WOLF CREEK
NUCLEAR OPERATING CORPORATION

Stephen L. Smith
Vice President Engineering

August 15, 2019

ET 19-0014

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555

Subject: Docket No. 50-482: Inservice Inspection (ISI) Program Relief Request Number I4R-07, to Utilize Code Case N-513-4, "Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or 3 Piping Section XI, Division 1"

To Whom It May Concern:

Pursuant to 10 CFR 50.55a(z)(2), Wolf Creek Nuclear Operating Corporation (WCNOC) hereby requests the Nuclear Regulatory Commission (NRC) approval of a proposed alternative to the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," on the basis that compliance with the specified requirements of this section would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety. Approval of this request would allow use of an acceptable alternative analysis method in lieu of immediate action for a degraded condition, and would allow WCNOC to perform additional extent of condition examinations on the affected systems while allowing time for safe and orderly long term repair actions, if necessary. Actions to remove degraded piping from service could have a detrimental overall risk impact by requiring a plant shutdown, thus requiring use of a system that is in standby during normal operation. Specifically, WCNOC is requesting to apply the evaluation methods of ASME Code Case N-513-4, "Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or 3 Piping Section XI, Division 1," to Class 2 and 3 moderate energy piping including elbows, bent pipe, reducers, expanders, and branch tees. This relief request to utilize Code Case N-513-4 will only be applied to systems/components that meet the applicability conditions in Code Case N-513-4.

The attachment to this letter provides the reason for the request and the proposed alternative. Enclosure I provides a marked up copy of N-513-3 highlighting the changes between it and N-513-4. Enclosure II provides a copy of N-513-4 for reference. We request your review and approval of this request by June 1, 2020.

A047
NRR

There are no regulatory commitments contained in this submittal. If you have any questions concerning this matter, please contact me at (620) 364-4093, or Ron Benham at (620) 364-4204.

Sincerely,

Stephen L. Smith

SLS/rlt

Attachment: Relief Request to utilize ASME Code Case N-513-4

Enclosures: I Marked up copy of N-513-3 highlighting the changes
II Copy of N-513-4

cc: S. A. Morris (NRC), w/a, w/e
N. O'Keefe (NRC), w/a, w/e
B. K. Singal (NRC), w/a, w/e
Senior Resident Inspector (NRC), w/a, w/e

Wolf Creek Nuclear Operating Corporation
10 CFR 50.55a Request I4R-07
Relief Requested In Accordance with
10 CFR 50.55a(z)(2)

10 CFR 50.55a Request Number I4R-07

Relief Requested
In Accordance with 10 CFR 50.55a(z)(2)

Proposed Alternative in Accordance with 10 CFR 50.55a(z)(2)
Alternatives to codes and standards requirements.

1. **ASME Code Component(s) Affected:**

   All American Society of Mechanical Engineers (ASME), Section XI, Class 2 and 3 components that meet the operational and configuration limitations of Code Case N-513-4, paragraphs 1 (a), 1 (b), 1 (c), and 1 (d).

2. **Applicable Code Edition and Addenda:**

   The applicable code edition and addenda for the Fourth Inservice Inspection Interval at Wolf Creek Generating Station is the 2007 Edition with 2008 Addenda of ASME Section XI (Reference 1).

3. **Applicable Code Requirement:**

   ASME Code, Section XI, IWC-3120 and IWC-3130 require that flaws exceeding the defined acceptance criteria be corrected by repair/replacement activities or evaluated and accepted by analytical evaluation. ASME Code, Section XI, IWD-3120(b) requires that components exceeding the acceptance standards of IWD-3400 be subject to supplemental examination, or to a repair/replacement activity.

4. **Reason for Request:**

   In accordance with 10 CFR 50.55a(z)(2), Wolf Creek Nuclear Operating Corporation (WCNOC), is requesting a proposed alternative to the ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," and the requirement to perform repair/replacement activities for degraded Class 2 and 3 piping whose maximum operating temperature does not exceed 200°F and whose maximum operating pressure does not exceed 275 psig. Moderately degraded piping could require a plant shutdown within the required action statement timeframes to repair observed degradation. Plant shutdown activities result in additional dose and plant risk that would be inappropriate when a degraded condition is demonstrated to retain adequate margin to complete the component's function. The use of an acceptable alternative analysis method in lieu of immediate action for a degraded condition will allow WCNOC to perform additional extent of condition examinations on the affected systems while allowing time for safe and orderly long term repair actions, if necessary. Actions to remove degraded piping from service could have a detrimental overall risk impact by requiring a plant shutdown, thus requiring use of a system that is in standby during normal operation. Accordingly, compliance with the current Code requirements results in a hardship without a compensating increase in the level of quality and safety.

ASME Code Case N-513-3 does not allow evaluation of flaws located away from attaching circumferential piping welds that are in elbows, bent pipe, reducers, expanders, and branch tees (as defined 1(c) of the Case). ASME Code Case N-513-3 also does not allow evaluation of flaws located in heat exchanger external tubing or piping. ASME Code Case N-513-4 provides guidance for evaluation of flaws in these locations.

5. Proposed Alternative and Basis for Use:

WCNOC is requesting approval to apply the evaluation methods of ASME Code Case N-513-4, "Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or 3 Piping Section XI, Division 1," to Class 2 and 3 components that meet the operational and configuration limitations of Code Case N-513-4, paragraphs 1 (a), 1 (b), 1 (c), and 1 (d) in order to avoid accruing additional personnel radiation exposure and increased plant risk associated with a plant shutdown to comply with the cited Code requirements.

The Nuclear Regulatory Commission (NRC) issued Generic Letter 90-05, "Guidance for Performing Temporary Non-Code Repair of ASME Code Class 1, 2, and 3 Piping (Generic Letter 90-05)," (Reference 2), addresses the acceptability of limited degradation in moderate energy piping. The generic letter defines conditions that would be acceptable to utilize temporary non-code repairs with NRC approval. The ASME recognized that relatively small flaws could remain in service without risk to the structural integrity of a piping system and developed Code Case N-513. NRC approval of Code Case N-513 versions in Regulatory Guide 1.147, "Inservice Inspection Code Case Acceptability, ASME Section XI, Division 1," (Reference 3) allows acceptance of partial through-wall or through-wall leaks for an operating cycle provided all conditions of the Code Case and NRC conditions are met. The Code Case also requires the Owner to demonstrate system operability considering the effects of leakage.

The ASME recognized that the limitations in Code Case N-513-3 were preventing needed use in piping components such as elbows, bent pipe, reducers, expanders, and branch tees and external tubing or piping attached to heat exchangers. Code Case N-513-4 was approved by the ASME to expand use on these locations and to revise several other areas of the Code Case. Enclosure I provides a marked-up N-513-3 version of the Code Case to highlight the changes in N-513-4 compared to the NRC approved N-513-3 version. Enclosure II provides the ASME approved Code Case N-513-4. The following provides a high level overview of the Code Case N-513-4 changes:

1. Revised the maximum allowed time of use from no longer than 26 months to the next scheduled refueling outage.
2. Added applicability to piping elbows, bent pipe, reducers, expanders, and branch tees where the flaw is located more than $(R_o t)^{1/2}$ from the centerline of the attaching circumferential piping weld.
3. Expanded use to external tubing or piping attached to heat exchangers.
4. Revised to limit the use to liquid systems.
5. Revised to clarify treatment of Service Level load combinations.
6. Revised to address treatment of flaws in austenitic pipe flux welds.
7. Revised to require minimum wall thickness acceptance criteria to consider longitudinal stress in addition to hoop stress.
8. Other minor editorial changes to improve the clarity of the Code Case.

WCNOC will apply ASME Code Case N-513-4 to evaluation of Class 2 and 3 components that are within the scope of the Code Case. Code Case N-513-4 utilizes technical evaluation approaches that are based on principals that are accepted in other Code documents already acceptable to the NRC. The application of this Code Case will maintain acceptable structural and leakage integrity while minimizing plant risk and personnel exposure by minimizing the number of plant transients that could be incurred if degradation is required to be repaired based on ASME Section XI acceptance criteria only.

6. Duration of Proposed Alternative:

The proposed alternative is for use of Code Case N-513-4 for Class 2 and Class 3 components within the scope of the Code Case. A Section XI compliant repair/replacement will be completed prior to exceeding the next refueling outage or allowable flaw size, whichever comes first. This relief request will be applied for the duration of the inservice inspection interval defined in Section 2 of this request or such time as the NRC approves Code Case N-513-4 in Regulatory Guide 1.147 or other document. If a flaw is evaluated near the end of the interval and the next refueling outage is in the subsequent interval the flaw may remain in service under this relief request until the next refueling outage.

7. Precedent:

None.

8. References:

1. ASME Code, Section XI, 2007 Edition with 2008 Addenda.

2. NRC Generic Letter 90-05, "Guidance for Performing Temporary Non-Code Repair of ASME Code Class 1, 2, and 3 Piping (Generic Letter 90-05)."

3. Regulatory Guide 1.147, "Inservice Inspection Code Case Acceptability, ASME Section XI, Division 1."

Enclosure I to ET 19-0014

Marked up copy of N-513-3 highlighting the changes
(16 pages)

Enclosure I

Record #12-841

Approval Date: January 26, 2009

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

Case N-513-4~~3~~
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 ~~evaluation period as defined in this Case~~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 joint;

(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~~b~~) 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~~c~~) 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 $(R_o t)^{1/2}$ 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_o/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~~d~~) 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 ~~demonstrate system operability~~ consider~~ing~~ effects of leakage in demonstrating system operability and performing plant flooding analyses.

~~*(e)* The evaluation period, τ_{allow}, is the operational time for which the temporary acceptance criteria are satisfied but not exceeding 26 months from the initial discovery of the condition.~~

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~~, τ_{allow},~~ at which the detected flaw will reach the allowable size. Alternatively, a flaw growth evaluation may be performed to predict the time~~, τ_{allow},~~ 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 wastage, 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 ~~observed by~~monitored daily ~~walkdowns~~ to confirm the analysis conditions used in the evaluation remain valid.

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

(h) Repair~~ or ~~/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~~ or ~~/replacement activities shall be in accordance with IWA-4000~~ or IWA-7000, respectively, in Editions and Addenda prior to the 1991 Addenda; and, in the 1991 Addenda and later, 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~~3~~. Nonferrous materials shall be evaluated in accordance with the requirements in 3.7~~4~~.

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 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 Fig. 1.

(b) For planar flaws in austenitic piping, the evaluation procedure in 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 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:

$$\ell_{all} = 1.58\sqrt{Rt}\left[\left(\frac{\sigma_f}{(SF_m)Z\sigma_h}\right)^2 - 1\right]^{1/2} \quad (1)$$

$$\sigma_h = pD_0/2t \quad (2)$$

$$\sigma_f = (S_y + S_u)/2 \quad (3)$$

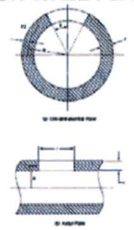
Note: Z has been added to equation (1).

where

p = pressure for the loading condition
D_0 = pipe outside diameter
σ_f = flow stress
S_y = Code specified yield strength
S_u = Code specified ultimate tensile strength and
SF_m = structural factor on primary membrane stress as specified in C-2622
Z = load multiplier for ductile flaw extension (equal to 1.0 when using limit load criteria)

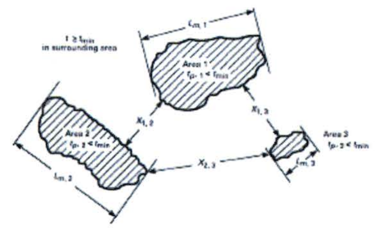
Material properties at the temperature of interest shall be used.

FIG. 1 THROUGH-WALL FLAW GEOMETRY



(c) For planar flaws in ferritic piping, the evaluation procedure of 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 Appendix C screening criteria for through-wall axial flaws, a/t shall be set to unity, and the reference limit load hoop stress, σ_l, shall be defined as σ_y/M_2. When through-wall axial flaws are evaluated in accordance with C-5400 or C-6400, the allowable length is defined by eqs. (1) through (3), with the appropriate structural factors from 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_b, and F applicable to through-wall flaws. Relations for F_m, F_b, 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_b, and F for a selected range of R/t. Geometry of a through-wall crack is shown in Fig. 1.

FIG. 2 SEPARATION REQUIREMENTS FOR ADJACENT THINNED AREAS



$X_{i,j}$ = minimum distance between areas i and j
$L_{m,i}$ = maximum extent of thinned area i
$L_{m,avg}$ = 0.5 ($L_{m,i}$ + $L_{m,j}$)

GENERAL NOTE: Combination of adjacent areas into an equivalent single area shall be based on dimensions and extents prior to combination.

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 $\sqrt{Rt_{nom}}$ or $2L_{m,avg}$ 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 Fig. 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 (b)(1) and (b)(2), or (b)(2) and (b)(3) are met.

(1) T~~t~~he remaining pipe thickness (t_p) is greater than or equal to the minimum wall thickness t_{min}:

$$t_{\min} = \frac{pD_0}{2(S+0.4p)} \quad (4)$$

where

p = maximum operating pressure at flaw location
S = allowable stress at operating temperature

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

(3) As an alternative to (b)(1)~~Alternatively~~, 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 Fig. 3.

(*i*~~1~~) When W_m is less than or equal to 0.5 $(R_ot)^{1/2}$, where R_o is the outside radius and W_m is defined in Fig. 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, (~~2~~*ii*) shall be met.

(*ii*~~2~~) When $L_{m(t)}$ is not greater than $(R_ot_{\min})^{1/2}$, t_{aloc} is determined from Curve 1 of Fig. 4, where $L_{m(t)}$ is defined in Fig. 3. When the above requirement is not satisfied, (~~3~~*iii*) shall be met.

(*iii*~~3~~) When L_m is less than or equal to 2.65 $(R_ot_{\min})^{1/2}$ and t_{nom} is greater than 1.13 t_{min}, t_{aloc} is determined by satisfying both of the following equations:

$$\frac{t_{aloc}}{t_{\min}} \geq \frac{1.5\sqrt{R_0 t_{\min}}}{L}\left[1-\frac{t_{nom}}{t_{\min}}\right]+1.0 \quad (5)$$

$$\frac{t_{aloc}}{t_{\min}} \geq \frac{0.353L_m}{\sqrt{R_0 t_{\min}}} \quad (6)$$

When the above requirements are not satisfied, (~~4~~*iv*) shall be met.

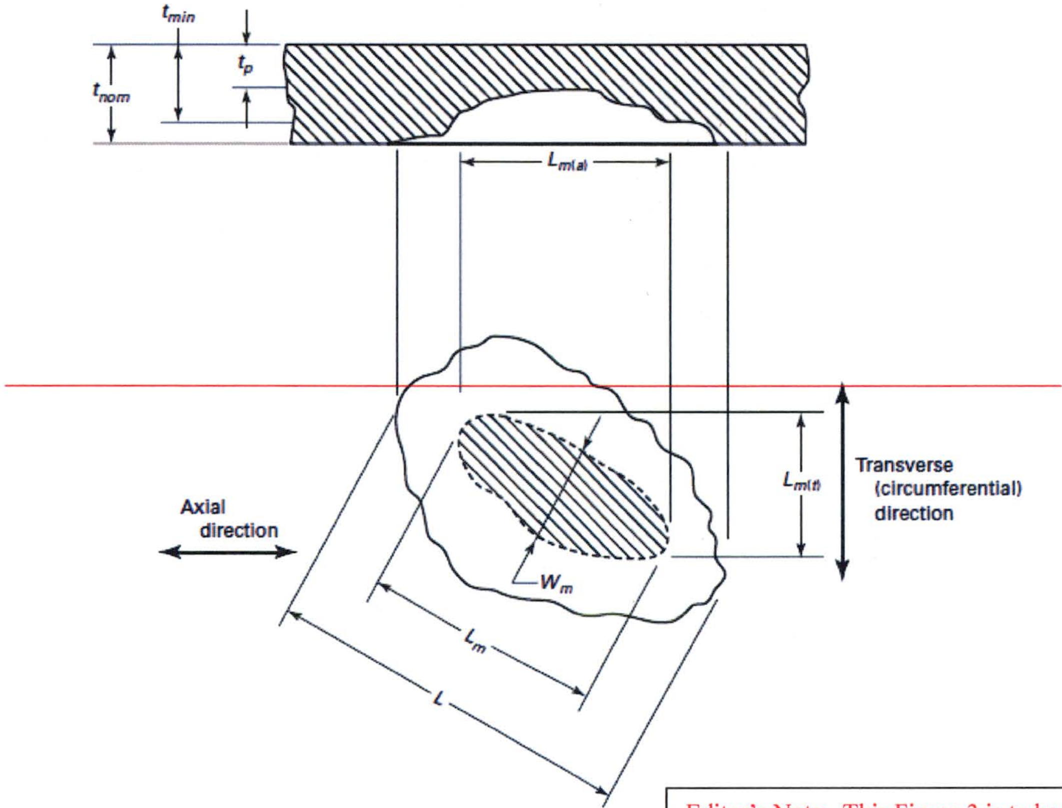
(*iv*~~4~~) When the requirements of (~~1~~*i*), (~~2~~*ii*), and (~~3~~*iii*) above are not satisfied, t_{aloc} is determined from Curve 2 of Fig. 4. ~~In addition, t_{aloc} shall satisfy the following equation:~~

$$\frac{t_{aloc}}{t_{\min}} \geq \frac{\left[0.5+\left(\frac{t_{nom}}{t_{\min}}\right)\left(\frac{\sigma_b}{S}\right)\right]}{1.8} \quad (7)$$

~~where σ_b is the nominal pipe longitudinal bending stress resulting from all Service Level B primary pipe loadings.~~

(c) When there is through-wall leakage along a portion of the thinned wall, as illustrated in Fig. 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 Fig. 6. When evaluating multiple flaws in accordance with 3.2(a), only the portions of the flaws contained within t_{adj} need be considered.

FIG. 3 ILLUSTRATION OF NONPLANAR FLAW DUE TO WALL THINNING



Editor's Note: This Figure 3 is to be deleted and replaced with the Figure 3 on the following page.

FIG. 3 ILLUSTRATION OF NONPLANAR FLAW DUE TO WALL THINNING

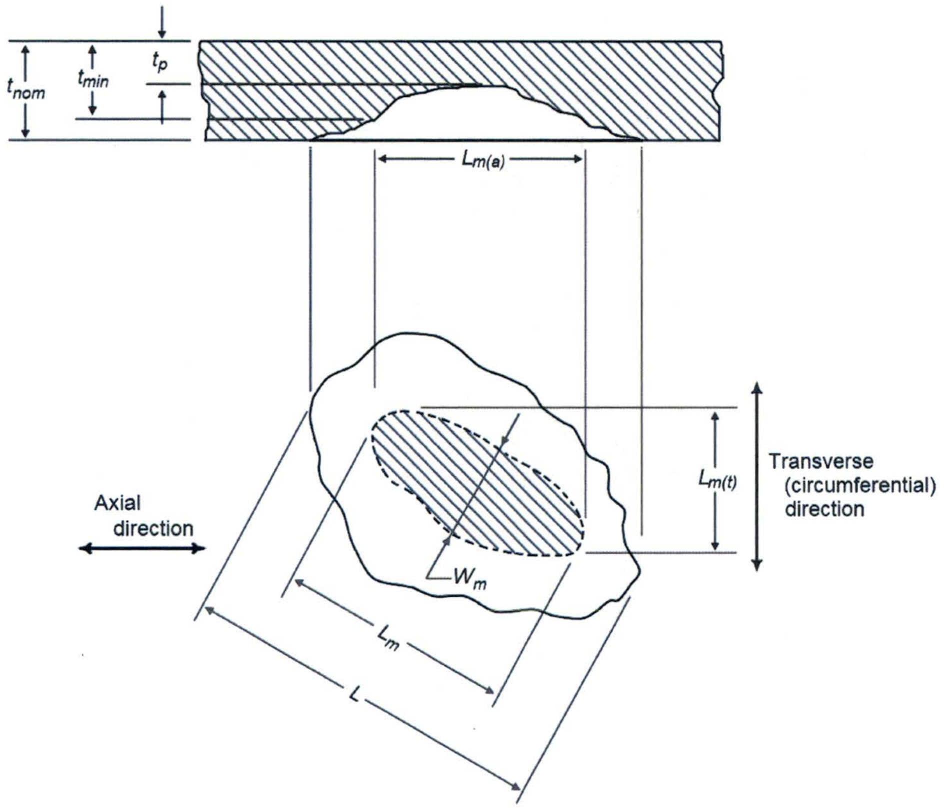


FIG. 4 ALLOWABLE WALL THICKNESS AND LENGTH OF LOCALLY THINNED AREA

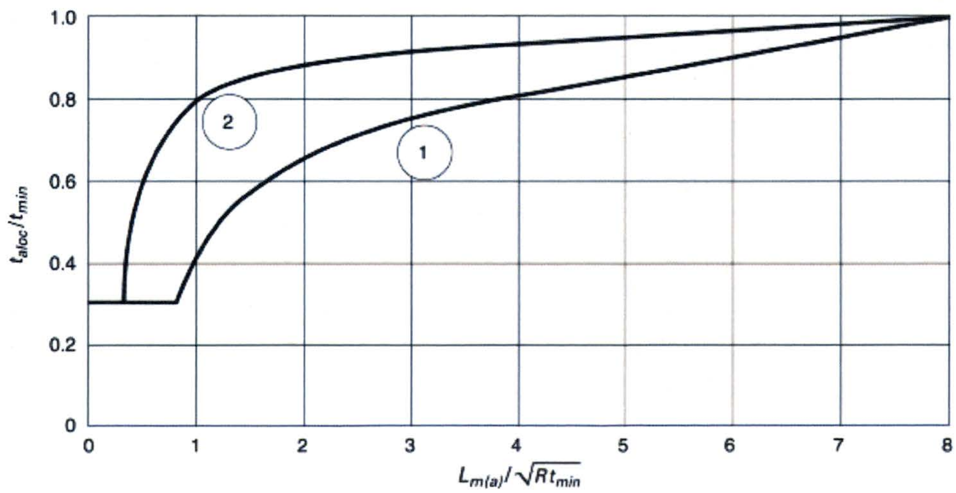
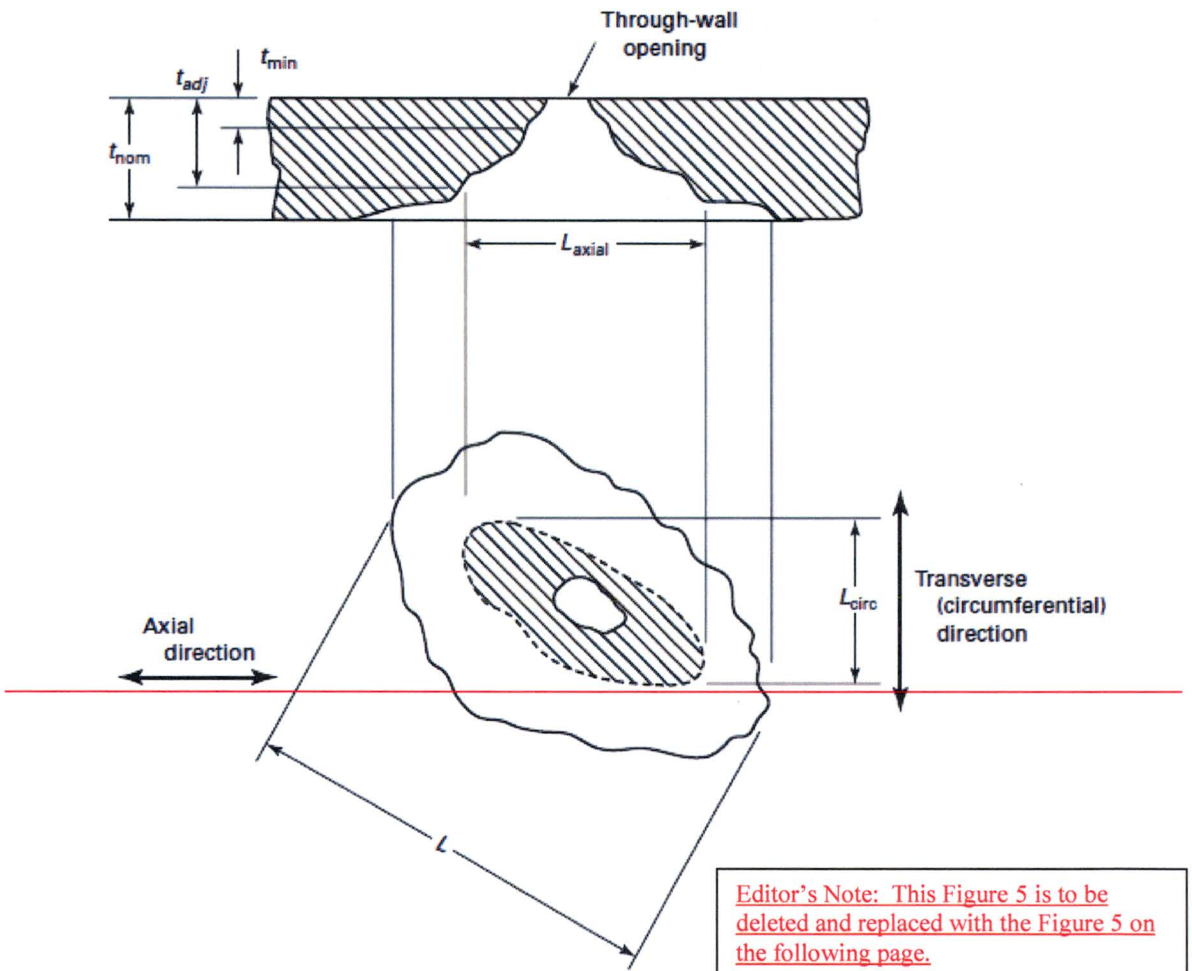
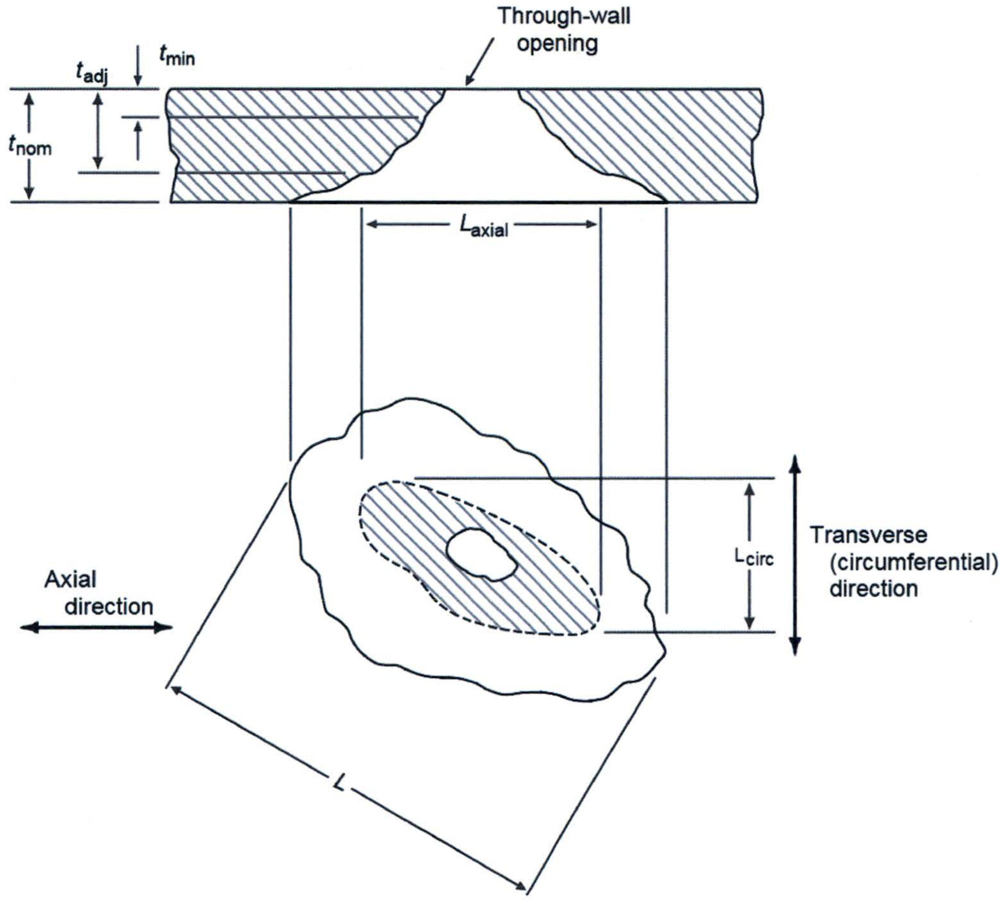


FIG. 5 ILLUSTRATION OF THROUGH-WALL NONPLANAR FLAW DUE TO WALL THINNING



Editor's Note: This Figure 5 is to be deleted and replaced with the Figure 5 on the following page.

FIG. 5 ILLUSTRATION OF THROUGH-WALL NONPLANAR FLAW DUE TO WALL THINNING



The minimum wall thickness, t_{min}, shall be determined by eq. (4). For evaluation purposes, the adjusted wall thickness, t_{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_{adj} as defined by t_{adj} as shown in Fig. 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 Fig. 6(b) shall satisfy:

$$d_{adj} \le \frac{1.5\sqrt{Rt_{adj}}\,(t_{adj} - t_{\min})}{t_{\min}} \qquad (78)$$

The remaining ligament average thickness, $t_{c,avg}$, over the degraded area bounded by d_{adj} shall satisfy:

$$t_{c,avg} \ge 0.353 d_{adj}\sqrt{\frac{P}{S}} \qquad (89)$$

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_{min}, shall be determined by eq. (4). The allowable through-wall lengths in the axial and circumferential directions shall be determined by varying t_{adj} shown in Fig. 5 from t_{nom} to t_{min}. The allowable through-wall flaw lengths based on t_{adj} shall be greater than or equal to the corresponding L_{axial} and L_{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, $t_{c,avg}$, over the degraded area bounded by L_{axial} and L_{circ} shall satisfy eq. (89).

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, σ_h, for elbow and bent pipe evaluation shall be:

$$\sigma_h = \left(\frac{pD_o}{2t}\right)\left[\frac{2R_{bend} + R_o \sin\phi}{2(R_{bend} + R_o \sin\phi)}\right] + \left(\frac{1.95}{h^{2/3}}\right)\frac{R_o M_b}{I} \qquad (9)$$

where

R_{bend} = elbow or bent pipe bend radius
ϕ = circumferential angle defined in Figure 7
h = flexibility characteristic
M_b = 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 $h \ge 0.1$.

The axial membrane pressure stress, σ_m, for elbow and bent pipe evaluation shall be:

$$\sigma_m = B_1\left(\frac{pD_o}{2t}\right) \qquad (10)$$

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, σ_b, for elbow and bent pipe evaluation shall be:

$$\sigma_b = B_2\left(\frac{D_o M_b}{2I}\right) \qquad (11)$$

where B_2 is a primary stress index as defined in Section III for the piping item.

The thermal expansion stress, σ_e, for elbow and bent pipe evaluation shall be:

$$\sigma_e = i\left(\frac{D_o M_e}{2I}\right) \qquad (12)$$

where

i = stress intensification factor as defined in the design Code for the piping item
M_e = 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. Fig. 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, σ_h, and axial membrane pressure stress, σ_m, for reducer or expander evaluation shall be:

$$\sigma_h = \left(\frac{pD_o}{2t}\right) \qquad (13)$$

$$\sigma_m = B_1\left(\frac{pD_o}{2t}\right) \qquad (14)$$

where D_o is the small end OD for flaws in the small end and the large end OD for all other flaws.

The axial bending stress, σ_b, and thermal expansion stress, σ_e, for reducer or expander evaluation shall be:

$$\sigma_b = B_2\left(\frac{D_o M_b}{2I}\right) \qquad (15)$$

$$\sigma_e = i\left(\frac{D_o M_e}{2I}\right) \qquad (16)$$

where I is 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 3.1 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. Evaluation of flaws in the region of branch reinforcement is outside the scope of this Case.

The hoop stress, σ_h, and axial membrane pressure stress, σ_m, for branch tee evaluation shall be determined from eq. (13) and eq. (14), respectively. The outside diameter for each of these equations shall be for the branch or run pipe, depending on the flaw location.

The axial bending stress, σ_b, and thermal expansion stress, σ_e, for branch tee evaluation shall be determined from eq. (15) and eq. (16), respectively.

3.63 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 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:

$$da / dt = S_T C K^n_{\max} \qquad (170)$$

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.$^{0.5}$, 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 x 10^{-8}
S_T = 1
n = 2.161

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

C = 1.79 x 10^{-7}
S_T = 3.71 x 10^8 $[10^{(0.01842\,T - 12.25)}]$
n = 2.161

The temperature, T, is the metal temperature in degrees Fahrenheit. The flaw growth rate curves for the above SCC growth mechanisms are shown in Figs. 97 and 108. Other growth rate parameters in eq. (170) may be used, provided they are supported by appropriate data.

3.74 Nonferrous Materials

For nonferrous materials, nonplanar and planar flaws may be evaluated following the general approach of 3.1 through 3.63. For planar flaws in ductile materials, the approach given ~~in 3.1(b) and 3.3~~for austenitic pipe may be used; otherwise, the approach given ~~in 3.1(c) and 3.3~~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.

FIG. 6 ILLUSTRATION OF ADJUSTED WALL THICKNESS AND EQUIVALENT HOLE DIAMETERS

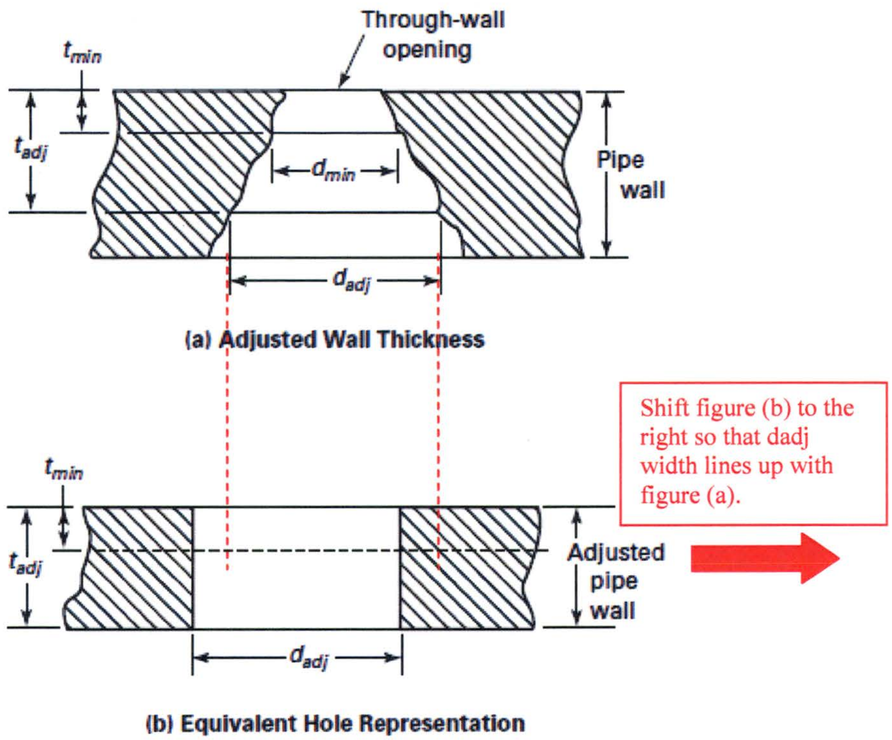


FIG. 7 CIRCUMFERENTIAL ANGLE DEFINED

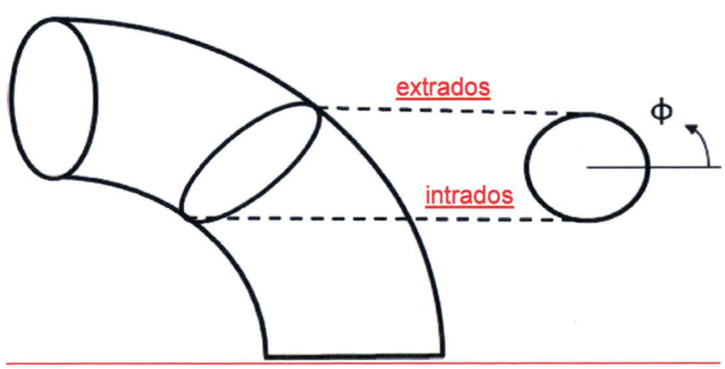
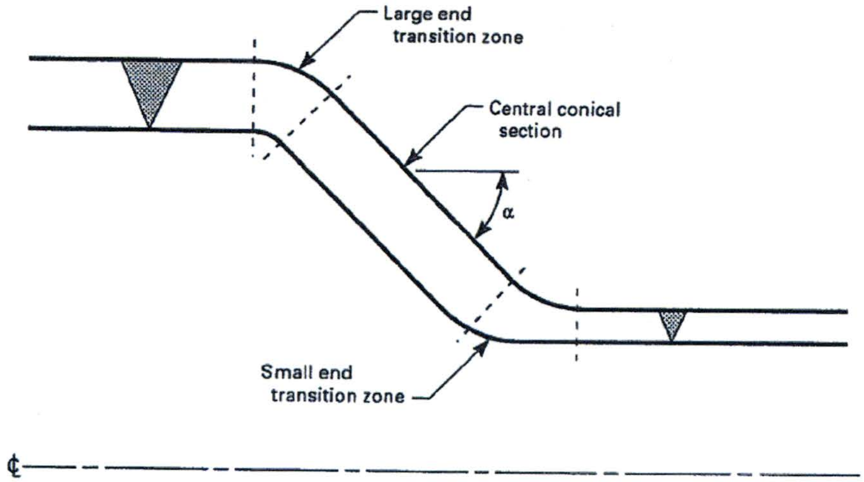
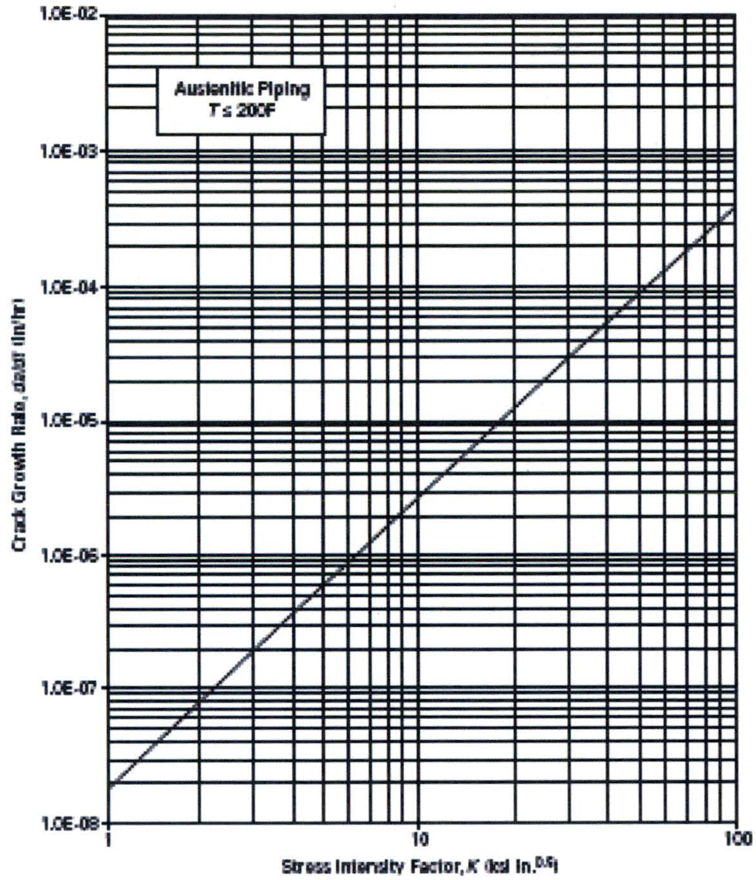


FIG. 8 ZONES OF A REDUCER OR EXPANDER



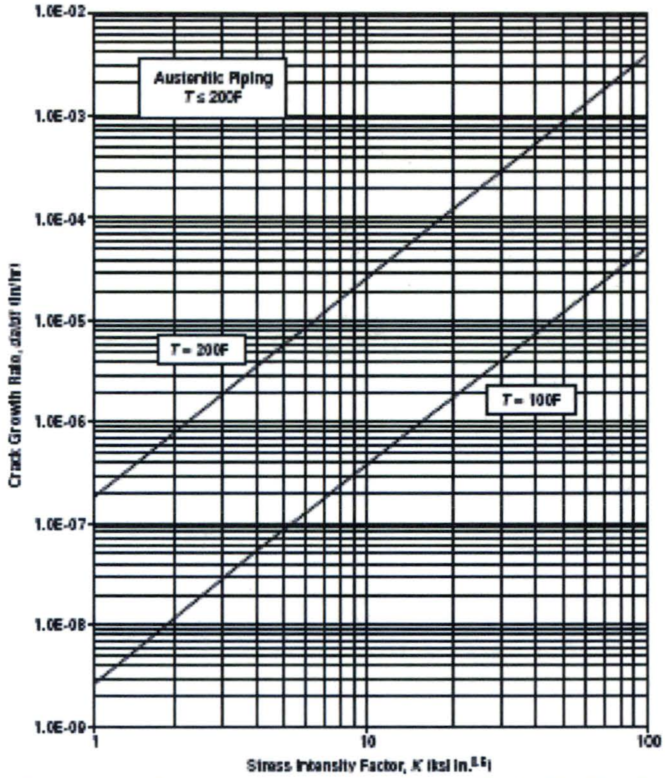
GENERAL NOTE:
Transition zones extend from the point on the ends where the diameter begins to change to the point on the central cone where the cone angle is constant.

FIG. 97 FLAW GROWTH RATE FOR IGSCC IN AUSTENITIC PIPING



GENERAL NOTE: (SI conversion: 1.0 in/hr = 7.06×10^{-3} mm/sec; 1.0 ksi in.$^{0.5}$ = 1.099 MPa m$^{0.5}$; °C = (°F - 32)/1.8).

FIG. 10~~8~~ FLAW GROWTH RATE FOR TGSCC IN AUSTENITIC PIPING



GENERAL NOTE: (SI conversion: 1.0 in/hr = 7.06×10^{-3} mm/sec; 1.0 ksi in.$^{0.5}$ = 1.099 MPa m$^{0.5}$; °C = (°F − 32)/1.8).

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 Appendix C, C-2621. For axial planar flaws, the structural factors for temporary acceptance are as specified in 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 $t_p \geq t_{aloc}$, where t_{aloc} is determined from 3.2(b). Straight pipe containing a nonplanar 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.

5 AUGMENTED EXAMINATION

An augmented volumetric examination or physical measurement to assess degradation of the affected system shall be performed as follows:

(a) From the engineering evaluation, the most susceptible locations shall be identified. A sample size of at least five of the most susceptible and accessible locations, or, if fewer than five, all susceptible and accessible locations shall be examined within 30 days of detecting the flaw.

(b) When a flaw is detected, an additional sample of the same size as defined in 5(a) shall be examined.

(c) This process shall be repeated within 15 days for each successive sample, until no significant flaw is detected or until 100% of susceptible and accessible locations have been examined.

6 NOMENCLATURE

B_1, B_2 = Section III primary stress indices
C = coefficient in the crack growth relationship
D_i = inside pipe diameter
D_o = outside pipe diameter
F = nondimensional stress intensity factor for through-wall axial flaw under hoop stress
F_b = nondimensional stress intensity factor for through-wall circumferential flaw under pipe bending stress
F_m = nondimensional stress intensity factor for through-wall circumferential flaw under membrane stress
I = moment of inertia based on evaluation thickness, t
K_{max} = maximum stress intensity factor under long term steady state conditions
L = maximum extent of a local thinned area with $t < t_{nom}$
L_{axial} = length of idealized through-wall planar flaw opening in the axial direction of the pipe, as illustrated in Fig. 5
L_{circ} = length of idealized through-wall planar flaw opening in the circumferential direction of the pipe, as illustrated in Fig. 5
L_m = maximum extent of a local thinned area with $t < t_{min}$
$L_{m(a)}$ = axial extent of wall thinning below t_{min}
$L_{m(t)}$ = circumferential extent of wall thinning below t_{min}
$L_{m,avg}$ = average of the extent of L_m below t_{min} for adjacent thinned areas
$L_{m,i}$ = maximum extent of thinned area, i
M_2 = bulging factor for axial flaw
M_b = resultant primary bending moment
M_e = resultant thermal expansion moment
R = mean pipe radius
R_{bend} = elbow or bent pipe centerline bend radius
R_o = outside pipe radius
S = allowable stress at operating temperature
SF_m = structural factor on primary membrane stress
S_T = coefficient for temperature dependence in the crack growth relationship
S_u = Code-specified ultimate tensile strength
S_y = Code-specified yield strength
T = metal temperature
W_m = maximum extent of a local thinned area perpendicular to L_m with $t < t_{min}$
$X_{i,j}$ = minimum distance between thinned areas i and j
Z = load multiplier for ductile flaw extension
a = flaw depth
c = half crack length
da/dt = flaw growth rate for stress corrosion cracking
d_{adj} = diameter equivalent circular hole at t_{adj}
d_{min} = diameter of equivalent circular hole at t_{min}
h = flexibility characteristic
i = stress intensification factor
ℓ = total crack length = $2c$
ℓ_{all} = allowable axial through-wall flaw length
n = exponent in the crack growth relationship

p = maximum operating pressure at flaw location

t = evaluation wall thickness, surrounding the degraded area

t_{adj} = adjusted wall thickness which is varied for evaluation purposes in the evaluation of a through-wall nonplanar flaw

t_{aloc} = allowable local thickness for a nonplanar flaw

$t_{c,avg}$ = average remaining wall thickness covering degraded area with through-wall leak bounded by d_{adj}

t_{min} = minimum wall thickness required for pressure loading

t_{nom} = nominal wall thickness

t_p = minimum remaining wall thickness

α = maximum cone angle at the center of a reducer

λ = nondimensional half crack length for through-wall axial flaw

ϕ = circumferential angle from elbow or bend flank

σ_b = axial bending stress for primary loading

σ_e = axial thermal expansion stress

σ_f = material flow stress

σ_h = pipe hoop stress due to pressure and bending moment (for elbows and bent pipe)

σ_b = nominal longitudinal bending stress for primary loading without stress intensification factor

σ_l = reference limit load hoop stress

σ_m = axial pressure stress

σ_y = material yield strength at temperature, as defined in C-4300

τ_{allow} = time required for the detected flaw to grow to the allowable flaw size, but not exceeding 26 months from the initial discovery of the condition

θ = half crack angle for through-wall circumferential flaw

7 APPLICABILITY

This Case is applicable from the 1983 Edition with the Winter 1985 Addenda, through the 2007 Edition with the 2008 Addenda. Reference to Appendix C in this Case shall apply to Appendix C of the 2004 Edition or later editions or addenda. For editions and or addenda prior to the 2004 Edition, Class 1 pipe flaw evaluation procedures may be used for other piping classes. As a matter of definition, the current term "structural factor" is equivalent to the term "safety factor," which is used in earlier editions and addenda.

Editor's Note: For Applicability Index, applicability is from 1996 Addenda to 2013 Edition.

MANDATORY APPENDIX I
RELATIONS FOR F_m, F_b, AND F FOR THROUGH-WALL FLAWS

I-1 DEFINITIONS

For through-wall flaws, the crack depth, (a,) will be replaced with half crack length, (c,) in the stress intensity factor equations in C-7300 and C-7400 of Section XI, Appendix C. Also, Q will be set equal to unity in C-7400.

I-2 CIRCUMFERENTIAL FLAWS

For a range of R/t between 5 and 20, the following equations for F_m and F_b may be used:

$$F_m = 1 + A_m (\theta/\pi)^{1.5} + B_m (\theta/\pi)^{2.5} + C_m (\theta/\pi)^{3.5}$$
$$F_b = 1 + A_b (\theta/\pi)^{1.5} + B_b (\theta/\pi)^{2.5} + C_b (\theta/\pi)^{3.5}$$

where

θ = half crack angle = c/R
R = mean pipe radius
t = evaluation pipe wall thickness

and

$$A_m = -2.02917 + 1.67763 (R/t) - 0.07987 (R/t)^2 + 0.00176 (R/t)^3$$
$$B_m = 7.09987 - 4.42394 (R/t) + 0.21036 (R/t)^2 - 0.00463 (R/t)^3$$
$$C_m = 7.79661 + 5.16676 (R/t) - 0.24577 (R/t)^2 + 0.00541 (R/t)^3$$
$$A_b = -3.26543 + 1.52784 (R/t) - 0.072698 (R/t)^2 + 0.0016011 (R/t)^3$$
$$B_b = 11.36322 - 3.91412 (R/t) + 0.18619 (R/t)^2 - 0.004099 (R/t)^3$$
$$C_b = -3.18609 + 3.84763 (R/t) - 0.18304 (R/t)^2 + 0.00403 (R/t)^3$$

Equations for F_m and F_b are accurate for R/t between 5 and 20 and become increasingly conservative for R/t greater than 20. Alternative solutions for F_m and F_b may be used when R/t is greater than 20.

I-3 AXIAL FLAWS

For internal pressure loading, the following equation for F may be used:

$$F = 1 + 0.072449\lambda + 0.64856\lambda^2 - 0.2327 \lambda^3 + 0.038154 \lambda^4 - 0.0023487 \lambda^5$$

where

c = half crack length
$\lambda = c/(Rt)^{1/2}$

The equation for F is accurate for λ between 0 and 5. Alternative solutions for F may be used when λ is greater than 5.

Enclosure II to ET 19-0014

Copy of N-513-4
(16 pages)

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 $(R_o t)^{1/2}$ 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_o/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 wastage, 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.

(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:

$$\ell_{\text{all}} = 1.58\sqrt{Rt}\left[\left(\frac{\sigma_f}{(SF_m)Z\sigma_h}\right)^2 - 1\right]^{1/2} \quad (1)$$

$$\sigma_h = pD_o/2t \quad (2)$$

$$\sigma_f = (S_y + S_u)/2 \quad (3)$$

where

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

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, σ_l, shall be defined as σ_y/M_2. 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_b, and F applicable to through-wall flaws. Relations for F_m, F_b, 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_b, 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 $2.5\sqrt{Rt_{\text{nom}}}$ or $2L_{m,\text{avg}}$ between adjacent thinned regions, where R is the mean radius of the piping item based on nominal wall thickness and $L_{m,\text{avg}}$ 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}:

$$t_{min} = \frac{pD_o}{2(S + 0.4p)} \tag{4}$$

where

p = maximum operating pressure at flaw location
S = allowable stress at operating temperature

(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 $(R_o t)^{1/2}$, where R_o 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 $L_{m(t)}$ is not greater than $(R_o t_{min})^{1/2}$, t_{aloc} is determined from Curve 1 of Figure 4, where $L_{m(t)}$ 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 × $(R_o t_{min})^{1/2}$ and t_{nom} is greater than $1.13 t_{min}$, t_{aloc} is determined by satisfying both of the following equations:

$$\frac{t_{aloc}}{t_{min}} \geq \frac{1.5\sqrt{R_o t_{min}}}{L}\left[1 - \frac{t_{nom}}{t_{min}}\right] + 1.0 \tag{5}$$

$$\frac{t_{aloc}}{t_{min}} \geq \frac{0.353 L_m}{\sqrt{R_o t_{min}}} \tag{6}$$

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

(-d) When the requirements of (-a), (-b), and (-c) above are not satisfied, t_{aloc} 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 (b)(1), 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, illustration (a). The diameter of the opening is equal to d_{adj} as defined by t_{adj} as shown in Figure 6, illustration (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, illustration (b) shall satisfy:

$$d_{adj} \leq \frac{1.5\sqrt{R t_{adj}}\,(t_{adj} - t_{min})}{t_{min}} \tag{7}$$

The remaining ligament average thickness, $t_{c,avg}$, over the degraded area bounded by d_{adj} shall satisfy:

$$t_{c,avg} \geq 0.353 d_{adj}\sqrt{\frac{p}{S}} \tag{8}$$

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_{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_{adj} shown in Figure 5 from t_{nom} to t_{min}. The allowable through-wall flaw lengths based on t_{adj} shall be greater than or equal to the corresponding L_{axial} and L_{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, $t_{c,avg}$, over the degraded area bounded by L_{axial} and L_{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, σ_h, for elbow and bent pipe evaluation shall be as follows:

$$\sigma_h = \left(\frac{pD_o}{2t}\right)\left[\frac{2R_{bend} + R_o \sin\phi}{2\left(R_{bend} + R_o \sin\phi\right)}\right] + \left(\frac{1.95}{h^{2/3}}\right)\frac{R_o M_b}{I} \quad (9)$$

where

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

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

The axial membrane pressure stress, σ_m, for elbow and bent pipe evaluation shall be as follows:

$$\sigma_m = B_1\left(\frac{pD_o}{2t}\right) \quad (10)$$

where

B_1 = primary stress index as defined in Section III for the piping item
= 0.5 for elbows and bent pipe

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

$$\sigma_b = B_2\left(\frac{D_o M_b}{2I}\right) \quad (11)$$

where

B_2 = primary stress index as defined in Section III for the piping item

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

$$\sigma_e = i\left(\frac{D_o M_e}{2I}\right) \quad (12)$$

where

i = stress intensification factor as defined in the design Code for the piping item
M_e = 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, σ_h, and axial membrane pressure stress, σ_m, for reducer or expander evaluation shall be as follows:

$$\sigma_h = \left(\frac{pD_o}{2t}\right) \quad (13)$$

$$\sigma_m = B_1\left(\frac{pD_o}{2t}\right) \quad (14)$$

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, σ_b, and thermal expansion stress, σ_e, for reducer or expander evaluation shall be as follows:

$$\sigma_b = B_2\left(\frac{D_o M_b}{2I}\right) \quad (15)$$

$$\sigma_e = i\left(\frac{D_o M_e}{2I}\right) \quad (16)$$

where

I = moment of inertia based on 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 3.1 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. Evaluation of flaws in the region of branch reinforcement is outside the scope of this Case.

The hoop stress, σ_h, and axial membrane pressure stress, σ_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 or run pipe, depending on the flaw location.

The axial bending stress, σ_b, and thermal expansion stress, σ_e, 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:

$$da/dt = S_T C K_{max}^n \tag{17}$$

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.$^{0.5}$, 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).

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

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 $t_p \geq t_{aloc}$, where t_{aloc} 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.

5 AUGMENTED EXAMINATION

An augmented volumetric examination or physical measurement to assess degradation of the affected system shall be performed as follows:

(a) From the engineering evaluation, the most susceptible locations shall be identified. A sample size of at least five of the most susceptible and accessible locations, or, if fewer than five, all susceptible and accessible locations shall be examined within 30 days of detecting the flaw.

(b) When a flaw is detected, an additional sample of the same size as defined in (a) shall be examined.

(c) This process shall be repeated within 15 days for each successive sample, until no significant flaw is detected or until 100% of susceptible and accessible locations have been examined.

6 NOMENCLATURE

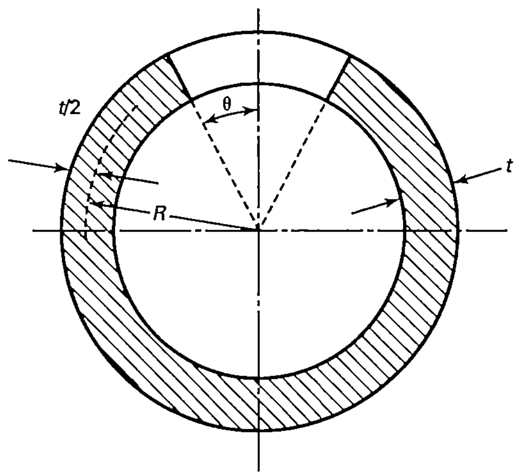
a = flaw depth
B_1, B_2 = Section III primary stress indices
c = half crack length
C = coefficient in the crack growth relationship
da/dt = flaw growth rate for stress corrosion cracking
d_{adj} = diameter equivalent circular hole at t_{adj}
D_i = inside pipe diameter
d_{min} = diameter of equivalent circular hole at t_{min}
D_o = outside pipe diameter
F = nondimensional stress intensity factor for through-wall axial flaw under hoop stress
F_b = nondimensional stress intensity factor for through-wall circumferential flaw under pipe bending stress
F_m = nondimensional stress intensity factor for through-wall circumferential flaw under membrane stress
h = flexibility characteristic
i = stress intensification factor
I = moment of inertia based on evaluation thickness, t
K_{max} = maximum stress intensity factor under long term steady state conditions

L = maximum extent of a local thinned area with $t < t_{nom}$
L_{axial} = length of idealized through-wall planar flaw opening in the axial direction of the pipe, as illustrated in Figure 5
L_{circ} = length of idealized through-wall planar flaw opening in the circumferential direction of the pipe, as illustrated in Figure 5
L_m = maximum extent of a local thinned area with $t < t_{min}$
$L_{m(a)}$ = axial extent of wall thinning below t_{min}
$L_{m(t)}$ = circumferential extent of wall thinning below t_{min}
$L_{m,avg}$ = average of the extent of L_m below t_{min} for adjacent thinned areas
$L_{m,i}$ = maximum extent of thinned area, i
M_2 = bulging factor for axial flaw
M_b = resultant primary bending moment
M_e = resultant thermal expansion moment
n = exponent in the crack growth relationship
p = maximum operating pressure at flaw location
R = mean pipe radius
R_{bend} = elbow or bent pipe centerline bend radius
R_o = outside pipe radius
S = allowable stress at operating temperature
SF_m = structural factor on primary membrane stress
S_T = coefficient for temperature dependence in the crack growth relationship
S_u = Code-specified ultimate tensile strength
S_y = Code-specified yield strength
T = metal temperature
t = evaluation wall thickness, surrounding the degraded area
t_{adj} = adjusted wall thickness which is varied for evaluation purposes in the evaluation of a through-wall nonplanar flaw
t_{aloc} = allowable local thickness for a nonplanar flaw
$t_{c,avg}$ = average remaining wall thickness covering degraded area with through-wall leak bounded by d_{adj}
t_{min} = minimum wall thickness required for pressure loading
t_{nom} = nominal wall thickness
t_p = minimum remaining wall thickness
W_m = maximum extent of a local thinned area perpendicular to L_m with $t < t_{min}$
$X_{i,j}$ = minimum distance between thinned areas i and j
Z = load multiplier for ductile flaw extension
ℓ = total crack length = $2c$
ℓ_{all} = allowable axial through-wall flaw length
Φ = circumferential angle from elbow or bend flank
α = maximum cone angle at the center of a reducer
θ = half crack angle for through-wall circumferential flaw
λ = nondimensional half crack length for through-wall axial flaw
σ_b = axial bending stress for primary loading
σ_e = axial thermal expansion stress
σ_f = material flow stress
σ_h = pipe hoop stress due to pressure and bending moment (for elbows and bent pipe)
σ_l = reference limit load hoop stress
σ_m = axial pressure stress
σ_y = material yield strength at temperature, as defined in C-4300

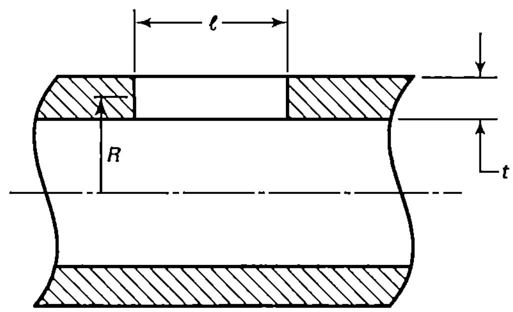
7 APPLICABILITY

Reference to Nonmandatory Appendix C in this Case shall apply to Nonmandatory Appendix C of the 2004 Edition or later editions or addenda. For editions or addenda prior to the 2004 Edition, Class 1 pipe flaw evaluation procedures may be used for other piping classes. As a matter of definition, the current term "structural factor" is equivalent to the term "safety factor," which is used in earlier editions and addenda.

Figure 1
Through-Wall Flaw Geometry

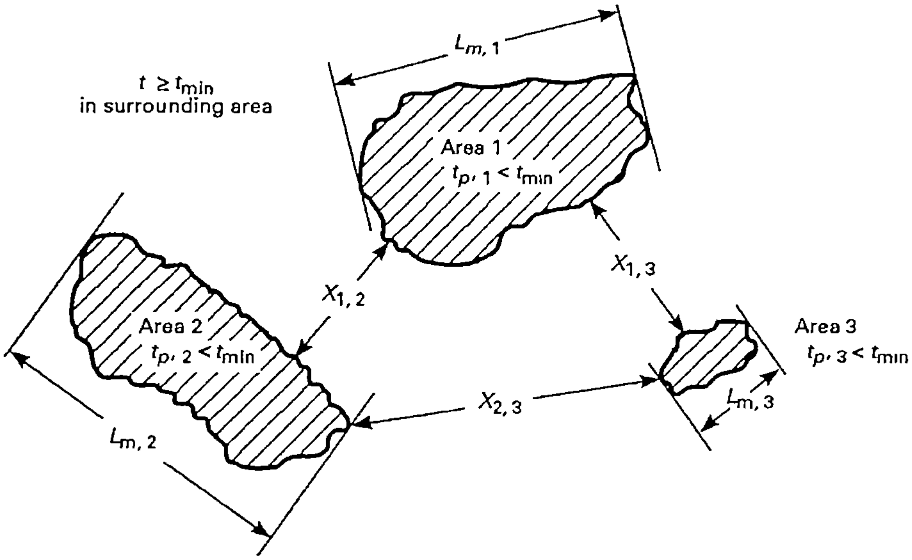


(a) Circumferential Flaw



(b) Axial Flaw

Figure 2
Separation Requirements for Adjacent Thinned Areas



Legend:

$L_{m,avj}$ = 0.5 ($L_{m,i}$ + $L_{m,j}$)
$L_{m,i}$ = maximum extent of thinned area i
$X_{i,j}$ = minimum distance between areas i and j

GENERAL NOTE: Combination of adjacent areas into an equivalent single area shall be based on dimensions and extents prior to combination.

Figure 3
Illustration of Nonplanar Flaw Due to Wall Thinning

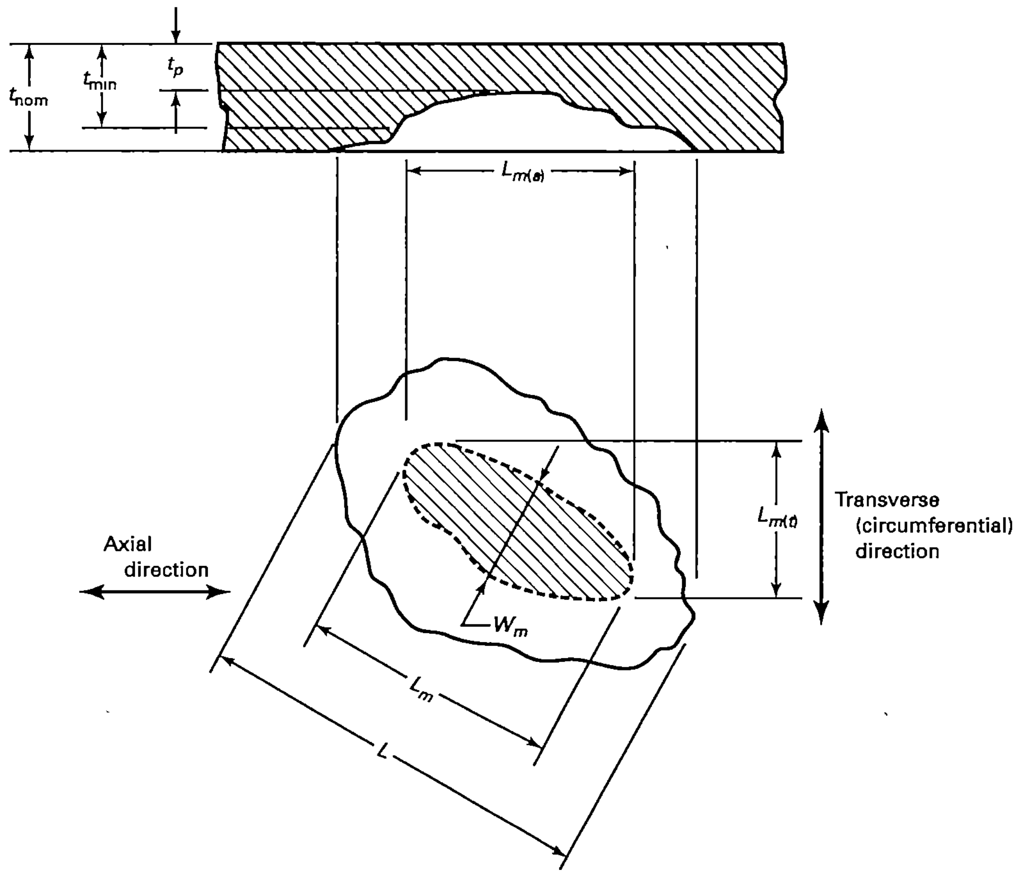


Figure 4
Allowable Wall Thickness and Length of Locally Thinned Area

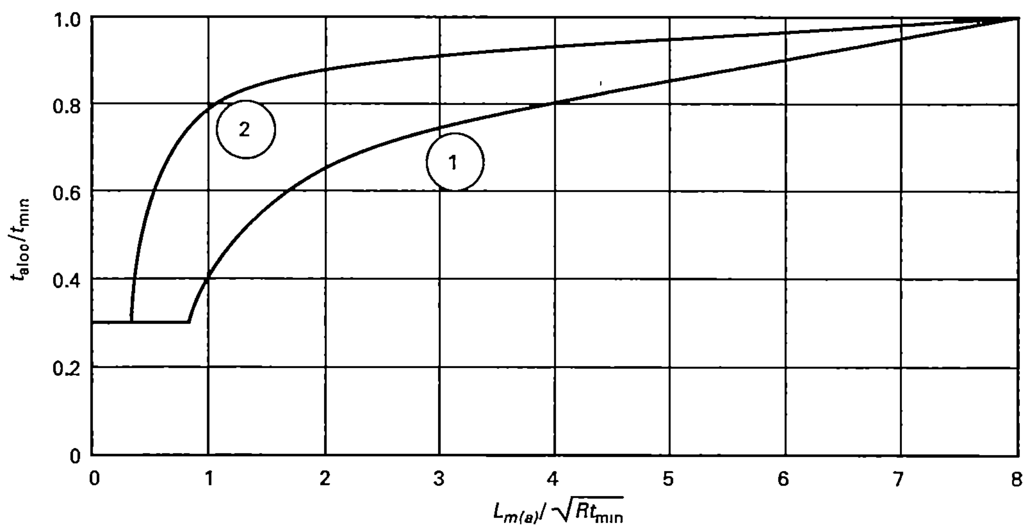


Figure 5
Illustration of Through-Wall Nonplanar Flaw Due to Wall Thinning

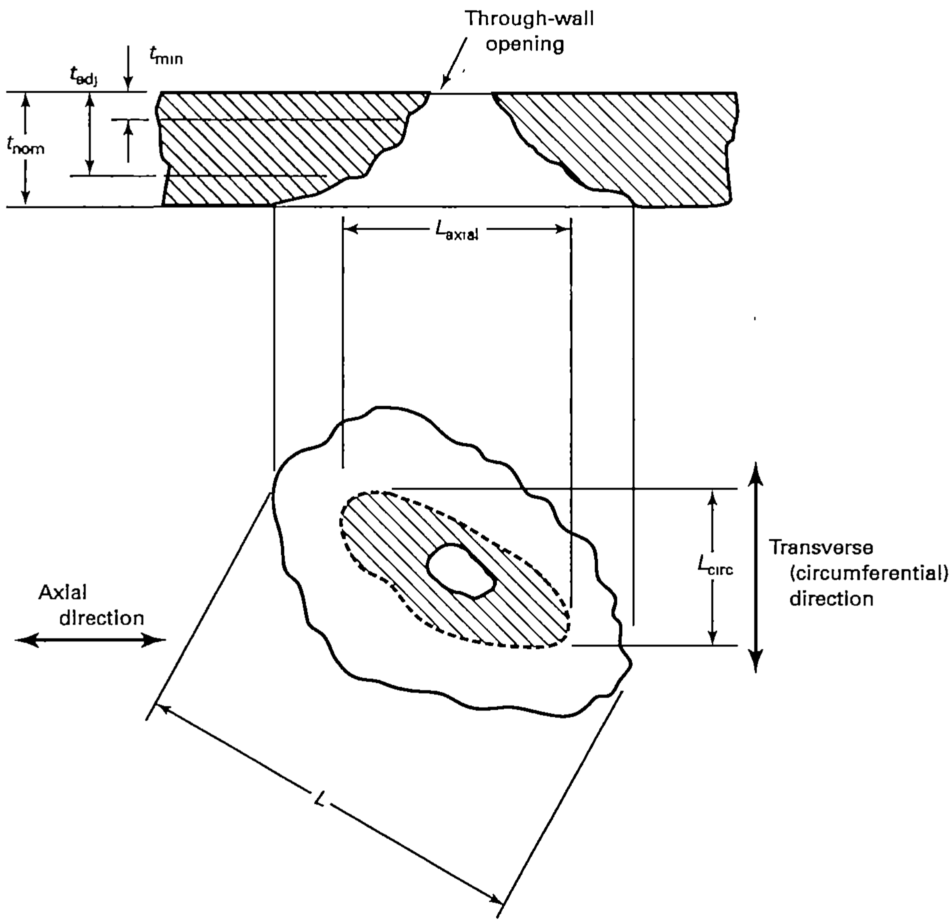
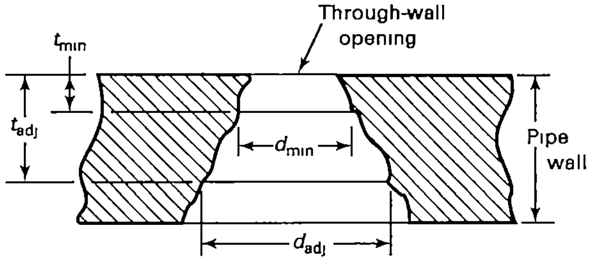
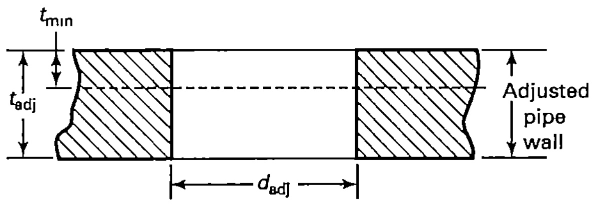


Figure 6
Illustration of Adjusted Wall Thickness and Equivalent Hole Diameter



(a) Adjusted Wall Thickness



(b) Equivalent Hole Representation

Figure 7
Circumferential Angle Defined

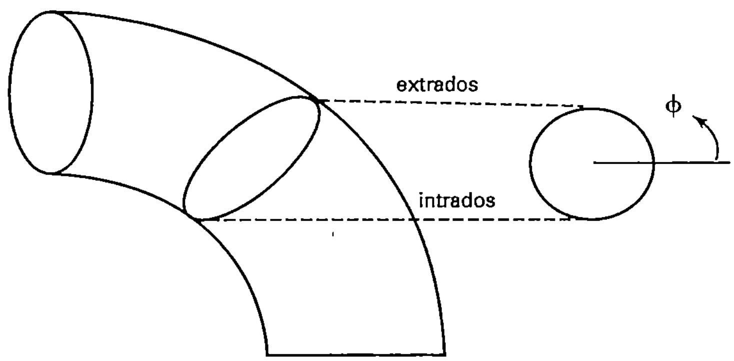
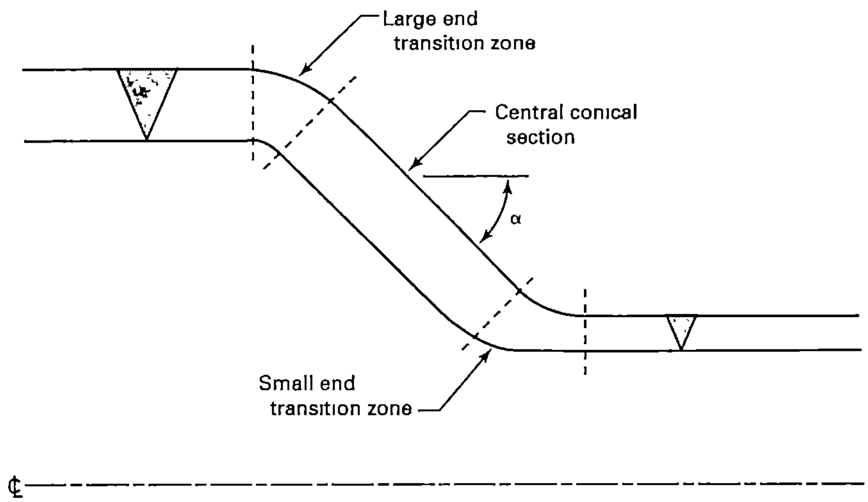
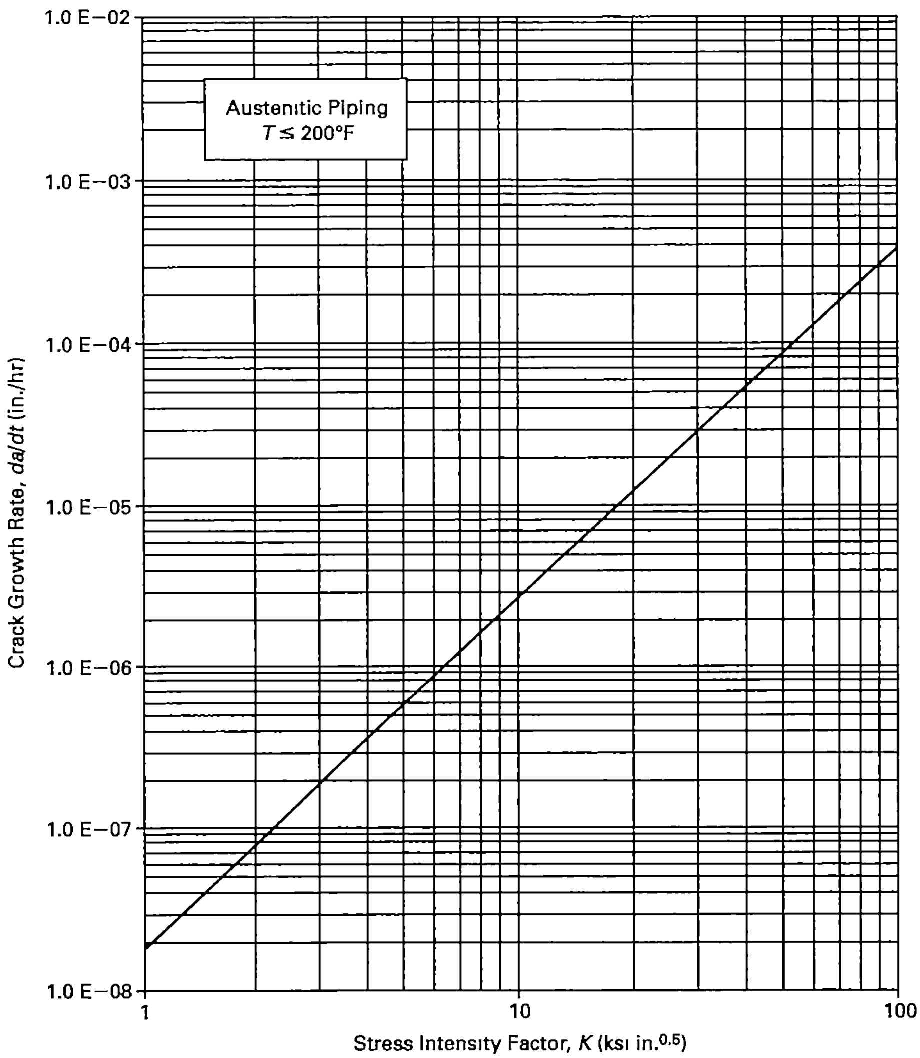


Figure 8
Zones of a Reducer or Expander



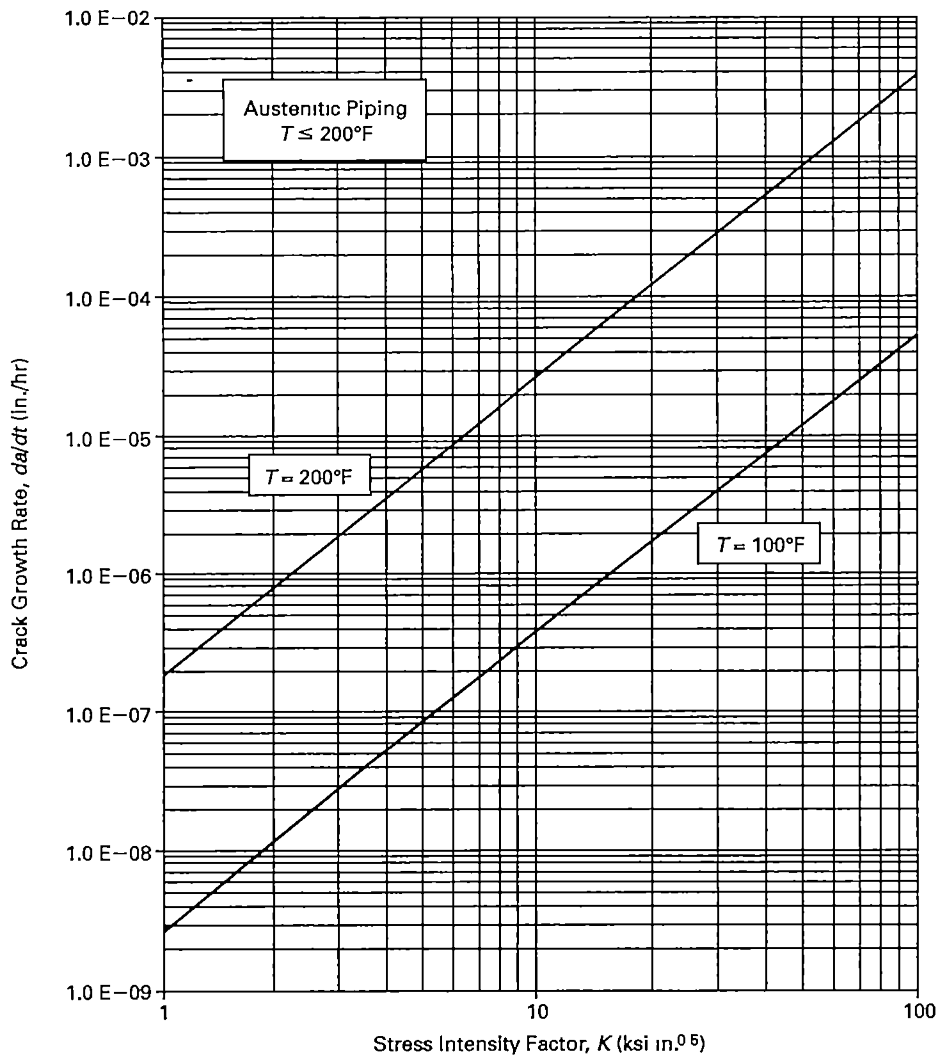
GENERAL NOTE: Transition zones extend from the point on the ends where the diameter begins to change to the point on the central cone where the cone angle is constant.

Figure 9
Flaw Growth Rate for IGSCC in Austenitic Piping



GENERAL NOTE. (SI conversion: 1.0 in./hr = 7.06×10^{-3} mm/sec; 1.0 ksi in.$^{0.5}$ = 1.099 MPa m$^{0.5}$; °C = [°F − 32]/1.8).

Figure 10
Flaw Growth Rate for TGSCC in Austenitic Piping



GENERAL NOTE: (SI conversion: 1.0 in./hr = 7.06 x 10^{-3} mm/sec; 1.0 ksi in.$^{0.5}$ = 1.099 MPa m$^{0.5}$; °C = [°F − 32]/1.8).

MANDATORY APPENDIX I
RELATIONS FOR F_m, F_b, AND F FOR THROUGH-WALL FLAWS

I-1 DEFINITIONS

For through-wall flaws, the crack depth, a, will be replaced with half crack length, c, in the stress intensity factor equations in C-7300 and C-7400 of Section XI, Nonmandatory Appendix C. Also, Q will be set equal to unity in C-7400.

I-2 CIRCUMFERENTIAL FLAWS

For a range of R/t between 5 and 20, the following equations for F_m and F_b may be used:

$$F_m = 1 + A_m(\theta/\pi)^{1.5} + B_m(\theta/\pi)^{2.5} + C_m(\theta/\pi)^{3.5}$$

where

A_m = $-2.02917 + 1.67763\ (R/t) - 0.07987\ (R/t)^2 + 0.00176\ (R/t)^3$
B_m = $7.09987 - 4.42394\ (R/t) + 0.21036\ (R/t)^2 - 0.00463\ (R/t)^3$
C_m = $7.79661 + 5.16676\ (R/t) - 0.24577\ (R/t)^2 + 0.00541\ (R/t)^3$

$$F_b = 1 + A_b(\theta/\pi)^{1.5} + B_b(\theta/\pi)^{2.5} + C_b(\theta/\pi)^{3.5}$$

where

A_b = $-3.26543 + 1.52784\ (R/t) - 0.072698\ (R/t)^2 + 0.0016011\ (R/t)^3$
B_b = $11.36322 - 3.91412\ (R/t) + 0.18619\ (R/t)^2 - 0.004099\ (R/t)^3$
C_b = $-3.18609 + 3.84763\ (R/t) - 0.18304\ (R/t)^2 + 0.00403\ (R/t)^3$

In the above equations:

R = mean pipe radius
t = evaluation wall thickness
θ = half crack angle = c/R

Equations for F_m and F_b are accurate for R/t between 5 and 20 and become increasingly conservative for R/t greater than 20. Alternative solutions for F_m and F_b may be used when R/t is greater than 20.

I-3 AXIAL FLAWS

For internal pressure loading, the following equation for F may be used:

$$F = 1 + 0.072449\lambda + 0.64856\lambda^2 - 0.2327\lambda^3 + 0.038154\lambda^4 - 0.0023487\lambda^5$$

where

c = half crack length
λ = $c/(Rt)^{1/2}$

The equation for F is accurate for λ between 0 and 5. Alternative solutions for F may be used when λ is greater than 5.