LOW TEMPERATURE OPERATION

UCS-65  SCOPE

The following paragraphs contain requirements for vessels and vessel parts constructed of carbon and low alloy steels with respect to minimum design metal temperatures.

UCS-66  MATERIALS

(a) Unless exempted by the rules of UG-20(f) or other rules of this Division, Figure UCS-66 shall be used to establish impact testing exemptions for steels listed in Part UCS. When Figure UCS-66 is used, impact testing is required for a combination of minimum design metal temperature (see UG-20) and governing thickness (as defined below) that is below the curve assigned to the subject material. If a minimum design metal temperature and governing thickness combination is on or above the curve, impact testing is not required by the rules of this Division, except as required by (j) below and UCS-67(a)(3) for weld metal. Components, such as shells, heads, nozzles, manways, reinforcing pads, flanges, tubesheets, flat cover plates, backing strips which remain in place, and attachments which are essential to the structural integrity of the vessel when welded to pressure-retaining components, shall be treated as separate components. Each component shall be evaluated for impact test requirements based on its individual material classification, governing thickness as defined in (1) and (2) below, and the minimum design metal temperature.

(1) The following governing thickness definitions apply when using Figure UCS-66:

(-a) Excluding castings, the governing thickness \( t_g \) of a welded part is as follows:

(-1) for butt joints except those in flat heads and tubesheets, the nominal thickness of the thickest welded joint [see Figure UCS-66.3, sketch (a)].

(-2) for corner, fillet, or lap-welded joints, including attachments as defined above, the thinner of the two parts joined.

(-3) for flat heads or tubesheets, the larger of (-2) above or the flat component thickness divided by 4.

(-4) for welded assemblies comprised of more than two components (e.g., nozzle-to-shell joint with reinforcing pad), the governing thickness and permissible minimum design metal temperature of each of the individual welded joints of the assembly shall be determined, and the warmest of the minimum design metal temperatures shall be used as the permissible minimum design metal temperature of the welded assembly. [See Figure UCS-66.3, sketch (b)].

(-5) if the governing thickness at any welded joint exceeds 4 in. (100 mm) and the minimum design metal temperature is colder than 120°F (50°C), impact tested material shall be used.

(-b) The governing thickness of a casting shall be its largest nominal thickness.

UCS-57  RADIOGRAPHIC EXAMINATION

In addition to the requirements of UW-11, complete radiographic examination is required for each butt-welded joint at which the thinner of the plate or vessel wall thicknesses at the welded joint exceeds the thickness limit above which full radiography is required in Table UCS-57.

### Table UCS-56.1

<table>
<thead>
<tr>
<th>Decrease in Temperature Below Minimum Specified Temperature, °F (°C)</th>
<th>Minimum Holding Time [Note (1)] at Decreased Temperature, hr</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 (28)</td>
<td>2</td>
<td>...</td>
</tr>
<tr>
<td>100 (56)</td>
<td>4</td>
<td>...</td>
</tr>
<tr>
<td>150 (83)</td>
<td>10</td>
<td>(2)</td>
</tr>
<tr>
<td>200 (111)</td>
<td>20</td>
<td>(2)</td>
</tr>
</tbody>
</table>

GENERAL NOTE: Applicable only when permitted in Tables UCS-56-1 through UCS-56-11.

NOTES:

(1) Minimum holding time for 1 in. (25 mm) thickness or less. Add 15 min per inch (25 mm) of thickness for thicknesses greater than 1 in. (25 mm).

(2) These lower postweld heat treatment temperatures permitted only for P-No. 1 Gr. Nos. 1 and 2 materials.

### Table UCS-57

<table>
<thead>
<tr>
<th>Nominal Thickness Above Which Butt-Welded Joints Shall Be Fully Radiographed, in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 (32)</td>
</tr>
<tr>
<td>3/16 (16)</td>
</tr>
<tr>
<td>0 (0)</td>
</tr>
<tr>
<td>1/6 (16)</td>
</tr>
<tr>
<td>0 (0)</td>
</tr>
<tr>
<td>1/6 (16)</td>
</tr>
<tr>
<td>0 (0)</td>
</tr>
<tr>
<td>1/6 (16)</td>
</tr>
<tr>
<td>1/6 (16)</td>
</tr>
<tr>
<td>0 (0)</td>
</tr>
</tbody>
</table>

GENERAL NOTE: Applicable only when permitted in Tables UCS-56-1 through UCS-56-11.
The governing thickness of flat nonwelded parts, such as bolted flanges, tubesheets, and flat heads, is the flat component thickness divided by 4.

The governing thickness of a nonwelded dished head [see Figure 1-6, sketch (c)] is the greater of the flat flange thickness divided by 4 or the minimum thickness of the dished portion.

If the governing thickness of the nonwelded part exceeds 6 in. (150 mm) and the minimum design metal temperature is colder than 120°F (50°C), impact tested material shall be used.

Examples of the governing thickness for some typical vessel details are shown in Figure UCS-66.3.

NOTE: The use of provisions in UCS-66 which waive the requirements for impact testing does not provide assurance that all test results for these materials would satisfy the impact energy requirements of UG-84 if tested.

When the coincident ratio defined in Figure UCS-66.1 is less than one, Figure UCS-66.1 provides a basis for the use of components made of Part UCS materials to have a colder MDMT than that derived from (a) above without impact testing. Use of Figure UCS-66.1 is not permitted for bolts and nuts.

(a) For such components, and for a MDMT of −55°F (−48°C) and warmer, the MDMT without impact testing determined in (a) above for the given material is

For pressure vessel attachments that are exposed to tensile stresses from internal pressure (e.g., nozzle reinforcement pads, horizontal vessel saddle attachments, and stiffening rings), the coincident ratio shall be that of the shell or head to which each component is attached.
and thickness may be reduced as determined from Figure UCS-66.2. If the resulting temperature is colder than the required MDMT, impact testing of the material is not required.

(b) Figure UCS-66.1 may also be used for components not stressed in general primary membrane tensile stress, such as flat heads, covers, tubesheets, and flanges. The MDMT of these components without impact testing as determined in (a) or (c) may be reduced as determined from Figure UCS-66.2. The ratio used in Step 3 of Figure UCS-66.2 shall be the ratio of maximum design pressure (MAP) of the component at the MDMT. If the resulting temperature is colder than the required MDMT, impact testing of the material is not required, provided the MDMT is not colder than $-55^\circ F$ ($-48^\circ C$).

(c) In lieu of using (b) above, the MDMT determined in (a) may be reduced for a flange attached by welding, by the same reduction as determined in (a) above for the neck or shell which the flange is attached.

NOTE: The bolt-up condition need not be considered when determining the temperature reduction for flanges.

(d) Longitudinal stress in the vessel due to net-section bending that results in general primary membrane tensile stress (e.g., due to wind or earthquake in a vertical vessel, at mid-span and in the plane of the saddles of a saddle-supported horizontal vessel, etc.) shall be considered when calculating the coincident ratio in Step 3 of Figure UCS-66.2 [See Note (2) of Figure UCS-66.2].
When the coincident ratio defined in Figure UCS-66.1 is greater than 0.35, the corresponding minimum design metal temperature shall not be colder than the impact test temperature less the allowable temperature reduction permitted in Figure UCS-66.1 and shall in no case be colder than $-155^\circ F \left(-104^\circ C\right)$. 

Materials produced and impact tested in accordance with the requirements of the specifications listed in Figure UG-84.1, General Note (c), are exempt from impact testing by the rules of this Division at minimum design metal temperatures not more than 5°F (3°C) colder than the test temperature required by the specification.

No impact testing is required for metal backing strips which remain in place made of materials assigned to Curve A of Figure UCS-66 in thicknesses not exceeding $\frac{7}{4}$ in. (6 mm) when the minimum design metal temperature is $-20^\circ F \left(-29^\circ C\right)$ or warmer.

For components made of Part UCS materials that are impact tested, Figure UCS-66.1 provides a basis for the use of these components at an MDMT colder than the impact test temperature.

For such components, the MDMT shall not be colder than the impact test temperature less the allowable temperature reduction as determined from Figure UCS-66.2.

Figure UCS-66.1 may also be used for components not stressed in general primary membrane tensile stress, such as flat heads, covers, tubesheets, and flanges. The MDMT shall not be colder than the impact test temperature less the allowable temperature reduction as determined from Figure UCS-66.2. The ratio used in Step 3 of Figure UCS-66.2 shall be the ratio of maximum design pressure at the MDMT to the maximum allowable pressure (MAP) of the component at the MDMT.

For pressure vessel attachments that are exposed to tensile stresses from internal pressure (e.g., nozzle reinforcement pads, horizontal vessel saddle attachments, and stiffening rings), the coincident ratio shall be that of the shell or head to which each component is attached.
(3) In lieu of using (2) above, the MDMT for a flange attached by welding shall not be colder than the impact test temperature less the allowable temperature reduction as determined in (1) above for the neck or shell to which the flange is attached.

(5) (a) The MDMT adjustment as determined in (1) above may be used for impact tested welding procedures or production welds.

(6) (a) The MDMT for the component shall not be colder than −155°F (−105°C).

(6) (b) When the base metal is exempt from impact testing by (g) above or by Figure UCS-66, Curve C or Curve D, −20°F (−29°C) is the coldest MDMT to be assigned for welded components that do not meet the requirements of UCS-67(a)(3).

**UCS-67 IMPACT TESTS OF WELDING PROCEDURES**

Except as exempted in UG-20(f), UCS-66, and UCS-68, the welding procedure qualification shall include impact tests of the weld metal and heat-affected zones (HAZ) in accordance with UG-84 when required by the following provisions. The minimum design metal temperature (MDMT) used below shall be either the MDMT stamped on the nameplate or the exemption temperature of the welded component before applying the temperature reduction permitted by UCS-66(b) or UCS-68(c).

(a) Welds made with filler metal shall be deposited using welding procedures qualified with impact testing in accordance with UG-84 when any of the following apply:

(1) when either base metal is required to be impact tested by the rules of this Division; or

(2) when the thickness of any individual weld pass exceeds 1/2 in. (13 mm) and the MDMT is colder than 70°F (21°C); or

(3) when joining base metals exempt from impact testing by UCS-66(g) or Figure UCS-66, Curve C or D and the MDMT is colder than −20°F (−29°C) but not colder than −55°F (−48°C). Qualification of the welding procedure with impact testing is not required when no individual weld pass in the production weld exceeds 1/4 in. (6 mm) in thickness; and each heat and/or lot of filler metal or combination of heat and/or lot of filler metal and batch of flux has been classified by their manufacturer through impact testing per the applicable SFA specification at a temperature not warmer than the MDMT. Additional testing beyond the scope of the SFA specification may be performed by the filler metal and/or flux manufacturer to expand their classification for a broader range of temperatures; or

(4) when joining base metals exempt from impact testing by UCS-66(g) and the MDMT is colder than −55°F (−48°C).

(b) Except for welds made as part of the material specification, welds in Part UCS materials made without filler metal shall be completed using welding procedures qualified with impact testing any of the following conditions apply:

(1) when either base metal is required to be impact tested by the rules of this Division; or

(2) the thickness at the weld exceeds 1/4 in. (13 mm) regardless of the MDMT; or

(3) when the thickness at the weld exceeds 1/16 in. (8 mm) and the MDMT is colder than 50°F (10°C); or

(4) when joining base metals exempt from impact testing by UCS-66(g) and the MDMT is colder than −55°F (−48°C).

**UCS-68 DESIGN**

(a) Welded joints shall comply with UW-2(b) when the minimum design metal temperature is colder than −55°F (−48°C), unless the coincident ratio defined in Figure UCS-66.1 is less than 0.35.

(b) Welded joints shall be postweld heat treated in accordance with the requirements of UW-40 when required by other rules of this Division. When the minimum design metal temperature is colder than −55°F (−48°C), and the coincident ratio defined in Figure UCS-66.1 is 0.35 or greater, postweld heat treatment is required, except that this requirement does not apply to the following welded joints, in vessels or vessel parts fabricated of P-No. 1 materials that are impact tested at the MDMT or colder in accordance with UG-84. The minimum average energy requirement for base metals and weldments shall be 25 ft-lb (34 J) instead of the values shown in Figure UG-84.1:

(1) Type 1 Category A and B joints, not including cone-to-cylinder junctions, which have been 100% radiographed. Category A and B joints attaching sections of unequal thickness shall have a transition with a slope not exceeding 3:1.

(2) the following welds:

(-a) fillet welds having leg dimensions not exceeding 3/8 in. (10 mm) attaching lightly loaded attachments, provided the attachment material and the attachment weld meet requirements of UCS-66 and UCS-67. “Lightly loaded attachment,” for this application, is defined as an attachment for which the stress in the attachment weld does not exceed 25% of the allowable stress.

(-b) seal welds defined in UW-20.2(c).

All such welds as described in (-a) and (-b) shall be examined by magnetic particle or liquid penetrant examination in accordance with Mandatory Appendix 6 or Mandatory Appendix 8.

(c) If postweld heat treating of a pressure-retaining weld is performed when it is not otherwise a requirement of this Division, a 30°F (17°C) reduction in impact testing exemption temperature may be given to the minimum permissible temperature from Figure UCS-66 for P-No. 1
3.11.2.5 Exemption From Impact Testing Based on Design Stress Values.

(a) A colder MDMT for a component than that derived from 3.11.2.2 or 3.11.2.3 may be determined in accordance with the procedure outlined below.

Step 1. For the welded part under consideration, determine the nominal thickness of the part, \( t_n \), and the required governing thickness of the part, \( t_g \), using 3.11.2.3(b).

Step 2. Determine the applicable material toughness curve to be used in Figure 3.7 for parts not subject to PWHT or Figure 3.8 for parts subject to PWHT. See 3.11.2.2(b) for materials having a specified minimum yield strength greater than 450 MPa (65 ksi).

Step 3. Determine the MDMT from Figure 3.7 for parts not subject to PWHT or Figure 3.8 for parts subject to PWHT based on the applicable toughness curve and the governing thickness, \( t_g \). For materials having a specified minimum yield strength greater than 450 MPa (65 ksi), the MDMT shall be determined by impact testing per 3.11.2.2(b).

Step 4. Based on the design loading conditions at the MDMT, determine the stress ratio, \( R_{ts} \), using one of the equations shown below. Note that this ratio can be computed in terms of required design thickness and nominal thickness, applied stress and allowable design stress, or applied pressure and maximum allowable working pressure based on the design rules in this Division or ASME/ANSI pressure–temperature ratings.

\[
R_{ts} = \frac{t_n E^*}{t_n CA}\quad \text{Thickness Basis} \quad (3.1)
\]

\[
R_{ts} = \frac{SE^*}{SE}\quad \text{(Stress Basis)} \quad (3.2)
\]

\[
R_{ts} = \frac{P_o}{P_{rating}}\quad \text{(Pressure–Temperature Rating Basis)} \quad (3.3)
\]

Step 5. Determine the final value of the MDMT and evaluate results.

(a) If the computed value of the \( R_{ts} \) ratio from Step 4 is less than or equal to 0.3 for Class 1, or 0.24 for Class 2, then set the MDMT to \(-104^\circ C (-155^\circ F)\).

(b) If the computed value of the \( R_{ts} \) ratio from Step 4 is greater than 0.3 for Class 1, or 0.24 for Class 2, then determine the temperature reduction, \( T_R \). If the specified minimum yield strength is less than or equal to 450 MPa (65 ksi), then determine \( T_R \) from Figure 3.12 for parts not subject to PWHT or Figure 3.13 for parts subject to PWHT based on the \( R_{ts} \) ratio from Step 4. If the specified minimum yield strength is greater than 450 MPa (65 ksi) for parts subject to PWHT, then determine the temperature reduction, \( T_R \) from eq. (3.4). The final computed value of the MDMT is determined using eq. (3.5). The reduction in the MDMT given by eq. (3.5) shall not exceed 55°C (100°F). Impact testing is not required if the specified MDMT is warmer than the computed MDMT. However, if the specified MDMT are colder than \(-48^\circ C (-55^\circ F)\), impact testing is required.

\[
T_R = \frac{-27.20656 - 76.98028 R_{ts} + 103.0992 R_{ts}^2 + 7.433649 \times 10^{-3} S^2}{1 - 1.986738 R_{ts} - 1.758474 \times 10^{-2} S^2 + 6.479035 \times 10^{-7} S^2} \quad (^\circ F, \text{ksi}) \quad (3.4)
\]

MDMT = MDMT_{STEP3} - T_R \quad (3.5)

(b) The procedure in 3.11.2.5(a) above is repeated for each welded part, and the warmest MDMT of all welded parts is the MDMT for the vessel.

(c) For a flange attached by welding, the procedure in 3.11.2.5(a) above can be used by determining the temperature reduction as determined for the neck or shell to which the flange is attached. The bolt-up condition need not be considered when determining the temperature reduction for flanges.
(d) For components not stressed in primary membrane tensile stress such as flat heads, covers, tubesheets, and flanges, the MDMT shall not be colder than the MDMT derived from 3.11.2.3 or the impact test temperature less the allowable temperature reduction as determined in 3.11.2.5(a). The ratio used in 3.11.2.5(a) shall be the ratio of the maximum design pressure at the MDMT to the maximum allowable pressure (MAP) of the component at the MDMT.

3.11.2.6 Adjusting the MDMT for Impact Tested Materials.

(a) For components that are impact tested, the components may be used at a MDMT colder than the impact test temperature, provided the stress ratio defined in 3.11.2.5(a), Step 4 is less than one and the MDMT is not colder than −104°C (−155°F). For such components, the MDMT shall not be colder than the impact test temperature less the allowable temperature reduction as determined from 3.11.2.5 (i.e., the starting point for the MDMT calculation in 3.11.2.5(a), Step 3, is the impact test temperature). [See 3.11.2.4(b)].

(b) One common usage of the exemptions in 3.11.2.5 and 3.11.2.6 will be for vessels in which the pressure is dependent on the vapor pressure of the contents (e.g., vessels in refrigeration, or hydrocarbon processing plants with operating systems that do not permit immediate repressurization). For such services, the primary thickness calculations (shell and head) normally will be made for the maximum design pressure coincident with the design (MDMT) temperature expected. The ratio of required thickness/nominal thickness as defined in 3.11.2.5(a), Step 4, for the design condition is then calculated. Thickness calculations are also made for other expected pressures at coincident temperature, along with the ΔT difference from the MDMT [see 3.11.2.5(a), Step 3], and the thickness ratio defined in 3.11.2.5(a), Step 4. Ratio/ΔT points that are on or below the line in Figure 3.12 (for as-welded parts) or Figure 3.13 (for PWHT or nonwelded parts), as applicable, are acceptable, but in no case may the operating temperature be colder than −104°C (−155°F). Comparison of pressure-temperature coincident ratios or stress coincident ratios may also be used as illustrated in 3.11.2.5(a), Step 4.

3.11.2.7 Vessel or Components Operating Below the MDMT. Vessels or components may be operated at temperatures colder than the MDMT stamped on the nameplate if:

(a) The provisions of 3.11.2 are met when using the reduced (colder) operating temperature as the MDMT, but in no case shall the operating temperature be colder than −104°C (−155°F); or

(b) For vessels or components whose thicknesses are based on pressure loading only, the coincident operating temperature may be as cold as the MDMT stamped on the nameplate less the allowable temperature reduction as determined from 3.11.2.5. The ratio used in 3.11.2.5(a), Step 4, of the procedure in 3.11.2.5 shall be the ratio of maximum pressure at the coincident operating temperature to the design pressure of the vessel at the stamped MDMT, but in no case shall the operating temperature be colder than −104°C (−155°F).

3.11.2.8 Establishment of the MDMT Using a Fracture Mechanics Methodology.

(a) In lieu of the procedures in 3.11.2.1 through 3.11.2.7, the MDMT may be established using a fracture mechanics approach. The fracture mechanics procedures shall be in accordance with API 579-1/ASME FFS, Part 9, Level 2 or Level 3.

(b) The assessment used to determine the MDMT shall include a systematic evaluation of all factors that control the susceptibility to brittle fracture, e.g., stresses from the applied loadings including thermal stresses, flaw size, fracture toughness of the base metal and welded joints, heat treatment, and the loading rate.

(c) The reference flaw size used in the fracture mechanics evaluation shall be a surface flaw with a depth of a = min[t/4, 25 mm (1 in.)] and a length of 2c = 6a where t is the thickness of the plate containing the reference flaw. If approved by the user, an alternative reference flaw size may be used based on the weld joint geometry and the NDE that will be used and demonstrated for qualification of the vessel (see Part 7).

(d) The material fracture toughness shall be established using the exemption curve for the material (see Notes to Figures 3.7 and 3.8) and MPC Charpy impact energy correlation described in API 579-1/ASME FFS-1, Appendix E, F.4. If approved by the user, an alternative material fracture toughness may be used based on fracture toughness test results.

(e) The MDMT established using a fracture mechanics approach shall not be colder than that given in 3.11.2.3(e).

3.11.2.9 Postweld Heat Treatment Requirements for Materials in Low Temperature Service.

(a) If the MDMT is colder than −48°C (−55°F) and the stress ratio defined in 3.11.2.5(a), Step 4 is greater than or equal to 0.3 for Class 1, or 0.24 for Class 2, then welded joints shall be subject to PWHT in accordance with the requirements of 6.4.2.

(b) The requirement in (a) above does not apply to the welded joints listed in (1) and (2) below in vessel or vessel parts fabricated of P-No. 1 materials that are impact tested at the MDMT or colder in accordance with 3.11.2.1. The minimum average energy requirement for base metal, weld metal, and heat-affected zones shall be 41 J (30 ft-lb) instead of the values shown in Figure 3.3 for parts not subject to PWHT or Figure 3.4 for parts subject to PWHT or for nonwelded parts.

For pressure vessel attachments that are exposed to tensile stresses from internal pressure (e.g., nozzle reinforcement pads, horizontal vessel saddle attachments, and stiffening rings), the coincident ratio shall be that of the shell or head to which each component is attached.