

**ASME B31T-2021**  
(Revision of ASME B31T-2018)

# Standard Toughness Requirements for Piping

**ASME Code for Pressure Piping, B31**

**AN AMERICAN NATIONAL STANDARD**



**The American Society of  
Mechanical Engineers**

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**AN AMERICAN NATIONAL STANDARD**



**The American Society of  
Mechanical Engineers**

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# FOREWORD

In 2000, the ASME B31 Code for Pressure Piping, Materials Technical Committee (MTC) determined that there was a need to develop a standard set of toughness requirements for piping components that can be adopted by reference by various codes, standards, and specifications. At the time, the requirements of the ASME B31 Code books varied, with some having no requirements at all.

This Standard is intended to provide requirements for evaluating the suitability of materials used in piping systems for piping that may be subject to brittle failure due to low-temperature service conditions.

Under direction of ASME Standards and Certification, both SI and U.S. Customary units are provided. The 2010 edition of this Standard was approved by the American National Standards Institute (ANSI) on April 20, 2010.

The 2015 edition of this Standard was approved by ANSI on October 21, 2015.

The 2018 edition of this Standard was approved by ANSI on December 6, 2018.

The 2021 edition of this Standard was approved by ANSI on July 15, 2021.

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|                         |                                                                                                                                                                                                                                                                                                                       |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Subject:                | Cite the applicable paragraph number(s) and the topic of the inquiry in one or two words.                                                                                                                                                                                                                             |
| Edition:                | Cite the applicable edition of the Standard for which the interpretation is being requested.                                                                                                                                                                                                                          |
| Question:               | Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. Please provide a condensed and precise question, composed in such a way that a "yes" or "no" reply is acceptable. |
| Proposed Reply(ies):    | Provide a proposed reply(ies) in the form of "Yes" or "No," with explanation as needed. If entering replies to more than one question, please number the questions and replies.                                                                                                                                       |
| Background Information: | Provide the Committee with any background information that will assist the Committee in understanding the inquiry. The Inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.                                 |

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# INTRODUCTION

The ASME B31 Code for Pressure Piping consists of a number of individually published Sections and Standards, each an American National Standard, under the direction of the ASME B31 Code for Pressure Piping Committee.

Rules for each Section reflect the kinds of piping installations considered during its development, as follows:

- B31.1 Power Piping: piping typically found in electric-generating stations, industrial and institutional plants, geothermal and solar power applications, and central and district heating and cooling systems
- B31.3 Process Piping: piping typically found in petroleum refineries; onshore and offshore petroleum and natural gas production facilities; chemical, pharmaceutical, textile, paper, ore-processing, semiconductor, and cryogenic plants; food- and beverage-processing facilities; and related processing plants and terminals
- B31.4 Pipeline Transportation Systems for Liquids and Slurries: piping that transports products that are predominately liquid between plants and terminals, and within terminals and pumping, regulating, and metering stations
- B31.5 Refrigeration Piping and Heat Transfer Components: piping for refrigerants and secondary coolants
- B31.8 Gas Transportation and Distribution Piping Systems: piping that transports products that are predominately gas between sources and terminals, including compressor, regulating, and metering stations and gas-gathering pipelines
- B31.9 Building Services Piping: piping typically found in industrial, institutional, commercial, and public buildings and multiunit residences that do not require the range of sizes, pressures, and temperatures covered by ASME B31.1
- B31.12 Hydrogen Piping and Pipelines: piping in gaseous and liquid hydrogen service and pipelines for gaseous hydrogen service

The following Codes and Standards provide guidance for a specific task found in one or more ASME B31 Section publications:

- B31E Seismic Design and Retrofit of Above-Ground Piping Systems: establishes a method for the seismic design of above-ground metallic piping systems in the scope of the ASME B31 Code for Pressure Piping
- B31G Remaining Strength of Corroded Pipelines: provides a simplified procedure to determine the effect of wall loss due to corrosion or corrosion-like defects on the pressure integrity in pipeline systems
- B31J Stress Intensification Factors (*i*-Factors), Flexibility Factors (*k*-Factors), and Their Determination for Metallic Piping Components: provides a standardized method to develop the stress intensification factors (*i*-factors), flexibility factors (*k*-factors), and sustained stress factors used in ASME B31 piping analysis
- B31P Standard Heat Treatments for Fabrication Processes: provides requirements for heat treatment of piping assemblies that meet the requirements of ASME B31 Code Sections
- B31Q Pipeline Personnel Qualification: establishes the requirements for developing and implementing an effective Pipeline Personnel Qualification Program
- B31T Standard Toughness Requirements for Piping: provides requirements for evaluating the suitability of materials used in piping systems for piping that may be subject to brittle failure due to low-temperature service conditions

This is ASME B31T, Standard Toughness Requirements for Piping. Hereafter, in this Introduction and in the text of ASME B31T, where the word “Standard” is used without specific identification, it means ASME B31T.

This Standard provides requirements for evaluating the suitability of materials used in piping systems for piping that may be subject to brittle failure due to low-temperature service conditions. While low-temperature service is

usually considered to be below ambient temperature, brittle failure can occur at temperatures above ambient temperature for certain combinations of materials, thicknesses, and stress levels. The definition of “low-temperature service” as used in this Standard, therefore, varies widely across the many applications for which piping systems are used. For a building service air line, low temperature may be 0°C (32°F), whereas for a cryogenic piping system, it could easily be -185°C (-300°F). However, the principles used to evaluate the suitability of a piping system as related to service temperature by evaluating the toughness of the material can be applied across a wide temperature range, and this Standard has been established to provide uniform guidance in this area.

Suitability of piping systems for low-temperature service is a function of several variables, including material properties, design loadings, and fabrication procedures. The three primary factors that generally control the susceptibility for brittle fracture are material toughness, crack size, and tensile stress level. There are a wide variety of services where low-temperature suitability need not even be considered; however, a screening criterion is necessary to determine this.

One objective of this Standard is to provide a simple approach to evaluate whether additional consideration is necessary to evaluate suitability for low-temperature service. This is done by establishing a low-temperature service limit for various materials. Services at or warmer than this limit are not considered low temperature, and additional considerations relative to suitability are not required.

For services colder than this limit, various requirements are provided that, when met, qualify the material for low-temperature services. These requirements include impact testing, qualification of welding and other fabrication procedures, and limiting the design loadings.

The low-temperature service limit established herein is based on a reasonable degree of assurance that at this temperature, the material will have a ductile failure mode. The actual ductile-to-brittle transition temperature for a given material specification will vary based on actual heat chemistry of the material and subsequent processing. For critical applications, the design engineer can select materials with a lower low-temperature service limit or require impact testing. On less-critical applications, material with a higher low-temperature service limit

may be acceptable. The final selection is left to the code, standard, or specification referencing this Standard and the design engineer (when permitted by the code, standard, or specification referencing this Standard).

To keep the number of sets of requirements to a minimum, material groupings have been established, and a unique set of requirements have been provided for each group. These groups are assigned “T-numbers” for easy reference. Although most materials used in piping systems are listed, some are not, and these unlisted materials are not addressed in this Standard. Where permitted by the code, standard, or specification referencing this Standard, these requirements may be used for unlisted materials. The code, standard, or specification referencing this Standard may establish the correct T-number group for the material or may invoke the testing and other requirements of this Standard using the worst-case assumption that the design minimum temperature is colder than the temperatures that would allow exemption from any of the requirements of this Standard. The guidelines for establishing the correct T-number group are provided in [Nonmandatory Appendix B](#).

Either International System (SI, also known as metric) or U.S. Customary (USC) units may be used with this edition. Local customary units may also be used to demonstrate compliance with this Standard. One system of units should be used consistently for requirements applying to a specific installation. It is the responsibility of the organization performing calculations to ensure that a consistent system of units is used.

The ASME B31 Committee is organized and operates under procedures of ASME that have been accredited by the American National Standards Institute. The Committee is continuing and keeps all Code Sections and Standards current with new developments in methods, materials, construction, and industrial practice.

This Standard may be invoked in whole or in part by various codes, standards, or specifications and is only mandatory when so invoked. The applicable edition of this Standard shall be as specified by the code, standard, or specification referencing this Standard. It is intended that this edition of the ASME B31T Standard not be retroactive. Users of this Standard are cautioned against making use of Standard revisions without assurance that they are acceptable to the proper authorities in the jurisdiction where the material is to be installed.

# ASME B31T-2021

## SUMMARY OF CHANGES

Following approval by the ASME B31 Committee and ASME, and after public review, ASME B31T-2021 was approved by the American National Standards Institute on July 15, 2021.

ASME B31T-2021 has replaced the word “Code” with “Standard” in all references to itself. In addition, this edition includes the following changes identified by a margin note, **(21)**.

| <i>Page</i> | <i>Location</i>      | <i>Change</i>                                                                                                                                                                                                                                                                                           |
|-------------|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| viii        | Introduction         | Added                                                                                                                                                                                                                                                                                                   |
| 1           | 1                    | Revised in its entirety                                                                                                                                                                                                                                                                                 |
| 1           | 2                    | (1) Definition of <i>fully deoxidized steel</i> revised<br>(2) Definition of <i>governing thickness</i> added                                                                                                                                                                                           |
| 1           | 3.2                  | First sentence revised                                                                                                                                                                                                                                                                                  |
| 2           | 3.3                  | Revised in its entirety                                                                                                                                                                                                                                                                                 |
| 2           | 3.4                  | Revised                                                                                                                                                                                                                                                                                                 |
| 2           | 3.5                  | Revised                                                                                                                                                                                                                                                                                                 |
| 3           | 3.7.1                | First two paragraphs revised                                                                                                                                                                                                                                                                            |
| 3           | 3.7.2.2              | Second paragraph revised                                                                                                                                                                                                                                                                                |
| 3           | 3.7.2.3              | First two paragraphs revised                                                                                                                                                                                                                                                                            |
| 5           | 3.7.4.2              | Last paragraph revised                                                                                                                                                                                                                                                                                  |
| 6           | 3.7.4.3              | Revised                                                                                                                                                                                                                                                                                                 |
| 6           | 4.1                  | Revised                                                                                                                                                                                                                                                                                                 |
| 6           | 4.2                  | Second paragraph and subpara. (a) revised                                                                                                                                                                                                                                                               |
| 8           | 5                    | Added                                                                                                                                                                                                                                                                                                   |
| 12          | Table 3.1-1          | Second column head revised                                                                                                                                                                                                                                                                              |
| 28          | Table 3.2-1          | (1) First A134 row and A167, A202, A226, A325, and A570 rows deleted<br>(2) Last A134 row, A283 row, and first two A320 rows revised<br>(3) Penultimate A193 row, last A453 row, A1011 row, and General Note (a) added                                                                                  |
| 36          | Table 4.5.1-1        | First column revised to show SI units as primary                                                                                                                                                                                                                                                        |
| 37          | Mandatory Appendix I | Title and first paragraph revised                                                                                                                                                                                                                                                                       |
| 38          | Figure I-1           | Title, axis and curve labels, and curve CS B revised                                                                                                                                                                                                                                                    |
| 39          | Figure I-1M          | Title and axis and curve labels revised                                                                                                                                                                                                                                                                 |
| 40          | Table I-1            | Column heads revised                                                                                                                                                                                                                                                                                    |
| 46          | Table III-1          | (1) CS –20, A226 and A325; CS A, A570; CS B, first A134; LA –20, A202; SS –325, A167; and SS –20, A167 rows deleted<br>(2) CS –20, F3125; CS A, A1011; SS –425, A193; SS –325, A453; and General Note (a) added<br>(3) CS A, last A134 and A283; SS –425, A320; and SS –325, A193 and A320 rows revised |

| <i>Page</i> | <i>Location</i>         | <i>Change</i>                                                                   |
|-------------|-------------------------|---------------------------------------------------------------------------------|
| 54          | Figure A-1              | First two boxes under “Low-Temperature Service Requirements Evaluation” revised |
| 55          | Nonmandatory Appendix B | “T-number(s)” revised to “T-number group(s)” throughout                         |

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# STANDARD TOUGHNESS REQUIREMENTS FOR PIPING

## (21) 1 GENERAL

### 1.1 Scope

This Standard provides requirements for evaluating the suitability of materials used in piping systems for piping that may be subject to brittle failure due to low-temperature service conditions.

### 1.2 Units of Measure

This Standard states values in both International System (SI, also known as metric) and U.S. Customary (USC) units. Within the text, the USC units are shown in parentheses or in separate tables. The values stated in each system are not exact equivalents; therefore, each system of units should be used independently of the other.

When separate equations are provided for SI and USC units, those equations shall be executed using variables in the units associated with the specific equation. The result obtained from execution of these equations may be converted to other units.

When necessary to convert from one system of units to another, conversion should be made by rounding the values to the number of significant digits of implied precision in the starting value but not less than four significant digits for use in calculations.

## (21) 2 GLOSSARY

*CVN*: the abbreviation for Charpy V-notch.

*design minimum temperature*: the lowest component temperature expected in service.

*fully deoxidized steel*: steel that has been deoxidized, either by the addition of strong deoxidizing agents or by vacuum treatment, to reduce the oxygen content to such a level that no reaction occurs between the carbon and oxygen during solidification. Also known as killed steel. Steels that are not fully deoxidized include rimmed, semi-killed, and capped steels. Limitations on the use of steels that are not fully deoxidized may be imposed by the code, standard, or specification referencing this Standard.

*governing thickness*: the thickness used in determining the low-temperature service limit of T-number groups CS A, CS B, CS C, and CS D in [Table 3.1-1](#). Unless defined differently in the code, standard, or specification referencing this Standard, this thickness is the nominal thickness

of the component or, for blind flanges and line blanks,  $\frac{1}{4}$  of the total thickness, where the total thickness is the thickness of the blind flange or line blank, including the thickness of the facing(s), if applicable.

*lower critical temperature*: the temperature at which the first phase change occurs when heating a metal.

*low-temperature service limit*: the design minimum temperature at which additional requirements for low-temperature service do not apply.

*NDT temperature*: the nil ductility transition temperature.

*stress ratio*: the ratio of the design stress to an allowable stress. (See [para. 3.6.2](#).)

*T-number*: a number assigned to a group of similar materials with similar low-temperature requirements. The number consists of the material type and a temperature characteristic, and possibly a suffix.

## 3 LOW-TEMPERATURE RANGES AND REQUIREMENTS

### 3.1 Low-Temperature Service Requirements

Low-temperature service requirements are contained in [Table 3.1-1](#). These requirements are established for T-number groups of materials with similar requirements. In addition to T-number group, in some cases, requirements are dependent on thickness and/or other characteristics as listed in [Table 3.1-1](#).

### 3.2 Material Groupings (Column 1 of [Table 3.1-1](#)) (21)

Listed materials are assigned T-number groups in [Table 3.2-1](#). (In addition, a table sorted by material type and T-number group that lists all materials in each T-number group is provided in [Mandatory Appendix III](#).) In determining the applicable T-number group for a material from [Table 3.2-1](#), consideration shall be given to the material specification, grade, and any other variables as established in the notes. The table separates the materials into types (carbon steels, low-alloy steels, etc.), and the group number is representative of the low-temperature service limit for the material; however, the low-temperature service limit may vary based on the design and fabrication requirements. Low-temperature service limits shall be determined from [Table 3.1-1](#). An "(A)" in the T-number group [e.g., CS -20(A)] indicates that materials of that group may not be used

at temperatures colder than the group number [e.g.,  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ )].

(21) **3.3 Governing Thickness and Notes (Columns 2 and 3 of Table 3.1-1)**

For T-number groups in which the low-temperature suitability varies significantly according to the material thickness, a governing thickness is listed in column 2 of Table 3.1-1 at various low-temperature service limit increments. When it is desired to refine the influence of the governing thickness, Mandatory Appendix I provides the continuous curves and tables that can be used at intermediate values or greater governing thicknesses. Since the governing thicknesses in Table I-1 of Mandatory Appendix I are generally derived based on uniform increments of temperature, the table does not contain uniform increments of governing thickness. The continuous curves in Figures I-1 and I-1M in Mandatory Appendix I should be consulted for the precise values.

For material T-number groups in which the low-temperature suitability is dependent on some other factor, those factors are given in the notes listed in column 3 of Table 3.1-1.

(21) **3.4 Low-Temperature Service Limit (Column 4 of Table 3.1-1)**

Column 4, the first temperature column in Table 3.1-1, is the low-temperature service limit. If the design minimum temperature is equal to or warmer than this value, then low-temperature requirements do not apply. Materials within a T-number group may be used at this temperature or temperatures warmer than this limit without imposing any of the requirements of this Standard. This limit considers material properties and the influence of fabrication processes on the material properties.

(21) **3.5 Material Requirements for Low-Temperature Service (Columns 5 and 6 of Table 3.1-1)**

Column 5 lists the minimum permitted temperature of the material. When a temperature is listed, this is the design minimum temperature permitted for the T-number group regardless of impact testing or any other requirements except as permitted by column 18, where the applied stress is limited to 30% of the allowable.

Column 6 contains the minimum temperature without impact testing for the material. If the design minimum temperature is equal to or warmer than this value, the material does not require impact testing. If the design minimum temperature is colder than this value, impact testing of the material is required. For carbon steels, this limit may vary with governing thickness or stress ratio. Additional rows are provided in Table 3.1-1 for governing thickness variations. Interpolation between governing thicknesses is permitted. Figures and a table

for the curves of the variation of temperature with governing thickness are provided in Mandatory Appendix I, and these may be used as an alternative to the values in Table 3.1-1. Permitted temperatures for stress ratios are provided for by using columns 10 through 18 instead of column 6 as discussed in para. 3.6.

**3.6 Design Requirements for Low-Temperature Service (Columns 10 Through 18 of Table 3.1-1)**

**3.6.1 Minimum Material Temperature Without Impact Testing.** Columns 10 through 17 list the minimum material temperature without impact testing based on design stresses and may be used for carbon steels provided

(a) the piping system is subjected to a hydrostatic test at no less than 1.5 times the design pressure

(b) the piping system is not subjected to unevaluated external loads such as maintenance loads, impact loads, and thermal shock

The curve used to generate columns 10 through 17 in Table 3.1-1 is provided in Mandatory Appendix II and may be used as an alternative to columns 10 through 17.

Column 18 lists the minimum low-temperature service limit achievable by limiting stresses to less than 10% of the tensile strength [i.e., the stress ratio (SR)  $\leq 0.3$ ] and may be used without any additional low-temperature service requirements. At these stress levels, the design margin is considered adequate to prevent a brittle fracture failure mode. The low-temperature service limit listed in column 18 may be used in lieu of that listed in column 4 when  $\text{SR} \leq 0.3$ .

**3.6.2 Stress Ratio.** The stress ratio is defined as the maximum of the following:

(a) nominal pressure stress (based on minimum pipe wall thickness less allowances) divided by the allowable stress at the design minimum temperature.

(b) for piping components with pressure ratings, the pressure for the condition under consideration divided by the pressure rating at the design minimum temperature.

(c) combined longitudinal stress due to pressure, dead weight, and displacement strain (stress intensification factors are not included in this calculation) divided by the allowable stress at the design minimum temperature. In calculating longitudinal stress, the forces and moments in the piping system shall be calculated using nominal dimensions, and the stresses shall be calculated using section properties based on the nominal dimensions less corrosion, erosion, and mechanical allowances.

In determining the stress ratio, the loadings coincident with the metal temperature under consideration may be used in lieu of maximum design values. Where there are several low-temperature design conditions, each shall be evaluated to determine the stress ratio.

### 3.7 Fabrication Requirements for Low-Temperature Service (Columns 7, 8, and 9 of Table 3.1-1)

- (21) **3.7.1 Temperature Limits.** Column 7 lists the minimum weld-permitted temperature. When a temperature is listed, this is the design minimum temperature permitted for welded construction for this T-number group, governing thickness, and notes regardless of impact testing or any other requirements. Use of the material is prohibited at temperatures colder than this temperature unless permitted by column 9.

Column 8 of Table 3.1-1 lists the design minimum temperature permitted for each T-number group without additional fabrication requirements. Alternatively, when stresses are limited to 30% of allowable, the temperatures in column 9 may be used instead of the values in column 8.

When materials are used at temperatures colder than those listed in column 8 or column 9, as applicable, the welding, bending, and forming procedures shall be qualified to verify that they do not result in significant loss of material toughness. In addition, weld filler metal shall meet the impact test requirements of para. 3.7.4.

#### 3.7.2 Welding Procedure Specifications

**3.7.2.1 General.** Welding procedures that are required by para. 3.7.1 to be qualified with impact testing shall be qualified for toughness, and the supplementary essential variables of ASME Boiler and Pressure Vessel Code (BPVC), Section IX shall apply. Temper bead welding procedures shall be prepared and qualified in accordance with Section IX using impact testing as the basis for acceptance.

Impact tests of the weld metal and heat-affected zone (HAZ) shall be performed in accordance with paras. 3.7.2.2 and 3.7.2.3 except that impact tests of the HAZ are not required for

(a) the qualification for welds in P-Nos. 1 and 3 materials that are postweld heat treated and are made by any process other than electroslag, electrogas, or thermit

(b) the qualification for weld deposit cladding or hardfacing on any base material

(c) that portion of the HAZ associated with gas tungsten arc welding (GTAW) root deposits with a maximum of two layers or 5 mm ( $\frac{3}{16}$  in.) thickness, whichever is less

- (21) **3.7.2.2 Test Specimens.** The weld procedure qualification impact test specimens shall be Charpy V-notch (CVN) specimens prepared and tested in accordance with the requirements in ASME BPVC, Section IX. A test shall consist of five specimens, all of which shall be tested at or below the design minimum temperature. The highest and lowest values of these specimens shall be disregarded, and the values of the three remaining specimens shall equal or exceed the impact value required for the base metal to be welded in production. Alternatively,

only three specimens may be prepared and tested, and the values of these three specimens shall equal or exceed the impact value required for the base material to be welded in production.

The impact specimen representing the weld deposit shall be located so that the longitudinal axis of the specimen is at least  $0.25t$  from a surface, where  $t$  is the thickness of the test weld and, where the thickness of the test assembly permits, not less than 10 mm ( $\frac{3}{8}$  in.) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified by the code, standard, or specification referencing this Standard 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 CVN specimen shall be normal to the surface of the weld.

Specimens representing the HAZ 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 specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for HAZ impact specimens shall be taken transverse to the axis of the weld and etched to define the HAZ. The notch of the CVN specimen shall be cut approximately normal to the material surface in such a manner as to include as much HAZ as possible in the resulting fracture. 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 HAZ values with base material values, CVN specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the HAZ specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the HAZ specimens, and the axis of the notch shall be normal to the surface of the base material.

- 3.7.2.3 Test Requirements.** The impact test requirements for the weld metal used for welding procedure qualification shall be the same as specified in section 4 for the base material to be welded or repaired. Retests in accordance with the provisions of para. 4.5.4 are permitted. Where two materials are to be joined by welding and have different toughness requirements, the test requirements of either material may be used (21)

for the weld metal unless otherwise specified by the code, standard, or specification referencing this Standard.

For CVN tests of the HAZ, three CVN specimens representing the HAZ material and three representing the unaffected base material shall be tested at the design minimum temperature of the base material. Where two different materials that have different toughness requirements are to be joined by welding, the test shall be conducted on the HAZ from each material and corresponding unaffected base material unless otherwise specified by the code, standard, or specification referencing this Standard. Test acceptance criteria are as follows:

(a) The CVN impact tests of the unaffected base material shall meet the requirements of this Standard. If the average lateral expansion values of the three HAZ specimens are equal to or greater than the average value for the unaffected base material CVN specimens, the qualification test shall be considered acceptable, and the values and testing temperature shall be recorded on the welding Procedure Qualification Record (PQR).

(b) If the average CVN lateral expansion for the HAZ of (a) is less than that for the unaffected base material, and the qualification test meets the other criteria of acceptance, the CVN test results may be recorded on the PQR. Data shall then be obtained as specified in (c) to provide an additive temperature for the adjustment to compensate for the HAZ toughness decrease as described in (d). Alternatively, the welding procedure qualification may be rewelded and retested.

(c) The data for development of the temperature adjustment ( $T_{ADJ}$ ) shall be developed by performing additional CVN tests on either the welding procedure qualification HAZ or the unaffected base material, or both, at temperatures that provide toughness values that meet or exceed those required for the thickness of material to be welded in production. The average toughness data for the HAZ and the unaffected base material shall be plotted on a property-temperature chart. The temperatures at which these two sets of data exhibit a common acceptable value of toughness for the production thickness involved shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the HAZ. This difference shall be used in (d) as  $T_{ADJ}$ . If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by this Standard will still apply as stated in (a). The CVN testing results shall be recorded on the PQR, and any offsetting  $T_{ADJ}$  or increased toughness requirements shall be noted on the PQR and on the Welding Procedure Specification (WPS).

(d) At least one of the following methods shall be used to compensate for the HAZ toughness decrease due to the welding procedure. More than one compensation method may be used on a part basis.

(1) The low-temperature service limit for all of the material to be welded in a production WPS supported by this PQR 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 WPS provided they exhibit CVN values that are no less than the minimum required lateral expansion value for the material plus the difference in average lateral expansion values between the unaffected base metal and the HAZ.

**3.7.3 Forming and Bending Processes.** Any process may be used to hot form, cold form, or bend material, including weld metal, provided the 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 warmer than 56°C (100°F) below the lower critical temperature of the material.

When required, the hot- or cold-forming process shall be qualified for impact properties as described below.

A procedure qualification test shall be conducted using specimens taken from material of the same specification, grade or class, and heat treatment, and with similar impact properties as required for the material to be used in production. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material to be used in production. Applicable tests shall be conducted to determine that the required impact properties of section 4 are met after straining.

**3.7.3.1 Materials Not Requiring Procedure Qualification Tests.** Procedure qualification tests are not required for the following materials:

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

(b) hot-formed material represented by test coupons that have been subjected to heat treatment representing the hot-forming procedure and the heat treatments to be applied to the parts

(c) material that has a final strain less than 0.5%

(d) material for which the final strain is less than that of a previously qualified procedure for that material

(e) material from which the impact testing in accordance with section 4 is performed on each heat and lot, as applicable, after forming

**3.7.3.2 Performance of 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 straining and after straining and heat treatment to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of section 4 and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following formulas:

For cylinders:

$$\% \text{ strain} = 50t/R_f[1 - (R_f/R_o)]$$

For spherical or dished surfaces:

$$\% \text{ strain} = 75t/R_f[1 - (R_f/R_o)]$$

For pipe:

$$\% \text{ strain} = 100r/R$$

where

$R$  = nominal bending radius to the centerline of the pipe, mm (in.)

$r$  = nominal radius of the pipe, mm (in.)

$R_f$  = final radius to the centerline of the shell, mm (in.)

$R_o$  = original radius (equal to infinity for a flat part), mm (in.)

$t$  = nominal thickness, mm (in.)

(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 CVN test 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 for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both lateral expansion and energy level data.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either of the following:

(1) the maximum change in nil ductility transition (NDT) temperature along with (-a) or (-b)

(-a) the maximum change of lateral expansion and energy at the temperature under consideration

(-b) the maximum change of temperature at the lateral expansion and energy levels under consideration

(2) when lateral expansion is the acceptance criterion, either the maximum change in temperature or the maximum change in lateral expansion

**3.7.3.3 Acceptance Criteria.** To be acceptable, the formed material used in production shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qual-

ified forming processes used. A new procedure qualification test is required when any of the changes in (a), (b), or (c) are made.

(a) The actual postweld heat treatment time at temperature is warmer than previously qualified unless the material is P-No. 1 and the thickness is less than 50 mm (2 in.). If the material is not postweld heat treated, the procedure shall 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 120°C (250°F) is used in the forming or bending operation but is not followed by a subsequent postweld heat treatment.

### 3.7.4 Weld Filler Metal

**3.7.4.1 General.** Weld filler metal for applications in which the design minimum temperature is colder than the temperature listed in column 8 or column 9 of Table 3.1-1, as applicable, shall be impact tested. The impact tests shall be conducted for

(a) each lot of covered, flux cored, metal cored, or fabricated electrodes

(b) each heat of bare electrodes, rod, or wire for use with the oxy fuel welding (OFW), gas metal arc welding (GMAW), GTAW, plasma arc welding (PAW), and electrogas welding (EGW) processes (ASME BPVC, Section IX, QW/QB-492)

(c) each heat of consumable inserts

(d) each combination of heat of bare electrodes and lot of submerged arc flux

(e) each combination of lot of fabricated electrodes and lot of submerged arc flux

(f) 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

(g) each combination of heat of bare electrodes and lot of electrosag flux

Where the specification for welding consumables specifies impact testing at a temperature equal to or colder than the design minimum temperature, testing of each heat/lot combination is not required, provided the filler metal will be used in the same heat treatment condition as is specified in the filler metal specification. Tests performed on the welding material in the qualification of weld procedures may satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used.

**3.7.4.2 Test Coupons.** The welding test coupon shall (21) be made using the welding process, filler metal specification and classification, minimum tensile strength, preheat and interpass temperatures, and postweld heat treatment to be used in the production welding using each process to be used in the production welding. The test coupon shall

be of sufficient size and thickness that the required test specimens can be removed.

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 an applicable WPS for production welding; see ASME BPVC, Section IX, QW-201.1.

The welding of the test coupon shall be performed within the range of preheat and interpass temperatures that 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 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 specimen 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 production welds. 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 the code, standard, or specification referencing this Standard for the material being tested, shall have a thickness within the range of 0.5 times 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 warmer than the holding temperature ranges of the code, standard, or specification referencing this Standard for the material being tested, shall have a thickness within the range of 0.9 times to 1.1 times the thickness of the welds to be made in production.

- (21) **3.7.4.3 Test Specimens.** Regardless of the welding process or welding material being tested, the impact test specimens shall be located and prepared in accordance with the requirements of ASME BPVC, Section II, Part C, SFA-5.1.

**3.7.4.4 Test Requirements.** Impact testing of the weld metal shall meet the requirements applicable to the base metal. Where different requirements exist for the two base metals, the weld metal may conform to either of the two requirements unless the requirement of para. 4.5.3 applies.

## 4 IMPACT TESTING METHODS AND ACCEPTANCE CRITERIA

### 4.1 General

(21)

When impact testing is required by section 3 or the code, standard, or specification referencing this Standard, it shall be done in accordance with this section unless otherwise required by the code, standard, or specification referencing this Standard.

### 4.2 Procedure

(21)

Impact testing of each product form of material for any specification (including welds in the components) shall be done using procedures and apparatus in accordance with ASTM A370, and in conformance with the impact testing requirements of the following specifications:

| Product Form | Specification       |
|--------------|---------------------|
| Pipe         | ASTM A333 or API 5L |
| Tube         | ASTM A334           |
| Fittings     | ASTM A420           |
| Forgings     | ASTM A350           |
| Castings     | ASTM A352           |
| Bolting      | ASTM A320           |
| Plate        | ASTM A20            |

The specific requirements of this section or the code, standard, or specification referencing this Standard shall also be met.

If a conflict exists between the requirements, the order of precedence shall be as follows:

- (a) the code, standard, or specification referencing this Standard
- (b) this Standard
- (c) the product form specification
- (d) ASTM A370

### 4.3 Test Specimens

Each set of impact test specimens shall consist of three specimen bars. All impact tests shall be made using standard 10-mm (0.394-in.) square-cross-section CVN specimen bars, except when the material shape or thickness does not permit. Charpy impact tests may be performed on specimens of full material thickness, which may be machined to remove surface irregularities. Alternatively, such material may be reduced in thickness to produce the largest possible Charpy subsize specimen. If subsize specimens are used, the test temperature shall be adjusted in accordance with para. 4.4.2. Toughness tests are not required when the maximum obtainable Charpy specimen has a width along the notch less than 2.5 mm (0.098 in.).

## 4.4 Test Temperatures

For all Charpy impact tests, the test temperature criteria in para. 4.4.1 or para. 4.4.2 shall be observed. The test specimens, as well as the handling tongs, shall be cooled for a sufficient length of time to reach the test temperature.

**4.4.1 For Materials With Thickness Equal to or Greater Than 10 mm (0.394 in.).** Where the largest attainable CVN specimen has a width along the notch of at least 8 mm (0.315 in.), the Charpy test using such a specimen shall be conducted at a temperature not warmer than the design minimum temperature. Where the largest possible test specimen has a width along the notch less than 8 mm (0.315 in.), the test shall be conducted at a temperature colder than the design minimum temperature in accordance with para. 4.4.2.

**4.4.2 For Materials With Thickness Less Than 10 mm (0.394 in.).** Where the largest attainable CVN specimen has a width along the notch of at least 80% of the material thickness, the Charpy test of such a specimen shall be conducted at a temperature not warmer than the design minimum temperature. Where the largest possible test specimen has a width along the notch of less than 80% of the material thickness, the test shall be conducted at a temperature colder than the design minimum temperature by an amount equal to the difference (referring to Table 4.4.2-1) between the temperature reduction corresponding to the actual material thickness and the temperature reduction corresponding to the Charpy specimen width actually tested. These temperature reduction criteria do not apply when Table 4.5.1-1 specifies lateral expansion for minimum required values.

$$\begin{aligned} \text{Test Temperature} = & (\text{Design Minimum Temperature}) + \\ & (\text{Temperature Reduction Based on} \\ & \text{Actual Material Thickness}) - \\ & (\text{Temperature Reduction Based on} \\ & \text{Charpy Impact Specimen Width}) \end{aligned}$$

For example, if the design minimum temperature is  $-20^{\circ}\text{C}$ , the actual material thickness is 6 mm, and the specimen is 4 mm, the test temperature is  $(-20) + 8.3 - 16.7 = -28.4^{\circ}\text{C}$ .

## 4.5 Acceptance Criteria

**4.5.1 Minimum Energy Requirements.** Except for bolting materials and high-alloy steels (P-Nos. 6, 7, and 8), the applicable minimum energy requirement for carbon and low-alloy steels and other materials with specified minimum tensile strengths less than 656 MPa (95 ksi) shall be those shown in Table 4.5.1-1. If subsized specimens are used, the minimum energy acceptance criteria may be reduced by the ratio of the test specimen width to the standard size width [10 mm (0.394 in.)].

**4.5.2 Lateral Expansion Requirements.** Carbon and low-alloy steels and other materials having specified minimum tensile strengths equal to or greater than 656 MPa (95 ksi), all bolting materials, and all high-alloy steels (P-Nos. 6, 7, and 8) shall have a lateral expansion opposite the notch of not less than 0.38 mm (0.015 in.) for all specimen sizes. The lateral expansion is the increase in width of the broken impact specimen over that of the unbroken specimen measured on the compression side, parallel to the line constituting the bottom of the V-notch (see ASTM A370). For bolting materials with specified minimum tensile strength greater than 656 MPa (95 ksi) and size less than or equal to M50 (2 in.), the impact requirements of ASTM A320 may be applied.

**4.5.3 Weld Impact Test Requirements.** Where two base metals having different impact acceptance criteria are joined by welding, the impact acceptance criteria for the weld metal shall be those of the base material having a specified minimum tensile strength most closely matching the specified minimum tensile strength of the weld metal.

### 4.5.4 Retests

**4.5.4.1 For Absorbed Energy Criteria.** When the average value of the three specimens equals or exceeds the minimum value permitted for a single specimen and the value for more than one specimen is below the required average value, or when the value for one specimen is below the minimum value permitted for a single specimen, a retest of three additional specimens shall be made. The value for each of these retest specimens shall equal or exceed the required average value.

**4.5.4.2 For Lateral Expansion Criterion.** If the value of lateral expansion for one specimen in a group of three is below 0.38 mm (0.015 in.) but not below 0.25 mm (0.010 in.), and if the average value for three specimens equals or exceeds 0.38 mm (0.015 in.), a retest of three additional specimens may be made, each of which shall equal or exceed the specified minimum value of 0.38 mm (0.015 in.). In the case of heat-treated materials, if the required values are not obtained in the retest or if the values in the initial test are below the minimum allowed for retest, the material may be re-heat treated and retested. After re-heat treatment, a set of three specimens shall be made. For acceptance, the lateral expansion of each of the specimens shall equal or exceed the specified minimum value of 0.38 mm (0.015 in.).

**4.5.4.3 For Erratic Test Results.** When an erratic result is caused by a defective specimen or there is uncertainty in the test procedure, a retest will be allowed.

**(21) 5 REFERENCES**

The following is a list of publications referenced in this Standard. Specific edition reference dates are not provided for ASME codes and standards. For ASME codes and standards, the latest published edition in effect at the time this Standard is specified is the specific edition referenced by this Standard, unless otherwise specified in the engineering design. Materials manufactured to other editions of the referenced API or ASTM specifications may be used if the designer verifies the material meets the requirements of the referenced edition of the specification.

API 5L-2018<sup>e1</sup>, Line Pipe

Publisher: American Petroleum Institute (API), 200 Massachusetts Avenue NW, Suite 1100, Washington, DC 20001-5571 ([www.api.org](http://www.api.org))

ASME Boiler and Pressure Vessel Code (BPVC), Section II, Part C: Specification for Welding Rods, Electrodes, and Filler Metals

ASME Boiler and Pressure Vessel Code (BPVC), Section IX: Qualification Standard for Welding, Brazing, and Fusing Procedures; Welders; Brazers; and Welding, Brazing, and Fusing Operators

ASME SFA-5.1/SFA-5.1M, Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding

Publisher: The American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY 10016-5990 ([www.asme.org](http://www.asme.org))

ASTM A20/A20M-2020, Standard Specification for General Requirements for Steel Plates for Pressure Vessels

ASTM A36/A36M-2019, Standard Specification for Carbon Structural Steel

ASTM A47/A47M-1999(R2018)<sup>e1</sup>, Standard Specification for Ferritic Malleable Iron Castings

ASTM A48/A48M-2003(R2016), Standard Specification for Gray Iron Castings

ASTM A53/A53M-2020, Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless

ASTM A105/A105M-2018, Standard Specification for Carbon Steel Forgings for Piping Applications

ASTM A106/A106M-2019a, Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service

ASTM A126-2004(R2019), Standard Specification for Gray Iron Castings for Valves, Flanges, and Pipe Fittings

ASTM A134/A134M-2019, Standard Specification for Pipe, Steel, Electric-Fusion (Arc)-Welded (Sizes NPS 16 and Over)

ASTM A135/A135M-2020, Standard Specification for Electric-Resistance-Welded Steel Pipe

ASTM A139/A139M-2016, Standard Specification for Electric-Fusion (Arc)-Welded Steel Pipe (NPS 4 and Over)

ASTM A178/A178M-2019, Standard Specification for Electric-Resistance-Welded Carbon Steel and Carbon-Manganese Steel Boiler and Superheater Tubes

ASTM A179/A179M-2019, Standard Specification for Seamless Cold-Drawn Low-Carbon Steel Heat-Exchanger and Condenser Tubes

ASTM A181/A181M-2014(R2020), Standard Specification for Carbon Steel Forgings, for General-Purpose Piping

ASTM A182/A182M-2020, Standard Specification for Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service

ASTM A192/A192M-2017, Standard Specification for Seamless Carbon Steel Boiler Tubes for High-Pressure Service

ASTM A193/A193M-2020, Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications

ASTM A194/A194M-2020a, Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both

ASTM A197/A197M-2000(R2019), Standard Specification for Cupola Malleable Iron

ASTM A203/A203M-2017, Standard Specification for Pressure Vessel Plates, Alloy Steel, Nickel

ASTM A204/A204M-2017, Standard Specification for Pressure Vessel Plates, Alloy Steel, Molybdenum

ASTM A210/A210M-2019, Standard Specification for Seamless Medium-Carbon Steel Boiler and Superheater Tubes

ASTM A214/A214M-2019, Standard Specification for Electric-Resistance-Welded Carbon Steel Heat-Exchanger and Condenser Tubes

ASTM A216/A216M-2018, Standard Specification for Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service

ASTM A217/A217M-2020, Standard Specification for Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service

ASTM A234/A234M-2019, Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service

ASTM A240/A240M-2020a, Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

ASTM A268/A268M-2020, Standard Specification for Seamless and Welded Ferritic and Martensitic Stainless Steel Tubing for General Service

- ASTM A269/A269M-2015a(R2019), Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service
- ASTM A278/A278M-2001(R2020), Standard Specification for Gray Iron Castings for Pressure-Containing Parts for Temperatures Up to 650°F (350°C)
- ASTM A283/A283M-2018, Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates
- ASTM A285/A285M-2017, Standard Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength
- ASTM A299/A299M-2017, Standard Specification for Pressure Vessel Plates, Carbon Steel, Manganese-Silicon
- ASTM A302/A302M-2017, Standard Specification for Pressure Vessel Plates, Alloy Steel, Manganese-Molybdenum and Manganese-Molybdenum-Nickel
- ASTM A307-2014<sup>e1</sup>, Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60 000 psi Tensile Strength
- ASTM A312/A312M-2019, Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes
- ASTM A320/A320M-2018, Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service
- ASTM A333/A333M-2018, Standard Specification for Seamless and Welded Steel Pipe for Low-Temperature Service and Other Applications With Required Notch Toughness
- ASTM A334/A334M-2004a(R2016), Standard Specification for Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service
- ASTM A335/A335M-2019a, Standard Specification for Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service
- ASTM A350/A350M-2018, Standard Specification for Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components
- ASTM A351/A351M-2018<sup>e1</sup>, Standard Specification for Castings, Austenitic, for Pressure-Containing Parts
- ASTM A352/A352M-2018a, Standard Specification for Steel Castings, Ferritic and Martensitic, for Pressure-Containing Parts, Suitable for Low-Temperature Service
- ASTM A353/A353M-2017, Standard Specification for Pressure Vessel Plates, Alloy Steel, Double-Normalized and Tempered 9% Nickel
- ASTM A354-2017<sup>e2</sup>, Standard Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners
- ASTM A358/A358M-2019, Standard Specification for Electric-Fusion-Welded Austenitic Chromium-Nickel Stainless Steel Pipe for High-Temperature Service and General Applications
- ASTM A369/A369M-2018a, Standard Specification for Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service
- ASTM A370-2020, Standard Test Methods and Definitions for Mechanical Testing of Steel Products
- ASTM A376/A376M-2019, Standard Specification for Seamless Austenitic Steel Pipe for High-Temperature Service
- ASTM A381/A381M-2018, Standard Specification for Metal-Arc-Welded Carbon or High-Strength Low-Alloy Steel Pipe for Use With High-Pressure Transmission Systems
- ASTM A387/A387M-2017a, Standard Specification for Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum
- ASTM A395/A395M-1999(R2018), Standard Specification for Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures
- ASTM A403/A403M-2020, Standard Specification for Wrought Austenitic Stainless Steel Piping Fittings
- ASTM A409/A409M-2019, Standard Specification for Welded Large Diameter Austenitic Steel Pipe for Corrosive or High-Temperature Service
- ASTM A414/A414M-2014(R2019), Standard Specification for Steel, Sheet, Carbon, and High-Strength, Low-Alloy for Pressure Vessels
- ASTM A420/A420M-2020, Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service
- ASTM A426/A426M-2018, Standard Specification for Centrifugally Cast Ferritic Alloy Steel Pipe for High-Temperature Service
- ASTM A437/A437M-2015, Standard Specification for Stainless and Alloy-Steel Turbine-Type Bolting Specially Heat Treated for High-Temperature Service
- ASTM A451/A451M-2020, Standard Specification for Centrifugally Cast Austenitic Steel Pipe for High-Temperature Service
- ASTM A453/A453M-2017, Standard Specification for High-Temperature Bolting, With Expansion Coefficients Comparable to Austenitic Stainless Steels
- ASTM A479/A479M-2020, Standard Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels
- ASTM A487/A487M-2020, Standard Specification for Steel Castings Suitable for Pressure Service
- ASTM A515/A515M-2017, Standard Specification for Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service
- ASTM A516/A516M-2017, Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate and Lower-Temperature Service
- ASTM A524-2017, Standard Specification for Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures
- ASTM A536-1984(R2019<sup>e1</sup>), Standard Specification for Ductile Iron Castings

- ASTM A537/A537M-2020, Standard Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel
- ASTM A553/A553M-2017<sup>e1</sup>, Standard Specification for Pressure Vessel Plates, Alloy Steel, Quenched and Tempered 7, 8, and 9% Nickel
- ASTM A563-2015, Standard Specification for Carbon and Alloy Steel Nuts
- ASTM A571/A571M-2001(R2019), Standard Specification for Austenitic Ductile Iron Castings for Pressure-Containing Parts Suitable for Low-Temperature Service
- ASTM A587-1996(R2019), Standard Specification for Electric-Resistance-Welded Low-Carbon Steel Pipe for the Chemical Industry
- ASTM A645/A645M-2010(R2016), Standard Specification for Pressure Vessel Plates, 5% and 5<sup>1</sup>/<sub>2</sub>% Nickel Alloy Steels, Specially Heat Treated
- ASTM A671/A671M-2020, Standard Specification for Electric-Fusion-Welded Steel Pipe for Atmospheric and Lower Temperatures
- ASTM A672/A672M-2019, Standard Specification for Electric-Fusion-Welded Steel Pipe for High-Pressure Service at Moderate Temperatures
- ASTM A675/A675M-2014(R2019), Standard Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties
- ASTM A691/A691M-2019, Standard Specification for Carbon and Alloy Steel Pipe, Electric-Fusion-Welded for High-Pressure Service at High Temperatures
- ASTM A789/A789M-2020, Standard Specification for Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service
- ASTM A790/A790M-2020, Standard Specification for Seamless and Welded Ferritic/Austenitic Stainless Steel Pipe
- ASTM A815/A815M-2020, Standard Specification for Wrought Ferritic, Ferritic/Austenitic, and Martensitic Stainless Steel Piping Fittings
- ASTM A995/A995M-2020, Standard Specification for Castings, Austenitic-Ferritic (Duplex) Stainless Steel, for Pressure-Containing Parts
- ASTM A1011/A1011M-2018a, Standard Specification for Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy With Improved Formability, and Ultra-High Strength
- ASTM B21/B21M-2020, Standard Specification for Naval Brass Rod, Bar, and Shapes
- ASTM B42-2020, Standard Specification for Seamless Copper Pipe, Standard Sizes
- ASTM B43-2020, Standard Specification for Seamless Red Brass Pipe, Standard Sizes
- ASTM B61-2015, Standard Specification for Steam or Valve Bronze Castings
- ASTM B62-2017, Standard Specification for Composition Bronze or Ounce Metal Castings
- ASTM B68/B68M-2019, Standard Specification for Copper Tube, Bright Annealed
- ASTM B75/B75M-2020, Standard Specification for Seamless Copper Tube
- ASTM B88-2020, Standard Specification for Seamless Copper Water Tube
- ASTM B96-2020, Standard Specification for Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes and Pressure Vessels
- ASTM B98/B98M-2013(R2019), Standard Specification for Copper-Silicon Alloy Rod, Bar, and Shapes
- ASTM B148-2018, Standard Specification for Aluminum-Bronze Sand Castings
- ASTM B150/B150M-2019, Standard Specification for Aluminum Bronze Rod, Bar, and Shapes
- ASTM B152/B152M-2019, Standard Specification for Copper Sheet, Strip, Plate, and Rolled Bar
- ASTM B169/B169M-2020, Standard Specification for Aluminum Bronze Sheet, Strip, and Rolled Bar
- ASTM B171/B171M-2018, Standard Specification for Copper-Alloy Plate and Sheet for Pressure Vessels, Condensers, and Heat Exchangers
- ASTM B187/B187M-2020, Standard Specification for Copper, Bus Bar, Rod, and Shapes and General Purpose Rod, Bar, and Shapes
- ASTM B280-2020, Standard Specification for Seamless Copper Tube for Air Conditioning and Refrigeration Field Service
- ASTM B283/B283M-2020, Standard Specification for Copper and Copper-Alloy Die Forgings (Hot-Pressed)
- ASTM B466/B466M-2018, Standard Specification for Seamless Copper-Nickel Pipe and Tube
- ASTM B467-2014, Standard Specification for Welded Copper-Nickel Pipe
- ASTM B493/B493M-2014(R2019), Standard Specification for Zirconium and Zirconium Alloy Forgings
- ASTM B523/B523M-2018, Standard Specification for Seamless and Welded Zirconium and Zirconium Alloy Tubes
- ASTM B550/B550M-2007(R2019), Standard Specification for Zirconium and Zirconium Alloy Bar and Wire
- ASTM B551/B551M-2012(R2017), Standard Specification for Zirconium and Zirconium Alloy Strip, Sheet, and Plate
- ASTM B584-2014, Standard Specification for Copper Alloy Sand Castings for General Applications
- ASTM B658/B658M-2011(R2020), Standard Specification for Seamless and Welded Zirconium and Zirconium Alloy Pipe
- ASTM F3125/F3125M-2019<sup>e2</sup>, Standard Specification for High Strength Structural Bolts and Assemblies, Steel and Alloy Steel, Heat Treated, Inch Dimensions 120 ksi and 150 ksi Minimum Tensile Strength, and Metric Dimensions 830 MPa and 1040 MPa Minimum Tensile Strength

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Table 3.1-1 Low-Temperature Service Requirements by Material Group

| SI Units [Note (1)] |       |                                                       |     |                       |                               |       |                                        |                                               |                                                                     |                              |                                              |                                              |     |     |     |     |     |     |      |     |     |      |                              |
|---------------------|-------|-------------------------------------------------------|-----|-----------------------|-------------------------------|-------|----------------------------------------|-----------------------------------------------|---------------------------------------------------------------------|------------------------------|----------------------------------------------|----------------------------------------------|-----|-----|-----|-----|-----|-----|------|-----|-----|------|------------------------------|
| 1                   | 2     | 3                                                     | 4   | Material              |                               |       | Weld                                   |                                               | Minimum Material Temperature, °C, Without Impacts for Stress Ratios |                              |                                              |                                              |     |     |     |     | 17  | 18  |      |     |     |      |                              |
|                     |       |                                                       |     | T-<br>Number<br>Group | Governing<br>Thickness,<br>mm | Notes | Low-<br>Temp., °C,<br>Service<br>Limit | Minimum<br>Material<br>Permitted<br>Temp., °C | Minimum<br>Temp., °C,<br>Without<br>Impacts                         | Minimum<br>Weld<br>Temp., °C | Temp., °C,<br>Without<br>Impacts<br>SR > 0.3 | Temp., °C,<br>Without<br>Impacts<br>SR ≤ 0.3 | 1   | 0.9 | 0.8 | 0.7 |     |     | 0.6  | 0.5 | 0.4 | >0.3 | Service<br>Limit<br>SR ≤ 0.3 |
|                     |       |                                                       |     |                       |                               |       |                                        |                                               |                                                                     |                              |                                              |                                              |     |     |     |     |     |     |      |     |     |      |                              |
| Carbon Steels       |       |                                                       |     |                       |                               |       |                                        |                                               |                                                                     |                              |                                              |                                              |     |     |     |     |     |     |      |     |     |      |                              |
| CS -55              | ...   | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -29 | -48                   | -48                           | ...   | -29                                    | -104                                          | -48                                                                 | -48                          | -48                                          | -48                                          | -48 | -48 | -48 | -48 | -48 | -48 | -104 |     |     |      |                              |
| CS -55              | ...   | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -29 | ...                   | -48                           | ...   | -29                                    | -104                                          | -48                                                                 | -48                          | -48                                          | -48                                          | -48 | -48 | -48 | -48 | -48 | -48 | -104 |     |     |      |                              |
| CS -50              | ...   | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -29 | -48                   | -48                           | ...   | -29                                    | -104                                          | -48                                                                 | -48                          | -48                                          | -48                                          | -48 | -48 | -48 | -48 | -48 | -48 | -104 |     |     |      |                              |
| CS -50              | ...   | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -29 | ...                   | -46                           | ...   | -29                                    | -104                                          | -46                                                                 | -48                          | -48                                          | -48                                          | -48 | -48 | -48 | -48 | -48 | -48 | -104 |     |     |      |                              |
| CS -20              | ...   | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -29 | -48                   | -48                           | ...   | -29                                    | -104                                          | -48                                                                 | -48                          | -48                                          | -48                                          | -48 | -48 | -48 | -48 | -48 | -48 | -104 |     |     |      |                              |
| CS -20              | ...   | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -29 | ...                   | -29                           | ...   | -29                                    | -104                                          | -29                                                                 | -34                          | -40                                          | -46                                          | -48 | -48 | -48 | -48 | -48 | -48 | -104 |     |     |      |                              |
| CS -20 (A)          | ...   | ...                                                   | -29 | -29                   | -29                           | ...   | -29                                    | -29                                           | N/A                                                                 | ...                          | ...                                          | ...                                          | ... | ... | ... | ... | ... | ... | ...  |     |     |      |                              |
| CS 0                | ...   | ...                                                   | -18 | -18                   | -18                           | ...   | -29                                    | -29                                           | -18                                                                 | -23                          | -29                                          | -34                                          | -40 | -48 | -48 | -48 | -48 | -48 | -104 |     |     |      |                              |
| CS +20 (A)          | ...   | ...                                                   | -7  | -7                    | -7                            | ...   | -7                                     | -7                                            | N/A                                                                 | ...                          | ...                                          | ...                                          | ... | ... | ... | ... | ... | ... | ...  |     |     |      |                              |
| CS A                | ≤10.0 | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -7  | -48                   | -48                           | ...   | -7                                     | -104                                          | -48                                                                 | -48                          | -48                                          | -48                                          | -48 | -48 | -48 | -48 | -48 | -48 | -104 |     |     |      |                              |

(21)

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| SI Units [Note (1)]    |                               |                                                          |                                       |                      |                                  |                                             |                                           |                                  |          |                                                       |               |     |     |     |     |     |     |      |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
|------------------------|-------------------------------|----------------------------------------------------------|---------------------------------------|----------------------|----------------------------------|---------------------------------------------|-------------------------------------------|----------------------------------|----------|-------------------------------------------------------|---------------|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|---|-----|----------|------------------------------|-----|---|--|--|--|
| 1                      | 2                             | 3                                                        | 4                                     | 5                    | 6                                |                                             | 7                                         | 8                                | 9        | Minimum Material Temperature, °C, Without Impacts for |               |     |     |     |     |     | 16  | 17   | 18  |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| T-<br>Number<br>Group  | Governing<br>Thickness,<br>mm | Notes                                                    | Low<br>Temp., °C,<br>Service<br>Limit | Material             |                                  | Minimum<br>Temp., °C,<br>Without<br>Impacts | Minimum<br>Weld<br>Permitted<br>Temp., °C | Weld                             |          | Temp., °C,<br>Without<br>Impacts                      | Stress Ratios |     |     |     |     |     |     | 0.4  | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1 | 0.3 | SR ≤ 0.3 | Service<br>Limit<br>SR ≤ 0.3 |     |   |  |  |  |
|                        |                               |                                                          |                                       | Minimum<br>Temp., °C | Temp., °C,<br>Without<br>Impacts |                                             |                                           | Temp., °C,<br>Without<br>Impacts | SR > 0.3 |                                                       | SR ≤ 0.3      | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |      |     |     |     |     |     |   |     |          |                              | 0.9 | 1 |  |  |  |
| Carbon Steels (Cont'd) |                               |                                                          |                                       |                      |                                  |                                             |                                           |                                  |          |                                                       |               |     |     |     |     |     |     |      |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | ≤10.0                         | Max. possible<br>Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -7                                    | ...                  | -7                               | ...                                         | ...                                       | -7                               | -104     | -7                                                    | -12           | -18 | -23 | -29 | -40 | -48 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | ≤11.1                         | ...                                                      | -4                                    | ...                  | -4                               | ...                                         | ...                                       | -4                               | -104     | -4                                                    | -9            | -15 | -21 | -26 | -37 | -48 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | ≤12.7                         | ...                                                      | -1                                    | ...                  | -1                               | ...                                         | ...                                       | -1                               | -104     | -1                                                    | -7            | -12 | -18 | -23 | -34 | -48 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | ≤15.2                         | ...                                                      | 4                                     | ...                  | 4                                | ...                                         | ...                                       | 4                                | -104     | 4                                                     | -1            | -7  | -12 | -18 | -29 | -48 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | ≤17.7                         | ...                                                      | 10                                    | ...                  | 10                               | ...                                         | ...                                       | 10                               | -104     | 10                                                    | 4             | -1  | -7  | -12 | -23 | -43 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | ≤21.6                         | ...                                                      | 16                                    | ...                  | 16                               | ...                                         | ...                                       | 16                               | -104     | 16                                                    | 10            | 4   | -1  | -7  | -18 | -37 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | ≤26.2                         | ...                                                      | 21                                    | ...                  | 21                               | ...                                         | ...                                       | 21                               | -104     | 21                                                    | 16            | 10  | 4   | -1  | -12 | -32 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | ≤31.1                         | ...                                                      | 27                                    | ...                  | 27                               | ...                                         | ...                                       | 27                               | -104     | 27                                                    | 21            | 16  | 10  | 4   | -7  | -26 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | ≤39.7                         | ...                                                      | 32                                    | ...                  | 32                               | ...                                         | ...                                       | 32                               | -104     | 32                                                    | 27            | 21  | 16  | 10  | -1  | -21 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | ≤51.6                         | ...                                                      | 38                                    | ...                  | 38                               | ...                                         | ...                                       | 38                               | -104     | 38                                                    | 32            | 27  | 21  | 16  | 4   | -15 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | ≤76.2                         | ...                                                      | 43                                    | ...                  | 43                               | ...                                         | ...                                       | 43                               | -104     | 43                                                    | 38            | 32  | 27  | 21  | 10  | -9  | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | ≤93.7                         | ...                                                      | 46                                    | ...                  | 46                               | ...                                         | ...                                       | 46                               | -104     | 46                                                    | 41            | 35  | 29  | 24  | 13  | -7  | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS A                   | >93.7                         | ...                                                      | 49                                    | ...                  | 49                               | ...                                         | ...                                       | 49                               | -104     | 49                                                    | 43            | 38  | 32  | 27  | 16  | -4  | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS B                   | ≤10.0                         | Max. possible<br>Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -29                                   | -48                  | -48                              | ...                                         | ...                                       | -29                              | -104     | -48                                                   | -48           | -48 | -48 | -48 | -48 | -48 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS B                   | ≤10.0                         | Max. possible<br>Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -29                                   | ...                  | -29                              | ...                                         | ...                                       | -29                              | -104     | -29                                                   | -34           | -40 | -46 | -48 | -48 | -48 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS B                   | ≤11.9                         | ...                                                      | -29                                   | ...                  | -29                              | ...                                         | ...                                       | -29                              | -104     | -29                                                   | -35           | -40 | -46 | -48 | -48 | -48 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS B                   | ≤14.5                         | ...                                                      | -22                                   | ...                  | -22                              | ...                                         | ...                                       | -22                              | -104     | -22                                                   | -27           | -33 | -38 | -44 | -48 | -48 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS B                   | ≤17.3                         | ...                                                      | -13                                   | ...                  | -13                              | ...                                         | ...                                       | -13                              | -104     | -13                                                   | -19           | -24 | -30 | -35 | -47 | -48 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS B                   | ≤21.1                         | ...                                                      | -7                                    | ...                  | -7                               | ...                                         | ...                                       | -7                               | -104     | -7                                                    | -12           | -18 | -23 | -29 | -40 | -48 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS B                   | ≤24.9                         | ...                                                      | -1                                    | ...                  | -1                               | ...                                         | ...                                       | -1                               | -104     | -1                                                    | -7            | -12 | -18 | -23 | -34 | -48 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |
| CS B                   | ≤30.2                         | ...                                                      | 4                                     | ...                  | 4                                | ...                                         | ...                                       | 4                                | -104     | 4                                                     | -1            | -7  | -12 | -18 | -29 | -48 | -48 | -104 |     |     |     |     |     |   |     |          |                              |     |   |  |  |  |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| SI Units [Note (1)]    |                               |                                                            |                                        |                                               |                                             |                                             |                                           |      |     |                                              |                                                                     |               |     |     |     |     |      |     |                                            |                                            |                                            |
|------------------------|-------------------------------|------------------------------------------------------------|----------------------------------------|-----------------------------------------------|---------------------------------------------|---------------------------------------------|-------------------------------------------|------|-----|----------------------------------------------|---------------------------------------------------------------------|---------------|-----|-----|-----|-----|------|-----|--------------------------------------------|--------------------------------------------|--------------------------------------------|
| 1                      | 2                             | 3                                                          | 4                                      | 5                                             | 6                                           |                                             | 7                                         | 8    |     | 9                                            | Minimum Material Temperature, °C, Without Impacts for Stress Ratios |               |     |     |     |     |      | 16  | 17                                         | 18                                         |                                            |
| T-<br>Number<br>Group  | Governing<br>Thickness,<br>mm | Notes                                                      | Low-<br>Temp., °C,<br>Service<br>Limit | Minimum<br>Material<br>Permitted<br>Temp., °C | Material                                    |                                             | Minimum<br>Weld<br>Permitted<br>Temp., °C | Weld |     | Temp., °C,<br>Without<br>Impacts<br>SR ≤ 0.3 | Temp., °C,<br>Without<br>Impacts<br>SR > 0.3                        | Stress Ratios |     |     |     |     |      |     | Temp., °C,<br>Service<br>Limit<br>SR ≤ 0.3 | Temp., °C,<br>Service<br>Limit<br>SR ≤ 0.3 | Temp., °C,<br>Service<br>Limit<br>SR ≤ 0.3 |
|                        |                               |                                                            |                                        |                                               | Minimum<br>Temp., °C,<br>Without<br>Impacts | Minimum<br>Temp., °C,<br>Without<br>Impacts |                                           | 1    | 0.9 |                                              |                                                                     | 0.8           | 0.7 | 0.6 | 0.5 | 0.4 | >0.3 |     |                                            |                                            |                                            |
| Carbon Steels (Cont'd) |                               |                                                            |                                        |                                               |                                             |                                             |                                           |      |     |                                              |                                                                     |               |     |     |     |     |      |     |                                            |                                            |                                            |
| CS B                   | ≤37.3                         | ...                                                        | 10                                     | ...                                           | 10                                          | ...                                         | ...                                       | 10   | ... | -104                                         | 10                                                                  | 4             | -1  | -7  | -12 | -23 | -43  | -48 | -104                                       |                                            |                                            |
| CS B                   | ≤47.0                         | ...                                                        | 16                                     | ...                                           | 16                                          | ...                                         | ...                                       | 16   | ... | -104                                         | 16                                                                  | 10            | 4   | -1  | -7  | -18 | -37  | -48 | -104                                       |                                            |                                            |
| CS B                   | ≤61.9                         | ...                                                        | 21                                     | ...                                           | 21                                          | ...                                         | ...                                       | 21   | ... | -104                                         | 21                                                                  | 16            | 10  | 4   | -1  | -12 | -32  | -48 | -104                                       |                                            |                                            |
| CS B                   | ≤82.6                         | ...                                                        | 27                                     | ...                                           | 27                                          | ...                                         | ...                                       | 27   | ... | -104                                         | 27                                                                  | 21            | 16  | 10  | 4   | -7  | -26  | -48 | -104                                       |                                            |                                            |
| CS B                   | ≤101.6                        | ...                                                        | 32                                     | ...                                           | 32                                          | ...                                         | ...                                       | 32   | ... | -104                                         | 32                                                                  | 27            | 21  | 16  | 10  | -1  | -21  | -48 | -104                                       |                                            |                                            |
| CS B                   | >101.6                        | ...                                                        | 49                                     | ...                                           | 49                                          | ...                                         | ...                                       | 49   | ... | -104                                         | 49                                                                  | 43            | 38  | 32  | 27  | 16  | -4   | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤10.0                         | Max. possible<br>Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -48                                    | -48                                           | -48                                         | ...                                         | ...                                       | -48  | ... | -104                                         | -48                                                                 | -48           | -48 | -48 | -48 | -48 | -48  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤10.0                         | Max. possible<br>Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | -29                                    | ...                                           | -48                                         | ...                                         | ...                                       | -29  | ... | -104                                         | -48                                                                 | -48           | -48 | -48 | -48 | -48 | -48  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤10.4                         | ...                                                        | -29                                    | ...                                           | -46                                         | ...                                         | ...                                       | -29  | ... | -104                                         | -46                                                                 | -48           | -48 | -48 | -48 | -48 | -48  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤11.2                         | ...                                                        | -29                                    | ...                                           | -40                                         | ...                                         | ...                                       | -29  | ... | -104                                         | -40                                                                 | -46           | -48 | -48 | -48 | -48 | -48  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤13.5                         | ...                                                        | -29                                    | ...                                           | -34                                         | ...                                         | ...                                       | -29  | ... | -104                                         | -34                                                                 | -40           | -46 | -48 | -48 | -48 | -48  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤16.5                         | ...                                                        | -29                                    | ...                                           | -29                                         | ...                                         | ...                                       | -29  | ... | -104                                         | -29                                                                 | -34           | -40 | -46 | -48 | -48 | -48  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤21.6                         | ...                                                        | -23                                    | ...                                           | -23                                         | ...                                         | ...                                       | -23  | ... | -104                                         | -23                                                                 | -29           | -34 | -40 | -46 | -48 | -48  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤27.4                         | ...                                                        | -18                                    | ...                                           | -18                                         | ...                                         | ...                                       | -18  | ... | -104                                         | -18                                                                 | -23           | -29 | -34 | -40 | -48 | -48  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤35.1                         | ...                                                        | -12                                    | ...                                           | -12                                         | ...                                         | ...                                       | -12  | ... | -104                                         | -12                                                                 | -18           | -23 | -29 | -34 | -46 | -48  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤44.5                         | ...                                                        | -7                                     | ...                                           | -7                                          | ...                                         | ...                                       | -7   | ... | -104                                         | -7                                                                  | -12           | -18 | -23 | -29 | -40 | -48  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤57.2                         | ...                                                        | -1                                     | ...                                           | -1                                          | ...                                         | ...                                       | -1   | ... | -104                                         | -1                                                                  | -7            | -12 | -18 | -23 | -34 | -48  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤74.7                         | ...                                                        | 4                                      | ...                                           | 4                                           | ...                                         | ...                                       | 4    | ... | -104                                         | 4                                                                   | -1            | -7  | -12 | -18 | -29 | -48  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤95.3                         | ...                                                        | 10                                     | ...                                           | 10                                          | ...                                         | ...                                       | 10   | ... | -104                                         | 10                                                                  | 4             | -1  | -7  | -12 | -23 | -43  | -48 | -104                                       |                                            |                                            |
| CS C                   | ≤101.6                        | ...                                                        | 11                                     | ...                                           | 11                                          | ...                                         | ...                                       | 11   | ... | -104                                         | 11                                                                  | 6             | 0   | -6  | -11 | -22 | -42  | -48 | -104                                       |                                            |                                            |
| CS C                   | >101.6                        | ...                                                        | 49                                     | ...                                           | 49                                          | ...                                         | ...                                       | 49   | ... | -104                                         | 49                                                                  | 43            | 38  | 32  | 27  | 16  | -4   | -48 | -104                                       |                                            |                                            |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| SI Units [Note (1)]    |                               |                                                       |                                 |                                   |                                             |                                           |                                                      |                                              |                                                                        |     |     |     |     |     |     |      |      |                                    |
|------------------------|-------------------------------|-------------------------------------------------------|---------------------------------|-----------------------------------|---------------------------------------------|-------------------------------------------|------------------------------------------------------|----------------------------------------------|------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|------|------|------------------------------------|
| 1                      | 2                             | 3                                                     | 4                               | 5                                 | 6                                           | 7                                         | 8                                                    | 9                                            | 10                                                                     | 11  | 12  | 13  | 14  | 15  | 16  | 17   | 18   |                                    |
| T-<br>Number<br>Group  | Governing<br>Thickness,<br>mm | Notes                                                 | Low-Temp., °C,<br>Service Limit | Material                          |                                             | Minimum<br>Weld<br>Temp., °C<br>Permitted | Weld<br>Temp., °C,<br>Without<br>Impacts<br>SR > 0.3 | Temp., °C,<br>Without<br>Impacts<br>SR ≤ 0.3 | Minimum Material Temperature, °C, Without Impacts for<br>Stress Ratios |     |     |     |     |     |     |      |      | Low-Temp.,<br>°C,<br>Service Limit |
|                        |                               |                                                       |                                 | Minimum<br>Temp., °C<br>Permitted | Minimum<br>Temp., °C,<br>Without<br>Impacts |                                           |                                                      |                                              | 1                                                                      | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | >0.3 |      |                                    |
| Carbon Steels (Cont'd) |                               |                                                       |                                 |                                   |                                             |                                           |                                                      |                                              |                                                                        |     |     |     |     |     |     |      |      |                                    |
| CS D                   | ≤12.7                         | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -48                             | -48                               | -48                                         | ...                                       | -48                                                  | -104                                         | -48                                                                    | -48 | -48 | -48 | -48 | -48 | -48 | -48  | -104 |                                    |
| CS D                   | ≤12.7                         | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -29                             | ...                               | -48                                         | ...                                       | -29                                                  | -104                                         | -48                                                                    | -48 | -48 | -48 | -48 | -48 | -48 | -48  | -104 |                                    |
| CS D                   | ≤14.7                         | ...                                                   | -29                             | ...                               | -46                                         | ...                                       | -29                                                  | -104                                         | -46                                                                    | -48 | -48 | -48 | -48 | -48 | -48 | -48  | -104 |                                    |
| CS D                   | ≤19.8                         | ...                                                   | -29                             | ...                               | -40                                         | ...                                       | -29                                                  | -104                                         | -40                                                                    | -46 | -48 | -48 | -48 | -48 | -48 | -48  | -104 |                                    |
| CS D                   | ≤25.4                         | ...                                                   | -29                             | ...                               | -34                                         | ...                                       | -29                                                  | -104                                         | -34                                                                    | -40 | -46 | -48 | -48 | -48 | -48 | -48  | -104 |                                    |
| CS D                   | ≤33.0                         | ...                                                   | -29                             | ...                               | -29                                         | ...                                       | -29                                                  | -104                                         | -29                                                                    | -34 | -40 | -46 | -48 | -48 | -48 | -48  | -104 |                                    |
| CS D                   | ≤42.9                         | ...                                                   | -23                             | ...                               | -23                                         | ...                                       | -23                                                  | -104                                         | -23                                                                    | -29 | -34 | -40 | -46 | -48 | -48 | -48  | -104 |                                    |
| CS D                   | ≤57.2                         | ...                                                   | -18                             | ...                               | -18                                         | ...                                       | -18                                                  | -104                                         | -18                                                                    | -23 | -29 | -34 | -40 | -48 | -48 | -48  | -104 |                                    |
| CS D                   | ≤74.6                         | ...                                                   | -12                             | ...                               | -12                                         | ...                                       | -12                                                  | -104                                         | -12                                                                    | -18 | -23 | -29 | -34 | -46 | -48 | -48  | -104 |                                    |
| CS D                   | ≤95.3                         | ...                                                   | -7                              | ...                               | -7                                          | ...                                       | -7                                                   | -104                                         | -7                                                                     | -12 | -18 | -23 | -29 | -40 | -48 | -48  | -104 |                                    |
| CS D                   | ≤101.6                        | ...                                                   | -5                              | ...                               | -5                                          | ...                                       | -5                                                   | -104                                         | -5                                                                     | -11 | -16 | -22 | -27 | -38 | -48 | -48  | -104 |                                    |
| CS D                   | >101.6                        | ...                                                   | 49                              | ...                               | 49                                          | ...                                       | 49                                                   | -104                                         | 49                                                                     | 43  | 38  | 32  | 27  | 16  | -4  | -48  | -104 |                                    |
| Low-Alloy Steels       |                               |                                                       |                                 |                                   |                                             |                                           |                                                      |                                              |                                                                        |     |     |     |     |     |     |      |      |                                    |
| LA -320                | ...                           | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -48                             | -196                              | -196                                        | -48                                       | -48                                                  | -104                                         | N/A                                                                    | ... | ... | ... | ... | ... | ... | ...  | N/A  |                                    |
| LA -320                | ...                           | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -29                             | ...                               | -196                                        | ...                                       | -29                                                  | -104                                         | N/A                                                                    | ... | ... | ... | ... | ... | ... | ...  | N/A  |                                    |
| LA -275                | ...                           | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -48                             | -171                              | -171                                        | -48                                       | -48                                                  | -104                                         | N/A                                                                    | ... | ... | ... | ... | ... | ... | ...  | N/A  |                                    |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| SI Units [Note (1)]       |                                             |                                           |                                                      |                                                       |                               |       |                                              |     |      |                                        |          |     |                                                                        |     |     |      |                                                       |      |    |
|---------------------------|---------------------------------------------|-------------------------------------------|------------------------------------------------------|-------------------------------------------------------|-------------------------------|-------|----------------------------------------------|-----|------|----------------------------------------|----------|-----|------------------------------------------------------------------------|-----|-----|------|-------------------------------------------------------|------|----|
| 1                         | 2                                           | 3                                         | 4                                                    | 5                                                     |                               |       | 7                                            | 8   | 9    | 10                                     |          |     |                                                                        |     |     |      |                                                       | 17   | 18 |
|                           |                                             |                                           |                                                      | T-<br>Number<br>Group                                 | Governing<br>Thickness,<br>mm | Notes |                                              |     |      | Low-<br>Temp., °C,<br>Service<br>Limit | Material |     | Minimum Material Temperature, °C, Without Impacts for<br>Stress Ratios |     |     |      |                                                       |      |    |
| 6                         | Minimum<br>Temp., °C,<br>Without<br>Impacts | Minimum<br>Weld<br>Permitted<br>Temp., °C | Weld<br>Temp., °C,<br>Without<br>Impacts<br>SR > 0.3 |                                                       |                               |       | Temp., °C,<br>Without<br>Impacts<br>SR ≤ 0.3 | 1   | 0.9  |                                        | 0.8      | 0.7 | 0.6                                                                    | 0.5 | 0.4 | >0.3 | Low-<br>Temp.,<br>°C,<br>Service<br>Limit<br>SR ≤ 0.3 |      |    |
| Low-Alloy Steels (Cont'd) |                                             |                                           |                                                      |                                                       |                               |       |                                              |     |      |                                        |          |     |                                                                        |     |     |      |                                                       |      |    |
| LA -275                   | ...                                         | ...                                       | -29                                                  | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | ...                           | -171  | ...                                          | -29 | -104 | N/A                                    | ...      | ... | ...                                                                    | ... | ... | ...  | ...                                                   | N/A  |    |
| LA -150                   | ...                                         | ...                                       | -48                                                  | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -101                          | -101  | -48                                          | -48 | -104 | N/A                                    | ...      | ... | ...                                                                    | ... | ... | ...  | ...                                                   | -104 |    |
| LA -150                   | ...                                         | ...                                       | -29                                                  | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | ...                           | -101  | ...                                          | -29 | -104 | N/A                                    | ...      | ... | ...                                                                    | ... | ... | ...  | ...                                                   | -104 |    |
| LA -100                   | ...                                         | ...                                       | -48                                                  | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -73                           | -73   | -48                                          | -48 | -104 | N/A                                    | ...      | ... | ...                                                                    | ... | ... | ...  | ...                                                   | -104 |    |
| LA -100                   | ...                                         | ...                                       | -29                                                  | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | ...                           | -73   | ...                                          | -29 | -104 | N/A                                    | ...      | ... | ...                                                                    | ... | ... | ...  | ...                                                   | -104 |    |
| LA -75                    | ...                                         | ...                                       | -48                                                  | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -59                           | -59   | ...                                          | -48 | -104 | N/A                                    | ...      | ... | ...                                                                    | ... | ... | ...  | ...                                                   | -104 |    |
| LA -75                    | ...                                         | ...                                       | -29                                                  | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | ...                           | -59   | ...                                          | -29 | -104 | N/A                                    | ...      | ... | ...                                                                    | ... | ... | ...  | ...                                                   | -104 |    |
| LA -55                    | ...                                         | ...                                       | -48                                                  | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -48                           | -48   | ...                                          | -48 | -104 | N/A                                    | ...      | ... | ...                                                                    | ... | ... | ...  | ...                                                   | -104 |    |
| LA -55                    | ...                                         | ...                                       | -29                                                  | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | ...                           | -48   | ...                                          | -29 | -104 | N/A                                    | ...      | ... | ...                                                                    | ... | ... | ...  | ...                                                   | -104 |    |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| SI Units [Note (1)]       |     |                                                         |      |                |                         |     |       |                              |     |     |                                    |                                    |                                  |                                          |                                     |                                                                     |     |     |      |    |     |     |     |     |     |
|---------------------------|-----|---------------------------------------------------------|------|----------------|-------------------------|-----|-------|------------------------------|-----|-----|------------------------------------|------------------------------------|----------------------------------|------------------------------------------|-------------------------------------|---------------------------------------------------------------------|-----|-----|------|----|-----|-----|-----|-----|-----|
| 1                         | 2   | 3                                                       | 4    | 5              |                         | 6   | 7     |                              | 8   | 9   | 10                                 |                                    |                                  |                                          |                                     |                                                                     |     |     | 17   | 18 |     |     |     |     |     |
|                           |     |                                                         |      | T-Number Group | Governing Thickness, mm |     | Notes | Low-Temp., °C, Service Limit |     |     | Material                           |                                    | Minimum Weld Permitted Temp., °C | Weld Temp., °C, Without Impacts SR > 0.3 | Temp., °C, Without Impacts SR ≤ 0.3 | Minimum Material Temperature, °C, Without Impacts for Stress Ratios |     |     |      |    |     |     |     |     |     |
|                           |     |                                                         |      |                |                         |     |       |                              |     |     | Minimum Temp., °C, Without Impacts | Minimum Temp., °C, Without Impacts |                                  |                                          |                                     | 1                                                                   | 0.9 | 0.8 |      |    | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 |
| Low-Alloy Steels (Cont'd) |     |                                                         |      |                |                         |     |       |                              |     |     |                                    |                                    |                                  |                                          |                                     |                                                                     |     |     |      |    |     |     |     |     |     |
| LA -40                    | ... | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -48  | -48            | -48                     | ... | -48   | -104                         | N/A | ... | ...                                | ...                                | ...                              | ...                                      | ...                                 | ...                                                                 | ... | ... | -104 |    |     |     |     |     |     |
| LA -40                    | ... | Max. possible Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | -29  | ...            | -40                     | ... | -29   | -104                         | N/A | ... | ...                                | ...                                | ...                              | ...                                      | ...                                 | ...                                                                 | ... | ... | -104 |    |     |     |     |     |     |
| LA -20                    | ... | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -48  | -48            | -48                     | ... | -48   | -104                         | N/A | ... | ...                                | ...                                | ...                              | ...                                      | ...                                 | ...                                                                 | ... | ... | -104 |    |     |     |     |     |     |
| LA -20                    | ... | Max. possible Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | -29  | ...            | -29                     | ... | -29   | -104                         | N/A | ... | ...                                | ...                                | ...                              | ...                                      | ...                                 | ...                                                                 | ... | ... | -104 |    |     |     |     |     |     |
| LA 0                      | ... | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -48  | -48            | -48                     | ... | -48   | -104                         | N/A | ... | ...                                | ...                                | ...                              | ...                                      | ...                                 | ...                                                                 | ... | ... | -104 |    |     |     |     |     |     |
| LA 0                      | ... | Max. possible Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | -18  | ...            | -18                     | ... | -18   | -104                         | N/A | ... | ...                                | ...                                | ...                              | ...                                      | ...                                 | ...                                                                 | ... | ... | -104 |    |     |     |     |     |     |
| LA +20                    | ... | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -48  | -48            | -48                     | ... | -48   | -104                         | N/A | ... | ...                                | ...                                | ...                              | ...                                      | ...                                 | ...                                                                 | ... | ... | -104 |    |     |     |     |     |     |
| LA +20                    | ... | Max. possible Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | -7   | ...            | -7                      | ... | -7    | -104                         | N/A | ... | ...                                | ...                                | ...                              | ...                                      | ...                                 | ...                                                                 | ... | ... | -104 |    |     |     |     |     |     |
| Stainless Steels          |     |                                                         |      |                |                         |     |       |                              |     |     |                                    |                                    |                                  |                                          |                                     |                                                                     |     |     |      |    |     |     |     |     |     |
| SS -425                   | ... | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -254 | ...            | -254                    | ... | -254  | -254                         | N/A | ... | ...                                | ...                                | ...                              | ...                                      | ...                                 | ...                                                                 | ... | ... | ...  |    |     |     |     |     |     |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| SI Units [Note (1)]       |                         |                                              |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                                     |     |     |     |     |     |     |     |     |                                       |
|---------------------------|-------------------------|----------------------------------------------|------------------------------|--------------------------------------|------------------------------------|----------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|---------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|---------------------------------------|
| 1                         | 2                       | 3                                            | 4                            | 5                                    | 6                                  |                                  | 7                                   | 8                                   | 9                                   | Minimum Material Temperature, °C, Without Impacts for Stress Ratios |     |     |     |     |     |     |     | 17  | 18                                    |
| T-Group                   | Governing Thickness, mm | Notes                                        | Low-Temp., °C, Service Limit | Minimum Material Permitted Temp., °C | Minimum Temp., °C, Without Impacts | Minimum Weld Permitted Temp., °C | Weld                                |                                     | Temp., °C, Without Impacts SR > 0.3 | Temp., °C, Without Impacts SR ≤ 0.3                                 | 1   | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | Low-Temp., °C, Service Limit SR ≤ 0.3 |
|                           |                         |                                              |                              |                                      |                                    |                                  | Temp., °C, Without Impacts SR > 0.3 | Temp., °C, Without Impacts SR ≤ 0.3 |                                     |                                                                     |     |     |     |     |     |     |     |     |                                       |
| Stainless Steels (Cont'd) |                         |                                              |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                                     |     |     |     |     |     |     |     |     |                                       |
| SS -425                   | ...                     | Carbon ≤0.1% and solution heat treated       | -101                         | ...                                  | -254                               | ...                              | ...                                 | -101                                | -104                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ... | ... | -104                                  |
| SS -425                   | ...                     | Carbon >0.1% or not solution heat treated    | -29                          | ...                                  | -29                                | ...                              | ...                                 | -29                                 | -104                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ... | ... | -104                                  |
| SS -325                   | ...                     | Max. possible Charpy $t < 2.5$ mm [Note (2)] | -198                         | ...                                  | -198                               | ...                              | ...                                 | -254                                | -254                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ... | ... | ...                                   |
| SS -325                   | ...                     | Carbon ≤0.1% and solution heat treated       | -101                         | ...                                  | -198                               | ...                              | ...                                 | -101                                | -104                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ... | ... | -104                                  |
| SS -325                   | ...                     | Carbon >0.1% or not solution heat treated    | -29                          | ...                                  | -29                                | ...                              | ...                                 | -29                                 | -104                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ... | ... | -104                                  |
| SS -60                    | ...                     | ...                                          | -29                          | ...                                  | -51                                | ...                              | ...                                 | -29                                 | -29                                 | N/A                                                                 | ... | ... | ... | ... | ... | ... | ... | ... | -104                                  |
| SS -20                    | ...                     | ...                                          | -29                          | ...                                  | -29                                | ...                              | ...                                 | -29                                 | -29                                 | N/A                                                                 | ... | ... | ... | ... | ... | ... | ... | ... | -104                                  |
| Nickel Alloys             |                         |                                              |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                                     |     |     |     |     |     |     |     |     |                                       |
| NI -325                   | ...                     | ...                                          | -198                         | ...                                  | -198                               | ...                              | ...                                 | -198                                | -198                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ... | ... | ...                                   |
| Cast Irons                |                         |                                              |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                                     |     |     |     |     |     |     |     |     |                                       |
| CI -20                    | ...                     | ...                                          | -29                          | ...                                  | ...                                | ...                              | N/P                                 | N/P                                 | N/P                                 | N/A                                                                 | ... | ... | ... | ... | ... | ... | ... | ... | ...                                   |
| CI -20(A)                 | ...                     | ...                                          | -29                          | -29                                  | N/A                                | N/P                              | N/P                                 | N/P                                 | N/P                                 | N/A                                                                 | ... | ... | ... | ... | ... | ... | ... | ... | ...                                   |
| Copper Alloys             |                         |                                              |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                                     |     |     |     |     |     |     |     |     |                                       |
| CU -452                   | ...                     | ...                                          | -269                         | ...                                  | -269                               | ...                              | ...                                 | -269                                | -269                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ... | ... | ...                                   |
| CU -325                   | ...                     | ...                                          | -198                         | ...                                  | -198                               | ...                              | ...                                 | -198                                | -198                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ... | ... | ...                                   |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| SI Units [Note (1)]             |                                |                                                          |                                        |                                               |                                             |                                           |                                              |                                                                        |     |     |     |     |     |     |     |      |      |                                                    |
|---------------------------------|--------------------------------|----------------------------------------------------------|----------------------------------------|-----------------------------------------------|---------------------------------------------|-------------------------------------------|----------------------------------------------|------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|------|------|----------------------------------------------------|
| 1                               | 2                              | 3                                                        | 4                                      | 5                                             | 6                                           | 7                                         | 8                                            | 9                                                                      | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17   | 18   |                                                    |
| T-<br>Number<br>Group           | Governing<br>Thickness,<br>mm  | Notes                                                    | Low-<br>Temp., °C,<br>Service<br>Limit | Material                                      |                                             | Weld                                      |                                              | Minimum Material Temperature, °C, Without Impacts for<br>Stress Ratios |     |     |     |     |     |     |     |      |      | Low-<br>Temp., °C,<br>Service<br>Limit<br>SR ≤ 0.3 |
|                                 |                                |                                                          |                                        | Minimum<br>Material<br>Permitted<br>Temp., °C | Minimum<br>Temp., °C,<br>Without<br>Impacts | Minimum<br>Weld<br>Permitted<br>Temp., °C | Temp., °C,<br>Without<br>Impacts<br>SR > 0.3 | Temp., °C,<br>Without<br>Impacts<br>SR ≤ 0.3                           | 1   | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | >0.3 |      |                                                    |
| Aluminum Alloys                 |                                |                                                          |                                        |                                               |                                             |                                           |                                              |                                                                        |     |     |     |     |     |     |     |      |      |                                                    |
| AL -452                         | ...                            | ...                                                      | -269                                   | ...                                           | -269                                        | ...                                       | -269                                         | -269                                                                   | N/A | ... | ... | ... | ... | ... | ... | ...  | ...  |                                                    |
| Titanium and Titanium Alloys    |                                |                                                          |                                        |                                               |                                             |                                           |                                              |                                                                        |     |     |     |     |     |     |     |      |      |                                                    |
| TI -75                          | ...                            | ...                                                      | -59                                    | ...                                           | -59                                         | ...                                       | -59                                          | -59                                                                    | N/A | ... | ... | ... | ... | ... | ... | ...  | ...  |                                                    |
| Zirconium and Zirconium Alloys  |                                |                                                          |                                        |                                               |                                             |                                           |                                              |                                                                        |     |     |     |     |     |     |     |      |      |                                                    |
| ZI -75                          | ...                            | ...                                                      | -59                                    | ...                                           | -59                                         | ...                                       | -59                                          | -59                                                                    | N/A | ... | ... | ... | ... | ... | ... | ...  | ...  |                                                    |
| U.S. Customary Units [Note (4)] |                                |                                                          |                                        |                                               |                                             |                                           |                                              |                                                                        |     |     |     |     |     |     |     |      |      |                                                    |
| 1                               | 2                              | 3                                                        | 4                                      | 5                                             | 6                                           | 7                                         | 8                                            | 9                                                                      | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17   | 18   |                                                    |
| T-<br>Number<br>Group           | Governing<br>Thickness,<br>in. | Notes                                                    | Low-<br>Temp., °F,<br>Service<br>Limit | Material                                      |                                             | Weld                                      |                                              | Minimum Material Temperature, °F, Without Impacts for<br>Stress Ratios |     |     |     |     |     |     |     |      |      | Low-<br>Temp., °F,<br>Service<br>Limit<br>SR ≤ 0.3 |
|                                 |                                |                                                          |                                        | Minimum<br>Material<br>Permitted<br>Temp., °F | Minimum<br>Temp., °F,<br>Without<br>Impacts | Minimum<br>Weld<br>Permitted<br>Temp., °F | Temp., °F,<br>Without<br>Impacts<br>SR > 0.3 | Temp., °F,<br>Without<br>Impacts<br>SR ≤ 0.3                           | 1   | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | >0.3 |      |                                                    |
| Carbon Steels                   |                                |                                                          |                                        |                                               |                                             |                                           |                                              |                                                                        |     |     |     |     |     |     |     |      |      |                                                    |
| CS -55                          | ...                            | Max. possible<br>Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -20                                    | -55                                           | -55                                         | ...                                       | -20                                          | -155                                                                   | -55 | -55 | -55 | -55 | -55 | -55 | -55 | -55  | -155 |                                                    |
| CS -55                          | ...                            | Max. possible<br>Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -20                                    | ...                                           | -55                                         | ...                                       | -20                                          | -155                                                                   | -55 | -55 | -55 | -55 | -55 | -55 | -55 | -55  | -155 |                                                    |
| CS -50                          | ...                            | Max. possible<br>Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -20                                    | -55                                           | -55                                         | ...                                       | -20                                          | -155                                                                   | -55 | -55 | -55 | -55 | -55 | -55 | -55 | -55  | -155 |                                                    |
| CS -50                          | ...                            | Max. possible<br>Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -20                                    | ...                                           | -50                                         | ...                                       | -20                                          | -155                                                                   | -50 | -55 | -55 | -55 | -55 | -55 | -55 | -55  | -155 |                                                    |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| U.S. Customary Units [Note (4)] |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|---------------------------------|---------|---------------------------------------------------------|-----|------------------------------|------------------------------------|----------------------------------|-----|----------------------------------------|----------------------------------------|---------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|------------------------------------------|------|
| 1                               | 2       | 3                                                       | 4   | Material                     |                                    |                                  | 7   | Weld                                   |                                        | Minimum Material Temperature, °F, Without Impacts for Stress Ratios |     |     |     |     |     |     | Low-Temp., °F, Service Limit<br>SR ≤ 0.3 |      |
|                                 |         |                                                         |     | Minimum Temp., °F, Permitted | Minimum Temp., °F, Without Impacts | Minimum Weld Permitted Temp., °F |     | Temp., °F, Without Impacts<br>SR > 0.3 | Temp., °F, Without Impacts<br>SR ≤ 0.3 | 1                                                                   | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 |                                          | >0.3 |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| Carbon Steels (Cont'd)          |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS -20                          | ...     | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -20 | -55                          | ...                                | -20                              | ... | -20                                    | -155                                   | -55                                                                 | -55 | -55 | -55 | -55 | -55 | -55 | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS -20                          | ...     | Max. possible Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | -20 | -20                          | ...                                | -20                              | ... | -20                                    | -155                                   | -20                                                                 | -30 | -40 | -50 | -55 | -55 | -55 | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS -20 (A)                      | ...     | ...                                                     | -20 | -20                          | ...                                | -20                              | ... | -20                                    | -20                                    | N/A                                                                 | ... | ... | ... | ... | ... | ... | ...                                      |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS 0                            | ...     | ...                                                     | 0   | 0                            | ...                                | 0                                | ... | -20                                    | -20                                    | 0                                                                   | -10 | -20 | -30 | -40 | -55 | -55 | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS +20 (A)                      | ...     | ...                                                     | 20  | 20                           | ...                                | 20                               | ... | 20                                     | 20                                     | N/A                                                                 | ... | ... | ... | ... | ... | ... | ...                                      |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS A                            | ≤0.394  | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | 20  | -55                          | ...                                | -55                              | ... | 20                                     | -155                                   | -55                                                                 | -55 | -55 | -55 | -55 | -55 | -55 | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS A                            | ≤0.394  | Max. possible Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | 20  | ...                          | 20                                 | ...                              | ... | 20                                     | -155                                   | 20                                                                  | 10  | 0   | -10 | -20 | -40 | -55 | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS A                            | ≤0.4375 | ...                                                     | 25  | ...                          | ...                                | 25                               | ... | 25                                     | -155                                   | 25                                                                  | 15  | 5   | -5  | -15 | -35 | -55 | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS A                            | ≤0.5    | ...                                                     | 30  | ...                          | ...                                | 30                               | ... | 30                                     | -155                                   | 30                                                                  | 20  | 10  | 0   | -10 | -30 | -55 | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS A                            | ≤0.6    | ...                                                     | 40  | ...                          | ...                                | 40                               | ... | 40                                     | -155                                   | 40                                                                  | 30  | 20  | 10  | 0   | -20 | -55 | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS A                            | ≤0.7    | ...                                                     | 50  | ...                          | ...                                | 50                               | ... | 50                                     | -155                                   | 50                                                                  | 40  | 30  | 20  | 10  | -10 | -45 | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS A                            | ≤0.85   | ...                                                     | 60  | ...                          | ...                                | 60                               | ... | 60                                     | -155                                   | 60                                                                  | 50  | 40  | 30  | 20  | 0   | -35 | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS A                            | ≤1.03   | ...                                                     | 70  | ...                          | ...                                | 70                               | ... | 70                                     | -155                                   | 70                                                                  | 60  | 50  | 40  | 30  | 10  | -25 | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS A                            | ≤1.25   | ...                                                     | 80  | ...                          | ...                                | 80                               | ... | 80                                     | -155                                   | 80                                                                  | 70  | 60  | 50  | 40  | 20  | -15 | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS A                            | ≤1.5625 | ...                                                     | 90  | ...                          | ...                                | 90                               | ... | 90                                     | -155                                   | 90                                                                  | 80  | 70  | 60  | 50  | 30  | -5  | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS A                            | ≤2.0325 | ...                                                     | 100 | ...                          | ...                                | 100                              | ... | 100                                    | -155                                   | 100                                                                 | 90  | 80  | 70  | 60  | 40  | 5   | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
| CS A                            | ≤3      | ...                                                     | 110 | ...                          | ...                                | 110                              | ... | 110                                    | -155                                   | 110                                                                 | 100 | 90  | 80  | 70  | 50  | 15  | -155                                     |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |
|                                 |         |                                                         |     |                              |                                    |                                  |     |                                        |                                        |                                                                     |     |     |     |     |     |     |                                          |      |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| U.S. Customary Units [Note (4)] |                          |                                                         |                              |                                       |                                    |                                  |                                     |                                     |     |                                                                     |     |     |     |     |     |      |          |  |                              |
|---------------------------------|--------------------------|---------------------------------------------------------|------------------------------|---------------------------------------|------------------------------------|----------------------------------|-------------------------------------|-------------------------------------|-----|---------------------------------------------------------------------|-----|-----|-----|-----|-----|------|----------|--|------------------------------|
| 1                               | 2                        | 3                                                       | 4                            | 5                                     | Material                           |                                  | 7                                   | 8                                   | 9   | Minimum Material Temperature, °F, Without Impacts for Stress Ratios |     |     |     |     |     |      |          |  | Low-Temp., °F, Service Limit |
| T-Group                         | Governing Thickness, in. | Notes                                                   | Low-Temp., °F, Service Limit | Minimum Temp., °F, Material Permitted | Minimum Temp., °F, Without Impacts | Minimum Weld Permitted Temp., °F | Temp., °F, Without Impacts SR > 0.3 | Temp., °F, Without Impacts SR ≤ 0.3 | 1   | 0.9                                                                 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | >0.3 | SR ≤ 0.3 |  |                              |
| Carbon Steels (Cont'd)          |                          |                                                         |                              |                                       |                                    |                                  |                                     |                                     |     |                                                                     |     |     |     |     |     |      |          |  |                              |
| CS A                            | ≤3.6875                  | ...                                                     | 115                          | ...                                   | 115                                | ...                              | 115                                 | -155                                | 115 | 105                                                                 | 95  | 85  | 75  | 55  | 20  | -55  | -155     |  |                              |
| CS A                            | >3.6875                  | ...                                                     | 120                          | ...                                   | 120                                | ...                              | 120                                 | -155                                | 120 | 110                                                                 | 100 | 90  | 80  | 60  | 25  | -55  | -155     |  |                              |
| CS B                            | ≤0.394                   | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -20                          | -55                                   | -55                                | ...                              | -20                                 | -155                                | -55 | -55                                                                 | -55 | -55 | -55 | -55 | -55 | -55  | -155     |  |                              |
| CS B                            | ≤0.394                   | Max. possible Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | -20                          | ...                                   | -20                                | ...                              | -20                                 | -155                                | -20 | -30                                                                 | -40 | -50 | -55 | -55 | -55 | -55  | -155     |  |                              |
| CS B                            | ≤0.47                    | ...                                                     | -20                          | ...                                   | -20                                | ...                              | -20                                 | -155                                | -20 | -30                                                                 | -40 | -50 | -55 | -55 | -55 | -55  | -155     |  |                              |
| CS B                            | ≤0.57                    | ...                                                     | -7                           | ...                                   | -7                                 | ...                              | -7                                  | -155                                | -7  | -17                                                                 | -27 | -37 | -47 | -55 | -55 | -55  | -155     |  |                              |
| CS B                            | ≤0.68                    | ...                                                     | 9                            | ...                                   | 9                                  | ...                              | 9                                   | -155                                | 9   | -1                                                                  | -11 | -21 | -31 | -51 | -55 | -55  | -155     |  |                              |
| CS B                            | ≤0.83                    | ...                                                     | 20                           | ...                                   | 20                                 | ...                              | 20                                  | -155                                | 20  | 10                                                                  | 0   | -10 | -20 | -40 | -55 | -55  | -155     |  |                              |
| CS B                            | ≤0.98                    | ...                                                     | 30                           | ...                                   | 30                                 | ...                              | 30                                  | -155                                | 30  | 20                                                                  | 10  | 0   | -10 | -30 | -55 | -55  | -155     |  |                              |
| CS B                            | ≤1.19                    | ...                                                     | 40                           | ...                                   | 40                                 | ...                              | 40                                  | -155                                | 40  | 30                                                                  | 20  | 10  | 0   | -20 | -55 | -55  | -155     |  |                              |
| CS B                            | ≤1.47                    | ...                                                     | 50                           | ...                                   | 50                                 | ...                              | 50                                  | -155                                | 50  | 40                                                                  | 30  | 20  | 10  | -10 | -45 | -55  | -155     |  |                              |
| CS B                            | ≤1.85                    | ...                                                     | 60                           | ...                                   | 60                                 | ...                              | 60                                  | -155                                | 60  | 50                                                                  | 40  | 30  | 20  | 0   | -35 | -55  | -155     |  |                              |
| CS B                            | ≤2.4385                  | ...                                                     | 70                           | ...                                   | 70                                 | ...                              | 70                                  | -155                                | 70  | 60                                                                  | 50  | 40  | 30  | 10  | -25 | -55  | -155     |  |                              |
| CS B                            | ≤3.25                    | ...                                                     | 80                           | ...                                   | 80                                 | ...                              | 80                                  | -155                                | 80  | 70                                                                  | 60  | 50  | 40  | 20  | -15 | -55  | -155     |  |                              |
| CS B                            | ≤4.00                    | ...                                                     | 90                           | ...                                   | 90                                 | ...                              | 90                                  | -155                                | 90  | 80                                                                  | 70  | 60  | 50  | 30  | -5  | -55  | -155     |  |                              |
| CS B                            | >4.00                    | ...                                                     | 120                          | ...                                   | 120                                | ...                              | 120                                 | -155                                | 120 | 110                                                                 | 100 | 90  | 80  | 60  | 25  | -55  | -155     |  |                              |
| CS C                            | ≤0.394                   | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -55                          | -55                                   | -55                                | ...                              | -55                                 | -155                                | -55 | -55                                                                 | -55 | -55 | -55 | -55 | -55 | -55  | -155     |  |                              |
| CS C                            | ≤0.394                   | Max. possible Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | -20                          | ...                                   | -55                                | ...                              | -20                                 | -155                                | -55 | -55                                                                 | -55 | -55 | -55 | -55 | -55 | -55  | -155     |  |                              |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| U.S. Customary Units [Note (4)] |                          |                                           |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                                     |     |     |     |     |     |     |     |                              |                |
|---------------------------------|--------------------------|-------------------------------------------|------------------------------|--------------------------------------|------------------------------------|----------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|---------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|------------------------------|----------------|
| 1                               | 2                        | 3                                         | 4                            | 5                                    | Material                           |                                  | 7                                   | 8                                   | 9                                   | Minimum Material Temperature, °F, Without Impacts for Stress Ratios |     |     |     |     |     |     |     | Low-Temp., °F, Service Limit |                |
| T-Number Group                  | Governing Thickness, in. | Notes                                     | Low-Temp., °F, Service Limit | Minimum Material Permitted Temp., °F | Minimum Temp., °F, Without Impacts | Minimum Weld Permitted Temp., °F | Weld                                |                                     | Temp., °F, Without Impacts SR ≤ 0.3 | Temp., °F, Without Impacts SR > 0.3                                 | 1   | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3                          | Limit SR ≤ 0.3 |
|                                 |                          |                                           |                              |                                      |                                    |                                  | Temp., °F, Without Impacts SR > 0.3 | Temp., °F, Without Impacts SR ≤ 0.3 |                                     |                                                                     |     |     |     |     |     |     |     |                              |                |
| Carbon Steels (Cont'd)          |                          |                                           |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                                     |     |     |     |     |     |     |     |                              |                |
| CS C                            | ≤0.41                    | ...                                       | -20                          | ...                                  | -50                                | ...                              | -20                                 | -155                                | -50                                 | -55                                                                 | -55 | -55 | -55 | -55 | -55 | -55 | -55 | -55                          | -155           |
| CS C                            | ≤0.44                    | ...                                       | -20                          | ...                                  | -40                                | ...                              | -20                                 | -155                                | -40                                 | -50                                                                 | -55 | -55 | -55 | -55 | -55 | -55 | -55 | -55                          | -155           |
| CS C                            | ≤0.53                    | ...                                       | -20                          | ...                                  | -30                                | ...                              | -20                                 | -155                                | -30                                 | -40                                                                 | -50 | -55 | -55 | -55 | -55 | -55 | -55 | -55                          | -155           |
| CS C                            | ≤0.65                    | ...                                       | -20                          | ...                                  | -20                                | ...                              | -20                                 | -155                                | -20                                 | -30                                                                 | -40 | -50 | -55 | -55 | -55 | -55 | -55 | -55                          | -155           |
| CS C                            | ≤0.85                    | ...                                       | -10                          | ...                                  | -10                                | ...                              | -10                                 | -155                                | -10                                 | -20                                                                 | -30 | -40 | -50 | -55 | -55 | -55 | -55 | -55                          | -155           |
| CS C                            | ≤1.08                    | ...                                       | 0                            | ...                                  | 0                                  | ...                              | 0                                   | -155                                | 0                                   | -10                                                                 | -20 | -30 | -40 | -55 | -55 | -55 | -55 | -55                          | -155           |
| CS C                            | ≤1.38                    | ...                                       | 10                           | ...                                  | 10                                 | ...                              | 10                                  | -155                                | 10                                  | 0                                                                   | -10 | -20 | -30 | -50 | -55 | -55 | -55 | -55                          | -155           |
| CS C                            | ≤1.75                    | ...                                       | 20                           | ...                                  | 20                                 | ...                              | 20                                  | -155                                | 20                                  | 10                                                                  | 0   | -10 | -20 | -40 | -55 | -55 | -55 | -55                          | -155           |
| CS C                            | ≤2.25                    | ...                                       | 30                           | ...                                  | 30                                 | ...                              | 30                                  | -155                                | 30                                  | 20                                                                  | 10  | 0   | -10 | -30 | -55 | -55 | -55 | -55                          | -155           |
| CS C                            | ≤2.94                    | ...                                       | 40                           | ...                                  | 40                                 | ...                              | 40                                  | -155                                | 40                                  | 30                                                                  | 20  | 10  | 0   | -20 | -55 | -55 | -55 | -55                          | -155           |
| CS C                            | ≤3.75                    | ...                                       | 50                           | ...                                  | 50                                 | ...                              | 50                                  | -155                                | 50                                  | 40                                                                  | 30  | 20  | 10  | -10 | -45 | -55 | -55 | -55                          | -155           |
| CS C                            | ≤4.00                    | ...                                       | 52                           | ...                                  | 52                                 | ...                              | 52                                  | -155                                | 52                                  | 42                                                                  | 32  | 22  | 12  | -8  | -43 | -55 | -55 | -55                          | -155           |
| CS C                            | >4.00                    | ...                                       | 120                          | ...                                  | 120                                | ...                              | 120                                 | -155                                | 120                                 | 110                                                                 | 100 | 90  | 80  | 60  | 25  | -55 | -55 | -55                          | -155           |
| CS D                            | ≤0.5                     | Max possible Charpy t < 2.5 mm [Note (2)] | -55                          | -55                                  | -55                                | ...                              | -55                                 | -155                                | -55                                 | -55                                                                 | -55 | -55 | -55 | -55 | -55 | -55 | -55 | -55                          | -155           |
| CS D                            | ≤0.5                     | Max possible Charpy t ≥ 2.5 mm [Note (3)] | -20                          | ...                                  | -55                                | ...                              | -20                                 | -155                                | -55                                 | -55                                                                 | -55 | -55 | -55 | -55 | -55 | -55 | -55 | -55                          | -155           |
| CS D                            | ≤0.58                    | ...                                       | -20                          | ...                                  | -50                                | ...                              | -20                                 | -155                                | -50                                 | -55                                                                 | -55 | -55 | -55 | -55 | -55 | -55 | -55 | -55                          | -155           |
| CS D                            | ≤0.78                    | ...                                       | -20                          | ...                                  | -40                                | ...                              | -20                                 | -155                                | -40                                 | -50                                                                 | -55 | -55 | -55 | -55 | -55 | -55 | -55 | -55                          | -155           |
| CS D                            | ≤1.0                     | ...                                       | -20                          | ...                                  | -30                                | ...                              | -20                                 | -155                                | -30                                 | -40                                                                 | -50 | -55 | -55 | -55 | -55 | -55 | -55 | -55                          | -155           |
| CS D                            | ≤1.3                     | ...                                       | -20                          | ...                                  | -20                                | ...                              | -20                                 | -155                                | -20                                 | -30                                                                 | -40 | -50 | -55 | -55 | -55 | -55 | -55 | -55                          | -155           |
| CS D                            | ≤1.6875                  | ...                                       | -10                          | ...                                  | -10                                | ...                              | -10                                 | -155                                | -10                                 | -20                                                                 | -30 | -40 | -50 | -55 | -55 | -55 | -55 | -55                          | -155           |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| U.S. Customary Units [Note (4)] |                                |                                                          |                                        |                                                          |                                             |                                           |                                                 |                                                                        |     |     |     |     |     |     |     |      |                                        |
|---------------------------------|--------------------------------|----------------------------------------------------------|----------------------------------------|----------------------------------------------------------|---------------------------------------------|-------------------------------------------|-------------------------------------------------|------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|------|----------------------------------------|
| 1                               | 2                              | 3                                                        | 4                                      | 5                                                        | 6                                           | 7                                         | 8                                               | 9                                                                      | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17   | 18                                     |
| T-<br>Number<br>Group           | Governing<br>Thickness,<br>in. | Notes                                                    | Low-<br>Temp., °F,<br>Service<br>Limit | Material                                                 |                                             | Weld                                      |                                                 | Minimum Material Temperature, °F, Without Impacts for<br>Stress Ratios |     |     |     |     |     |     |     |      | Low-<br>Temp., °F,<br>Service<br>Limit |
|                                 |                                |                                                          |                                        | Minimum<br>Temp., °F,<br>Permitted<br>Without<br>Impacts | Minimum<br>Temp., °F,<br>Without<br>Impacts | Minimum<br>Weld<br>Permitted<br>Temp., °F | Temp.,<br>°F,<br>Without<br>Impacts<br>SR > 0.3 | Temp.,<br>°F,<br>Without<br>Impacts<br>SR ≤ 0.3                        | 1   | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | >0.3 |                                        |
|                                 |                                |                                                          |                                        |                                                          |                                             |                                           |                                                 |                                                                        |     |     |     |     |     |     |     |      |                                        |
| Carbon Steels (Cont'd)          |                                |                                                          |                                        |                                                          |                                             |                                           |                                                 |                                                                        |     |     |     |     |     |     |     |      |                                        |
| CS D                            | ≤2.25                          | ...                                                      | 0                                      | ...                                                      | 0                                           | ...                                       | 0                                               | -155                                                                   | 0   | -10 | -20 | -30 | -40 | -55 | -55 | -55  | -155                                   |
| CS D                            | ≤2.9375                        | ...                                                      | 10                                     | ...                                                      | 10                                          | ...                                       | 10                                              | -155                                                                   | 10  | 0   | -10 | -20 | -30 | -50 | -55 | -55  | -155                                   |
| CS D                            | ≤3.75                          | ...                                                      | 20                                     | ...                                                      | 20                                          | ...                                       | 20                                              | -155                                                                   | 20  | 10  | 0   | -10 | -20 | -40 | -55 | -55  | -155                                   |
| CS D                            | ≤4.00                          | ...                                                      | 23                                     | ...                                                      | 23                                          | ...                                       | 23                                              | -155                                                                   | 23  | 13  | 3   | -7  | -17 | -37 | -55 | -55  | -155                                   |
| CS D                            | >4.00                          | ...                                                      | 120                                    | ...                                                      | 120                                         | ...                                       | 120                                             | -155                                                                   | 120 | 110 | 100 | 90  | 80  | 60  | 25  | -55  | -155                                   |
| Low-Alloy Steels                |                                |                                                          |                                        |                                                          |                                             |                                           |                                                 |                                                                        |     |     |     |     |     |     |     |      |                                        |
| LA -320                         | ...                            | Max. possible<br>Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -55                                    | -320                                                     | -320                                        | -55                                       | -55                                             | -155                                                                   | N/A | ... | ... | ... | ... | ... | ... | ...  | N/A                                    |
| LA -320                         | ...                            | Max. possible<br>Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -20                                    | ...                                                      | -320                                        | ...                                       | -20                                             | -155                                                                   | N/A | ... | ... | ... | ... | ... | ... | ...  | N/A                                    |
| LA -275                         | ...                            | Max. possible<br>Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -55                                    | -275                                                     | -275                                        | -55                                       | -55                                             | -155                                                                   | N/A | ... | ... | ... | ... | ... | ... | ...  | N/A                                    |
| LA -275                         | ...                            | Max. possible<br>Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -20                                    | ...                                                      | -275                                        | ...                                       | -20                                             | -155                                                                   | N/A | ... | ... | ... | ... | ... | ... | ...  | N/A                                    |
| LA -150                         | ...                            | Max. possible<br>Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -55                                    | -150                                                     | -150                                        | -55                                       | -55                                             | -155                                                                   | N/A | ... | ... | ... | ... | ... | ... | ...  | -155                                   |
| LA -150                         | ...                            | Max. possible<br>Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -20                                    | ...                                                      | -150                                        | ...                                       | -20                                             | -155                                                                   | N/A | ... | ... | ... | ... | ... | ... | ...  | -155                                   |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| U.S. Customary Units [Note (4)] |     |                                                         |     |                              |                                    |                                  |                                     |                                     |                                                       |     |     |     |     |     |     |     |                                       |
|---------------------------------|-----|---------------------------------------------------------|-----|------------------------------|------------------------------------|----------------------------------|-------------------------------------|-------------------------------------|-------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|---------------------------------------|
| 1                               | 2   | 3                                                       | 4   | Material                     |                                    |                                  | Weld                                |                                     | Minimum Material Temperature, °F, Without Impacts for |     |     |     |     |     |     |     | Low-Temp., °F, Service Limit SR ≤ 0.3 |
|                                 |     |                                                         |     | Minimum Temp., °F, Permitted | Minimum Temp., °F, Without Impacts | Minimum Weld Permitted Temp., °F | Temp., °F, Without Impacts SR > 0.3 | Temp., °F, Without Impacts SR ≤ 0.3 | 1                                                     | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 |                                       |
|                                 |     |                                                         |     |                              |                                    |                                  |                                     |                                     |                                                       |     |     |     |     |     |     |     |                                       |
| Low-Alloy Steels (Cont'd)       |     |                                                         |     |                              |                                    |                                  |                                     |                                     |                                                       |     |     |     |     |     |     |     |                                       |
| LA -100                         | ... | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -55 | -100                         | -100                               | -55                              | -55                                 | -155                                | N/A                                                   | ... | ... | ... | ... | ... | ... | ... | -155                                  |
|                                 |     |                                                         |     |                              |                                    |                                  |                                     |                                     |                                                       |     |     |     |     |     |     |     |                                       |
| LA -100                         | ... | Max. possible Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | -20 | ...                          | -100                               | ...                              | -20                                 | -155                                | N/A                                                   | ... | ... | ... | ... | ... | ... | ... | -155                                  |
|                                 |     |                                                         |     |                              |                                    |                                  |                                     |                                     |                                                       |     |     |     |     |     |     |     |                                       |
| LA -75                          | ... | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -55 | -75                          | -75                                | ...                              | -55                                 | -155                                | N/A                                                   | ... | ... | ... | ... | ... | ... | ... | -155                                  |
|                                 |     |                                                         |     |                              |                                    |                                  |                                     |                                     |                                                       |     |     |     |     |     |     |     |                                       |
| LA -75                          | ... | Max. possible Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | -20 | ...                          | -75                                | ...                              | -20                                 | -155                                | N/A                                                   | ... | ... | ... | ... | ... | ... | ... | -155                                  |
|                                 |     |                                                         |     |                              |                                    |                                  |                                     |                                     |                                                       |     |     |     |     |     |     |     |                                       |
| LA -55                          | ... | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -55 | -55                          | -55                                | ...                              | -55                                 | -155                                | N/A                                                   | ... | ... | ... | ... | ... | ... | ... | -155                                  |
|                                 |     |                                                         |     |                              |                                    |                                  |                                     |                                     |                                                       |     |     |     |     |     |     |     |                                       |
| LA -55                          | ... | Max. possible Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | -20 | ...                          | -55                                | ...                              | -20                                 | -155                                | N/A                                                   | ... | ... | ... | ... | ... | ... | ... | -155                                  |
|                                 |     |                                                         |     |                              |                                    |                                  |                                     |                                     |                                                       |     |     |     |     |     |     |     |                                       |
| LA -40                          | ... | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -55 | -55                          | -55                                | ...                              | -55                                 | -155                                | N/A                                                   | ... | ... | ... | ... | ... | ... | ... | -155                                  |
|                                 |     |                                                         |     |                              |                                    |                                  |                                     |                                     |                                                       |     |     |     |     |     |     |     |                                       |
| LA -40                          | ... | Max. possible Charpy<br><i>t</i> ≥ 2.5 mm<br>[Note (3)] | -20 | ...                          | -40                                | ...                              | -20                                 | -155                                | N/A                                                   | ... | ... | ... | ... | ... | ... | ... | -155                                  |
|                                 |     |                                                         |     |                              |                                    |                                  |                                     |                                     |                                                       |     |     |     |     |     |     |     |                                       |
| LA -20                          | ... | Max. possible Charpy<br><i>t</i> < 2.5 mm<br>[Note (2)] | -55 | -55                          | -55                                | ...                              | -55                                 | -155                                | N/A                                                   | ... | ... | ... | ... | ... | ... | ... | -155                                  |
|                                 |     |                                                         |     |                              |                                    |                                  |                                     |                                     |                                                       |     |     |     |     |     |     |     |                                       |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| U.S. Customary Units [Note (4)] |                          |                                                       |                              |                              |                                    |                                  |                                     |                                     |                                                                     |     |     |     |     |     |     |      |     |                                       |
|---------------------------------|--------------------------|-------------------------------------------------------|------------------------------|------------------------------|------------------------------------|----------------------------------|-------------------------------------|-------------------------------------|---------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|------|-----|---------------------------------------|
| 1                               | 2                        | 3                                                     | 4                            | 5                            | Material                           |                                  | Weld                                |                                     | 9                                                                   | 10  | 11  | 12  | 13  | 14  | 15  | 16   | 17  | 18                                    |
| T-Group                         | Governing Thickness, in. | Notes                                                 | Low-Temp., °F, Service Limit | Minimum Temp., °F, Permitted | Minimum Temp., °F, Without Impacts | Minimum Weld Permitted Temp., °F | Temp., °F, Without Impacts SR > 0.3 | Temp., °F, Without Impacts SR ≤ 0.3 | Minimum Material Temperature, °F, Without Impacts for Stress Ratios |     |     |     |     |     |     |      |     | Low-Temp., °F, Service Limit SR ≤ 0.3 |
|                                 |                          |                                                       |                              |                              |                                    |                                  |                                     |                                     | 1                                                                   | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | >0.3 |     |                                       |
| Low-Alloy Steels (Cont'd)       |                          |                                                       |                              |                              |                                    |                                  |                                     |                                     |                                                                     |     |     |     |     |     |     |      |     |                                       |
| LA -20                          | ...                      | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | -20                          | ...                          | -20                                | ...                              | -20                                 | -155                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ...  | ... | -155                                  |
| LA 0                            | ...                      | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -55                          | -55                          | -55                                | ...                              | -55                                 | -155                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ...  | ... | -155                                  |
| LA 0                            | ...                      | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | 0                            | ...                          | 0                                  | ...                              | -20                                 | -155                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ...  | ... | -155                                  |
| LA +20                          | ...                      | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -55                          | -55                          | -55                                | ...                              | -55                                 | -155                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ...  | ... | -155                                  |
| LA +20                          | ...                      | Max. possible Charpy<br>$t \geq 2.5$ mm<br>[Note (3)] | 20                           | ...                          | 20                                 | ...                              | -20                                 | -155                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ...  | ... | -155                                  |
| Stainless Steels                |                          |                                                       |                              |                              |                                    |                                  |                                     |                                     |                                                                     |     |     |     |     |     |     |      |     |                                       |
| SS -425                         | ...                      | Max. possible Charpy<br>$t < 2.5$ mm<br>[Note (2)]    | -425                         | ...                          | -425                               | ...                              | -425                                | -425                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ...  | ... | ...                                   |
| SS -425                         | ...                      | Carbon ≤0.1% and solution heat treated                | -150                         | ...                          | -425                               | ...                              | -150                                | -155                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ...  | ... | -155                                  |
| SS -425                         | ...                      | Carbon >0.1% or not solution heat treated             | -20                          | ...                          | -20                                | ...                              | -20                                 | -155                                | N/A                                                                 | ... | ... | ... | ... | ... | ... | ...  | ... | -155                                  |

Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)

| U.S. Customary Units [Note (4)] |                          |                                                   |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                       |               |     |     |     |     |     |      |                              |                                   |
|---------------------------------|--------------------------|---------------------------------------------------|------------------------------|--------------------------------------|------------------------------------|----------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------------------------|---------------|-----|-----|-----|-----|-----|------|------------------------------|-----------------------------------|
| 1                               | 2                        | 3                                                 | 4                            | 5                                    | Material                           |                                  | 7                                   | 8                                   | 9                                   | Minimum Material Temperature, °F, Without Impacts for |               |     |     |     |     |     |      | Low-Temp., °F, Service Limit |                                   |
| T-Number Group                  | Governing Thickness, in. | Notes                                             | Low-Temp., °F, Service Limit | Minimum Material Permitted Temp., °F | Minimum Temp., °F, Without Impacts | Minimum Weld Permitted Temp., °F | Weld                                |                                     | Temp., °F, Without Impacts SR ≤ 0.3 | Temp., °F, Without Impacts SR > 0.3                   | Stress Ratios |     |     |     |     |     |      |                              | Temp., °F, Service Limit SR ≤ 0.3 |
|                                 |                          |                                                   |                              |                                      |                                    |                                  | Temp., °F, Without Impacts SR > 0.3 | Temp., °F, Without Impacts SR ≤ 0.3 |                                     |                                                       | 1             | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4  | >0.3                         |                                   |
| Stainless Steels (Cont'd)       |                          |                                                   |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                       |               |     |     |     |     |     |      |                              |                                   |
| SS -325                         | ...                      | Max. possible Charpy <i>t</i> < 2.5 mm [Note (2)] | -325                         | ...                                  | -325                               | ...                              | -425                                | -425                                | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | ...  |                              |                                   |
| SS -325                         | ...                      | Carbon ≤0.1% and solution heat treated            | -150                         | ...                                  | -325                               | ...                              | -150                                | -155                                | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | -155 |                              |                                   |
| SS -325                         | ...                      | Carbon >0.1% or not solution heat treated         | -20                          | ...                                  | -20                                | ...                              | -20                                 | -155                                | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | -155 |                              |                                   |
| SS -60                          | ...                      | ...                                               | -20                          | ...                                  | -60                                | ...                              | -20                                 | -20                                 | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | -155 |                              |                                   |
| SS -20                          | ...                      | ...                                               | -20                          | ...                                  | -20                                | ...                              | -20                                 | -20                                 | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | -155 |                              |                                   |
| Nickel Alloys                   |                          |                                                   |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                       |               |     |     |     |     |     |      |                              |                                   |
| NI -325                         | ...                      | ...                                               | -325                         | ...                                  | -325                               | ...                              | -325                                | -325                                | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | ...  |                              |                                   |
| Cast Irons                      |                          |                                                   |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                       |               |     |     |     |     |     |      |                              |                                   |
| CI -20                          | ...                      | ...                                               | -20                          | ...                                  | ...                                | N/P                              | N/P                                 | N/P                                 | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | ...  |                              |                                   |
| CI -20(A)                       | ...                      | ...                                               | -20                          | -20                                  | N/A                                | N/P                              | N/P                                 | N/P                                 | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | ...  |                              |                                   |
| Copper Alloys                   |                          |                                                   |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                       |               |     |     |     |     |     |      |                              |                                   |
| CU -452                         | ...                      | ...                                               | -452                         | ...                                  | -452                               | ...                              | -452                                | -452                                | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | ...  |                              |                                   |
| CU -325                         | ...                      | ...                                               | -325                         | ...                                  | -325                               | ...                              | -325                                | -325                                | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | ...  |                              |                                   |
| Aluminum Alloys                 |                          |                                                   |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                       |               |     |     |     |     |     |      |                              |                                   |
| AL -452                         | ...                      | ...                                               | -452                         | ...                                  | -452                               | ...                              | -452                                | -452                                | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | ...  |                              |                                   |
| Titanium and Titanium Alloys    |                          |                                                   |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                       |               |     |     |     |     |     |      |                              |                                   |
| TI -75                          | ...                      | ...                                               | -75                          | ...                                  | -75                                | ...                              | -75                                 | -75                                 | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | ...  |                              |                                   |
| Zirconium and Zirconium Alloys  |                          |                                                   |                              |                                      |                                    |                                  |                                     |                                     |                                     |                                                       |               |     |     |     |     |     |      |                              |                                   |
| ZI -75                          | ...                      | ...                                               | -75                          | ...                                  | -75                                | ...                              | -75                                 | -75                                 | N/A                                 | ...                                                   | ...           | ... | ... | ... | ... | ... | ...  |                              |                                   |

**Table 3.1-1 Low-Temperature Service Requirements by Material Group (Cont'd)****GENERAL NOTES:**

- (a) N/A = not applicable.
- (b) N/P = not permitted.
- (c) SR = stress ratio per [para. 3.6.2](#).

**NOTES:**

- (1) All temperatures are in degrees Celsius.
- (2) This line is applicable if the maximum Charpy specimen obtainable from the product is less than 2.5 mm (0.098 in.).
- (3) This line is applicable if the maximum Charpy specimen obtainable from the product is equal to or greater than 2.5 mm (0.098 in.).
- (4) All temperatures are in degrees Fahrenheit.

(21)

**Table 3.2-1 Material Groupings by Material Specification**

| Specification | Type/Grade/Class/Condition/Temper/UNS                                       | T-Number Group | Material Type    | Product Form | Notes    |
|---------------|-----------------------------------------------------------------------------|----------------|------------------|--------------|----------|
| A36           | ...                                                                         | CS A           | Carbon steels    | PL           | ...      |
| A47           | Grade 32510                                                                 | CI -20(A)      | Cast irons       | C            | ...      |
| A48           | Grade 20, 25, 30, 35, 40, 45, 50, 55, 60                                    | CI -20         | Cast irons       | C            | ...      |
| A53           | Grade A (Type F)                                                            | CS +20(A)      | Carbon steels    | P            | ...      |
| A53           | Grade A (except Type F), B                                                  | CS B           | Carbon steels    | P            | ...      |
| A105          | ...                                                                         | CS -20         | Carbon steels    | FI & FO      | ...      |
| A106          | Grade A, B, C                                                               | CS B           | Carbon steels    | P            | ...      |
| A126          | Class A, B, C                                                               | CI -20         | Cast irons       | C            | ...      |
| A134          | A283 Grade C, D                                                             | CS A           | Carbon steels    | P            | ...      |
| A134          | A285 Grade A, B                                                             | CS B           | Carbon steels    | P            | ...      |
| A134          | A285 Grade C                                                                | CS A           | Carbon steels    | P            | ...      |
| A134          | A36                                                                         | CS A           | Carbon steels    | P            | ...      |
| A134          | A1011 Designation SS Grade 30, 33, 36 Type 1 and 2, 40, 45 Type 1 and 2, 50 | CS A           | Carbon steels    | P            | ...      |
| A135          | Grade A, B                                                                  | CS B           | Carbon steels    | P            | ...      |
| A139          | Grade A, B, C, D, E                                                         | CS A           | Carbon steels    | P            | ...      |
| A178          | Grade A, C                                                                  | CS -20         | Carbon steels    | T            | ...      |
| A179          | ...                                                                         | CS -20         | Carbon steels    | T            | ...      |
| A181          | Class 60, 70                                                                | CS A           | Carbon steels    | FI & FO      | ...      |
| A182          | Grade F1, F2, F5, F5a, F9, F11, F12, F21, F22, F91                          | LA -20         | Low-alloy steels | FI & FO      | ...      |
| A182          | Grade F10                                                                   | SS -325        | Stainless steels | FI & FO      | (3)      |
| A182          | Grade F10                                                                   | SS -20         | Stainless steels | FI & FO      | (4)      |
| A182          | Grade F304, F304L, F316, F316L                                              | SS -425        | Stainless steels | FI & FO      | ...      |
| A182          | Grade F304H, F316H, F317L, F321, F321H, F347, F347H, F348, F348H            | SS -325        | Stainless steels | FI & FO      | ...      |
| A182          | Grade F310                                                                  | SS -325        | Stainless steels | FI & FO      | (3), (5) |
| A182          | Grade F310                                                                  | SS -20         | Stainless steels | FI & FO      | (4), (5) |
| A182          | Grade F6a                                                                   | SS -20         | Stainless steels | FI & FO      | (5)      |
| A182          | Grade F60 (S32205)                                                          | SS -20         | Stainless steels | FI & FO      | (5)      |
| A182          | Grade S32760                                                                | SS -60         | Stainless steels | FI & FO      | ...      |
| A192          | ...                                                                         | CS -20         | Carbon steels    | T            | ...      |
| A193          | Grade B5 ≤4 in., B16 ≤4 in.                                                 | LA -20         | Low-alloy steels | B            | ...      |
| A193          | Grade B6                                                                    | SS -20         | Stainless steels | B            | ...      |
| A193          | Grade B7 (≤2½ in.)                                                          | LA -55         | Low-alloy steels | B            | ...      |
| A193          | Grade B7 (>2½ in., ≤4 in.)                                                  | LA -40         | Low-alloy steels | B            | ...      |
| A193          | Grade B7M (≤4 in.)                                                          | LA -55         | Low-alloy steels | B            | ...      |
| A193          | Grade B8 Class 1, B8C Class 1                                               | SS -425        | Stainless steels | B            | ...      |
| A193          | Grade B8 Class 2, B8C Class 2, B8M, B8T                                     | SS -325        | Stainless steels | B            | (6)      |
| A194          | Grade 1                                                                     | CS -20         | Carbon steels    | N            | ...      |
| A194          | Grade 3                                                                     | LA -20         | Low-alloy steels | N            | ...      |
| A194          | Grade 6                                                                     | SS -20         | Stainless steels | N            | ...      |

Table 3.2-1 Material Groupings by Material Specification (Cont'd)

| Specification | Type/Grade/Class/Condition/Temper/UNS                   | T-Number Group | Material Type    | Product Form | Notes         |
|---------------|---------------------------------------------------------|----------------|------------------|--------------|---------------|
| A194          | Grade 2, 2H, 2HM                                        | CS -55         | Carbon steels    | N            | ...           |
| A194          | Grade 7, 7M                                             | LA -150        | Low-alloy steels | N            | ...           |
| A194          | Grade 8, 8CA, 8FA, 8MA, 8TA                             | SS -325        | Stainless steels | N            | ...           |
| A194          | Grade 8A                                                | SS -425        | Stainless steels | N            | ...           |
| A197          | ...                                                     | CI -20(A)      | Cast irons       | C            | ...           |
| A203          | Grade A, B, D, E                                        | LA -20         | Low-alloy steels | PL           | ...           |
| A204          | Grade A, B, C                                           | LA -20         | Low-alloy steels | PL           | ...           |
| A210          | Grade A-1                                               | CS -20         | Carbon steels    | T            | ...           |
| A214          | ...                                                     | CS -20         | Carbon steels    | T            | ...           |
| A216          | Grade WCA, WCB, WCC                                     | CS -20         | Carbon steels    | C            | ...           |
| A217          | Grade C5, C12, WC1, WC4, WC5, WC6, WC9                  | LA -20         | Low-alloy steels | C            | ...           |
| A217          | Grade CA-15                                             | SS -20         | Stainless steels | C            | (5)           |
| A234          | Grade WP1, WP5, WP9, WP11, WP12, WP22, WP91             | LA -20         | Low-alloy steels | FI           | ...           |
| A234          | Grade WPB, WPC                                          | CS B           | Carbon steels    | FI           | ...           |
| A240          | Type 305                                                | SS -325        | Stainless steels | PL           | (1), (3)      |
| A240          | Type 305                                                | SS -20         | Stainless steels | PL           | (2) or (4)    |
| A240          | Type 302, 317, 317L, 321, 321H, 347, 348                | SS -325        | Stainless steels | PL           | (1)           |
| A240          | Type 302, 317, 317L, 321H, 348                          | SS -20         | Stainless steels | PL           | (2)           |
| A240          | Type 304, 304L, 316, 316L                               | SS -425        | Stainless steels | PL           | (1)           |
| A240          | Type 304, 304L, 316, 316L, 321, 347                     | SS -20         | Stainless steels | PL           | (2)           |
| A240          | Type 309S, 310S                                         | SS -325        | Stainless steels | PL           | (1), (5)      |
| A240          | Type 309S, 310S                                         | SS -20         | Stainless steels | PL           | (2), (5)      |
| A240          | Type 405, 410, 410S, 420, 429, X8M                      | SS -20         | Stainless steels | PL           | (5)           |
| A240          | UNS S32205                                              | SS -20         | Stainless steels | PL           | (5)           |
| A240          | UNS S32760                                              | SS -60         | Stainless steels | PL           | ...           |
| A268          | Grade TP405, TP409, TP410, TP430, TP430Ti, TP433, TP436 | SS -20         | Stainless steels | T            | (5)           |
| A269          | Grade TP304, TP304L, TP316, TP316L                      | SS -425        | Stainless steels | P            | (1)           |
| A269          | Grade TP304, TP304L, TP316, TP316L                      | SS -20         | Stainless steels | P            | (2)           |
| A278          | Class 20, 25, 30, 35, 40, 45, 50, 60                    | CI -20         | Cast irons       | C            | ...           |
| A283          | Grade C, D                                              | CS A           | Carbon steels    | PL           | ...           |
| A285          | Grade A, B                                              | CS B           | Carbon steels    | PL           | ...           |
| A285          | Grade C                                                 | CS A           | Carbon steels    | PL           | ...           |
| A299          | ...                                                     | CS A           | Carbon steels    | PL           | ...           |
| A302          | Grade A, B, C, D                                        | LA -20         | Low-alloy steels | PL           | ...           |
| A307          | Grade B                                                 | CS -20         | Carbon steels    | B            | ...           |
| A312          | Grade TP304, TP304L, TP316, TP316L                      | SS -425        | Stainless steels | P            | (1)           |
| A312          | Grade TP304, TP304L, TP316, TP316L                      | SS -20         | Stainless steels | P            | (2)           |
| A312          | Grade TP304H, TP316H, TP321H, TP347H, TP348H            | SS -325        | Stainless steels | P            | ...           |
| A312          | Grade TP309, TP310                                      | SS -325        | Stainless steels | P            | (1), (3), (5) |

Table 3.2-1 Material Groupings by Material Specification (Cont'd)

| Specification | Type/Grade/Class/Condition/Temper/UNS                        | T-Number Group | Material Type    | Product Form | Notes           |
|---------------|--------------------------------------------------------------|----------------|------------------|--------------|-----------------|
| A312          | Grade TP309, TP310                                           | SS -20         | Stainless steels | P            | (2) or (4), (5) |
| A312          | Grade TP317, TP317L, TP321, TP347, TP348                     | SS -325        | Stainless steels | P            | (1)             |
| A312          | Grade TP317, TP317L, TP321, TP347, TP348                     | SS -20         | Stainless steels | P            | (2)             |
| A320          | Grade B8 Class 1, B8C Class 1                                | SS -425        | Stainless steels | B            | ...             |
| A320          | Grade B8 Class 2, B8C Class 2, B8F, B8M, B8T                 | SS -325        | Stainless steels | N            | ...             |
| A320          | Grade L7, L43                                                | LA -150        | Low-alloy steels | B            | (7)             |
| A320          | Grade L7A, L7B, L7C                                          | LA -150        | Low-alloy steels | B            | (7)             |
| A320          | Grade L7M                                                    | LA -100        | Low-alloy steels | B            | (7)             |
| A333          | Grade 8                                                      | LA -320        | Low-alloy steels | P            | (7)             |
| A333          | Grade 1, 6                                                   | CS -50         | Carbon steels    | P            | (7)             |
| A333          | Grade 3, 4                                                   | LA -150        | Low-alloy steels | P            | (7)             |
| A333          | Grade 7, 9                                                   | LA -100        | Low-alloy steels | P            | (7)             |
| A334          | Grade 3                                                      | LA -150        | Low-alloy steels | T            | (7)             |
| A334          | Grade 8                                                      | LA -320        | Low-alloy steels | T            | (7)             |
| A334          | Grade 1, 6                                                   | CS -50         | Carbon steels    | T            | (7)             |
| A334          | Grade 7, 9                                                   | LA -100        | Low-alloy steels | T            | (7)             |
| A335          | Grade P1, P2, P5, P5b, P5c, P9, P11, P12, P15, P21, P22, P91 | LA -20         | Low-alloy steels | P            | ...             |
| A350          | Grade LF1                                                    | CS -20         | Carbon steels    | FI & FO      | (7)             |
| A350          | Grade LF2 Class 1                                            | CS -50         | Carbon steels    | FI & FO      | (7)             |
| A350          | Grade LF2 Class 2                                            | CS 0           | Carbon steels    | FI & FO      | (7)             |
| A350          | Grade LF3                                                    | LA -150        | Low-alloy steels | FI & FO      | (7)             |
| A351          | Grade CE20N, CH20, CK20, HK30, HK40                          | SS -20         | Stainless steels | C            | (5)             |
| A351          | Grade CF8C, CF10MC, CH8, CH10, CN7M                          | SS -325        | Stainless steels | C            | ...             |
| A351          | Grade HT30                                                   | SS -325        | Stainless steels | C            | (1)             |
| A351          | Grade CF3, CF3A, CF3M, CF8, CF8A, CF8M                       | SS -425        | Stainless steels | C            | ...             |
| A352          | Grade LC1                                                    | LA -75         | Low-alloy steels | C            | (7)             |
| A352          | Grade LC2                                                    | LA -100        | Low-alloy steels | C            | (7)             |
| A352          | Grade LC3                                                    | LA -150        | Low-alloy steels | C            | (7)             |
| A352          | Grade LCB                                                    | CS -50         | Carbon steels    | C            | (7)             |
| A353          | ...                                                          | LA -320        | Low-alloy steels | PL           | (7)             |
| A354          | Grade BC                                                     | LA 0           | Low-alloy steels | B            | ...             |
| A354          | Grade BD                                                     | LA +20         | Low-alloy steels | B            | ...             |
| A358          | Grade 304, 304L, 316, 316L                                   | SS -425        | Stainless steels | P            | (1)             |
| A358          | Grade 304, 304L, 316, 316L                                   | SS -20         | Stainless steels | P            | (2)             |
| A358          | Grade 309S, 310S                                             | SS -325        | Stainless steels | P            | (1), (5)        |
| A358          | Grade 309S, 310S                                             | SS -20         | Stainless steels | P            | (2), (5)        |
| A358          | Grade 321, 347, 348, S34565                                  | SS -325        | Stainless steels | P            | (1)             |
| A358          | Grade 321, 347, 348, S34565                                  | SS -20         | Stainless steels | P            | (2)             |

Table 3.2-1 Material Groupings by Material Specification (Cont'd)

| Specification | Type/Grade/Class/Condition/Temper/UNS                                    | T-Number Group | Material Type    | Product Form | Notes           |
|---------------|--------------------------------------------------------------------------|----------------|------------------|--------------|-----------------|
| A369          | Grade FP1, FP2, FP3b, FP5, FP9, FP11, FP12, FP21, FP22                   | LA -20         | Low-alloy steels | P            | ...             |
| A369          | Grade FPA                                                                | CS B           | Carbon steels    | P            | ...             |
| A369          | Grade FPB                                                                | CS -20         | Carbon steels    | P            | ...             |
| A376          | Grade 16-8-2H                                                            | SS -325        | Stainless steels | P            | (1), (5)        |
| A376          | Grade 16-8-2H                                                            | SS -20         | Stainless steels | P            | (2), (5)        |
| A376          | Grade TP304, TP316                                                       | SS -425        | Stainless steels | P            | (1)             |
| A376          | Grade TP304, TP316, TP321, TP347, TP348                                  | SS -20         | Stainless steels | P            | (2)             |
| A376          | Grade TP304H, TP316H, TP321, TP321H, TP347, TP347H, TP348                | SS -325        | Stainless steels | P            | (1)             |
| A376          | Grade TP304H, TP316H, TP321H, TP347H                                     | SS -20         | Stainless steels | P            | (2)             |
| A381          | Class Y35, Y42, Y46, Y48, Y50, Y52, Y56, Y60                             | CS A           | Carbon steels    | P            | ...             |
| A387          | Grade 2, 5, 9, 11, 12, 21, 22, 91                                        | LA -20         | Low-alloy steels | PL           | ...             |
| A395          | ...                                                                      | CI -20(A)      | Cast irons       | C            | ...             |
| A403          | Grade WP304, WP304L, WP316, WP316L                                       | SS -425        | Stainless steels | FI           | ...             |
| A403          | Grade WP304H, WP316H, WP317, WP317L, WP321, WP321H, WP347H, WP347, WP348 | SS -325        | Stainless steels | FI           | ...             |
| A403          | Grade WP309, WP310                                                       | SS -325        | Stainless steels | FI           | (3), (5)        |
| A403          | Grade WP309, WP310                                                       | SS -20         | Stainless steels | FI           | (4), (5)        |
| A409          | Grade TP304, TP316                                                       | SS -425        | Stainless steels | P            | (1)             |
| A409          | Grade TP304, TP316                                                       | SS -20         | Stainless steels | P            | (2)             |
| A409          | Grade TP309, TP310                                                       | SS -20         | Stainless steels | P            | (2) or (4), (5) |
| A409          | Grade TP309, TP310                                                       | SS -325        | Stainless steels | P            | (1), (3), (5)   |
| A409          | Grade TP317, TP321, TP347, TP348                                         | SS -325        | Stainless steels | P            | (1)             |
| A409          | Grade TP317, TP321, TP347, TP348                                         | SS -20         | Stainless steels | P            | (2)             |
| A414          | Grade A                                                                  | CS B           | Carbon steels    | PL           | ...             |
| A414          | Grade B, C, D, E, F, G                                                   | CS A           | Carbon steels    | PL           | ...             |
| A420          | Grade WPL3                                                               | LA -150        | Low-alloy steels | FI           | (7)             |
| A420          | Grade WPL6                                                               | CS -50         | Carbon steels    | FI           | (7)             |
| A420          | Grade WPL8                                                               | LA -320        | Low-alloy steels | FI           | (7)             |
| A426          | Grade CP1, CP2, CP5, CP5b, CP9, CP11, CP12, CP15, CP21, CP22             | LA -20         | Low-alloy steels | P            | ...             |
| A426          | Grade CPCA-15                                                            | SS -20         | Stainless steels | P            | (5)             |
| A437          | Grade B4B, B4C                                                           | SS -20         | Stainless steels | B            | ...             |
| A451          | Grade CPE20N, CPH8, CPH10, CPH20, CPK20                                  | SS -20         | Stainless steels | P            | (5)             |
| A451          | Grade CPF8, CPF8C, CPF8M, CPF10MC                                        | SS -20         | Stainless steels | P            | ...             |
| A453          | Grade 651 Class A, 651 Class B                                           | SS -20         | Stainless steels | B            | ...             |
| A453          | Grade 660 Class A, 660 Class B                                           | SS -325        | Stainless steels | B            | ...             |
| A479          | Type 304H, 316, 316H                                                     | SS -325        | Stainless steels | PL           | (8)             |
| A479          | Type 304, 304L, 316L                                                     | SS -425        | Stainless steels | PL           | (8)             |
| A487          | Grade CA6NM                                                              | SS -20         | Stainless steels | C            | (5)             |
| A515          | Grade 60                                                                 | CS B           | Carbon steels    | PL           | ...             |

Table 3.2-1 Material Groupings by Material Specification (Cont'd)

| Specification | Type/Grade/Class/Condition/Temper/UNS                                                   | T-Number Group | Material Type    | Product Form | Notes |
|---------------|-----------------------------------------------------------------------------------------|----------------|------------------|--------------|-------|
| A515          | Grade 65, 70                                                                            | CS A           | Carbon steels    | PL           | ...   |
| A516          | Grade 55, 60 not normalized                                                             | CS C           | Carbon steels    | PL           | (9)   |
| A516          | Grade 55, 60, 65, 70 normalized                                                         | CS D           | Carbon steels    | PL           | (9)   |
| A516          | Grade 65, 70 not normalized                                                             | CS B           | Carbon steels    | PL           | (9)   |
| A524          | Grade I, II                                                                             | CS -20         | Carbon steels    | P            | ...   |
| A536          | Grade 60-40-18, 65-45-12                                                                | CI -20         | Cast irons       | C            | ...   |
| A537          | Class 1                                                                                 | CS D           | Carbon steels    | PL           | ...   |
| A553          | Type 2                                                                                  | LA -275        | Low-alloy steels | PL           | (7)   |
| A553          | Type 1                                                                                  | LA -320        | Low-alloy steels | PL           | (7)   |
| A563          | Grade A                                                                                 | CS -20(A)      | Carbon steels    | N            | ...   |
| A571          | Type D-2M Class 1                                                                       | CI -20         | Cast irons       | C            | (10)  |
| A587          | ...                                                                                     | CS -20         | Carbon steels    | P            | ...   |
| A645          | ...                                                                                     | LA -275        | Low-alloy steels | PL           | (7)   |
| A671          | Grade CA55 (A285 Gr C), CB70 (A515 Gr 70), CK75 (A299), CMS75 (A299)                    | CS A           | Carbon steels    | P            | ...   |
| A671          | Grade CB60 (A515 Gr 60)                                                                 | CS B           | Carbon steels    | P            | ...   |
| A671          | Grade CC60 (A516 Gr 60) not normalized                                                  | CS C           | Carbon steels    | P            | (9)   |
| A671          | Grade CC65 (A516 Gr 65), CC70 (A516 Gr 70) not normalized                               | CS B           | Carbon steels    | P            | (9)   |
| A671          | Grade CC60 (A516 Gr 60), CC65 (A516 Gr 65), CC70 (A516 Gr 70) normalized                | CS D           | Carbon steels    | P            | (9)   |
| A671          | Grade CD70 (A537 Cl 1)                                                                  | CS D           | Carbon steels    | P            | ...   |
| A671          | Grade CF70, CF71                                                                        | LA -20         | Low-alloy steels | P            | ...   |
| A672          | Grade A45 (A285 Gr A), A50 (A285 Gr B), B60 (A515 Gr 60)                                | CS B           | Carbon steels    | P            | ...   |
| A672          | Grade A55 (A285 Gr C), B65 (A515 Gr 65), B70 (A515 Gr 70), N75 (A299)                   | CS A           | Carbon steels    | P            | ...   |
| A672          | Grade C55 (A516 Gr 55), C60 (A516 Gr 60) not normalized                                 | CS C           | Carbon steels    | P            | (9)   |
| A672          | Grade C65 (A516 Gr 65), C70 (A516 Gr 70) not normalized                                 | CS B           | Carbon steels    | P            | (9)   |
| A672          | Grade C55 (A516 Gr 55), C60 (A516 Gr 60), C65 (A516 Gr 65), C70 (A516 Gr 70) normalized | CS D           | Carbon steels    | P            | (9)   |
| A672          | Grade D70 (A537 Cl 1)                                                                   | CS D           | Carbon steels    | P            | ...   |
| A672          | Grade L65, L70, L75                                                                     | LA -20         | Low-alloy steels | P            | ...   |
| A675          | Grade 45, 50, 55, 60, 65, 70, 80                                                        | CS -20         | Carbon steels    | B            | (11)  |
| A691          | Grade ½CR, 1CR, 1¼CR, 2¼CR, 3CR, 5CR, 9CR, CM-65, CM-70, CM-75, P91                     | LA -20         | Low-alloy steels | P            | ...   |
| A691          | Grade CMS-75 (A299)                                                                     | CS A           | Carbon steels    | P            | ...   |
| A691          | Grade CMSH-70 (A537 Cl 1)                                                               | CS D           | Carbon steels    | P            | ...   |
| A789          | UNS S31803, S32304, S32750, S32760                                                      | SS -60         | Stainless steels | T            | ...   |
| A789          | UNS S32205                                                                              | SS -20         | Stainless steels | P            | (5)   |
| A789          | UNS S32900                                                                              | SS -20         | Stainless steels | T            | ...   |
| A790          | UNS S31803, S32304, S32750, S32760                                                      | SS -60         | Stainless steels | P            | ...   |

Table 3.2-1 Material Groupings by Material Specification (Cont'd)

| Specification | Type/Grade/Class/Condition/Temper/UNS                                                              | T-Number Group | Material Type    | Product Form | Notes |
|---------------|----------------------------------------------------------------------------------------------------|----------------|------------------|--------------|-------|
| A790          | UNS S32205                                                                                         | SS -20         | Stainless steels | P            | (5)   |
| A790          | UNS S32900                                                                                         | SS -20         | Stainless steels | P            | ...   |
| A815          | UNS S32205                                                                                         | SS -20         | Stainless steels | FI & FO      | (5)   |
| A815          | UNS S32760                                                                                         | SS -60         | Stainless steels | FI & FO      | ...   |
| A995          | Grade 2A, 6A                                                                                       | SS -60         | Stainless steels | C            | ...   |
| A1011         | Designation SS Grade 30, 33, 36 Type 1 and 2, 40, 45 Type 1 and 2, 50                              | CS A           | Carbon steels    | PL           | ...   |
| API 5L        | Grade A, A25 (Smls & ERW), B                                                                       | CS B           | Carbon steels    | P            | ...   |
| API 5L        | Grade A25 (Butt weld)                                                                              | CS -20(A)      | Carbon steels    | P            | ...   |
| API 5L        | Grade X42, X46, X52, X56, X60, X65, X70, X80                                                       | CS A           | Carbon steels    | P            | ...   |
| API 5L        | Grade X42, X46, X52, X56, X60, X65, X70, X80                                                       | CS B           | Carbon steels    | P            | (12)  |
| B21           | UNS C46400, C48200, C48500                                                                         | CU -325        | Copper alloys    | B            | (11)  |
| B42           | UNS C10200, C12000, C12200                                                                         | CU -452        | Copper alloys    | P            | ...   |
| B43           | UNS C23000                                                                                         | CU -452        | Copper alloys    | P            | ...   |
| B61           | UNS C92200                                                                                         | CU -325        | Copper alloys    | C            | ...   |
| B62           | UNS C83600                                                                                         | CU -325        | Copper alloys    | C            | ...   |
| B68           | UNS C12200                                                                                         | CU -452        | Copper alloys    | T            | ...   |
| B75           | UNS C10200, C12000, C12200                                                                         | CU -452        | Copper alloys    | T            | ...   |
| B88           | UNS C12200                                                                                         | CU -452        | Copper alloys    | T            | ...   |
| B96           | UNS C65500                                                                                         | CU -452        | Copper alloys    | PL           | ...   |
| B98           | UNS C65100, C65500, C66100                                                                         | CU -325        | Copper alloys    | B            | (11)  |
| B148          | UNS C95200, C95300, C95500                                                                         | CU -452        | Copper alloys    | C            | ...   |
| B148          | UNS C95400, C95600                                                                                 | CU -325        | Copper alloys    | C            | ...   |
| B150          | UNS C61400, C63000, C64200                                                                         | CU -325        | Copper alloys    | B            | (11)  |
| B152          | UNS C10200, C10400, C10500, C10700, C12200, C12300                                                 | CU -452        | Copper alloys    | PL           | ...   |
| B169          | UNS C61400                                                                                         | CU -452        | Copper alloys    | PL           | ...   |
| B171          | UNS C70600, C71500                                                                                 | CU -452        | Copper alloys    | PL           | ...   |
| B187          | UNS C10200, C11000, C12000, C12200                                                                 | CU -325        | Copper alloys    | B            | (11)  |
| B280          | UNS C12200                                                                                         | CU -452        | Copper alloys    | T            | ...   |
| B283          | UNS C11000, C46400, C65500                                                                         | CU -452        | Copper alloys    | FO           | ...   |
| B283          | UNS C37700, C48500, C67500                                                                         | CU -325        | Copper alloys    | FO           | ...   |
| B466          | UNS C70600, C71000                                                                                 | CU -452        | Copper alloys    | P & T        | ...   |
| B467          | UNS C70600, C71500                                                                                 | CU -452        | Copper alloys    | P            | ...   |
| B493          | Grade R60702, R60705                                                                               | ZI -75         | Zirconium        | FO           | ...   |
| B523          | Grade R60702, R60705                                                                               | ZI -75         | Zirconium        | T            | ...   |
| B550          | Grade R60702, R60705                                                                               | ZI -75         | Zirconium        | PL           | ...   |
| B551          | Grade R60702, R60705                                                                               | ZI -75         | Zirconium        | PL           | ...   |
| B584          | UNS C86200, C86300, C86400, C86500, C86700, C90300, C90500, C92200, C92300, C97300, C97600, C97800 | CU -325        | Copper alloys    | C            | ...   |
| B658          | Grade R60702, R60705                                                                               | ZI -75         | Zirconium        | P            | ...   |
| Various       | Various                                                                                            | NI -325        | Nickel alloys    | ...          | ...   |

**Table 3.2-1 Material Groupings by Material Specification (Cont'd)**

| Specification | Type/Grade/Class/Condition/Temper/UNS | T-Number Group | Material Type | Product Form | Notes |
|---------------|---------------------------------------|----------------|---------------|--------------|-------|
| Various       | Various                               | AL -452        | Aluminum      | ...          | ...   |
| Various       | Various                               | TI -75         | Titanium      | ...          | ...   |

## GENERAL NOTES:

(a) Specifications are ASTM unless otherwise indicated.

(b) Product form abbreviations are

B = bolts

C = castings

FI = fittings

FO = forgings

N = nuts

P = pipe

PL = plates, sheets, and bars

T = tube

## NOTES:

(1) Solution heat treated after forming.

(2) Not solution heat treated after forming.

(3) Carbon content  $\leq 0.10\%$ .(4) Carbon content  $> 0.10\%$ .

(5) This material may have low impact properties at room temperature after being exposed to high service temperatures.

(6) Strain-hardened varieties of this carbide solution-treated bolting material can also be used at the low temperatures indicated.

(7) Material specification requires impact testing.

(8) Strain-hardened varieties of this material can also be used at the low temperatures indicated.

(9) This materials group depends on whether they are normalized.

(10) Minimum temperature  $-195^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) with impact testing.

(11) Bar specification used for making bolting material.

(12) T-number group CS B may be used only when normalized or quenched and tempered.

**Table 4.4.2-1 Charpy Impact Test (Absorbed Energy)  
Temperature Reduction for Material or Specimens  
<10 mm (0.394 in.)**

| Actual Material Thickness or Charpy<br>Impact Specimen Width [Note (1)] |       | Temperature<br>Reduction Below<br>Design Minimum<br>Temperature |    |
|-------------------------------------------------------------------------|-------|-----------------------------------------------------------------|----|
| mm                                                                      | in.   | °C                                                              | °F |
| 10 (full-size standard bar)                                             | 0.394 | 0                                                               | 0  |
| 9                                                                       | 0.354 | 0                                                               | 0  |
| 8                                                                       | 0.315 | 0                                                               | 0  |
| 7.5 ( $\frac{3}{4}$ -size bar)                                          | 0.295 | 2.8                                                             | 5  |
| 7                                                                       | 0.276 | 4.4                                                             | 8  |
| 6.67 ( $\frac{2}{3}$ -size bar)                                         | 0.262 | 5.6                                                             | 10 |
| 6                                                                       | 0.236 | 8.3                                                             | 15 |
| 5 ( $\frac{1}{2}$ -size bar)                                            | 0.197 | 11.1                                                            | 20 |
| 4                                                                       | 0.157 | 16.7                                                            | 30 |
| 3.33 ( $\frac{1}{3}$ -size bar)                                         | 0.131 | 19.4                                                            | 35 |
| 3                                                                       | 0.118 | 22.2                                                            | 40 |
| 2.5 ( $\frac{1}{4}$ -size bar)                                          | 0.098 | 27.8                                                            | 50 |

GENERAL NOTE: These temperature reduction criteria do not apply when Table 4.5.1-1 specifies lateral expansion for minimum required values.

NOTE: (1) Straight-line interpolation for intermediate values is permitted.

(21)

**Table 4.5.1-1 Minimum Required Charpy V-Notch Impact Values**

| Specified Minimum Tensile Strength                                                         | Number of Specimens (See Para. 4.5.4 for Retests) | Energy (Standard Size Specimens) |        |                                    |        |
|--------------------------------------------------------------------------------------------|---------------------------------------------------|----------------------------------|--------|------------------------------------|--------|
|                                                                                            |                                                   | Fully Deoxidized Steels          |        | Other Than Fully Deoxidized Steels |        |
|                                                                                            |                                                   | J                                | ft-lbf | J                                  | ft-lbf |
| Carbon, Low-Alloy Steels, and Other Materials (Other Than Steels in P-Numbers 6, 7, and 8) |                                                   |                                  |        |                                    |        |
| 448 MPa (65 ksi) and less                                                                  | Average for three specimens                       | 18                               | 13     | 14                                 | 10     |
|                                                                                            | Minimum for one specimen                          | 14                               | 10     | 10                                 | 7      |
| Over 448 MPa (65 ksi) to 517 MPa (75 ksi)                                                  | Average for three specimens                       | 20                               | 15     | 18                                 | 13     |
|                                                                                            | Minimum for one specimen                          | 16                               | 12     | 14                                 | 10     |
| Over 517 MPa (75 ksi ) to 656 MPa (95 ksi)                                                 | Average for three specimens                       | 27                               | 20     | ...                                | ...    |
|                                                                                            | Minimum for one specimen                          | 20                               | 15     | ...                                | ...    |
| Lateral Expansion                                                                          |                                                   |                                  |        |                                    |        |
| Over 656 MPa (95 ksi)                                                                      | Minimum for three specimens                       | 0.38 mm (0.015 in.)              |        |                                    |        |
| Steels in P-Numbers 6, 7, and 8                                                            |                                                   |                                  |        |                                    |        |
| All                                                                                        | Minimum for three specimens                       | 0.38 mm (0.015 in.)              |        |                                    |        |

## MANDATORY APPENDIX I IMPACT TEST EXEMPTION CURVES

(21)

Refer to [paras. 3.3](#) and [3.5](#) for applicability of the impact test exemption curves in [Figures I-1](#) and [I-1M](#) and [Table I-1](#) of this Appendix.

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(21) Figure I-1 Impact Test Exemption Curves for T-Number Groups CS A, CS B, CS C, and CS D (U.S. Customary Units)

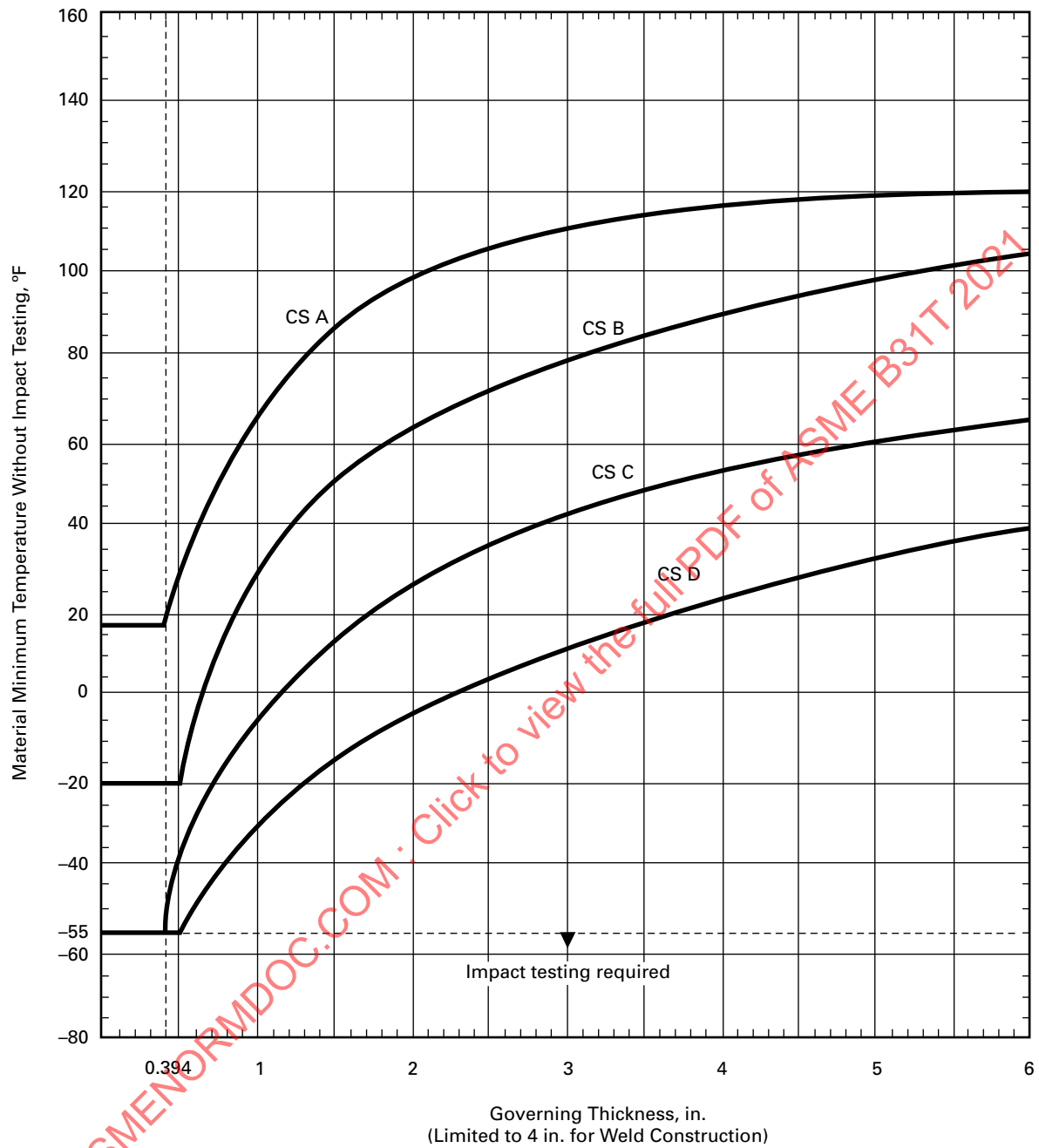
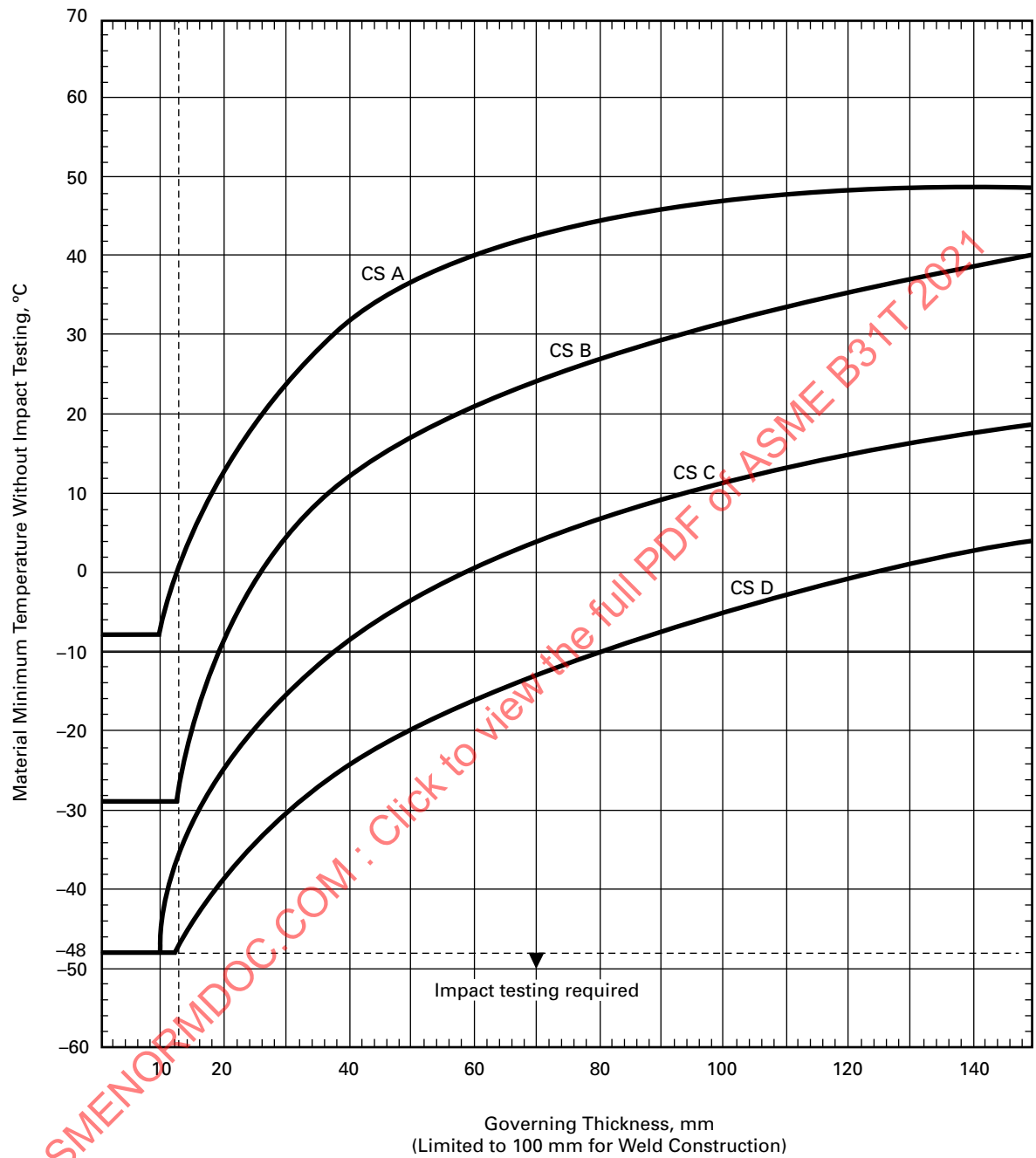


Figure I-1M Impact Test Exemption Curves for T-Number Groups CS A, CS B, CS C, and CS D (SI Units)

(21)



(21)

Table I-1 Tabular Values for Figures I-1 and I-1M

| U.S. Customary Units     |                                                         |            |            |            | SI Units                |                                                         |            |            |            |
|--------------------------|---------------------------------------------------------|------------|------------|------------|-------------------------|---------------------------------------------------------|------------|------------|------------|
| Governing Thickness, in. | Material Minimum Temperature Without Impact Testing, °F |            |            |            | Governing Thickness, mm | Material Minimum Temperature Without Impact Testing, °C |            |            |            |
|                          | Curve CS A                                              | Curve CS B | Curve CS C | Curve CS D |                         | Curve CS A                                              | Curve CS B | Curve CS C | Curve CS D |
| 0.25                     | 18                                                      | -20        | -55        | -55        | 6.4                     | -8                                                      | -29        | -48        | -48        |
| 0.3125                   | 18                                                      | -20        | -55        | -55        | 7.9                     | -8                                                      | -29        | -48        | -48        |
| 0.375                    | 18                                                      | -20        | -55        | -55        | 9.5                     | -8                                                      | -29        | -48        | -48        |
| 0.4375                   | 25                                                      | -20        | -40        | -55        | 11.1                    | -4                                                      | -29        | -40        | -48        |
| 0.5                      | 32                                                      | -20        | -34        | -55        | 12.7                    | 0                                                       | -29        | -37        | -48        |
| 0.5625                   | 37                                                      | -7         | -26        | -51        | 14.3                    | 3                                                       | -22        | -32        | -46        |
| 0.625                    | 43                                                      | 2          | -22        | -48        | 15.9                    | 6                                                       | -17        | -30        | -44        |
| 0.6875                   | 48                                                      | 9          | -18        | -45        | 17.5                    | 9                                                       | -13        | -28        | -43        |
| 0.75                     | 53                                                      | 15         | -15        | -42        | 19.1                    | 12                                                      | -9         | -26        | -41        |
| 0.8125                   | 57                                                      | 20         | -12        | -38        | 20.6                    | 14                                                      | -7         | -24        | -39        |
| 0.875                    | 61                                                      | 25         | -9         | -36        | 22.2                    | 16                                                      | -4         | -23        | -38        |
| 0.9375                   | 65                                                      | 29         | -6         | -33        | 23.8                    | 18                                                      | -2         | -21        | -36        |
| 1                        | 68                                                      | 33         | -3         | -30        | 25.4                    | 20                                                      | 1          | -19        | -34        |
| 1.0625                   | 72                                                      | 36         | -1         | -28        | 27.0                    | 22                                                      | 2          | -18        | -33        |
| 1.125                    | 75                                                      | 39         | 2          | -26        | 28.6                    | 24                                                      | 4          | -17        | -32        |
| 1.1875                   | 77                                                      | 42         | 4          | -23        | 30.2                    | 25                                                      | 6          | -16        | -31        |
| 1.25                     | 80                                                      | 44         | 6          | -21        | 31.8                    | 27                                                      | 7          | -14        | -29        |
| 1.3125                   | 82                                                      | 46         | 8          | -19        | 33.3                    | 28                                                      | 8          | -13        | -28        |
| 1.375                    | 84                                                      | 48         | 10         | -18        | 34.9                    | 29                                                      | 9          | -12        | -28        |
| 1.4375                   | 86                                                      | 49         | 12         | -16        | 36.5                    | 30                                                      | 9          | -11        | -27        |
| 1.5                      | 88                                                      | 51         | 14         | -14        | 38.1                    | 31                                                      | 11         | -10        | -26        |
| 1.5625                   | 90                                                      | 53         | 16         | -13        | 39.7                    | 32                                                      | 12         | -9         | -25        |
| 1.625                    | 92                                                      | 55         | 17         | -11        | 41.3                    | 33                                                      | 13         | -8         | -24        |
| 1.6875                   | 93                                                      | 57         | 19         | -10        | 42.9                    | 34                                                      | 14         | -7         | -23        |
| 1.75                     | 94                                                      | 58         | 20         | -8         | 44.5                    | 34                                                      | 14         | -7         | -22        |
| 1.8125                   | 96                                                      | 59         | 22         | -7         | 46.0                    | 36                                                      | 15         | -6         | -22        |
| 1.875                    | 97                                                      | 61         | 23         | -6         | 47.6                    | 36                                                      | 16         | -5         | -21        |
| 1.9375                   | 98                                                      | 62         | 24         | -5         | 49.2                    | 37                                                      | 17         | -4         | -21        |
| 2                        | 99                                                      | 63         | 26         | -4         | 50.8                    | 37                                                      | 17         | -3         | -20        |
| 2.0625                   | 100                                                     | 64         | 27         | -3         | 52.4                    | 38                                                      | 18         | -3         | -19        |
| 2.125                    | 101                                                     | 65         | 28         | -2         | 54.0                    | 38                                                      | 18         | -2         | -19        |
| 2.1875                   | 102                                                     | 66         | 29         | -1         | 55.6                    | 39                                                      | 19         | -2         | -18        |
| 2.25                     | 102                                                     | 67         | 30         | 0          | 57.2                    | 39                                                      | 19         | -1         | -18        |
| 2.3125                   | 103                                                     | 68         | 31         | 1          | 58.7                    | 39                                                      | 20         | -1         | -17        |
| 2.375                    | 104                                                     | 69         | 32         | 2          | 60.3                    | 40                                                      | 21         | 0          | -17        |
| 2.4375                   | 105                                                     | 70         | 33         | 3          | 61.9                    | 41                                                      | 21         | 1          | -16        |
| 2.5                      | 105                                                     | 71         | 34         | 4          | 63.5                    | 41                                                      | 22         | 1          | -16        |
| 2.5625                   | 106                                                     | 71         | 35         | 5          | 65.1                    | 41                                                      | 22         | 2          | -15        |
| 2.625                    | 107                                                     | 73         | 36         | 6          | 66.7                    | 42                                                      | 23         | 2          | -14        |

Table I-1 Tabular Values for Figures I-1 and I-1M (Cont'd)

| U.S. Customary Units     |                                                         |            |            |            | SI Units                |                                                         |            |            |            |
|--------------------------|---------------------------------------------------------|------------|------------|------------|-------------------------|---------------------------------------------------------|------------|------------|------------|
| Governing Thickness, in. | Material Minimum Temperature Without Impact Testing, °F |            |            |            | Governing Thickness, mm | Material Minimum Temperature Without Impact Testing, °C |            |            |            |
|                          | Curve CS A                                              | Curve CS B | Curve CS C | Curve CS D |                         | Curve CS A                                              | Curve CS B | Curve CS C | Curve CS D |
| 2.6875                   | 107                                                     | 73         | 37         | 7          | 68.3                    | 42                                                      | 23         | 3          | -14        |
| 2.75                     | 108                                                     | 74         | 38         | 8          | 69.9                    | 42                                                      | 23         | 3          | -13        |
| 2.8125                   | 108                                                     | 75         | 39         | 8          | 71.4                    | 42                                                      | 24         | 4          | -13        |
| 2.875                    | 109                                                     | 76         | 40         | 9          | 73.0                    | 43                                                      | 24         | 4          | -13        |
| 2.9375                   | 109                                                     | 77         | 40         | 10         | 74.6                    | 43                                                      | 25         | 4          | -12        |
| 3                        | 110                                                     | 77         | 41         | 11         | 76.2                    | 43                                                      | 25         | 5          | -12        |
| 3.0625                   | 111                                                     | 78         | 42         | 12         | 77.8                    | 44                                                      | 26         | 6          | -11        |
| 3.125                    | 111                                                     | 79         | 43         | 12         | 79.4                    | 44                                                      | 26         | 6          | -11        |
| 3.1875                   | 112                                                     | 80         | 44         | 13         | 81.0                    | 44                                                      | 27         | 7          | -11        |
| 3.25                     | 112                                                     | 80         | 44         | 14         | 82.6                    | 44                                                      | 27         | 7          | -10        |
| 3.3125                   | 113                                                     | 81         | 45         | 15         | 84.1                    | 45                                                      | 27         | 7          | -9         |
| 3.375                    | 113                                                     | 82         | 46         | 15         | 85.7                    | 45                                                      | 28         | 8          | -9         |
| 3.4375                   | 114                                                     | 83         | 46         | 16         | 87.3                    | 46                                                      | 28         | 8          | -9         |
| 3.5                      | 114                                                     | 83         | 47         | 17         | 88.9                    | 46                                                      | 28         | 8          | -8         |
| 3.5625                   | 114                                                     | 84         | 48         | 17         | 90.5                    | 46                                                      | 29         | 9          | -8         |
| 3.625                    | 115                                                     | 85         | 49         | 18         | 92.1                    | 46                                                      | 29         | 9          | -8         |
| 3.6875                   | 115                                                     | 85         | 49         | 19         | 93.7                    | 46                                                      | 29         | 9          | -7         |
| 3.75                     | 116                                                     | 86         | 50         | 20         | 95.3                    | 47                                                      | 30         | 10         | -7         |
| 3.8125                   | 116                                                     | 87         | 51         | 21         | 96.8                    | 47                                                      | 31         | 11         | -6         |
| 3.875                    | 116                                                     | 88         | 51         | 21         | 98.4                    | 47                                                      | 31         | 11         | -6         |
| 3.9375                   | 117                                                     | 88         | 52         | 22         | 100.0                   | 47                                                      | 32         | 11         | -6         |
| 4                        | 117                                                     | 89         | 52         | 23         | 101.6                   | 47                                                      | 32         | 11         | -5         |
| 4.0625                   | 117                                                     | 90         | 53         | 23         | 103.2                   | 47                                                      | 32         | 12         | -5         |
| 4.125                    | 118                                                     | 90         | 54         | 24         | 104.8                   | 48                                                      | 32         | 12         | -4         |
| 4.1875                   | 118                                                     | 91         | 54         | 25         | 106.4                   | 48                                                      | 33         | 12         | -4         |
| 4.25                     | 118                                                     | 91         | 55         | 25         | 108.0                   | 48                                                      | 33         | 13         | -4         |
| 4.3125                   | 118                                                     | 92         | 55         | 26         | 109.5                   | 48                                                      | 33         | 13         | -3         |
| 4.375                    | 119                                                     | 93         | 56         | 27         | 111.1                   | 48                                                      | 34         | 13         | -3         |
| 4.4375                   | 119                                                     | 93         | 56         | 27         | 112.7                   | 48                                                      | 34         | 13         | -3         |
| 4.5                      | 119                                                     | 94         | 57         | 28         | 114.3                   | 48                                                      | 34         | 14         | -2         |
| 4.5625                   | 119                                                     | 94         | 57         | 29         | 115.9                   | 48                                                      | 34         | 14         | -2         |
| 4.625                    | 119                                                     | 95         | 58         | 29         | 117.5                   | 48                                                      | 35         | 14         | -2         |
| 4.6875                   | 119                                                     | 95         | 58         | 30         | 119.1                   | 48                                                      | 35         | 14         | -1         |
| 4.75                     | 119                                                     | 96         | 59         | 30         | 120.7                   | 48                                                      | 36         | 15         | -1         |
| 4.8125                   | 119                                                     | 96         | 59         | 31         | 122.2                   | 48                                                      | 36         | 15         | -1         |
| 4.875                    | 119                                                     | 97         | 60         | 31         | 123.8                   | 48                                                      | 36         | 16         | -1         |
| 4.9375                   | 119                                                     | 97         | 60         | 32         | 125.4                   | 48                                                      | 36         | 16         | 0          |
| 5                        | 119                                                     | 97         | 60         | 32         | 127.0                   | 48                                                      | 36         | 16         | 0          |

Table I-1 Tabular Values for Figures I-1 and I-1M (Cont'd)

| U.S. Customary Units     |                                                         |            |            |            | SI Units                |                                                         |            |            |            |
|--------------------------|---------------------------------------------------------|------------|------------|------------|-------------------------|---------------------------------------------------------|------------|------------|------------|
| Governing Thickness, in. | Material Minimum Temperature Without Impact Testing, °F |            |            |            | Governing Thickness, mm | Material Minimum Temperature Without Impact Testing, °C |            |            |            |
|                          | Curve CS A                                              | Curve CS B | Curve CS C | Curve CS D |                         | Curve CS A                                              | Curve CS B | Curve CS C | Curve CS D |
| 5.0625                   | 119                                                     | 98         | 61         | 33         | 128.6                   | 48                                                      | 37         | 16         | 1          |
| 5.125                    | 119                                                     | 98         | 61         | 33         | 130.2                   | 48                                                      | 37         | 16         | 1          |
| 5.1875                   | 119                                                     | 98         | 62         | 34         | 131.8                   | 48                                                      | 37         | 17         | 1          |
| 5.25                     | 119                                                     | 99         | 62         | 34         | 133.4                   | 48                                                      | 37         | 17         | 1          |
| 5.3125                   | 119                                                     | 99         | 62         | 35         | 134.9                   | 48                                                      | 37         | 17         | 2          |
| 5.375                    | 119                                                     | 100        | 63         | 35         | 136.5                   | 48                                                      | 38         | 17         | 2          |
| 5.4375                   | 119                                                     | 100        | 63         | 36         | 138.1                   | 48                                                      | 38         | 17         | 2          |
| 5.5                      | 119                                                     | 100        | 63         | 36         | 139.7                   | 48                                                      | 38         | 17         | 2          |
| 5.5625                   | 119                                                     | 101        | 64         | 36         | 141.3                   | 48                                                      | 38         | 18         | 2          |
| 5.625                    | 119                                                     | 101        | 64         | 37         | 142.9                   | 48                                                      | 38         | 18         | 3          |
| 5.6875                   | 119                                                     | 102        | 64         | 37         | 144.5                   | 48                                                      | 39         | 18         | 3          |
| 5.75                     | 120                                                     | 102        | 65         | 38         | 146.1                   | 49                                                      | 39         | 18         | 3          |
| 5.8125                   | 120                                                     | 103        | 65         | 38         | 147.6                   | 49                                                      | 39         | 18         | 3          |
| 5.875                    | 120                                                     | 103        | 66         | 38         | 149.2                   | 49                                                      | 39         | 19         | 3          |
| 5.9375                   | 120                                                     | 104        | 66         | 39         | 150.8                   | 49                                                      | 40         | 19         | 4          |
| 6                        | 120                                                     | 104        | 66         | 39         | 152.4                   | 49                                                      | 40         | 19         | 4          |