Case N-843
Alternative Pressure Testing Requirements Following Repairs or Replacements for Class 1 Piping Between the First and Second Inspection Isolation Valves
Section XI, Division 1

Inquiry: What alternative rules to the test pressure required by IWB-5221 may be applied following repair or replacement activities for that portion of Class 1 boundary between the first and second isolation valves in the injection path of Class 2 safety systems?

Reply: It is the opinion of the Committee that for the portions of the Class 1 boundary between the first and second isolation valves in the injection path of standby safety systems, the system leakage test following repair or replacement activities may be conducted at the test pressure required for the plant for the periodic leakage test.
Proposed Code Case N-XXX

Case N-XXX
Alternative Pressure Testing Requirements Following Repair/Replacement Activities for Class 1 Piping between the First and Second Injection Isolation Valves, Section XI, Division 1

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Reply: It is the opinion of the Committee that for the portions of the Class 1 boundary between the first and second isolation valves in the injection path of standby safety systems, the system leakage test following repair/replacement activities may be conducted at the test pressure required for the plant for the periodic leakage test.

and $J_{1m}$ shall replace $J_{1e}$ when this Charpy correlation is used. In the absence of specific data, the upper-shelf temperature for ferritic piping steels shall be 200°F (95°C), or the upper-shelf temperatures in Table C-8321-2 may be used for flaws in wall thickness less than or equal to 2.0 in. (51 mm). A lower temperature may be used to define upper-shelf behavior when it is determined from valid heat-specific CVN tests.

C-8322  **Toughness Properties for Axially Oriented Flaws**

The toughness, $J_{1e}$, in the CL direction shall be obtained directly from heat-specific experiments or from correlations with heat-specific CVN data or reasonable lower-bound CVN data. If heat-specific or reasonable lower-bound $K_{1e}$ data for ferritic piping materials with specified minimum yield not greater than 40 ksi (280 MPa) are available for the CL direction, a conservative estimate for $J_{1e}$ shall be determined from the following:

$$J_{1e} = \frac{1000 (K_{1e})^2}{E}$$

Alternatively, values for $J_{1e}$ shall be obtained from Table C-8322-1. In the absence of specific data, the upper-shelf temperature for ferritic piping steels shall be 200°F (95°C), or the upper-shelf temperatures in Table C-8321-2 may be used for flaws in wall thickness less than or equal to 2.0 in. (51 mm). A lower temperature may be used to define upper-shelf behavior when determined from valid heat-specific CVN test.

C-8330  **OTHER PIPING MATERIALS**

For other piping materials, including nonferrous alloys and cast austenitic stainless steel with high ferrite content, similar procedures may be used to establish $J_{1e}$, $K_{1e}$, or $K_e$. Material condition, testing parameters, test results, and toughness correlations shall be appropriate for the pipe material and flaw orientation under evaluation.

C-8400  **FATIGUE CRACK GROWTH RATE**

(13)  

C-8410  **AUSTENITIC STEELS**

The fatigue crack growth behavior of austenitic stainless steels is affected by temperature, $R$ ratio ($K_{1min}/K_{1max}$), and environment. Reference fatigue crack growth rates for air and water environments are given by the following:

(a) Reference fatigue crack growth behavior of cast and wrought austenitic stainless steels and their welds exposed to air environments (e.g., subsurface flaws) are given by eq. C-8210[a](1) with $n = 3.3$ and

$$C_0 = CS$$

where $C$ is a scaling parameter to account for temperature and is given by

(U.S. Customary Units)

$$C = 10^{[ -10.009 + 8.12 \times 10^{-3}T - 1.13 \times 10^{-6}T^2 + 1.02 \times 10^{-9}T^3 ]}$$

(SI Units)

$$C = 10^{[ -10.009 + 8.12 \times 10^{-3}T - 1.13 \times 10^{-6}T^2 + 1.02 \times 10^{-9}T^3 ]}$$

### Table C-8322-1

<table>
<thead>
<tr>
<th>Material Properties for Ferritic Steel Base Metals and Weldments — Axial Flaws</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_y$ (ksi)</td>
</tr>
<tr>
<td>27.1</td>
</tr>
<tr>
<td>(187)</td>
</tr>
</tbody>
</table>
**Table C-8321-1**

Material Properties for Ferritic Steel Base Metals and Weldments — Circumferential Flaws

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>[Note (1)]</td>
<td>[Note (3)]</td>
</tr>
<tr>
<td>[Note (2)]</td>
<td></td>
</tr>
<tr>
<td>Category [Note (1)]</td>
<td>[Note (3)]</td>
</tr>
<tr>
<td>[Note (2)]</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>27.1 (187)</td>
</tr>
<tr>
<td>2</td>
<td>27.1 (187)</td>
</tr>
<tr>
<td></td>
<td>600 (105)</td>
</tr>
<tr>
<td></td>
<td>350 (61)</td>
</tr>
<tr>
<td></td>
<td>27.3 (180)</td>
</tr>
<tr>
<td></td>
<td>27.3 (180)</td>
</tr>
<tr>
<td></td>
<td>45 (8)</td>
</tr>
<tr>
<td></td>
<td>45 (8)</td>
</tr>
</tbody>
</table>

**NOTES:**

(1) Material Category 1: Seamless or welded wrought ferritic steel pipe and pipe fittings that have a specified minimum yield strength not greater than 40 ksi (280 MPa) and welds made with E7015, E7018, and E7018 electrodes in the as-welded or postweld heat treated conditions.

(2) Material Category 2: All other ferritic shielded metal arc and submerged arc welds with a specified minimum tensile strength not greater than 80 ksi (550 MPa) in the as-welded or postweld heat treated conditions.

**Table C-8321-2**

Temperature for Onset of Upper-Shelf Behavior for Axial and Circumferential Flaws in Ferritic Steel Base Metals and Weldments

<table>
<thead>
<tr>
<th>Wall Thickness (in. mm)</th>
<th>Surface Flaws Temperature °F (°C)</th>
<th>Through-Wall Flaws Temperature °F (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥0.25 (6)</td>
<td>-45 (-43)</td>
<td>6 (-14)</td>
</tr>
<tr>
<td>0.375 (10)</td>
<td>-4 (-20)</td>
<td>49 (9)</td>
</tr>
<tr>
<td>0.50 (13)</td>
<td>22 (-6)</td>
<td>73 (23)</td>
</tr>
<tr>
<td>0.625 (16)</td>
<td>35 (2)</td>
<td>86 (30)</td>
</tr>
<tr>
<td>0.75 (19)</td>
<td>43 (6)</td>
<td>94 (35)</td>
</tr>
<tr>
<td>1.00 (25)</td>
<td>52 (11)</td>
<td>104 (40)</td>
</tr>
<tr>
<td>1.25 (32)</td>
<td>58 (15)</td>
<td>110 (43)</td>
</tr>
<tr>
<td>1.50 (38)</td>
<td>65 (17)</td>
<td>114 (46)</td>
</tr>
<tr>
<td>1.75 (44)</td>
<td>66 (19)</td>
<td>118 (49)</td>
</tr>
<tr>
<td>2.00 (51)</td>
<td>70 (21)</td>
<td>121 (50)</td>
</tr>
</tbody>
</table>

**GENERAL NOTES:**

(a) This table is applicable to piping and portions of adjoining pipe fittings within a distance of $(R_p/2)^{1/2}$ from the weld centerline. The weld geometry and weld-base-metal interface are defined in Figure C-1.100.1. Applicability of this table to wrought carbon steel pipe fittings is limited to those fittings that have been heat-treated and subsequently normalized or annealed in accordance with the requirements of the material specification (e.g., Section II, Part A).

(b) The values of temperature in this table may be interpolated to determine temperatures for intermediate values of wall thickness.
TABLE C-8321-1
MATERIAL PROPERTIES FOR FERRITIC STEEL BASE
METALS AND WELDMENTS — CIRCUMFERENTIAL
FLAWS

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Notes</td>
<td>σy (ksi)</td>
<td>Jc (in.-lb/in.²)</td>
</tr>
<tr>
<td>(1), (2)</td>
<td>600</td>
<td>27.3</td>
</tr>
<tr>
<td>1</td>
<td>27.1</td>
<td>27.3</td>
</tr>
<tr>
<td>2</td>
<td>27.1</td>
<td>350</td>
</tr>
</tbody>
</table>

NOTES:
(1) Material Category 1: Seamless or welded wrought ferritic steel pipe and pipe fittings that have a specified minimum yield strength not greater than 40 ksi (276 MPa) and welds made with E7015, E7016, and E7018 electrodes in the as-welded or postweld heat treated conditions.
(2) Material Category 2: All other ferritic shielded metal arc and submerged arc welds with a specified minimum tensile strength not greater than 80 ksi (552 MPa) in the as-welded or postweld heat treated conditions.

TABLE C-8322-1
MATERIAL PROPERTIES FOR FERRITIC STEEL BASE
METALS AND WELDMENTS — AXIAL FLAWS

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>σy (ksi)</td>
<td>Jc (in.-lb/in.²)</td>
</tr>
<tr>
<td>27.1</td>
<td>300</td>
</tr>
</tbody>
</table>

correlations with heat-specific CVN data or reasonable lower-bound CVN data. If heat-specific or reasonable lower-bound Kic data for ferritic piping materials with specified minimum yield not greater than 40 ksi (276 MPa) are available for the CL direction, a conservative estimate for Jc shall be determined from the following:

\[ J_{ic} = 1000 \left( K_{ic} \right)^2 / E \]

Alternatively, values for Jc shall be obtained from Table C-8322-1. In the absence of specific data, the upper-shelf temperature for ferritic piping steels shall be 200°F. A lower temperature may be used to define upper-shelf behavior when determined from valid heat-specific CVN test.

C-8330 OTHER PIPING MATERIALS

For other piping materials, including nonferrous alloys and cast austenitic stainless steel with high ferrite content, similar procedures may be used to establish Jlc, Klc, or Kc. Material condition, testing parameters, test results, and toughness correlations shall be appropriate for the pipe material and flaw orientation under evaluation.

C-8400 FATIGUE CRACK GROWTH RATE

C-8410 Austenitic Steels

The fatigue crack growth behavior of austenitic stainless steels is affected by temperature, R ratio (Kmin / Kmax), and environment. Reference fatigue crack growth rates for air and water environments are given by the following:

(a) Reference fatigue crack growth behavior of cast and wrought austenitic stainless steels and their welds exposed to air environments (e.g., subsurface flaws) are given by Eq. (1) with \( n = 3.3 \) and

\[ C_o = CS \]  

(16)

where \( C \) is a scaling parameter to account for temperature and is given by

\[ C = 10 \left[ 10.009 + 8.12 \times 10^4 T - 1.13 \times 10^6 T^2 + 1.02 \times 10^9 T^3 \right] \]

where \( T \) is the metal temperature in °F (\( T \leq 800°F \)), and \( S \) is a scaling parameter to account for R ratio and is given by:

\[ S = 1.0 \quad \text{when} \quad R \leq 0 \]
\[ = 1.0 + 1.8 R \quad \text{when} \quad 0 < R \leq 0.79 \]
\[ = -43.35 + 57.97 R \quad \text{when} \quad 0.79 < R \leq 1.0 \]

The scaling constant \( C_o \) from Eq. (16) produces fatigue crack growth rates in the units of in./cycle when \( \Delta K_f \) is in the units of ksi in.\(^{0.5} \) and is intended for use when data from the product form are not available. Reference fatigue crack growth rate curves using Eqs. (1) and (16) are provided in Fig. C-8410-1.

(b) Reference fatigue crack growth rates for austenitic stainless steels exposed to water environments are in the course of preparation.
The remaining ligament average thickness, $t_{c,\text{avg}}$, over the degraded area bounded by $d_{\text{adj}}$ shall satisfy:

$$t_{c,\text{avg}} \geq 0.353d_{\text{adj}}\sqrt{\frac{P}{S}}$$  \hspace{1cm} (8)

In addition, the pipe section including the equivalent hole representation shall meet the longitudinal stress limits in the design Code for the piping.

If a flaw growth analysis is performed, the growth in flaw dimensions shall consider the degradation mechanisms as relevant to the application. The flaw is acceptable when there is sufficient thickness in the degraded area to provide the required area reinforcement.

(d) Alternatively, if there is a through-wall opening along a portion of the thinned wall as illustrated in Figure 5 the flaw may be evaluated as two independent planar through-wall flaws, one oriented in the axial direction and the other oriented in the circumferential direction. The minimum wall thickness $t_{\text{min}}$, shall be determined by (b)(1), eq. (4). The allowable through-wall lengths in the axial and circumferential directions shall be determined by varying $t_{\text{adj}}$ shown in Figure 5 from $t_{\text{nom}}$ to $t_{\text{min}}$. The allowable through-wall flaw lengths based on $t_{\text{adj}}$ shall be greater than or equal to the corresponding $L_{\text{axial}}$ and $L_{\text{circ}}$ (see Figure 5) as determined from 3.1(a) and 3.1(b) or 3.1(c), as appropriate. The remaining ligament average thickness, $t_{c,\text{avg}}$, over the degraded area bounded by $L_{\text{axial}}$ and $L_{\text{circ}}$ shall satisfy (c), eq. (8).

3.3 THROUGH-WALL FLAWS IN ELBOWS AND BENT PIPE

Through-wall flaws in elbows and bent pipe may be evaluated using the straight pipe procedures given in 3.1 or 3.2(d), provided the stresses used in the evaluation are adjusted, to account for the geometry differences, as described below. Alternative methods may be used to calculate the stresses used in evaluation.

The hoop stress, $\sigma_h$, for elbow and bent pipe evaluation shall be as follows:

$$\sigma_h = \left(\frac{\rho_d}{2r}\right)\left(\frac{2R_{\text{bend}} + R_b \sin \phi}{2(R_{\text{bend}} + R_b \sin \phi)}\right) + \left(\frac{1.95}{h^{0.7}}\right)\frac{R_b M_b}{I}$$  \hspace{1cm} (9)

where

- $h = \text{flexibility characteristic}$
- $I = \text{moment of inertia based on evaluation wall thickness,} t$
- $M_b = \text{resultant primary bending moment}$
- $R_{\text{bend}} = \text{elbow or bent pipe bend radius}$
- $\phi = \text{circumferential angle defined in Figure 7}$

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The minimum wall thickness, \( t_{\text{min}} \), shall be determined by eq. (4). For evaluation purposes, the adjusted wall thickness, \( t_{\text{adj}} \), is a postulated thickness as shown in Fig. 6. The pipe wall thickness is defined as the thickness of the pipe in the non-degraded region as shown in Fig. 6(a). The diameter of the opening is equal to \( d_{\text{adj}} \) as defined by \( t_{\text{adj}} \) as shown in Fig. 6(a). The postulated value for \( t_{\text{adj}} \) shall be greater than \( t_{\text{min}} \) and shall not exceed the pipe wall thickness. The \( t_{\text{adj}} \) value may be varied between \( t_{\text{min}} \) and the pipe wall thickness to determine whether there is a combination of \( t_{\text{adj}} \) and \( d_{\text{adj}} \) that satisfies the branch reinforcement requirements.

The values of \( t_{\text{adj}} \) and \( d_{\text{adj}} \) of Fig. 6(b) shall satisfy:

\[
d_{\text{adj}} \geq \frac{1.5R_{\text{d}}(t_{\text{adj}} - t_{\text{min}})}{t_{\text{min}}} \quad (7)
\]

The remaining ligament average thickness, \( t_{\text{avg}} \), over the degraded area bounded by \( d_{\text{adj}} \) shall satisfy:

\[
t_{\text{avg}} \geq 0.353d_{\text{adj}}\sqrt{\frac{P}{S}} \quad (8)
\]

In addition, the pipe section including the equivalent hole representation shall meet the longitudinal stress limits in the design Code for the piping.

If a flaw growth analysis is performed, the growth in flaw dimensions shall consider the degradation mechanisms as relevant to the application. The flaw is acceptable when there is sufficient thickness in the degraded area to provide the required area reinforcement.

(d) Alternatively, if there is a through-wall opening along a portion of the thinned wall as illustrated in Fig. 5 the flaw may be evaluated as two independent planar through-wall flaws, one oriented in the axial direction and the other oriented in the circumferential direction. The minimum wall thickness \( t_{\text{min}} \) shall be determined by eq. (4). The allowable through-wall lengths in the axial and circumferential directions shall be determined by varying \( t_{\text{adj}} \) shown in Fig. 5 from \( t_{\text{nom}} \) to \( t_{\text{min}} \). The allowable through-wall flaw lengths based on \( t_{\text{adj}} \) shall be greater than or equal to the corresponding \( L_{\text{axial}} \) and \( L_{\text{circ}} \) (see Fig. 5) as determined from 3.1(a) and 3.1(b) or 3.1(c), as appropriate. The remaining ligament average thickness, \( t_{\text{avg}} \), over the degraded area bounded by \( L_{\text{axial}} \) and \( L_{\text{circ}} \) shall satisfy eq. (8).

### 3.3 Through-wall Flaws in Elbows and Bent Pipe

Through-wall flaws in elbows and bent pipe may be evaluated using the straight pipe procedures given in 3.1 or 3.2(d), provided the stresses used in the evaluation are adjusted, to account for the geometry differences, as described below. Alternative methods may be used to calculate the stresses used in evaluation.

The hoop stress, \( \sigma_h \), for elbow and bent pipe evaluation shall be:

\[
\sigma_h = \left( \frac{pd_{\text{e}}}{2t} \right) \left[ \frac{2R_{\text{bend}} + R_y \sin \phi}{2(R_{\text{bend}} + R_y \sin \phi)} \right] + \left( \frac{1.95}{h^{0.3}} \right) \frac{R_{\text{avg}}}{I} \quad (9)
\]

where

- \( R_{\text{bend}} \) = elbow or bent pipe bend radius
- \( \phi \) = circumferential angle defined in Figure 7
- \( h \) = flexibility characteristic
- \( M_{\text{avg}} \) = resultant primary bending moment
- \( I \) = moment of inertia based on evaluation wall thickness, \( t \)

Equation 9 is only applicable for elbows and bent pipe where \( h \geq 0.1 \).

The axial membrane pressure stress, \( \sigma_m \), for elbow and bent pipe evaluation shall be:

\[
\sigma_m = B_1 \left( \frac{pd_{\text{e}}}{2t} \right) \quad (10)
\]

where \( B_1 \) is a primary stress index as defined in Section III for the piping item. \( B_1 \) shall be equal to 0.5 for elbows and bent pipe.

The axial bending stress, \( \sigma_b \), for elbow and bent pipe evaluation shall be:

\[
\sigma_b = B_3 \left( \frac{D_e M_{\text{avg}}}{2I} \right) \quad (11)
\]

where \( B_3 \) is a primary stress index as defined in Section III for the piping item.

The thermal expansion stress, \( \sigma_t \), for elbow and bent pipe evaluation shall be:

\[
\sigma_t = i \left( \frac{D_e M_{\text{avg}}}{2I} \right) \quad (12)
\]

where

- \( i \) = stress intensification factor as defined in the design Code for the piping item
- \( M_{\text{e}} \) = resultant thermal expansion moment