ILLUSTRATIONS OF TYPICAL SUPPORT EXAMINATION BOUNDARIES (CONT'D)

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NON INTEGRAL SUPPORT

FIG. IWF-1300-1  ILLUSTRATIONS OF TYPICAL SUPPORT EXAMINATION BOUNDARIES (CONT'D)
CASES OF ASME BOILER AND PRESSURE VESSEL CODE

CASE

N-513-4

Approval Date: May 7, 2014

Code Cases will remain available for use until annulled by the applicable Standards Committee.

Case N-513-4
Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or 3 Piping
Section XI, Division 1

Inquiry: What requirements may be used for temporary acceptance of flaws, including through-wall flaws, in moderate energy Class 2 or 3 piping including elbows, bent pipe, reducers, expanders, and branch tees, without performing a repair/replacement activity?

Reply: It is the opinion of the Committee that the following requirements may be used to accept flaws, including through-wall flaws, in moderate energy Class 2 or 3 piping including elbows, bent pipe, reducers, expanders, and branch tees, without performing a repair/replacement activity for a limited time, not exceeding the time to the next scheduled refueling outage.

1 SCOPE

(a) These requirements apply to the ASME Section III, ANSI B31.1, and ANSI B31.7 piping classified by the Owner as Class 2 or 3 that is accessible for inspection. The provisions of this Case do not apply to the following:

(1) pumps, valves, expansion joints, and heat exchangers, except as provided in (b)
(2) weld metal of socket welded joints
(3) leakage through a flange joints
(4) threaded connections employing nonstructural seal welds for leakage protection

(b) This Case may be applied to heat exchanger external tubing or piping, provided the flaw is characterized in accordance with 2(a) and leakage is monitored.

(c) The provisions of this Case apply to Class 2 or 3 piping in liquid systems whose maximum operating temperature does not exceed 200°F (93°C) and whose maximum operating pressure does not exceed 275 psig (1.9 MPa).

(d) The following flaw evaluation criteria are permitted for pipe and tube including elbows, bent pipe, reducers, expanders, and branch tees. The straight pipe flaw evaluation criteria are permitted for adjoining fittings and flanges to a distance of \((R_{ch}t)^{1/4}\) from the weld centerline.

(e) The piping design Code shall be used in determining the stress indices \(B_1\) and \(B_2\), and stress intensification factor, \(i\), for flaw evaluation following Code applicability limits in terms of component geometry, such as \(D_{ch}/t_{nom}\) ratio. If the piping design Code does not provide stress indices, Section III, 2004 Edition or later Editions and Addenda may be used to define \(B_1\) and \(B_2\).

(f) The provisions of this Case demonstrate the integrity of the item and not the consequences of leakage. It is the responsibility of the Owner to consider effects of leakage in demonstrating system operability and performing plant flooding analyses.

2 PROCEDURE

(a) The flaw geometry shall be characterized by volumetric inspection methods or by physical measurement. The full pipe circumference at the flaw location shall be inspected to characterize the length and depth of all flaws in the pipe section.

(b) Flaw shall be classified as planar or nonplanar.

(c) When multiple flaws, including irregular (compound) shape flaws, are detected, the interaction and combined area loss of flaws in a given pipe section shall be accounted for in the flaw evaluation.

(d) A flaw evaluation shall be performed to determine the conditions for flaw acceptance. Section 3 provides accepted methods for conducting the required analysis.

(e) Frequent periodic inspections of no more than 30 day intervals shall be used to determine if flaws are growing and to establish the time, at which the detected flaw will reach the allowable size. Alternatively, a flaw growth evaluation may be performed to predict the time at which the detected flaw will grow to the allowable size.

The flaw growth analysis shall consider the relevant growth mechanisms such as general corrosion or warpage, fatigue, or stress corrosion cracking. When a flaw growth analysis is used to establish the allowable time for temporary operation, periodic examinations of no more than 90 day intervals shall be conducted to verify the flaw growth analysis predictions.

(f) For through-wall leaking flaws, leakage shall be monitored daily to confirm the analysis conditions used in the evaluation remain valid.

The Committee's function is to establish rules of safety, relating only to pressure integrity, governing the construction of boilers, pressure vessels, transport tanks and nuclear components, and in-service inspection for pressure integrity of nuclear components and transport tanks, and to interpret these rules when questions arise regarding their intent. This Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks and nuclear components and the in-service inspection of nuclear components and transport tanks. The user of the Code should refer to other pertinent codes, standards, laws, regulations or other relevant documents.

1 (N-513-4)

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(g) If examinations reveal flaw growth rate to be unacceptable, a repair/replacement activity shall be performed.

(h) Repair/replacement activities shall be performed no later than when the predicted flaw size from either periodic inspection or by flaw growth analysis exceeds the acceptance criteria of 4, or during the next scheduled refueling outage, whichever occurs first. Repair/replacement activities shall be in accordance with IWA-4000.

(i) Evaluations and examination shall be documented in accordance with IWA-6300. The Owner shall document the use of this Case on the applicable data report form.

3 FLAW EVALUATION

Planar flaws in straight pipe shall be evaluated in accordance with the requirements in 3.1. Nonplanar flaws in straight pipe shall be evaluated in accordance with the requirements in 3.2. Through-wall flaws in elbows and bent pipe shall be evaluated in accordance with the requirements in 3.3. Through-wall flaws in reducers, expanders, and branch tees shall be evaluated in accordance with the requirements in 3.4 and 3.5 respectively. Flaw growth evaluation shall be performed in accordance with the requirements in 3.6. Nonferrous materials shall be evaluated in accordance with the requirements in 3.7.

For all flaw evaluations, all Service Level load combinations shall be evaluated to determine the most limiting allowable flaw size.

3.1 PLANAR FLAWS IN STRAIGHT PIPE

(a) For planar flaws, the flaw shall be bounded by a rectangular or circumferential planar area in accordance with the methods described in Section XI Nonmandatory Appendix C. IWA-3300 shall be used to determine when multiple proximate flaws are to be evaluated as a single flaw. The geometry of a through-wall planar flaw is shown in Figure 1.

(b) For planar flaws in austenitic piping, the evaluation procedure in Nonmandatory Appendix C shall be used. Flaw depths up to 100% of wall thickness may be evaluated. When through-wall circumferential flaws are evaluated, the formulas for evaluation given in C-5320 or C-6320 as applicable of Nonmandatory Appendix C may be used, with the flaw depth to thickness ratio, a/t, equal to unity.

When through-wall axial flaws are evaluated, the allowable flaw length is:

\[
\rho_{fl} = 1.58 \sqrt{\rho_{fl}} \left[ \frac{\sigma_f}{(SF_m S_f)} \right]^{1/2} - 1 \tag{1}
\]

\[
\sigma_f = pD_o / 2t \tag{2}
\]

\[
\sigma_f = (S_y + S_f) / 2 \tag{3}
\]

where
- \( D_o \) = pipe outside diameter
- \( p \) = pressure for the loading condition
- \( SF_m \) = structural factor on primary membrane stress as specified in C-2622
- \( S_y \) = Code specified ultimate tensile strength and
- \( S_f \) = Code specified yield strength
- \( \sigma_f \) = flow stress
- \( Z \) = load multiplier for ductile flaw extension (equal to 1.0 when using limit load criteria)

Material properties at the temperature of interest shall be used.
(c) For planar flaws in ferritic piping, the evaluation procedure of Nonmandatory Appendix C shall be used. Flaw depths up to 100% of wall thickness may be evaluated. Flaw depth, \( a \), is defined in Figures C-4310-1 and C-4310-2. When through-wall circumferential flaws are evaluated in accordance with C-5300 or C-6300, the flaw depth to thickness ratio, \( a/t \), shall be set to unity. When applying the Nonmandatory Appendix C screening criteria for through-wall axial flaws, \( a/t \) shall be set to unity, and the reference limit load hoop stress, \( \sigma_R \), shall be defined as \( \sigma_R = (\frac{2}{M_{cr}}) \). When through-wall axial flaws are evaluated in accordance with C-5400 or C-6400, the allowable length is defined by eqs. (b)(1) through (b)(3), with the appropriate structural factors from Nonmandatory Appendix C, C-2622. When through-wall flaws are evaluated in accordance with C-7300 or C-7400, the formulas for evaluation given in C-4300 may be used, but with values for \( F_m \), \( F_p \), and \( F \) applicable to through-wall flaws. Relations for \( F_m \), \( F_p \), and \( F \) that take into account flaw shape and pipe geometry (\( R/t \) ratio) shall be used. The appendix to this Case provides equations for \( F_m \), \( F_p \), and \( F \) for a selected range of \( R/t \). Geometry of a through-wall crack is shown in Figure 1.

3.2 NONPLANAR FLAWS IN STRAIGHT PIPE

(a) The evaluation shall consider the depth and extent of the affected area and require that the wall thickness exceed \( t_{min} \) for a distance that is the greater of 2.5 \( \sqrt{R_{t_{nom}}} \) or 2\( L_{m_{avg}} \) between adjacent thinned regions, where \( R \) is the mean radius of the piping item based on nominal wall thickness and \( L_{m_{avg}} \) is the average of the extent of \( L_m \) below \( t_{min} \) for adjacent areas (see Figure 2). Alternatively, the adjacent thinned regions shall be considered a single thinned region in the evaluation.

(b) For nonplanar flaws, the pipe is acceptable when either (1) and (2), or (2) and (3) are met.

1. The remaining pipe thickness, \( t_{p} \), is greater than or equal to the minimum wall thickness \( t_{min} \):

\[
t_{min} = \frac{p_{tot}}{2(S + 0.4p)}
\]

(4)

2. The remaining degraded pipe section meets the longitudinal stress limits in the design Code for the piping.

3. As an alternative to (1), an evaluation of the remaining pipe thickness, \( t_{p} \), may be performed as given below. The evaluation procedure is a function of the depth and the extent of the affected area as illustrated in Figure 3.

(a) When \( W_m \) is less than or equal to 0.5 \( (R_0 t) \)\(^{1/2} \), where \( R_0 \) is the outside radius and \( W_m \) is defined in Figure 3, the flaw can be classified as a planar flaw and evaluated in accordance with 3.1(a) through 3.1(c), above. When the above requirement is not satisfied, (b) shall be met.

(b) When \( L_{m_{avg}} \) is greater than \( (R_0 t_{min}) \)\(^{1/2} \) and \( t_{avg} \) is determined from Curve 1 of Figure 4, where \( L_{m_{avg}} \) is defined in Figure 3. When the above requirement is not satisfied, (c) shall be met.

(c) When \( L_m \) is less than or equal to 2.65 \( (R_0 t_{min}) \)\(^{1/2} \) and \( f_{nom} \) is greater than 1.13 \( t_{min} \), \( t_{avg} \) is determined by satisfying both of the following equations:

\[
\frac{t_{avg}}{t_{min}} \geq \frac{1.5(R_0 t_{min})^{-1/2}}{1} - \frac{f_{nom}}{t_{min}} + 1.0
\]

(5)

\[
\frac{t_{avg}}{\sqrt{R_0 t_{min}}} \geq \frac{0.353L_m}{L_{m_{avg}}}
\]

(6)

When the above requirements are not satisfied, (d) shall be met.

(d) When the requirements of (a), (b), and (c) are not satisfied, \( t_{avg} \) is determined from Curve 2 of Figure 4.

(c) When there is through-wall leakage along a portion of the thinned wall, as illustrated in Figure 5, the flaw may be evaluated by the branch reinforcement method. The thinned area including the through-wall opening shall be represented by a circular penetration at the flaw location. Only the portion of the flaw lying within \( t_{adj} \) need be considered as illustrated in Figure 6. When evaluating multiple flaws in accordance with (a), only the portions of the flaws contained within \( t_{adj} \) need be considered.

The minimum wall thickness, \( t_{min} \), shall be determined by \( t_{min} \geq R_0 f_{nom} \), eq. (4). For evaluation purposes, the adjusted wall thickness, \( t_{adj} \), is a postulated thickness as shown in Figure 6. The pipe wall thickness is defined as the thickness of the pipe in the non-degraded region as shown in Figure 6(a). The diameter of the opening is equal to \( d_{adj} \) as defined by \( t_{adj} \) as shown in Figure 6(a). The postulated value for \( t_{adj} \) shall be greater than \( t_{min} \) and shall not exceed the pipe wall thickness. The \( t_{adj} \) value may be varied between \( t_{min} \) and the pipe wall thickness to determine whether there is a combination of \( t_{adj} \) and \( d_{adj} \) that satisfies the branch reinforcement requirements.

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

\[
d_{adj} \leq \frac{1.5 \sqrt{R_0 f_{adj} (t_{adj} - t_{min})}}{t_{min}}
\]

(7)

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

\[
t_{c_{avg}} \geq \frac{0.353d_{adj} \sqrt{P}}{S}
\]

(8)
The axial membrane pressure stress, $\sigma_m$, for elbow and bent pipe evaluation shall be as follows:

$$\sigma_m = B_1 \left( \frac{P D}{2 t} \right)$$

(10)

where

$B_1 = \text{primary stress index as defined in Section III for the piping item}$

$= 0.5 \text{ for elbows and bent pipe}$

The axial bending stress, $\sigma_b$, for elbow and bent pipe evaluation shall be as follows:

$$\sigma_b = B_2 \left( \frac{P D M}{2 t} \right)$$

(11)

where

$B_2 = \text{primary stress index as defined in Section III for the piping item}$

The thermal expansion stress, $\sigma_e$, for elbow and bent pipe evaluation shall be as follows:

$$\sigma_e = i \left( \frac{P D M}{2 t} \right)$$

(12)

where

$i = \text{stress intensification factor as defined in the design Code for the piping item}$

$M = \text{resultant thermal expansion moment}$

3.4 THROUGH-WALL FLAWS IN REDUCERS AND EXPANDERS

Through-wall flaws in reducers and expanders 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. Figure 8 illustrates the reducer and expander zones discussed below. Evaluation of flaws in the small end transition zone is outside the scope of this Case.
The hoop stress, \( \sigma_h \), and axial membrane pressure stress, \( \sigma_m \), for reducer or expander evaluation shall be as follows:

\[
\sigma_h = \frac{P D_o}{2t}
\]

\[
\sigma_m = \frac{P D-o}{2t}
\]

where

\( D_o = \) small-end O.D. for flaws in the small-end and the large-end O.D. for all other flaws

The axial bending stress, \( \sigma_b \), and thermal expansion stress, \( \sigma_a \), for reducer or expander evaluation shall be as follows:

\[
\sigma_b = B_2 \left( \frac{D_o M_b}{2L} \right)
\]

\[
\sigma_a = \left( \frac{D_o M_a}{2L} \right)
\]

\( L = \) based on the degraded section

3.5 THROUGH-WALL FLAWS IN BRANCH TEES

Branch reinforcement requirements shall be met in accordance with the design Code. If the design Code did not require reinforcement, for evaluation purposes, a reinforcement region is defined as a region of radius \( D_i \) of the branch pipe from the center of the branch connection. Through-wall flaws in branch tees outside of the reinforcement region may be evaluated using the straight pipe procedures given in 3.2 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. Evaluation of flaws in the region of branch reinforcement is outside the scope of this Case.

The hoop stress, \( \sigma_h \), and axial membrane pressure stress, \( \sigma_m \), for branch tee evaluation shall be determined from eq. 3.4(13) and eq. 3.4(14), respectively. The outside diameter for each of these equations shall be for the branch on run pipe, depending on the flaw location. The axial bending stress, \( \sigma_b \), and thermal expansion stress, \( \sigma_a \), for branch tee evaluation shall be determined from eq. 3.4(15) and eq. 3.4(16) respectively.

3.6 FLAW GROWTH EVALUATION

If a flaw growth analysis is performed, the growth analysis shall consider both corrosion and crack-growth mechanisms as relevant to the application.

In performing a flaw growth analysis, the procedures in Article C-3000 may be used as guidance. Relevant growth rate mechanisms shall be considered. When stress corrosion cracking (SCC) is active, the following growth rate equation shall be used:

\[
da/dt = S_p C \max^n
\]
where $da/dt$ is flaw growth rate in inches/hour, $K_{max}$ is the maximum stress intensity factor under long-term steady state conditions in ksi in. $S_T$ is a temperature correction factor, and $C$ and $n$ are material constants.

For intergranular SCC in austenitic steels, where $T \leq 200°F$ (93°C),

\[
C = 1.79 \times 10^{-8} \\
n = 2.161 \\
S_T = 1
\]

For transgranular SCC in austenitic steels, where $T \leq 200°F$ (93°C),

\[
C = 1.79 \times 10^{-7} \\
n = 2.161 \\
S_T = 3.71 \times 10^8 \left[10^{0.01842 T - 12.25}\right]
\]

The temperature, $T$, is the metal temperature in degrees Fahrenheit. The flaw growth rate curves for the above SCC growth mechanisms are shown in Figures 9 and 10. Other growth rate parameters in eq. (17) may be used, provided they are supported by appropriate data.

### 3.7 NONFERROUS MATERIALS

For nonferrous materials, nonplanar and planar flaws may be evaluated following the general approach of 3.1 through 3.6. For planar flaws in ductile materials, the approach given for austenitic pipe may be used; otherwise, the approach given for ferritic pipe should be applied. Structural factors provided in 4 shall be used. It is the responsibility of the evaluator to establish conservative estimates of strength and fracture toughness for the piping material.

### 4 ACCEPTANCE CRITERIA

Piping containing a circumferential planar flaw is acceptable for temporary service when flaw evaluation provides a margin using the structural factors in
Nonmandatory Appendix C, C-2621. For axial planar flaws, the structural factors for temporary acceptance are as specified in Nonmandatory Appendix C, C-2622. Straight pipe containing a nonplanar part through-wall flaw is acceptable for temporary service if the remaining pipe section meets the longitudinal stress limits in the design Code for the piping and $t_p \geq t_{aoc}$, where $t_{aoc}$ is determined from 3.2(b). Straight pipe containing a nonplanar part through-wall flaw is acceptable for temporary service when the flaw conditions of 3.2(c) or 3.2(d) are satisfied. An elbow or bent pipe containing a nonplanar through-wall flaw is acceptable for temporary service if the flaw conditions of 3.3 are satisfied. A reducer or expander containing a nonplanar through-wall flaw is acceptable for temporary service if the flaw conditions of 3.4 are satisfied. A branch tee containing a nonplanar through-wall flaw is acceptable for temporary service if the flaw conditions of 3.5 are satisfied.
Case N-830
Direct Use of Master Fracture Toughness Curve for Pressure-Retaining Materials of Class 1 Vessels
Section XI

Inquiry: Is it permissible to use a material-specific Master Curve as an alternative fracture toughness curve for crack initiation, \( K_{IC} \), in Section XI, Division 1, Nonmandatory Appendices A and G, for Class 1 pressure-retaining materials, other than bolting?

Reply: It is the opinion of the Committee that a material-specific Master Curve fracture toughness curve generated in accordance with ASTM E1921 may be used as an alternative fracture toughness curve, \( K_{IC} \), in Section XI, Division 1, Nonmandatory Appendices A and G, for Class 1 pressure-retaining materials, other than bolting, with the following additional requirements:

(a) Fracture toughness testing for specific base metal or weld materials in the irradiated or nonirradiated condition shall be performed in accordance with ASTM E1921, “Standard Test Method for the Determination of Reference Temperature, \( T_o \), for Ferritic Steels in the Transition Range.” The minimum test requirements of the test method shall be satisfied for the specific material being evaluated. Test data shall satisfy all of the validity requirements specified in the test method.

(b) Test specimen location and orientation shall meet the requirements of NB-3002 for Charpy V-notch specimens. Any of the specimen geometries in accordance with ASTM E1921 may be used.

(c) The value of \( T_o \) for the test data shall be obtained by the method in (a) above.

(d) Using the value of \( T_o \), a 95% lower tolerance bound Master Curve toughness (ksi-in.0.5 or MPa-m0.5) is calculated from the following equations:

\[ K_{IC} - \text{lower 95\%} = 22.9 + 33.3 \exp\left[0.0106 (T - T_o)\right] \]  

\[ K_{IC} - \text{lower 95\%} = 25.2 + 36.6 \exp\left[0.019 (T - T_o)\right] \]

The Master Curve \( K_{IC} \) curve is defined as this 95% lower tolerance bound curve.

(e) The Master Curve \( K_{IC} \) curve (\( K_{IC, lower 95\%} \)) as a function of \((T - T_o)\) may be used as an alternative to the \( K_{IC} \) curve defined in Section XI, Division 1, Nonmandatory Appendix A, A-4200 or Nonmandatory Appendix G, G-2210 as related to \((T - RT)\).

(f) Plant-specific applications are subject to review and approval by the regulatory authority having jurisdiction at the plant site. For highly irradiated reactor pressure vessel steel exhibiting large fracture toughness shifts, consideration may be given to limiting the lower shelf of \( K_{IC, lower 95\%} \) to a value consistent with the current \( K_{IC} \) curve.

---

1 These equations may also be expressed in terms of \( RT_o \):

(a) (U.S. Customary Units) \( K_{IC} - \text{lower 95\%} = 22.9 + 33.3 \exp\left[0.0106 (T - RT_o + 35)\right] \) ksi-in.0.5 and °F

(b) (SI Units) \( K_{IC} - \text{lower 95\%} = 25.2 + 36.6 \exp\left[0.019 (T - RT_o + 19.4)\right] \) MPa-m0.5 and °C

The Committee's function is to establish rules of safety, relating only to pressure integrity, governing the construction of boilers, pressure vessels, transport tanks and nuclear components, and in-service inspection for pressure integrity of nuclear components and transport tanks, and to interpret these rules when questions arise regarding their intent. This Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks and nuclear components, and the in-service inspection of nuclear components and transport tanks. The user of the Code should refer to other pertinent codes, standards, laws, regulations or other relevant documents.
Case N-830
Direct Use of Master Fracture Toughness Curve for Pressure Retaining Materials of Class 1 Vessels
Section XI, Division 1

Inquiry: Is it permissible to use a material-specific Master Curve as an alternative fracture toughness curve for crack initiation, K<sub>IC</sub>, in Section XI, Division 1, Appendices A and G, for Class 1 pressure retaining materials, other than bolting?

Reply: It is the opinion of the Committee that a material-specific Master Curve fracture toughness curve generated in accordance with ASTM E 1921 may be used as an alternative fracture toughness curve, K<sub>IC</sub>, in Section XI, Division 1, Appendices A and G, for Class 1 pressure retaining materials, other than bolting, with the following additional requirements.

1. Fracture toughness testing for specific base metal or weld materials in the irradiated or non-irradiated condition shall be performed in accordance with ASTM E 1921, "Standard Test Method for the Determination of Reference Temperature, T<sub>r</sub>, for Ferritic Steels in the Transition Range." The minimum test requirements of the test method shall be satisfied for the specific material being evaluated. Test data shall satisfy all of the validity requirements specified in the test method.

2. Test specimen location and orientation shall meet the requirements of NB-2322 for Charpy V-notch specimens. Any of the specimen geometries in accordance with ASTM E 1921 may be used.

3. The value of T<sub>r</sub>, for the test data shall be obtained by the method in (1) above.

4. Using the value of T<sub>r</sub>, a 95% lower tolerance bound Master Curve toughness (ksi-in<sup>1/2</sup> or MPa-m<sup>1/2</sup>) is calculated from the following equations:

   (U.S. Customary Units)
   \[ K_{IC, lower 95\%} = 22.9 + 33.3 \exp \left( 0.0106 \left( T - T_0 \right) \right) \]

   (SI Units)
   \[ K_{IC, lower 95\%} = 25.2 + 36.6 \exp \left( 0.019 \left( T - T_0 \right) \right) \]

   The Master Curve K<sub>IC</sub> curve is defined as this 95% lower tolerance bound curve.

5. The Master Curve K<sub>IC</sub> curve, K<sub>IC, curve (KIC, lower 95%)</sub>, as a function of (T - T<sub>0</sub>) may be used as an alternative to the K<sub>IC</sub> curve defined in A-200 or G-2210 as related to (T - RT<sub>eff</sub>).

6. Plant-specific applications are subject to review and approval by the regulatory authority having jurisdiction at the plant site. For highly irradiated reactor pressure vessel steels exhibiting large fracture toughness shifts, consideration may be given to limiting the lower shelf of K<sub>IC, lower 95%</sub> to a value consistent with the current K<sub>IC</sub> curve.

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Note 1: These equations may also be expressed in terms of RT<sub>eff</sub>:

   \[ K_{IC, lower 95\%} = 22.9 + 33.3 \exp \left( 0.0106 \left( T - RT_0 + 35 \right) \right) \] in units of ksi-in<sup>1/2</sup> and °F

   \[ K_{IC, lower 95\%} = 25.2 + 36.6 \exp \left( 0.019 \left( T - RT_0 + 19.4 \right) \right) \] in units of MPa-m<sup>1/2</sup> and °C