be followed.

APPENDIX B—STEELS

B.1 General

The purpose of this appendix is to identify several obsolete steel specifications formerly used for the construction of many vessels. All steels listed in this appendix should be assigned to Curve A in Figure D-1. The toughness of these steels is considered to be no better than the toughnesses specified in ASTM A 283, A 285, and A 515, which do not contain requirements that enhance low-temperature properties. Any other steels that are not listed in this appendix should also be assigned to Curve A unless sufficient information is available to assign them to a lower curve.

B.2 Codes Previously Used for the Construction of Vessels

B.2.1 1934 API CODE

The first edition of the API *Code for Unfired Pressure Vessels* (discontinued in 1956) listed the following ASTM carbon steel plate specifications, some of which were used for many years:

a. A 7.
b. A 10.
c. A 30.
d. A 70.
e. A 113.
f. A 149.
g. A 150.

The specifications listed in Items a–g were variously designated for structural steel for bridges, locomotives, and rail cars or for boiler and firebox steel for locomotives and stationary service. ASTM A 149 and A 150 were applicable to high-tensile-strength carbon steel plates for pressure vessels.

B.2.2 1934 ASME CODE, SECTION VIII

Few very old ASME vessels will be found that contain obsolete-specification steels except for those listed in B.2.1. However, the 1934 edition of Section VIII of the ASME Code listed a series of ASME steel specifications, including S 1 and S 2 for forge welding; S 26 and S 27 for carbon steel plates; and S 25 for open-hearth iron. The titles of some of these specifications are similar to the ASTM specifications listed in the 1934 edition of the API *Code for Unfired Pressure Vessels*.

B.2.3 LATER CODES

Most of the obsolete steel specifications found in later editions of the ASME Code are listed in B.2.1 and B.2.2, with the important exceptions of ASTM A 201 and A 212 and their ASME "SA" counterparts. These two steels were replaced in strength grades by the four grades specified in ASTM A 515 and the four grades specified in ASTM A 516. Steel in accordance with ASTM A 212 was made only in strength grades the same as Grades 65 and 70 and has accounted for several known brittle failures. Steels in conformance with ASTM A 201 and A 212 should be assigned to Curve A unless it can be established that the steel was produced by fine-grain practice, which may have enhanced the toughness properties.

B.3 Steel Product Forms Other Than Plate

No attempt has been made to make a list of obsolete specifications for tubes, pipes, forgings, bars, and castings. Unless specific information to the contrary is available, all of these product forms should be assigned to Curve A.

APPENDIX C—INSPECTION

C.1 General

This recommended practice has emphasized the importance of determining that existing vessels are in satisfactory condition when they are evaluated for low-temperature service. Inspections for the determination of condition should follow usual good practices. API 510 is recommended as a guide for maintenance inspections, rating, repair, and alterations. Further details on how to conduct inspections along with descriptions of conditions that cause deterioration are given in Chapters III, IV, and VI and the Appendix of the API *Guide for Inspection of Refinery Equipment*. All chapters, as well as the Appendix, are published and sold separately. The Appendix applies more to new construction and repair welding than it does to re-inspections.

C.2 Purpose

The purpose of this appendix is to emphasize the importance of detecting cracks and similar sharp notches, especially those that may have developed in service. Brittle fractures are most often initiated at sharp notches although severe stress concentrations at geometric discontinuities sometimes act as initiators (for example, at the toe of a fillet weld that attaches a reinforcing plate at an opening or support).

C.3 Cracks

C.3.1 Cracks in and near welds constitute the majority of sharp notches and have been responsible for the initiation of a number of brittle fractures. Cracks have developed at arc strikes and at attachment welds with and without undercuts.

C.3.2 Size-for-size, surface cracks are more likely to initiate brittle fracture than are buried cracks, according to fracture-mechanics concepts. Equally as important, surface cracks are more likely to initiate and propagate stably in service than are buried cracks.

C.3.3 Magnetic-particle inspection is very useful in determining if vessels are in satisfactory condition. (AC yoke is preferred for magnetic-particle inspection to avoid arcs at prod contacts.) Radiographic inspection is far less effective than magnetic-particle inspection in detecting surface weld defects. Ultrasonic inspection, like radiographic inspection, can effectively find buried defects but is usually inferior to magnetic-particle inspection for the detection of surface flaws. Acoustic-emission inspection may be useful during hydrotesting to detect cracks. Indications of defects are followed up with one of the other inspection methods to verify and characterize cracking. Liquid-penetrant inspection can be considered as an alternative to magnetic-particle inspection but is often less sensitive.

C.3.4 In refinery service, the surface cracks of most concern are probably those caused by corrosion of the inside surface of vessels. Hydrogen-embrittlement cracking of welds and heat-affected zones has been well documented in such services as the overhead streams of fluid catalytic-cracking units as well as units that use hydrofluoric acids. Cracking in and at the edge of hydrogen blisters in the same services is not unusual. Stress corrosion cracking in acid-gas removal units, such as those using monoethanolamine, has been severe. Postweld heat treatment, whether of new vessels or weld-repaired vessels, may reduce the occurrence of several types of stress corrosion cracking.

C.3.5 Secondary to corrosion-induced cracks are those left from initial construction and those caused by fatigue. Cracks and cracklike flaws may also result from creep, thermal fatigue, graphitization, and improper repairs and alterations.

APPENDIX D—IMPACT TEST EXEMPTION CURVES

D.1 General

The curves included in Figure UCS-66 of the 1989 edition of the ASME Code are reproduced in this recommended practice as Figure D-1. Their primary use is in conjunction with Section 2 of this recommended practice in evaluating service conditions for Category II vessels.

Because the wide variation in toughness properties results in some inexactness of the curves, periodic revisions may be necessary; however, the assignment of steels to the curves is believed to be conservative in most cases.

Users of this recommended practice are responsible for confirming the validity of the curves by comparing them to the curves in the most recent edition of the ASME Code.

In the application of the exemption curves, the thickness of each component should be determined according to the definition given in the ASME Code, which states that the following thickness limitations apply when Figure UCS-66 is used:

a. The governing thickness of a welded part, excluding castings, is (1) for butt joints, the nominal thickness of the thickest welded joint and (2) for corner joints or lap welds, the thinner of the two parts joined. If the thickness at any welded joint exceeds 4 inches, impact tested steel should be used.
b. The governing thickness of a casting should be its largest nominal thickness.
c. The governing thickness of nonwelded parts such as bolted flanges, tubesheets, and flat heads is the smallest governing thickness of the shell, head, or nozzle at the corresponding bolted joint. If the nonwelded thickness exceeds 6 inches and the minimum design metal temperature is less than 120°F, impact tested steel should be used.

Components such as shells, heads, nozzles, manways, reinforcing pads, flanges, tubesheets, flat cover plates, and welded attachments to pressure-containing components should be treated as separate components. Each component should be evaluated for impact test requirements based on its individual classification and thickness as defined in Items a–c and its minimum design metal temperature.

D.2 Assignment of Materials to Curves

D.2.1 CURVE A

Curve A is assigned all carbon and low-alloy steel plates, structural shapes, and bars that are not listed to be assigned to Curves B, C, and D.

D.2.2 CURVE B

Curve B is assigned the materials specified by the following:

a. SA 285, Grades A and B.
b. SA 414, Grade A.
c. SA 442, Grade 55 greater than 1 inch, if material is not produced to fine-grain practice and normalized.
d. SA 442, Grade 60, if material is not produced to fine-grain practice and normalized.
e. SA 515, Grades 55 and 60.
f. SA 516, Grades 65 and 70, if material is not normalized.
g. SA 612, if material is not normalized.
h. SA 662, Grade B, if material is not normalized.
i. SA 724, if material is not normalized.

In addition, curve B is assigned all materials that are assigned to Curve A if they are produced to fine-grain practice and normalized and are not listed for Curves C and D.

Except for bolting (see D.2.5), plates, structural shapes, forgings, and bars, all other product forms (such as pipe, fittings, and tubing) not listed for Curves C and D are assigned to Curve B.

Parts permitted under ASME *Boiler and Pressure Vessel Code* UG 11 should be assigned to Curve B even when they are fabricated from plate that would otherwise be assigned to a different curve.

D.2.3 CURVE C

Curve C is assigned the materials specified by the following:

a. SA 182, Grades 21 and 22, if the material is normalized and tempered.
b. SA 302, Grades C and D.
c. SA 336, Grades F21 and F22, if the material is normalized and tempered.
d. SA 387, Grades 21 and 22, if the material is normalized and tempered.
e. SA 442, Grade 55 less than or equal to 1 inch, if the material is not produced to fine-grain practice and normalized.
f. SA 516, Grades 55 and 60, if the material is not normalized.
g. SA 533, Grades B and C.
h. SA 662, Grade A.

Curve C is also assigned all materials that are assigned to Curve B if they are produced to fine-grain practice and normalized and are not listed for Curve D.

D.2.4 CURVE D

Curve D is assigned the materials specified by the following: