7 SUMMARY

An extensive evaluation has been carried out to characterize the loads and stresses that exist in the head penetrations at St. Lucie Unit 2. Three-dimensional finite element models were constructed, and all pertinent loads on the penetrations were analyzed [6]. These loads included internal pressure and thermal expansion effects typical of steady state operation. In addition, residual stresses due to the welding of the penetrations to the vessel head were considered.

Results of the analyses reported here are consistent with the axial orientation and location of flaws that have been found in service in a number of plants. The largest stress component is the hoop stress and the maximum stresses were found to exist at the attachment weld. The most important loading conditions were found to be those which reside on the penetration for the majority of the time. These conditions are the steady state loading and the residual stresses.

These stresses are important because the cracking that has been observed to date in operating plants has been determined to result from primary water stress corrosion cracking (PWSCC). These stresses were used in the fracture mechanics calculations to predict the future growth of flaws postulated to exist in the head penetrations. A crack growth law was developed specifically for the operating temperature of the vessel head at St. Lucie Unit 2 based on the EPRI recommendation, which is consistent with laboratory data as well as crack growth results for operating plants.

The crack growth predictions contained in Section 6 show that the future growth of cracks which might be found in the penetrations will be typically moderate, however, a number of effective full power years would be required for any significant extensions.

The examples in Appendix C show that the most important figures used in evaluating the detected flaws in the head penetrations are Figures 6-2 through 6-10 for the axial surface flaws, and Figure 6-11 for circumferential flaws postulated near the top of the attachment weld. Figures 6-12 through 6-20 provide valuable information on the projected growth of through-wall flaws, but may be of limited practical application with the current acceptance criteria. However, there is an important safety aspect to the through-wall flaw evaluation charts in that they demonstrate that flaw propagation above the weld will be very limited.

7.1 SAFETY ASSESSMENT

It is appropriate to examine the safety consequences of an indication that might be found. The indication, even if it were to propagate through the penetration nozzle wall, would have only minor consequences since the pressure boundary would not be broken, unless it were to propagate above the weld.

Further propagation of the indication would not change its orientation, since the hoop stresses in the penetration nozzle are much larger than the axial stresses. Therefore, it is extremely unlikely that the head penetration would be severed.

If the indication were to propagate to a position above the weld, a leak could result, but the magnitude of such a leak would be very small, because the crack could not open significantly due to the tight fit between the penetration nozzle and the vessel head. Such a leak would have no immediate impact on the structural integrity of the system, but could lead to wastage in the ferritic steel of the vessel head as the borated primary water concentrates due to evaporation. Davis Besse has demonstrated the consequence of ignoring such leaks.

Any indication is unlikely to propagate very far up the penetration nozzle above the weld since the hoop stresses decrease in this direction, causing the indication to slow down and stop before it reaches the outside surface of the head.

The high likelihood that the indication will not propagate up the penetration nozzle beyond the vessel head ensures that no catastrophic failure of the head penetration will occur. The indication will be enveloped in the vessel head itself, which precludes the opening of the crack and limits leakage.

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APPENDIX A

ALLOWABLE AREAS OF LACK OF FUSION: WELD FUSION ZONES

There are two fusion zones of interest for the head penetration nozzle attachment welds, the penetration nozzle itself (Alloy 600) and the reactor vessel head material (A533B ferritic steel). The operating temperature of the upper head region of the St. Lucie Unit 2 is 313°C (596°F) and the materials will be very ductile. The toughness of both materials is quite high and any flaw propagation along either of the fusion zones will be totally ductile.

Two generic calculations were completed for the fusion zones, one for the critical flaw size, and the second one for the allowable flaw size, which includes the margins required in the ASME code. The simpler case is the Alloy 600 fusion zone, where the potential failure will be a pure shearing of the penetration as the pressurized penetration nozzle is forced outward from the vessel head, as shown in Figure A-1.

The failure criterion will be that the average shear stress along the fusion line exceeds the limit shear stress. For the critical flaw size, the limiting shear stress is the shear flow stress, which is equal to half the tensile flow stress, according to the Tresca criterion. The tensile flow stress is the average of the yield stress and ultimate tensile stress of the material. The criterion for Alloy 600 tubes in the upper head region is:

$$\text{Average shear stress} < \text{shear flow stress} = 26.85 \text{ ksi}$$

This value was taken from the ASME Code, Section III, Appendix I, at 600°F.

For each penetration, the axial force, which produces this shear stress, results from the internal pressure. Since each penetration has the same outer diameter, the axial force is the same. The average shear stress increases as the load carrying area decreases (the area of lack of fusion increases). When this increasing lack of fusion area increases the stress to the point at which it equals the flow stress, failure occurs. This point may be termed the critical flaw size. This criterion is actually somewhat conservative. Alternatively, use of the Von Mises failure criterion would have set the shear flow stress equal to 60 percent of the axial flow stress, and would therefore have resulted in larger critical flaw sizes.

The allowable flaw size, as opposed to the critical flaw size discussed above, was calculated using the allowable limit of Section III of the ASME Code, paragraph NB 3227.2. The criterion for allowable shear stress then becomes:

$$\text{Average shear stress} < 0.6\ S_m = 13.98 \text{ ksi}$$

where:

S_m = the ASME Code limiting design stress from Section III, Appendix I.

The above approach was used to calculate the allowable flaw size and critical flaw size for the outermost and center penetrations. The results show that a very large area of lack of fusion can be tolerated by the head penetrations, regardless of their orientation. These results can be illustrated for the outermost CEDM penetration.

The total surface contact area for the fusion zone on the outermost head penetration is 17.4 in^2. The calculations above result in a required area to avoid failure of only 1.45 in^2, and using the ASME Code criteria, the area required is 2.79 in^2. These calculations show that as much as 83.9 percent of the weld may be unfused, and the code acceptance criteria can still be met.

To envision the extent of lack of fusion allowed, Figure A-2 was prepared. In this figure, the weld fusion region for the outermost penetration has been shown in an unwrapped, or developed view. The figure shows the extent of lack of fusion allowed in terms of limiting lengths for a range of circumferential lack of fusion. This figure shows that the allowable vertical length of lack of fusion for a full circumferential unfused region is 84 percent of the weld length. Conversely, for a region of lack of fusion extending the full vertical length of the weld, the circumferential extent is limited to 302 degrees. The extent of lack of fusion which would cause failure is labeled "critical" on this figure, and is even larger. The dimensions shown on this figure are based on an assumed rectangular area of lack of fusion.

The full extent of this allowable lack of fusion is shown in Figure A-3, where the axes have been expanded to show the full extent of the head penetration-weld fusion line. This figure shows that a very large area of lack of fusion is allowed for the outer most penetration. Similar results were found for the center penetration, where the weld fusion area is somewhat smaller at 16.1 in^2.

A similar calculation was also carried out for the fusion zone between the weld and the vessel head, and the result is shown in Figure A-4. The allowable area of unfused weld for this location is 84.8 percent of the total area. This approach to evaluating the fusion zone with the carbon steel vessel head is only approximate, but may provide a realistic estimate of the allowable. Note that even a complete lack of fusion in this region would not result in penetration nozzle ejection, because the weld to the head penetration would prevent the penetration nozzle from moving up through the vessel head.

The allowable lack of fusion for the weld fusion zone to the vessel head using the approximate approach may be somewhat in doubt, because of the different geometry, where one cannot ensure that the failure would be due to pure shear. To investigate this concern, additional finite element models were constructed with various degrees of lack of fusion discretely modeled, ranging from 30 to 65 percent. The stress intensities around the circumference of the penetration were calculated to provide for the effects of all the stresses, as opposed to the shear stress only, as used above. When the average stress intensity reaches the flow stress (53.7 ksi), failure is expected to occur. The code allowable stress intensity is 1.5 S_m, or 35 ksi, using the lower of the Alloy 600 and ferritic allowables at 316°C (600°F).

The results of this series of analyses are shown in Figure A-5, where it is clear that large areas of lack of fusion are allowed. As the area of lack of fusion increases, the stresses redistribute themselves, and that the stress intensity does not increase in proportion to the area lost. These results seem to confirm that shear stress is the only important stress governing the critical flaw size for the vessel head fusion zone as well.

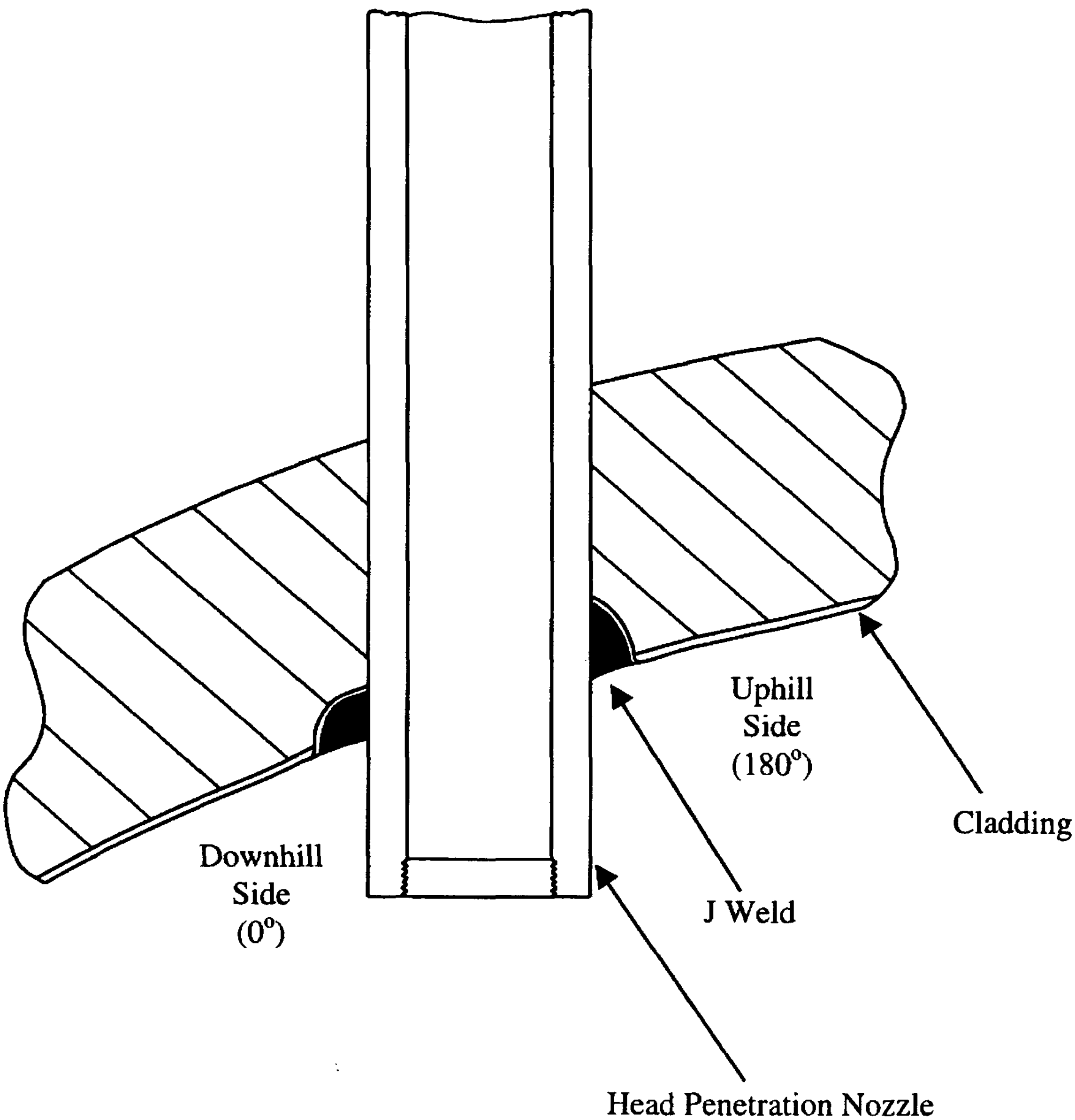


Figure A-1 Typical Head Penetration

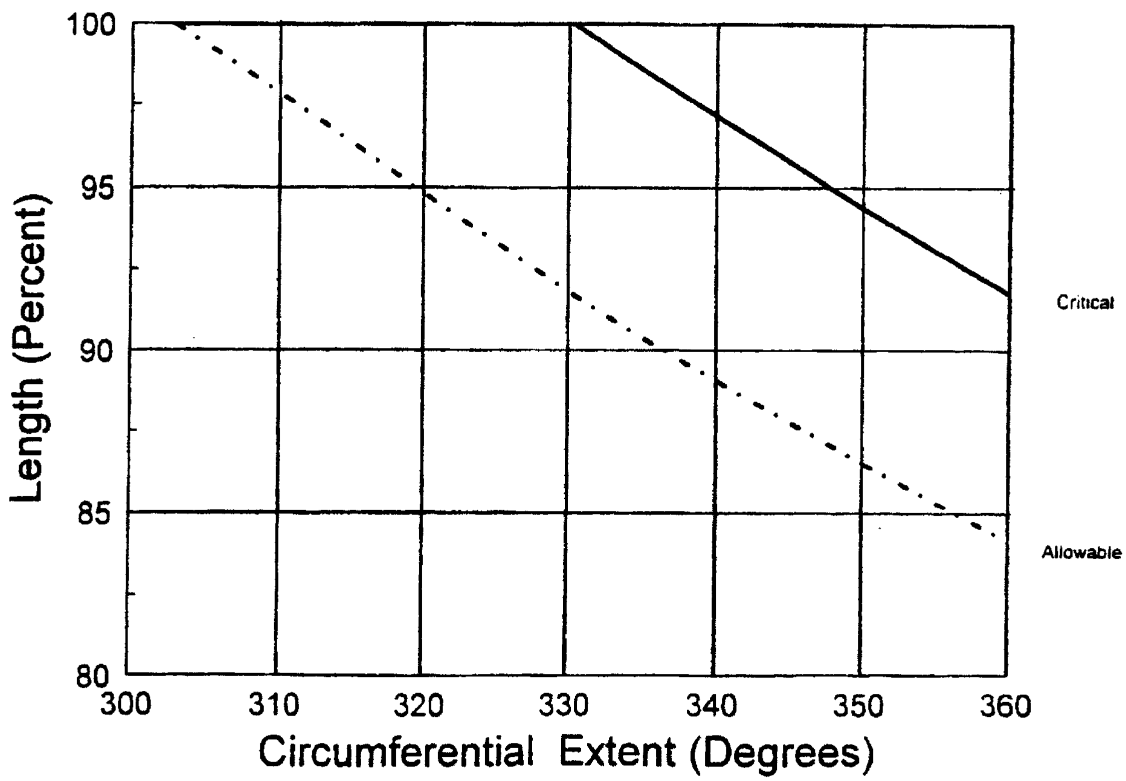


Figure A-2 Allowable Regions of Lack of Fusion for the Outermost Penetration Tube to Weld Fusion Zone: Detailed View

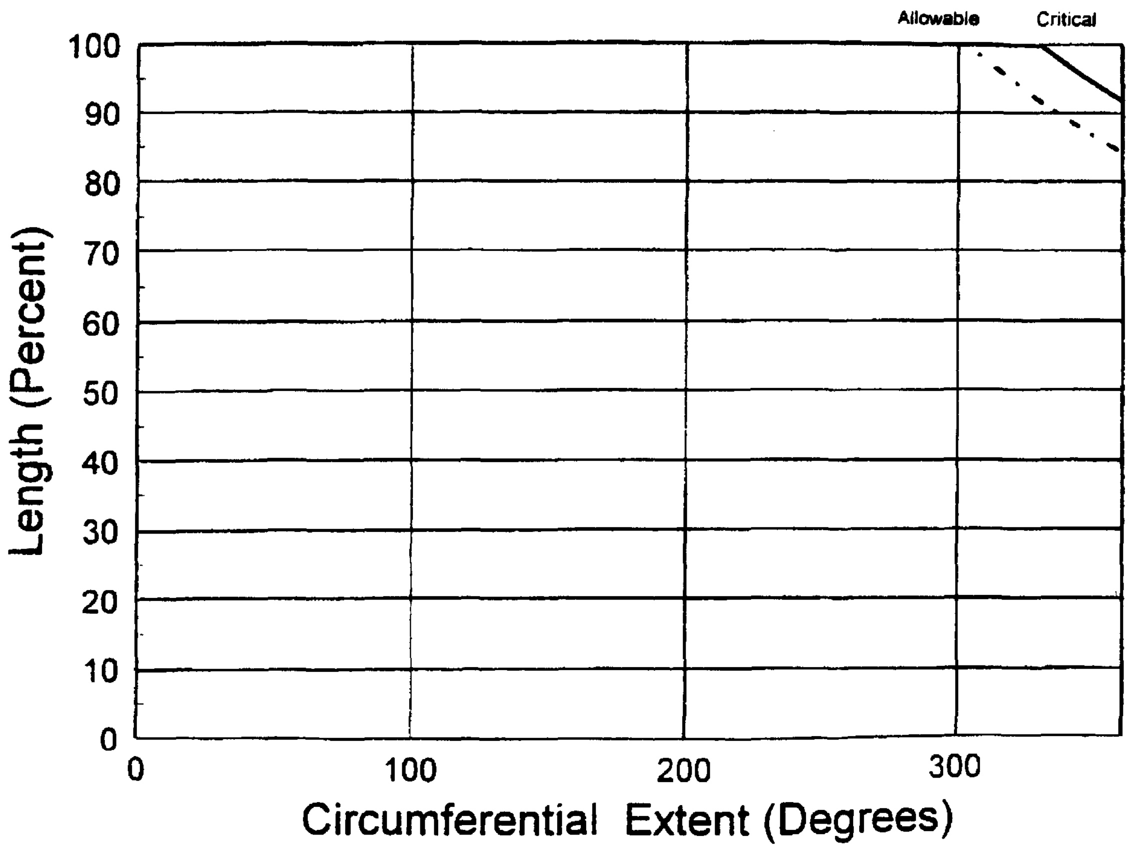


Figure A-3 Allowable Regions of Lack of Fusion for the Outermost Penetration Tube to Weld Fusion Zone

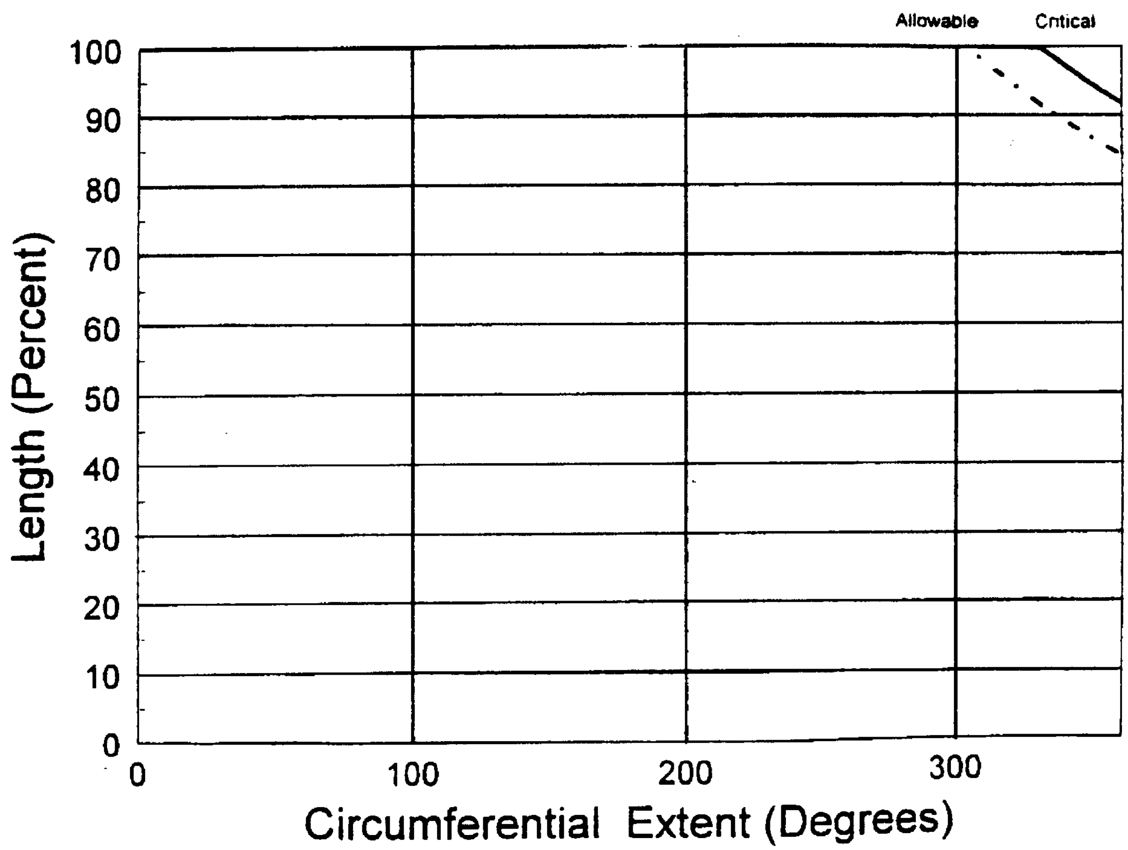


Figure A-4 Allowable Regions of Lack of Fusion for all Penetrations: Weld to Vessel Fusion Zone

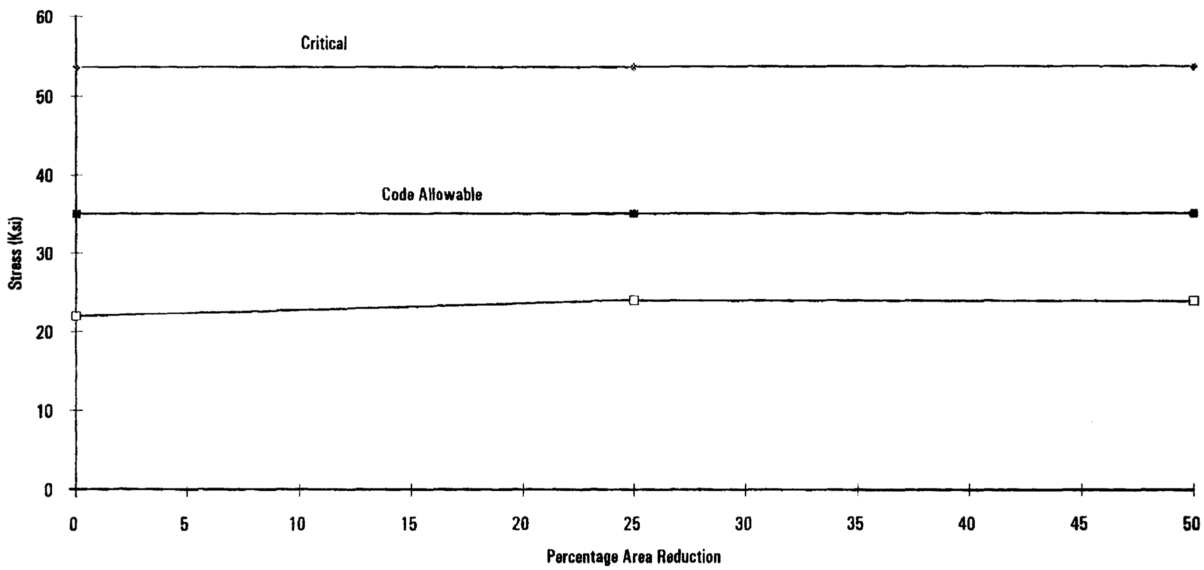


Figure A-5 Allowable Regions of Lack of Fusion for the Weld to Vessel Fusion Zone

APPENDIX B

FLAW TOLERANCE EVALUATION GUIDELINES

The following guidelines are provided to assist in determining the allowable service time for a typical flaw found during inspections. The section entitled "Additional guidelines" is provided to assist in evaluating flaws not specifically covered in the enclosed flaw tolerance charts.

Definition of Terms

a = Flaw depth.

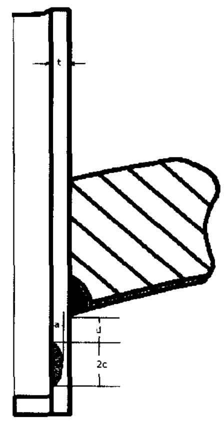
t = Wall thickness (0.661 inches for CEDM, 0.407 inches for ICI with counterbore, and 0.154 for Head Vent).

a/t = Ratio of flaw depth to wall thickness.

d = Distance below or above the weld (See diagram below)

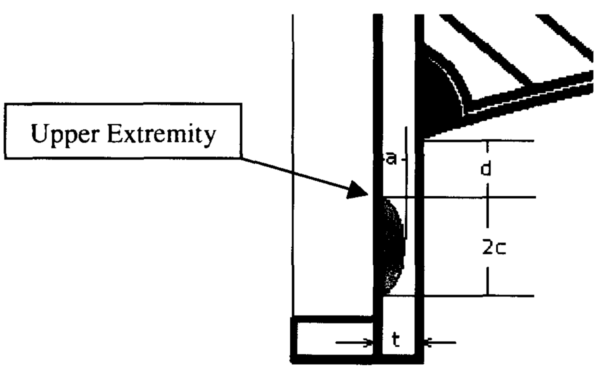
c = Flaw half-length (2c shall be the full length of the flaw)

aspect ratio = 2c/a = Flaw length / depth



The subscript "initial" refers to the state at which the flaw is found

The subscript "final" refers to the state at which the flaw has reached the acceptance criteria (Table 6-1)



Procedure I (See Example 3 in Appendix C)

Used For:
- *Inside, Axial Surface Flaws At the Attachment Weld*
- *Inside, Axial Surface Flaws 0.5" or More Above the Weld*

1. Determine Location and Orientation of the Flaw
   - Axial or Circumferential
   - Inside or Outside Surface
   - Above, At or Below Attachment Weld
   - Uphill or Downhill

2. Go to Table 1-1 to obtain the Penetration Nozzle Locality Angle

3. Identify the Applicable Flaw Tolerance Chart(s)
   - At the Weld
   - 0.5" Above the Weld

4. Determine the Ratio $a_{initial}/t$ (Flaw Depth / Wall Thickness)

5. Determine the Initial Reference Time for the Flaw
   - Draw a horizontal line intersecting the vertical axis at the value of $a_{initial}/t$
   - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
   - The initial reference time for the flaw is where the vertical line intersects the horizontal axis.

6. Go to Table 6-1 to Determine Acceptance Criteria
   - Acceptance criteria will provide the final allowable flaw depth (a_{final})
   - Determine the acceptable a_{final}/t ratio

7. Determine the Final Reference Time for the Flaw
   - Draw a horizontal line intersecting the vertical axis at value of allowable a_{final}/t
   - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
   - The final reference time for the flaw is where the vertical line intersects the horizontal axis.

8. Determine the Remaining Service Life
   - Remaining Service Life = Final Reference Time – Initial Reference Time

Procedure II (See Examples 1and 4 in Appendix C)

Used For:
- *Inside, Axial Surface Flaws 0.5" or More Below the Attachment Weld*

Inside, Axial Surface flaws 0.5" or more below the attachment weld may require the use of more than one flaw tolerance chart. The following guidelines can be used to determine the remaining service life if the flaw length ($2c_{final}$) grows within 0.5" below the weld before the flaw depth (a_{final}) reaches the acceptance criteria (Table 6-1).

1. Determine the final length of the flaw ($2c_{final}$)
   - Assume initial aspect ratio ($2c_{initial}/a_{initial}$) is maintained
   - Determine allowable flaw depth (a_{final}) based on acceptance criteria (Table 6-1)
   - Final length equals the product of aspect ratio and allowable flaw depth

$$2c_{final} = \frac{2c_{initial}}{a_{initial}} \cdot a_{final}$$

2. Determine the distance between the upper extremity of the flaw and the bottom of the weld

$$d_{final} = d_{initial} - (c_{final} - c_{initial})$$

3. Determine if the flaw will grow within 0.5" below the weld
   - If $d_{final} \geq 0.5$", the flaw will not grow within 0.5" below the weld and the remaining service life can be determined using the guidelines for Procedure I.
   - If $d_{final} < 0.5$", separate charts should be used for the time that the upper extremity grows to 0.5" below the weld, and the time that it grows from 0.5" below the weld to the acceptance criteria (Table 6-1). Evaluation continues with Step 4 of this section.

4. Determine Location of the Flaw
   - Uphill or Downhill

5. Go to Table 1-1 to obtain the Penetration Nozzle Locality Angle

6. Identify the Applicable Flaw Tolerance Charts
   - At the Weld and 0.5" Below the Weld

7. Determine the Ratio a/t when the upper extremity of the flaw is 0.5" below the weld.
   - Assume initial aspect ratio ($2c_{initial}/a_{initial}$) is maintained.
   - Determine flaw length ($c_{0.5\text{" below}}$) when upper extremity reaches 0.5" below the weld.

$$c_{0.5\text{" below}} = c_{initial} + d_{initial} - 0.5$$

   - Determine flaw depth ($a_{0.5\text{" below}}$) at which the upper extremity reaches 0.5" below the weld.

$$a_{0.5\text{" below}} = 2c_{0.5\text{" below}} * (a_{initial} / 2c_{initial})$$

   - Determine ratio a/t

$$\text{Ratio} = a_{0.5\text{" below}} / t$$

8. Determine the initial reference time for the flaw (use 0.5" below the weld flaw tolerance chart)
   - Draw a horizontal line intersecting the vertical axis at the value of $a_{initial}/t$.
   - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
   - The initial reference time for the flaw is where the vertical line intersects the horizontal axis.

9. Determine the final reference time for the flaw to grow to 0.5" below the weld (use 0.5" below the weld flaw tolerance chart)
   - Draw a horizontal line intersecting the vertical axis at value of $a_{0.5'' \text{below}}/t$.
   - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
   - The final reference time for the flaw is where the vertical line intersects the horizontal axis.

10. Determine the Service Life for the flaw to grow to 0.5" below the weld
    - Service $\text{Life}_{0.5'' \text{below}}$ = Final Reference $\text{Time}_{0.5'' \text{below}}$ – Initial Reference $\text{Time}_{0.5'' \text{below}}$

11. Go to Table 6-1 to Determine Acceptance Criteria
    - Acceptance criteria will provide the final allowable flaw depth (a_{final})
    - Determine the acceptable a_{final}/t ratio

12. Determine the initial reference time for the flaw to grow from 0.5" below the weld to the acceptance criteria (use at the weld flaw tolerance chart)
    - Draw a horizontal line intersecting the vertical axis at the value of $a_{0.5'' \text{below}}/t$.
    - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
    - The initial reference time for the flaw is where the vertical line intersects the horizontal axis.

13. Determine the final reference time for the flaw to grow from 0.5" below the weld to the acceptance criteria (use the at the weld flaw tolerance chart)
    - Draw a horizontal line intersecting the vertical axis at value of a_{final}/t.
    - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
    - The final reference time for the flaw is where the vertical line intersects the horizontal axis.

14. Determine the Service Life for the flaw to grow from 0.5" below the weld to the acceptance criteria.

    Service $\text{Life}_{\text{at weld}}$ = Final Reference $\text{Time}_{\text{at weld}}$ – Initial Reference $\text{Time}_{\text{at weld}}$

15. Determine the Remaining Service Life
    Remaining Service Life = Service $\text{Life}_{0.5'' \text{below}}$ + Service $\text{Life}_{\text{at weld}}$

See the additional guideline #5 on page B-8 for a quicker, yet more conservative, evaluation of flaws 0.5" below the attachment weld that cross zones before reaching the acceptance criteria.

Procedure III (See Example 2 in Appendix C)

Used For:
- *Outside, Axial Surface Flaws Below the Attachment Weld*

Outside, Axial Surface flaws below the attachment weld may have a flaw length ($2c_{final}$) that will grow into the weld before its depth (a_{final}) can reach the acceptance criteria (Table 6-1). The following guidelines can be used to determine the remaining service life if the upper extremity of the flaw reaches the bottom of the weld before the acceptance criteria is met.

1. Determine the final length of the flaw ($2c_{final}$)
   - Assume initial aspect ratio ($2c_{initial}/a_{initial}$) is maintained
   - Determine allowable flaw depth (a_{final}) based on acceptance criteria (Table 6-1)
   - Final length equals the product of aspect ratio and allowable flaw depth

$$2c_{final} = \frac{2c_{initial}}{a_{initial}} \cdot a_{final}$$

2. Determine the distance between the upper extremity of the flaw and the bottom of the weld

$$d_{final} = d_{initial} - \left(c_{final} - c_{initial}\right)$$

3. Determine if the flaw will grow into the weld
   - If $d_{final} > 0$, the flaw will not grow into the weld and the remaining service life can be determined using the guidelines for Procedure I.
   - If $d_{final} \leq 0$, the flaw will grow into the weld and evaluation continues with Step 4 of this section.

4. Determine Location of the Flaw
   - Uphill or Downhill

5. Go to Table 1-1 to obtain the Penetration Nozzle Locality Angle

6. Identify the Applicable Flaw Tolerance Charts
   - Outside Surface , Below the Attachment Weld

7. Determine the Ratio a/t when the upper extremity of the flaw reaches the bottom of the weld
   - Assume initial aspect ratio ($2c_{initial}/a_{initial}$) is maintained
   - Determine flaw length ($c_{bottom\ of\ weld}$) when the upper extremity reaches the bottom of the weld

$$c_{bottom\ of\ weld} = c_{initial} + d_{initial}$$

Determine flaw depth ($a_{bottom\ of\ weld}$) at which the upper extremity reaches the bottom of the weld

$$a_{bottom\ of\ weld} = 2c_{bottom\ of\ weld} * (a_{initial} / 2c_{initial})$$

Determine ratio a/t at which the upper extremity reaches the bottom of the weld

$$\text{Ratio} = a_{\text{bottom of weld}} / t$$

8. Determine the initial reference time for the flaw
   - Draw a horizontal line intersecting the vertical axis at the value of $a_{initial}/t$
   - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve
   - The initial reference time for the flaw is where the vertical line intersects the horizontal axis

9. Determine the final reference time for the flaw to grow to the bottom of the weld
   - Draw a horizontal line intersecting the vertical axis at the value of $a_{\text{bottom of weld}} / t$.
   - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
   - The final reference time for the flaw is where the vertical line intersects the horizontal axis.

10. Determine the Service Life for the flaw to grow to the bottom of the weld
    Service Life $_{\text{bottom of weld}}$ = Final Reference Time $_{\text{bottom of weld}}$ – Initial Reference Time $_{\text{bottom of weld}}$

Procedure IV (See Example 5 in Appendix C)

Used For:
- *Axial Through-Wall Flaws Below the Weld*

1. Go to Table 1-1 to obtain the Penetration Nozzle Locality Angle

2. Identify the Applicable Flaw Tolerance Chart(s)
   - Nozzle Locality Angle
   - Uphill or Downhill

3. Determine the Initial Reference Time for the Flaw
   - Draw a horizontal line intersecting the vertical axis at the value corresponding to the location of the crack tip with respect to the bottom weld.
   - Draw a vertical line downward at the point where the horizontal line intersects the applicable penetration nozzle locality angle curve.
   - The initial reference time for the flaw is where the vertical line intersects the horizontal axis.

4. Determine the Final Reference Time for the Flaw
   - Draw a vertical line downward at the point where the CEDM bottom weld horizontal line intersects the penetration nozzle locality angle curve.
   - The final reference time for the flaw is where the vertical line intersects the horizontal axis.

5. Determine the Remaining Service Life
   - Remaining Service Life = Final reference Time – Initial Reference Time

Additional Guidelines

1. If a flaw is found in a penetration nozzle for which no specific analysis was performed and there is a uniform trend as a function of penetration nozzle angle, interpolation between penetration nozzles is the best approach.

2. If a flaw is found in a penetration nozzle for which no specific analysis was performed and there is no apparent trend as a function of penetration nozzle angle, the result for the penetration nozzle with the closest angle should be used.

3. If a flaw is found which has a depth smaller than any depth shown for the penetration nozzle angle of interest, the initial flaw depth should be assumed to be the same as the smallest depth analyzed for that particular penetration nozzle.

4. The flaw evaluation charts are applicable for aspect ratio of 6 or less. Consult with Westinghouse if the as-found flaw has an aspect ratio larger than 6.0.

5. In the Procedure II guidelines, flaws whose upper extremities grow within 0.5" below the weld require the use of both the 0.5" below the weld and "at the weld" flaw tolerance charts. To avoid the use of these two charts, the "at the weld" charts may solely be used in determining the service life. This shall provide a conservative estimate of the crack growth due to a larger stress field.

6. All references to service life are in effective full power years.

7. Results are only provided for the uphill and downhill sides of the selected penetration nozzles. If flaws are found in locations between the uphill and downhill side, use the results for either the uphill or downhill location, whichever is closer.

APPENDIX C

EXAMPLE PROBLEMS

The flaw tolerance charts in Figures 6-2 through 6-21 can be used with the acceptance criteria of Section 6.5 to determine the available service life. This appendix uses the guidelines of Appendix B to present a few examples illustrating the use of these figures. The example cases are listed in Table C-1.

Example 1 – Determine the service life of an axially oriented inside surface flaw whose upper extremity is located 1.25" below the weld on the uphill side of penetration no. 40, the penetration locality angle must first obtained from Table 1-1. In this case, the locality angle is 29.1 degrees and the initial flaw depth is 0.078" ($a_{initial}$) and the initial flaw length is 0.195" ($2c_{initial}$). Assuming that the initial aspect ratio of 2.5:1 is maintained throughout the time that the inside surface flaw becomes a through-wall flaw, the final length of the flaw ($2c_{final}$) will be 1.653". The upper extremity of the flaw is now located 0.521" below the weld and validates the use of a single crack growth curve. The crack growth curve for the 29.1 degrees nozzle angle of Figure 6-2 is applicable and Figure 6-2 has been reproduced as Figure C-1. The flaw is initially 11.8 percent of the wall thickness, and a straight line is drawn horizontally at a/t = 0.118 that intersects the crack growth curve. Using the acceptance criteria in Table 6-1, the service life can then be determined as the remaining time for this flaw to grow to the limit of 100 percent of the wall thickness or approximately 4.2 years (labeled as Service Life in Figure C-1).

Example 2 – In this case, the flaw is identical in size to that used in Example 1, but located on the outside surface and on the downhill side of penetration no. 40. This flaw, just as the flaw in Example 1, will not cross into the weld region. The applicable curve to use is Figure 6-10. The ratio a/t and initial reference time are likewise found using the same approach as used in Example 1. Using the acceptance criteria in Table 6-1, the determination of service life is illustrated in Figure C-2, where we can see that the result is approximately 1.8 years.

Example 3 – An axial inside surface flaw is located at the weld and on the downhill side of penetration no. 1. The initial length of the flaw is 0.250" and the initial depth is 0.05". From Table 1-1, the angle of this penetration nozzle is 0.0 degrees. The applicable curve is Figure 6-5 and is reproduced here as Figure C-3. In this case, the initial flaw depth is 7.6 percent of the wall thickness. The initial reference time can be found by drawing a horizontal line at a/t = 0.076. Using the acceptance criteria in Table 6-1, the allowable service life can then be determined as the time for the flaw to reach a depth of 75 percent of the wall thickness. The final reference time is found through a horizontal line drawn at a/t = 0.75. The service life can be determined through the intersection points of these lines and the crack growth curve. The resulting service life is approximately 5.4 years, as shown in Figure C-3.

Example 4 – In this case, we have postulated an axial inside surface flaw with an upper extremity located 1.0 inch below the attachment weld on the downhill side of penetration no. 40 (29.1 degrees). The flaw has an initial depth of 0.079" and an initial length of 0.394". Assuming that the initial aspect ratio of 5:1 (0.394" / 0.079") is maintained as the flaw propagates into the nozzle wall, the final length of a through-wall flaw would be 3.31" long (0.661" x 5). The location of the upper extremity of this flaw would have reached within 0.5 inch below the weld as it propagates into the nozzle wall (1.0 – ((3.31" / 2) – (0.394" / 2))). Therefore the evaluation will require the use of two flaw charts. The first step is to estimate the time required for the initial flaw to grow to within 0.5 inch of the weld. This can be accomplished with the use of Figure 6-3 and is reproduced here as Figure C-4a. The upper extremity is 1 inch below the weld and is assumed to grow until the extremity is 0.5 inches below the weld. The final half-length of the flaw when it reaches 0.5 inches below the weld will be the sum of the initial half-length and the 0.5 inches it has grown or 0.697" ((0.394" / 2 + 1.0" – 0.5"). Multiplying this by two and then dividing by the aspect ratio ((2 x 0.697") / 5.0) gives the flaw depth (0.279") when the upper extremity is 0.5 inches below the weld. Figure C-4a can be used to find the time it takes to grow from 12.0% through-wall (a/t = 0.079" / 0.661" = 0.12) to 42% through-wall (a/t = 0.279" /0.661" = 0.42). The time is estimated as 5.8 years. Using the flaw depth calculated previously (a/t = 0.42) as the initial flaw depth, the curves in Figure 6-5 reproduced here as Figure C-4b, for inside surface flaws near the weld can be used to determine the remaining service time before the flaw depth reaches the allowable flaw size. Using the acceptance criteria in Table 6-1, Figure C-4b shows an additional 1 years of service life for a total of 6.8 years (Consult additional guidelines #5 for a simplified, more conservative approach).

Example 5 – This case is an axial through-wall flaw with its upper extremity located 0.40 inches below the weld region on the uphill side of penetration no. 101. The angle of the penetration nozzle is 55.3 degrees as shown in Table 1-1. The crack growth curves of Figure 6-19 are applicable and has been reproduced as Figure C-5. The initial reference time is found by drawing a horizontal line 0.40 inches below the line representing the bottom of the weld, then dropping a vertical line to the x axis. The final reference time is found by drawing a vertical line where the crack growth curve intersects the bottom of the weld horizontal line. The service life is estimated to be approximately 3.3 years for the initial flaw to grow to the bottom of the attachment weld.

The examples show that the most important figures used in evaluating the detected flaws in the head penetrations are Figures 6-2 through 6-10 for the axial surface flaws, and Figure 6-11 for circumferential flaws postulated near the top of the attachment weld. Figures 6-12 through 6-20 provide valuable information on the projected growth of through-wall flaws, but may be of limited practical application with the current acceptance criteria. However, there is an important safety aspect to the through-wall flaw evaluation charts in that they demonstrate that flaw propagation above the weld will be very limited.

Table C-1 Example Problem Inputs: Initial Flaw Sizes and Locations

No.	Orientation	Vertical Location	Circum. Location	Penetration Angle	Length (2c)	Depth (a)	a/t	Asp. Ratio	Wall Thick. (t)	Pen. No.	Source Figure
1	Axial - Inside Surface	1.25" Below Weld	Uphill	29.1°	0.195"	0.078"	0.118	2.5:1	0.661"	40	6-2
2	Axial – Outside Surface	1.25" Below Weld	Downhill	29.1°	0.195"	0.078"	0.118	2.5:1	0.661"	40	6-10
3	Axial - Inside Surface	At Weld	Downhill	0.0°	0.250"	0.05"	0.076	5:1	0.661"	1	6-5
4	Axial - Inside Surface	1.0" Below Weld	Downhill	29.1°	0.394"	0.079"	0.120	5:1	0.661"	40	6-3, 6-5
5	Axial Through-Wall	0.4" Below Weld	Uphill	55.3°	--	--	--	--	0.407"*	101	6-19

*When evaluating for ICI nozzles, use the thickness of counterbore at all time.

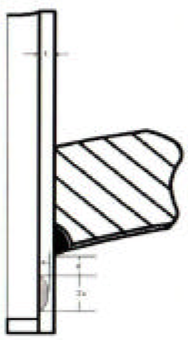
No.	Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	Source Figure	a/t	Asp. Ratio	Wall Thick. (t)
1	Axial – Inside Surface	1.25" Below Weld	Uphill	40	0.195"	0.078"	29.1°	6-2	0.118	2.5:1	0.661"

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L
Below Weld (ID)	t	No Limit

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle
40	CEDM	29.1



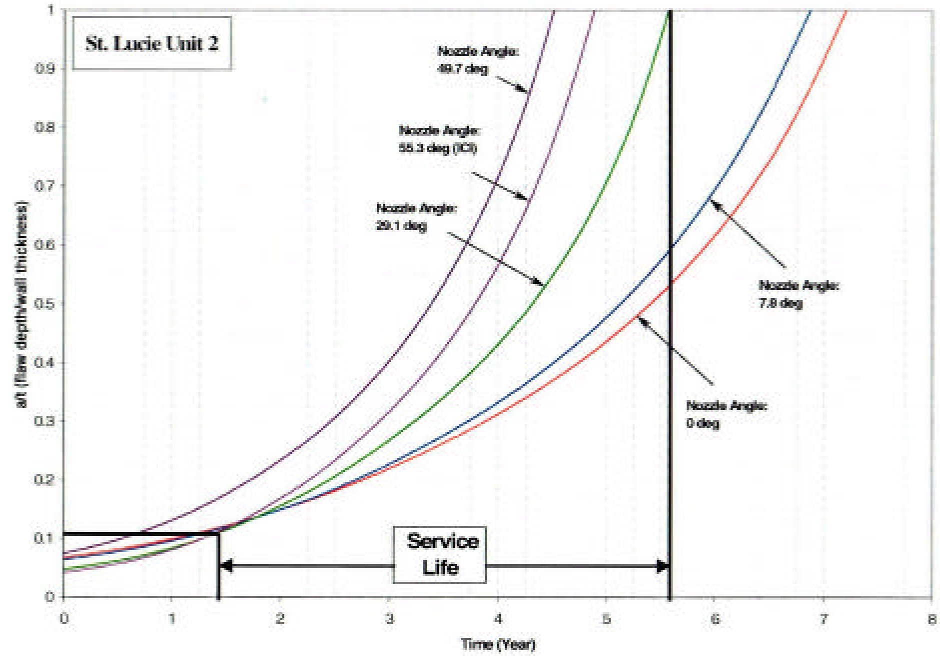


Figure C-1 Example Problem 1

No.	Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	Source Figure	a/t	Asp. Ratio	Wall Thick. (t)
2	Axial – Outside Surface	1.25" Below Weld	Downhilll	40	0.195"	0.078"	29.1°	6-10	0.118	2.5:1	0.661"

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L
Below Weld (OD)	t	No Limit

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle
40	CEDM	29.1

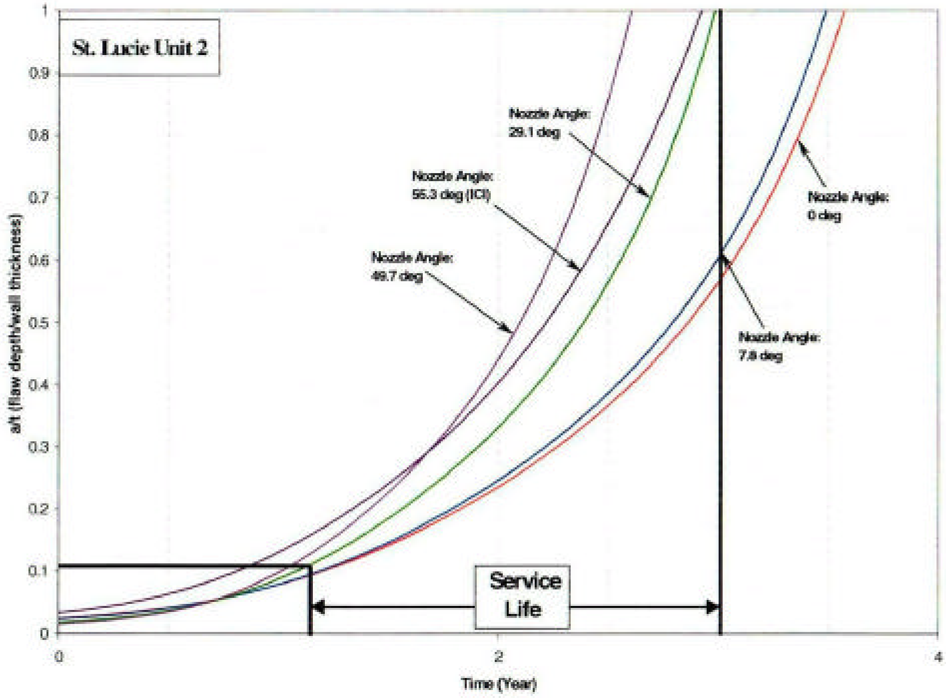


Figure C-2 Example Problem 2

C02

No.	Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	Source Figure	a/t	Asp. Ratio	Wall Thick. (t)
3	Axial – Inside Surface	At Weld	Downhill	1	0.250"	0.050"	0.0°	6-5	0.076	5:1	0.661"

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L
At and Above Weld (ID)	0.75 t	No Limit

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle
1	CEDM	0.0

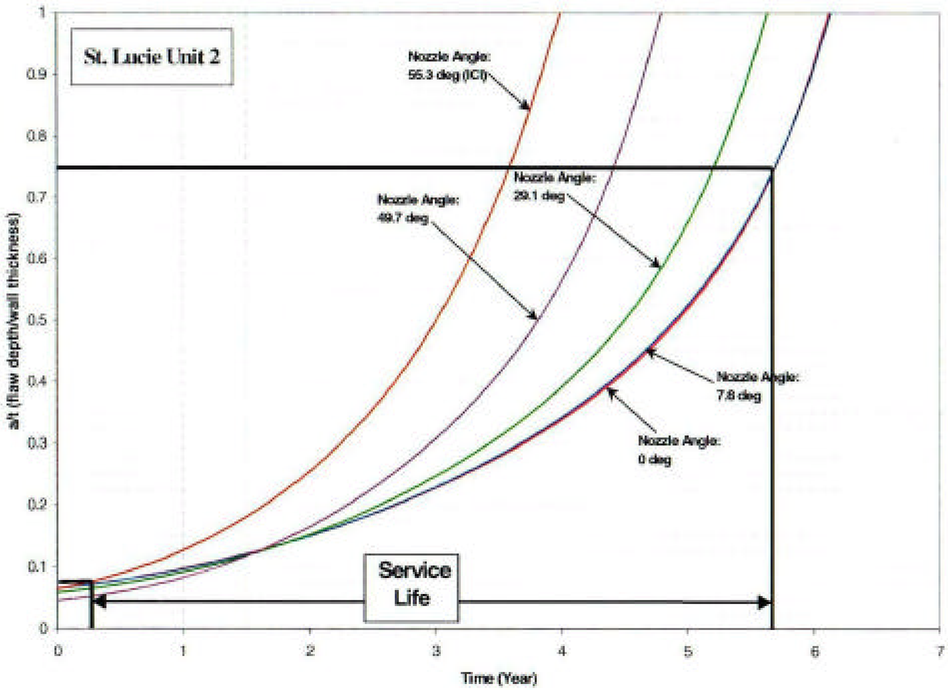


Figure C-3 Example Problem 3

C03

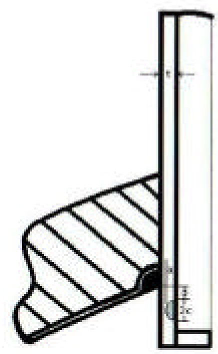
No.	Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	Source Figure	a/t	Asp. Ratio	Wall Thick. (t)
4	Axial – Inside Surface	1.0" Below Weld	Downhill	40	0.394"	0.079"	29.1°	6-3, 6-5	0.12	5:1	0.661"

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L
Below Weld (ID)	t	No Limit

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle
40	CEDM	29.1



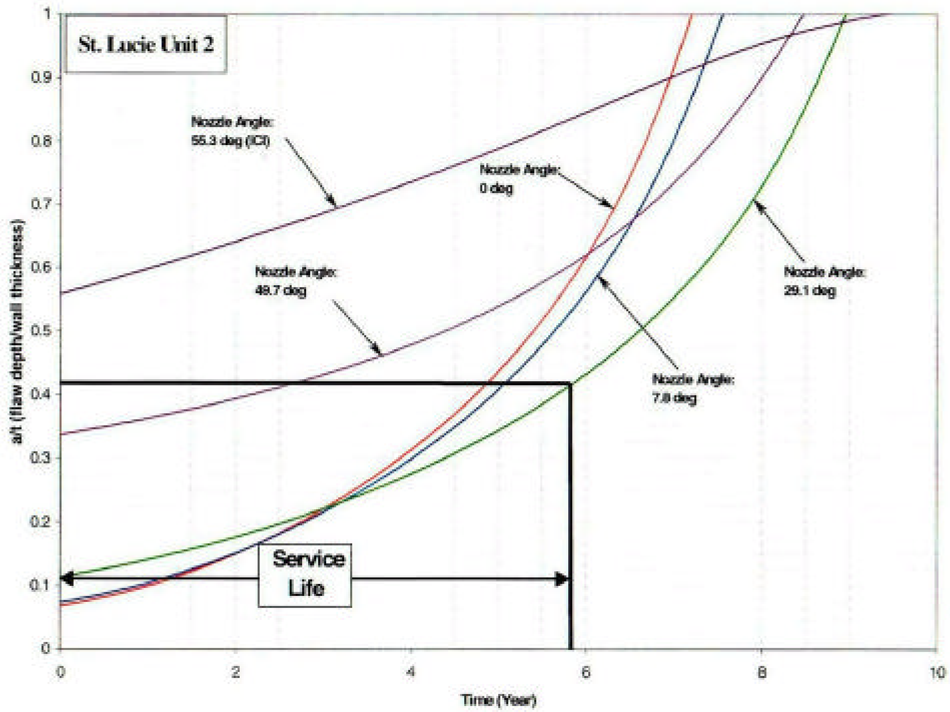


Figure C-4a Example Problem 4 (See also Figure C-4b)

No.	Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	Source Figure	a/t	Asp. Ratio	Wall Thick. (t)
4	Axial – Inside Surface	1.0" Below Weld	Downhill	40	0.394"	0.079"	29.1°	6-3, 6-5	0.12	5:1	0.407"

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L
At Weld (ID)	0.75 t	No Limit

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle
40	CEDM	29.1

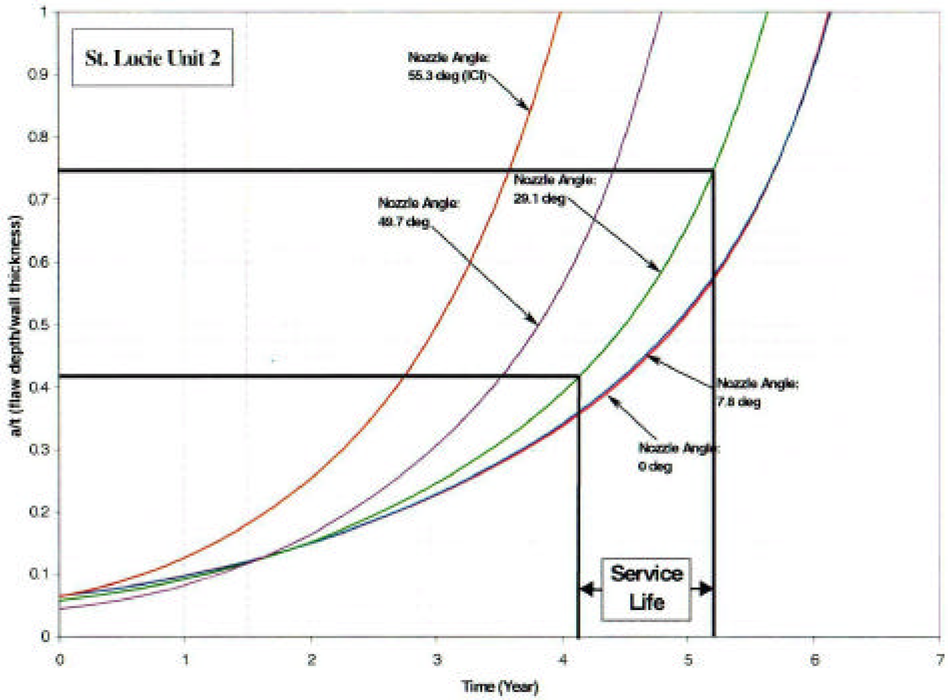


Figure C-4b Example Problem 4 (See also Figure C-4a)

C05

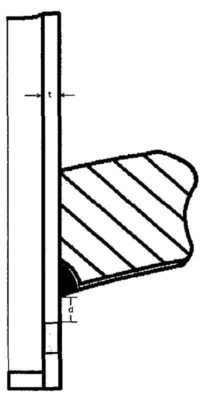
No.	Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	Source Figure	a/t	Asp. Ratio	Wall Thick. (t)
5	Axial – Through Wall	0.4" Below Weld	Uphill	101	--	--	55.3°	6-19	--	--	0.407"

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L
Below Weld (ID)	t	Bottom Weld

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle
101	ICI	55.3



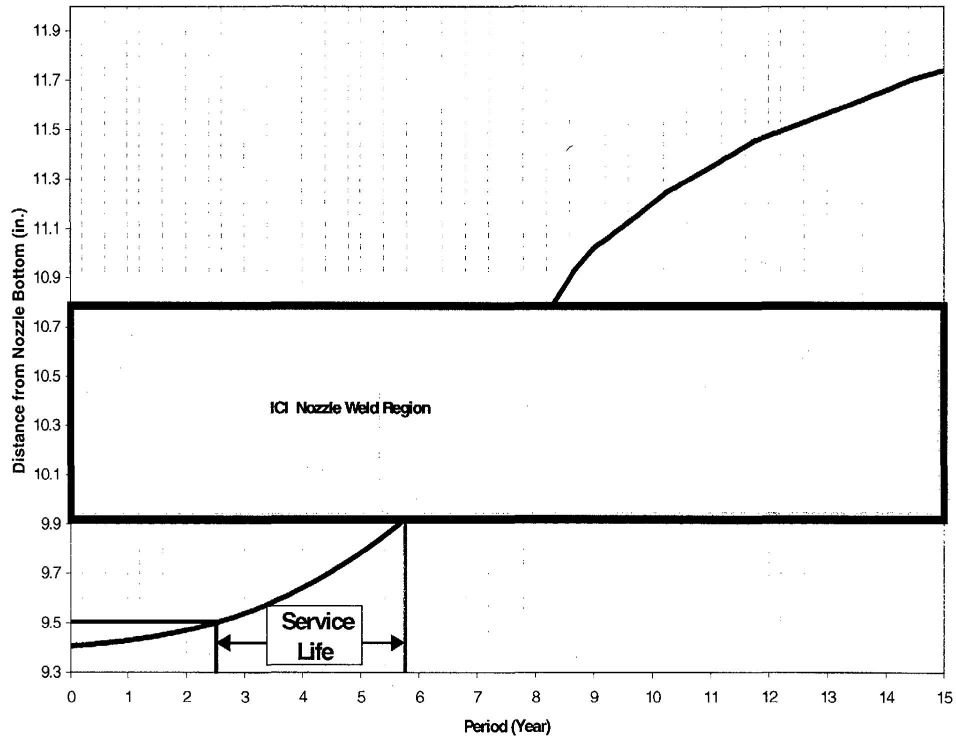


Figure C-5 Example Problem 5

APPENDIX D

WORKSHEETS

Table D-1 St. Lucie Unit 2 Head Penetration Nozzles with the Intersection Angles Identified

Nozzle No.	Type	Angle (Degrees)		Nozzle No.	Type	Angle (Degrees)		Nozzle No.	Type	Angle (Degrees)
1	CEDM	0.0		35	CEDM	25.2		69	CEDM	42.4
2	CEDM	7.8		36	CEDM	29.1		70	CEDM	42.4
3	CEDM	7.8		37	CEDM	29.1		71	CEDM	42.4
4	CEDM	11.0		38	CEDM	29.1		72	CEDM	42.4
5	CEDM	11.0		39	CEDM	29.1		73	CEDM	42.4
6	CEDM	11.0		40	CEDM	29.1		74	CEDM	42.4
7	CEDM	11.0		41	CEDM	29.1		75	CEDM	42.4
8	CEDM	15.6		42	CEDM	29.1		76	CEDM	42.4
9	CEDM	15.6		43	CEDM	29.1		77	CEDM	42.4
10	CEDM	15.6		44	CEDM	32.6		78	CEDM	42.4
11	CEDM	15.6		45	CEDM	32.6		79	CEDM	42.4
12	CEDM	17.6		46	CEDM	32.6		80	CEDM	43.4
13	CEDM	17.6		47	CEDM	32.6		81	CEDM	43.4
14	CEDM	17.6		48	CEDM	33.8		82	CEDM	43.4
15	CEDM	17.6		49	CEDM	33.8		83	CEDM	43.4
16	CEDM	17.6		50	CEDM	33.8		84	CEDM	43.4
17	CEDM	17.6		51	CEDM	33.8		85	CEDM	43.4
18	CEDM	17.6		52	CEDM	33.8		86	CEDM	43.4
19	CEDM	17.6		53	CEDM	33.8		87	CEDM	43.4
20	CEDM	22.4		54	CEDM	33.8		88	CEDM	49.7
21	CEDM	22.4		55	CEDM	33.8		89	CEDM	49.7
22	CEDM	22.4		56	CEDM	34.9		90	CEDM	49.7
23	CEDM	22.4		57	CEDM	34.9		91	CEDM	49.7
24	CEDM	23.9		58	CEDM	34.9		92	ICI	55.3
25	CEDM	23.9		59	CEDM	34.9		93	ICI	55.3
26	CEDM	23.9		60	CEDM	37.1		94	ICI	55.3
27	CEDM	23.9		61	CEDM	37.1		95	ICI	55.3
28	CEDM	25.2		62	CEDM	37.1		96	ICI	55.3
29	CEDM	25.2		63	CEDM	37.1		97	ICI	55.3
30	CEDM	25.2		64	CEDM	37.1		98	ICI	55.3
31	CEDM	25.2		65	CEDM	37.1		99	ICI	55.3
32	CEDM	25.2		66	CEDM	37.1		100	ICI	55.3
33	CEDM	25.2		67	CEDM	37.1		101	ICI	55.3
34	CEDM	25.2		68	CEDM	42.4				

Table D-2 Summary of R.V. Head Penetration Flaw Acceptance Criteria (Limits for Future Growth)				
	Axial		**Circumferential**	
Location	a_f	ℓ	a_f	ℓ
Below Weld (ID)	t	no limit	t	.75 circ.
At and Above Weld (ID)	0.75 t	no limit	*	*
Below Weld (OD)	t	no limit	t	.75 circ.
Above Weld (OD)	*	*	*	*

Note: Surface flaws of any size in the attachment weld are not acceptable.

* Requires case-by-case evaluation and discussion with regulatory authority.

a_f = Flaw Depth
ℓ = Flaw Length
t = Wall Thickness

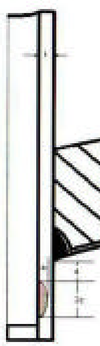
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	_____ " Below Weld	Uphill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



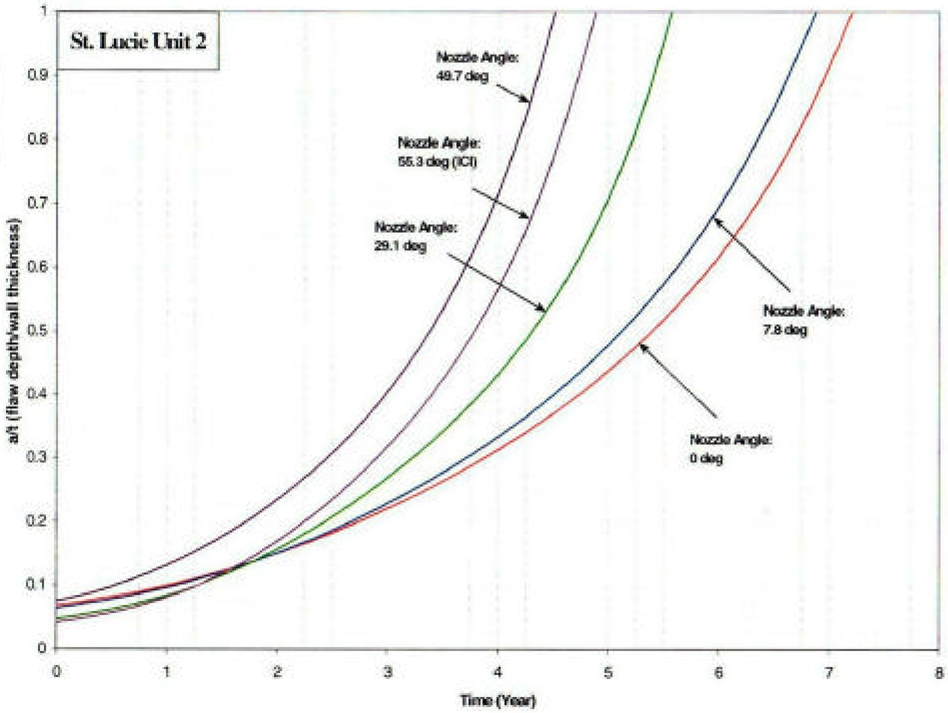


Figure D-1 Inside, Axial Surface Flaws, .5" Below the Attachment Weld, Nozzle Uphill Side - Crack Growth Predictions

C06

Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	_____ " Below Weld	Downhill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle

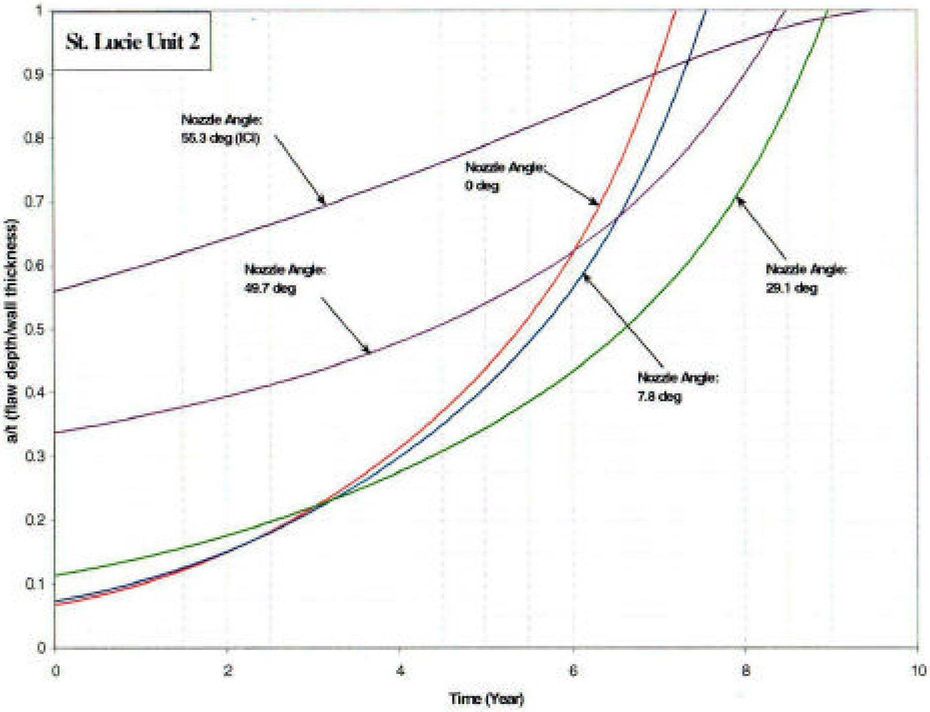


Figure D-2 Inside, Axial Surface Flaws, .5" Below the Attachment Weld, Nozzle Downhill Side - Crack Growth Predictions

C07

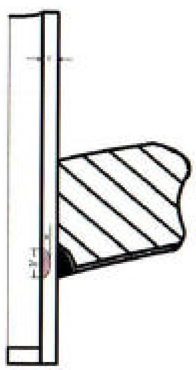
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	At Weld	Uphill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



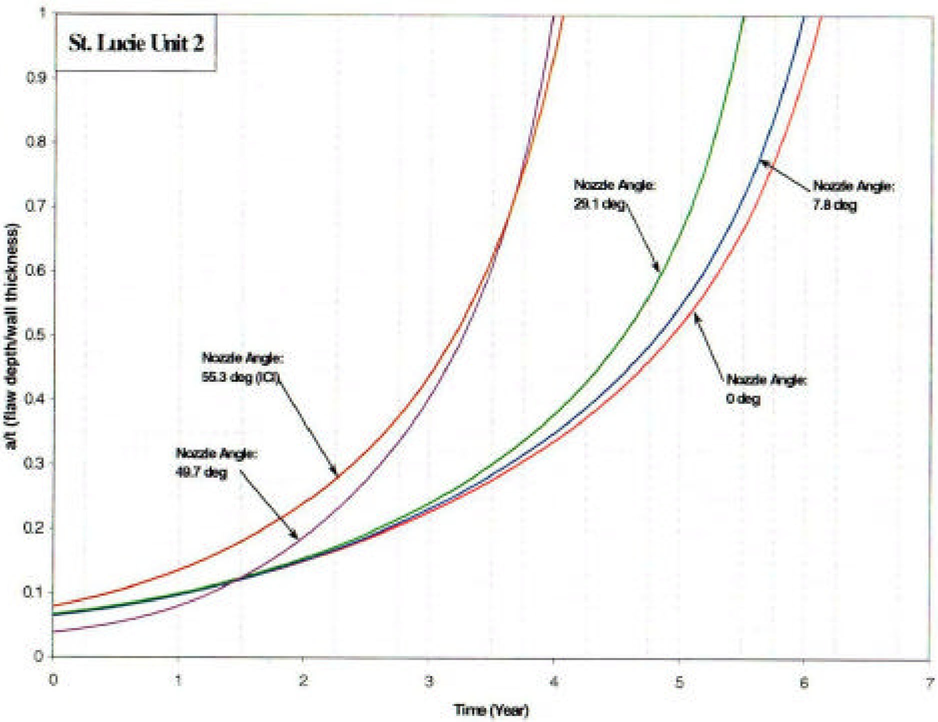


Figure D-3 Inside, Axial Surface Flaws, At the Attachment Weld, Nozzle Uphill Side - Crack Growth Predictions

C08

Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	At Weld	Downhill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle

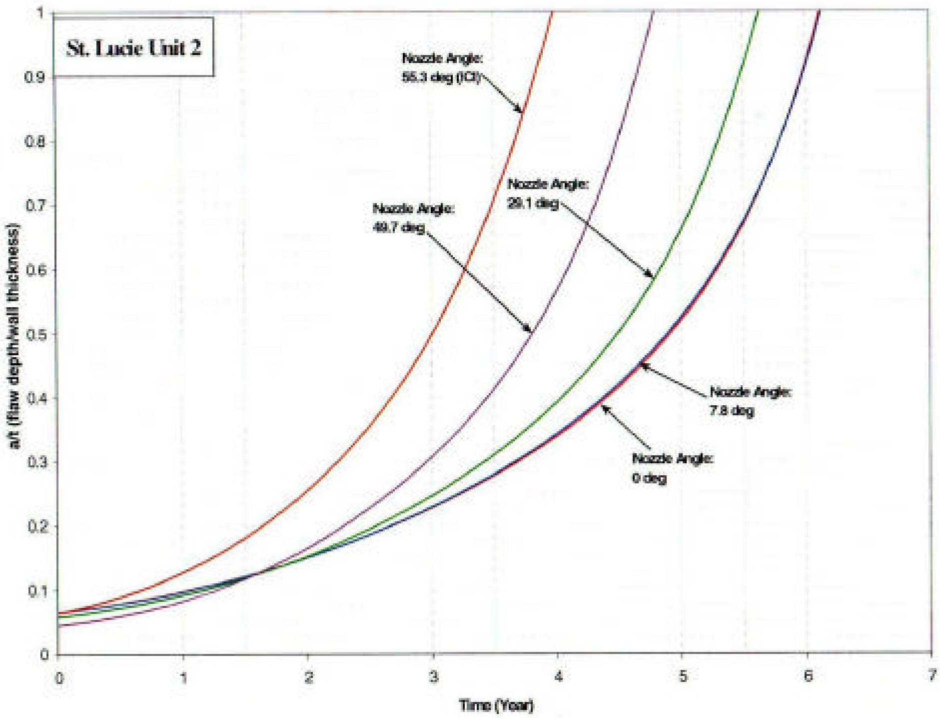


Figure D-4 Inside, Axial Surface Flaws, At the Attachment Weld, Nozzle Downhill Side - Crack Growth Predictions

C09

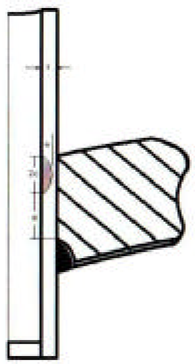
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	______" Above Weld	Uphill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



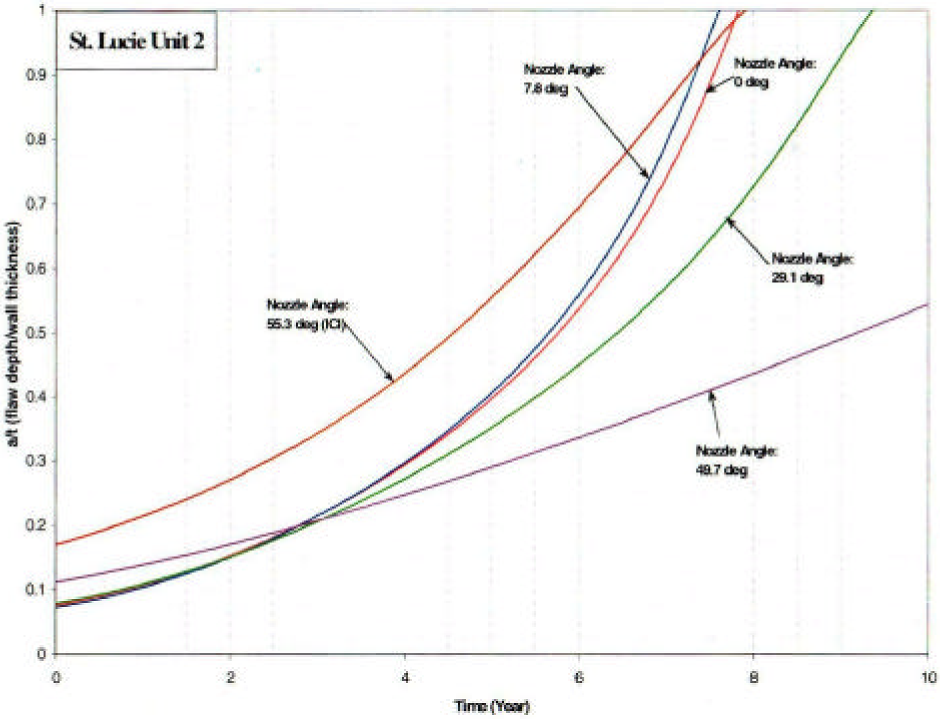


Figure D-5 Inside, Axial Surface Flaws, .5" Above the Attachment Weld, Nozzle Uphill Side - Crack Growth Predictions

C10

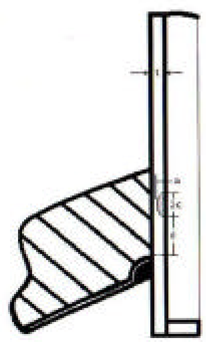
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	______" Above Weld	Downhill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



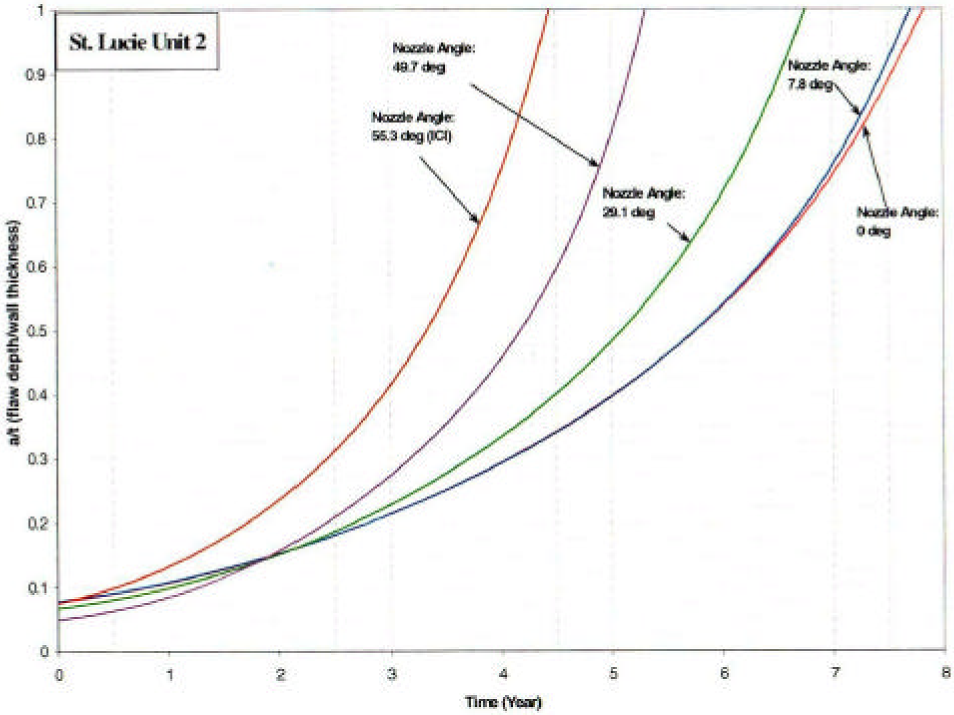


Figure D-6 Inside, Axial Surface Flaws, .5" Above the Attachment Weld, Nozzle Downhill Side - Crack Growth Predictions

C11

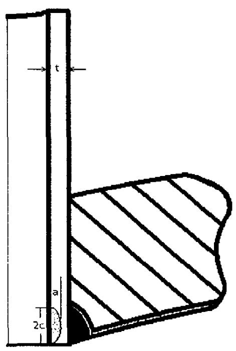
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Inside Surface	At Weld	Uphill / Downhill	Head Vent						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



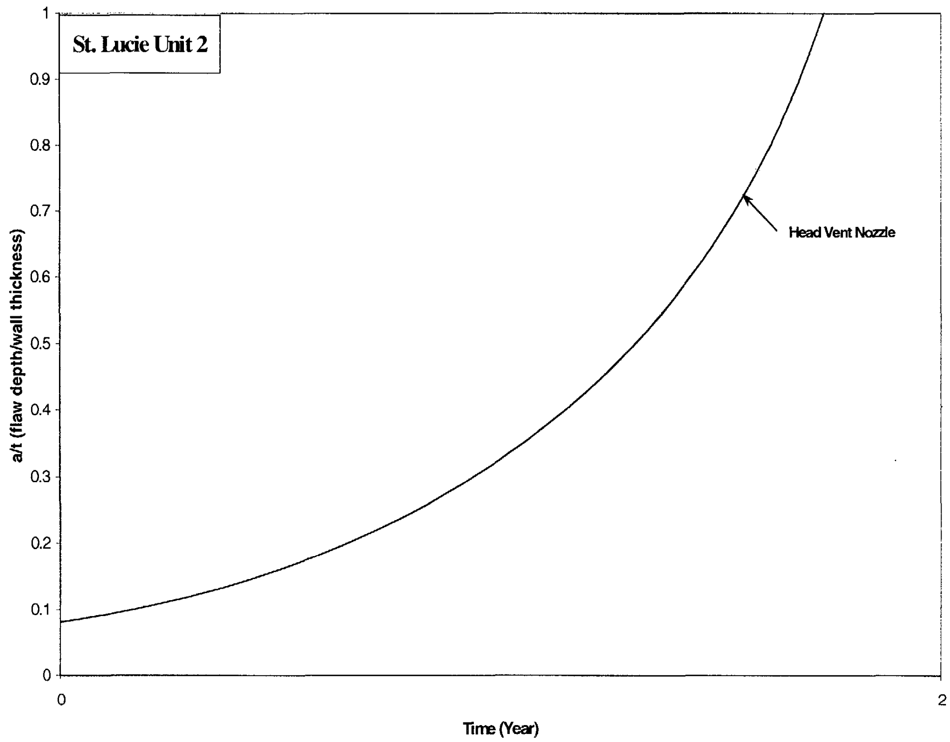


Figure D-7 Inside, Axial Surface Flaws, At the Attachment Weld, Head Vent, Nozzle Downhill Side - Crack Growth Predictions

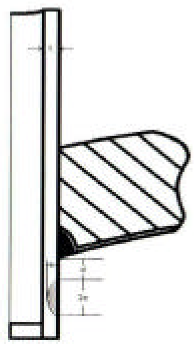
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Outside Surface	______ " Below Weld	Uphill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



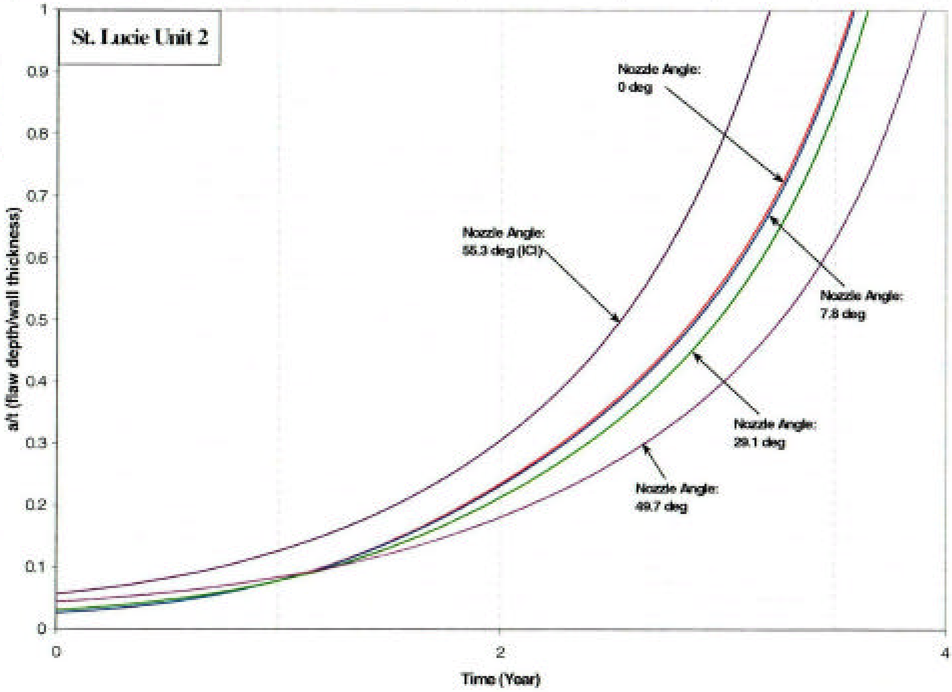


Figure D-8 Outside, Axial Surface Flaws, Below the Attachment Weld, Nozzle Uphill Side - Crack Growth Predictions

C12

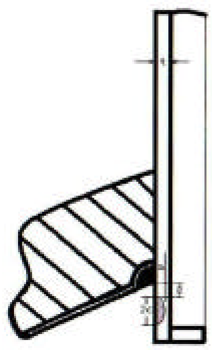
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Outside Surface	_____ " Below Weld	Downhill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



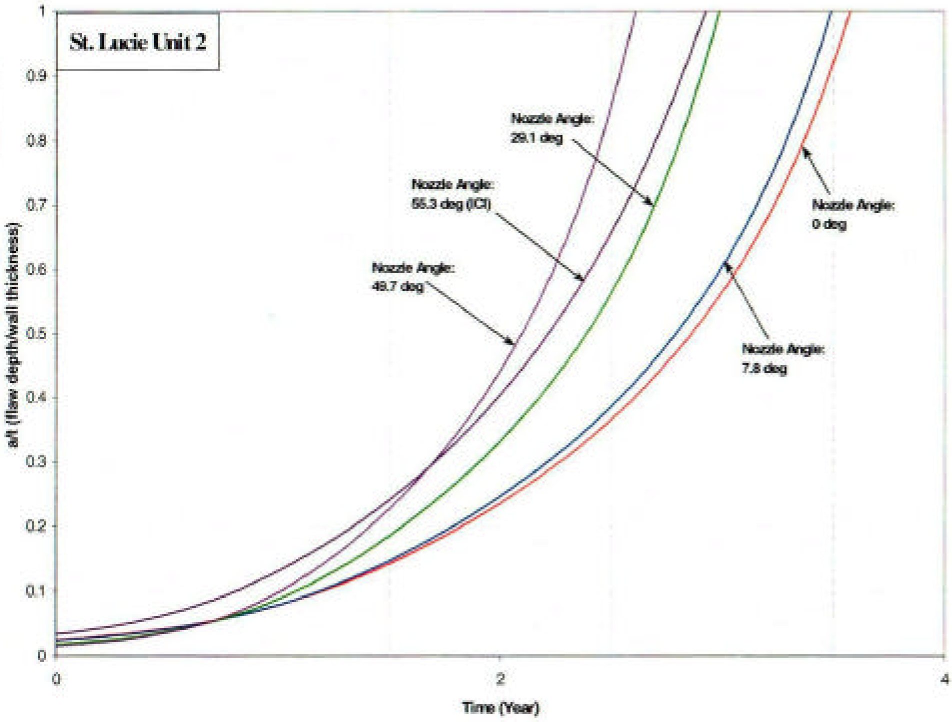


Figure D-9 Outside, Axial Surface Flaws, Below the Attachment Weld, Nozzle Downhill Side - Crack Growth Predictions

C13

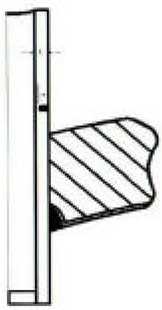
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Circum. – Outside Surface	______" Above Weld	N/A							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



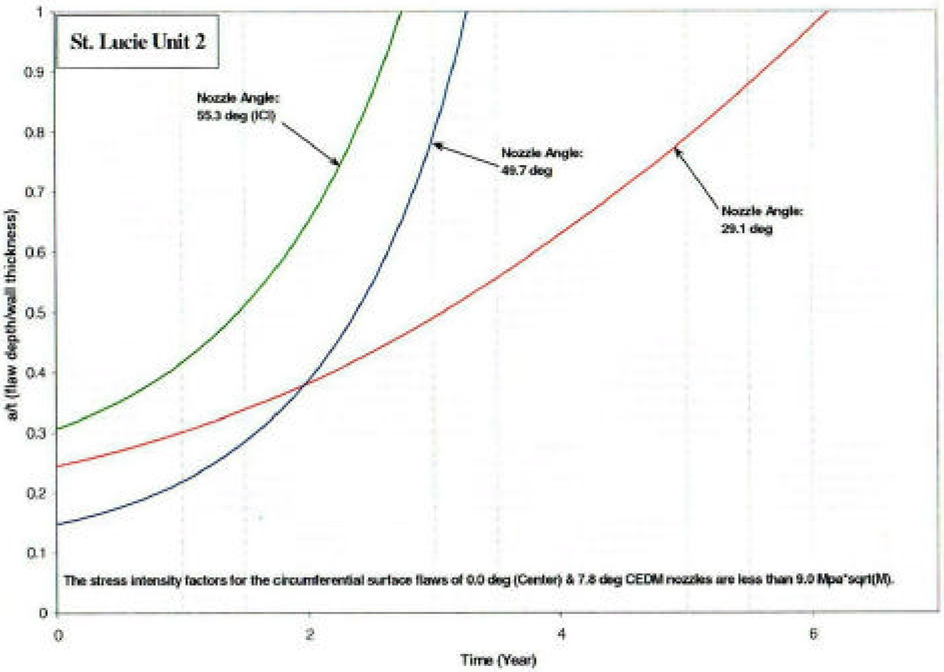


Figure D-10 Outside, Circumferential Surface Flaws, Along the Top of the Attachment Weld - Crack Growth Predictions (MRP Factor of 2.0 Included)

C14

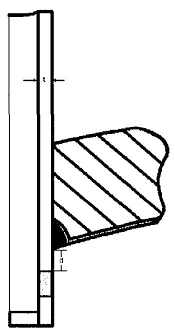
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______ " Below Weld	Uphill / Downhill	0.0°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



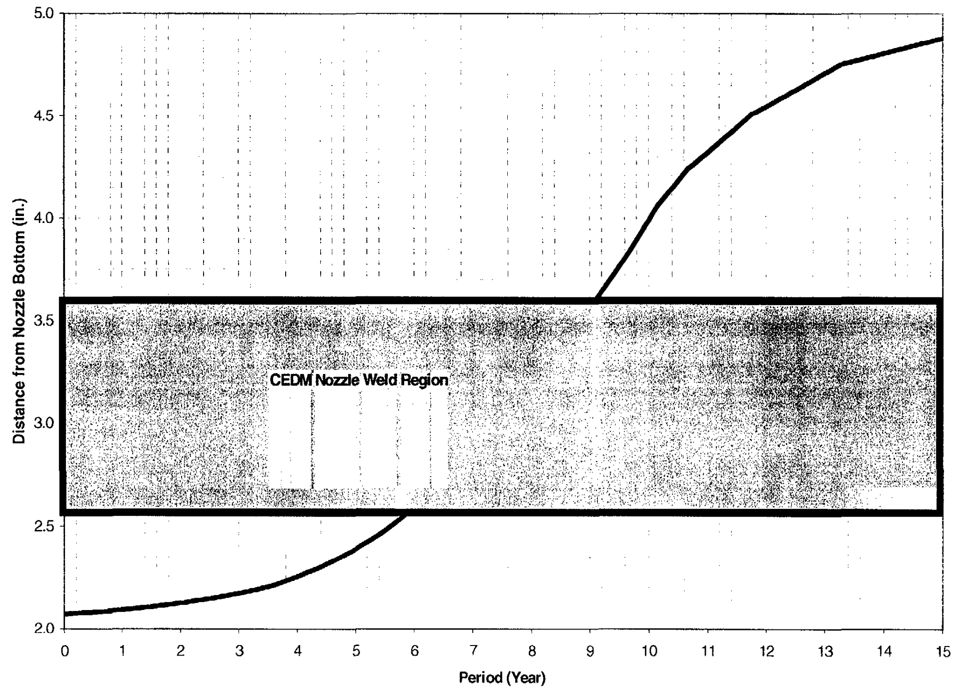


Figure D-11 Through-Wall Axial Flaws Located in the Center CEDM (0.0 Degrees) Penetration, Uphill and Downhill Side - Crack Growth Predictions

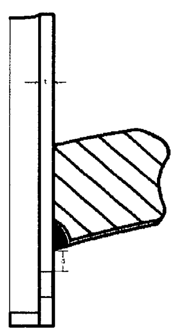
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______" Below Weld	Uphill	7.8°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	L

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



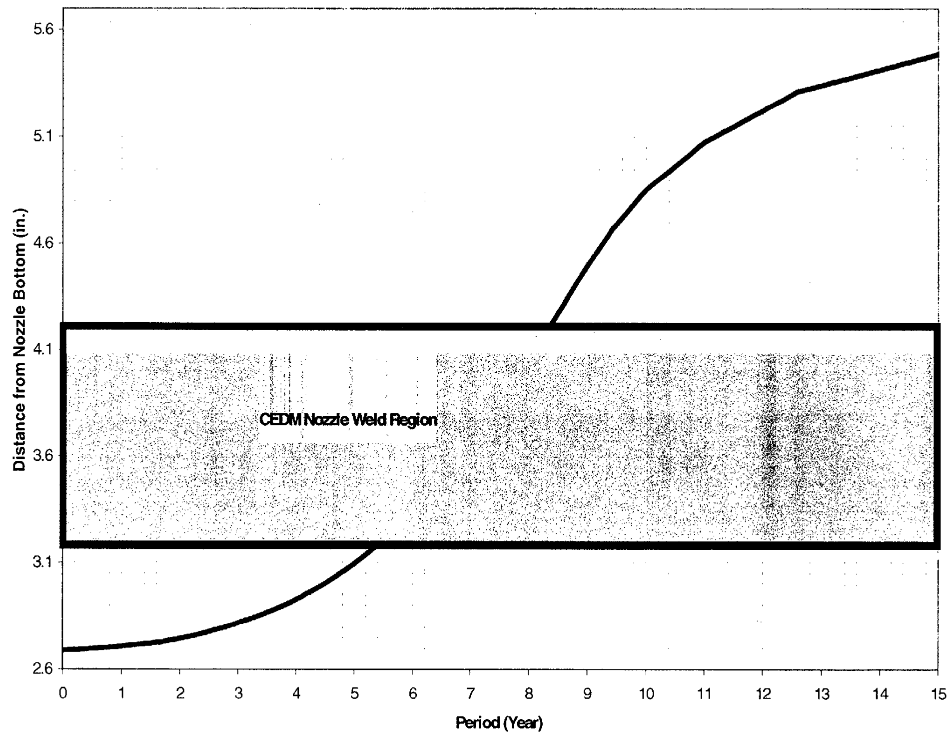


Figure D-12 Through-Wall Axial Flaws Located in the 7.8 Degree Row of Penetrations, Uphill Side - Crack Growth Predictions

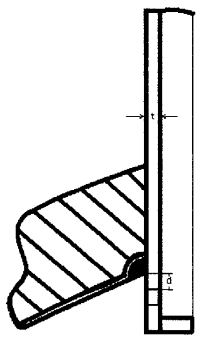
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______ " Below Weld	Downhill	7.8°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



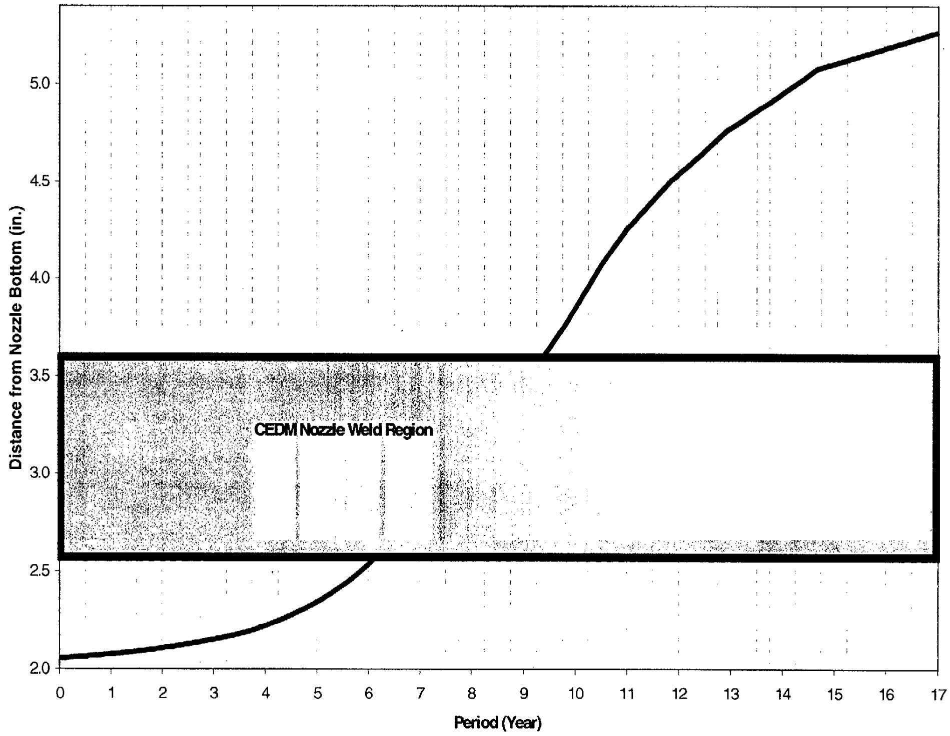


Figure D-13 Through-Wall Axial Flaws Located in the 7.8 Degree Row of Penetrations, Downhill Side - Crack Growth Predictions

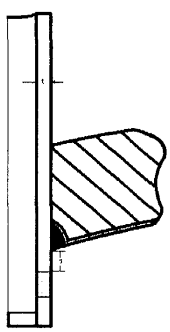
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______ " Below Weld	Uphill	29.1°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



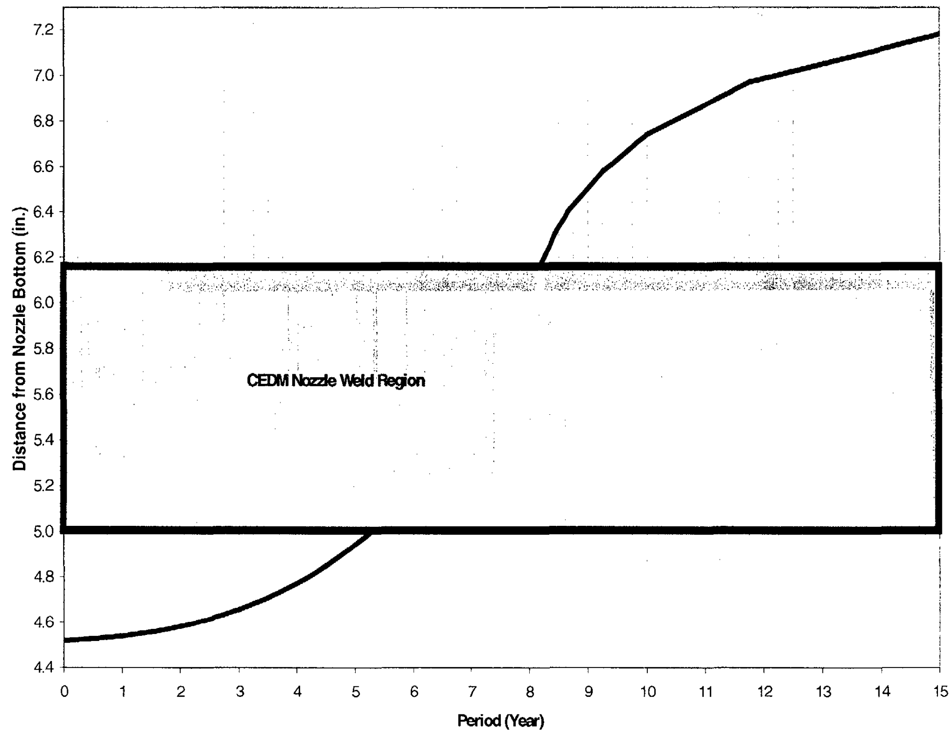


Figure D-14 Through-Wall Axial Flaws Located in the 29.1 Degree Row of Penetrations, Uphill Side - Crack Growth Predictions

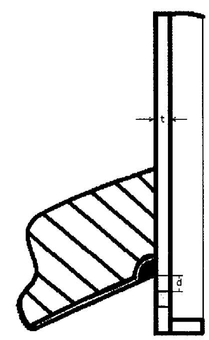
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______" Below Weld	Downhill	29.1°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



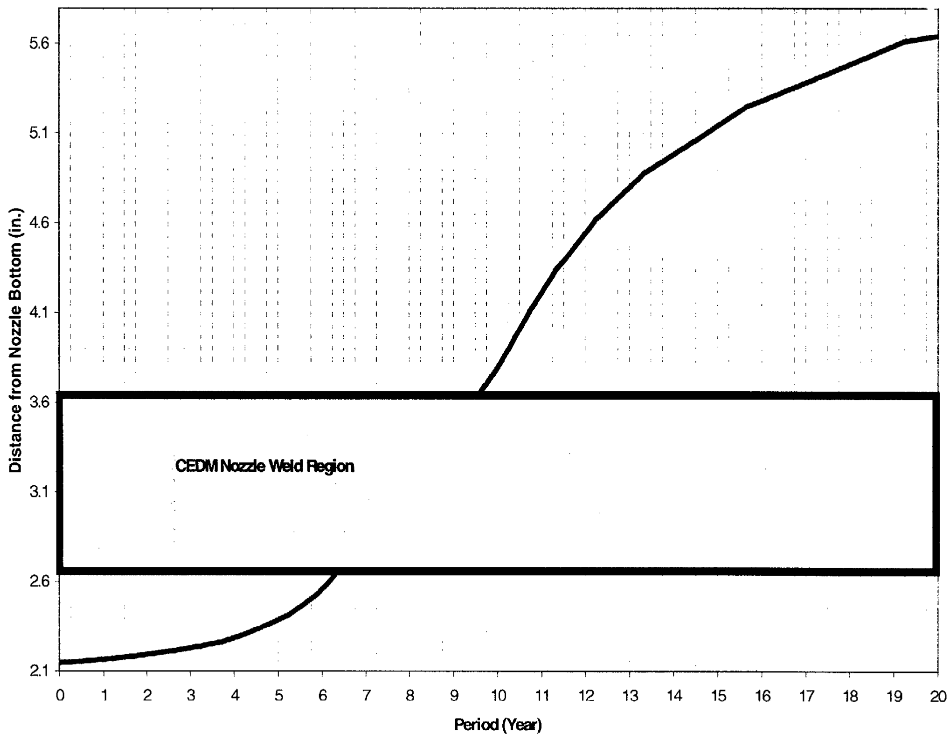


Figure D-15 Through-Wall Axial Flaws Located in the 29.1 Degree Row of Penetrations, Downhill Side - Crack Growth Predictions

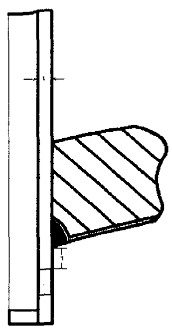
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______" Below Weld	Uphill	49.7°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



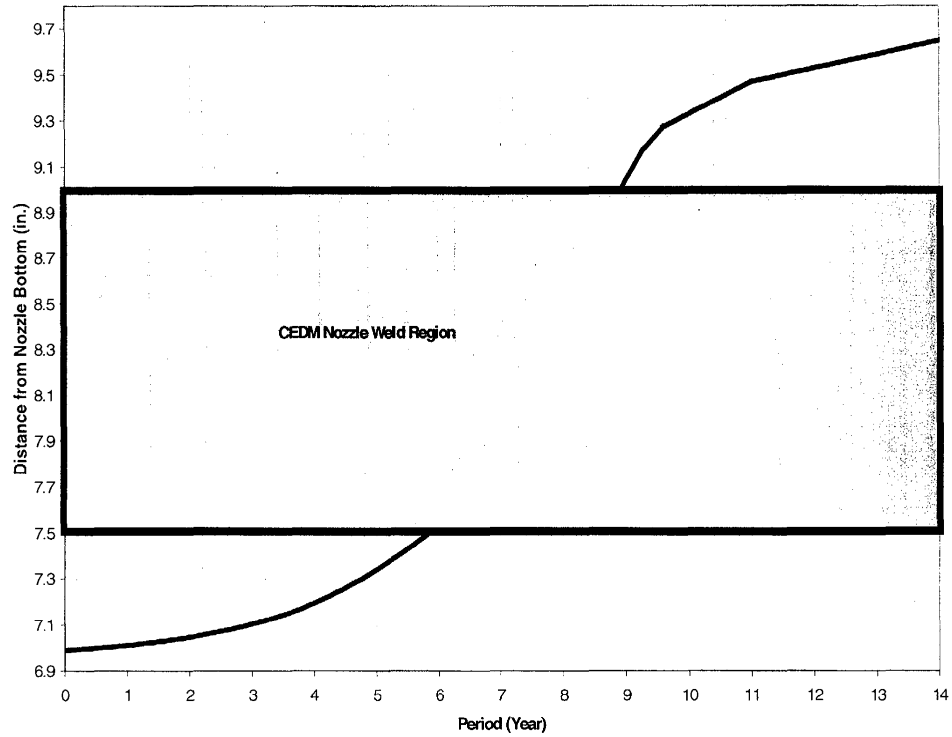


Figure D-16 Through-Wall Axial Flaws Located in the 49.7 Degree Row of Penetrations, Uphill Side - Crack Growth Predictions

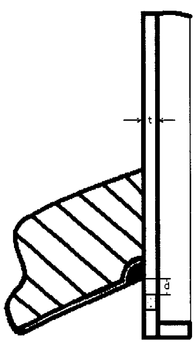
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______ " Below Weld	Downhill	49.7°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



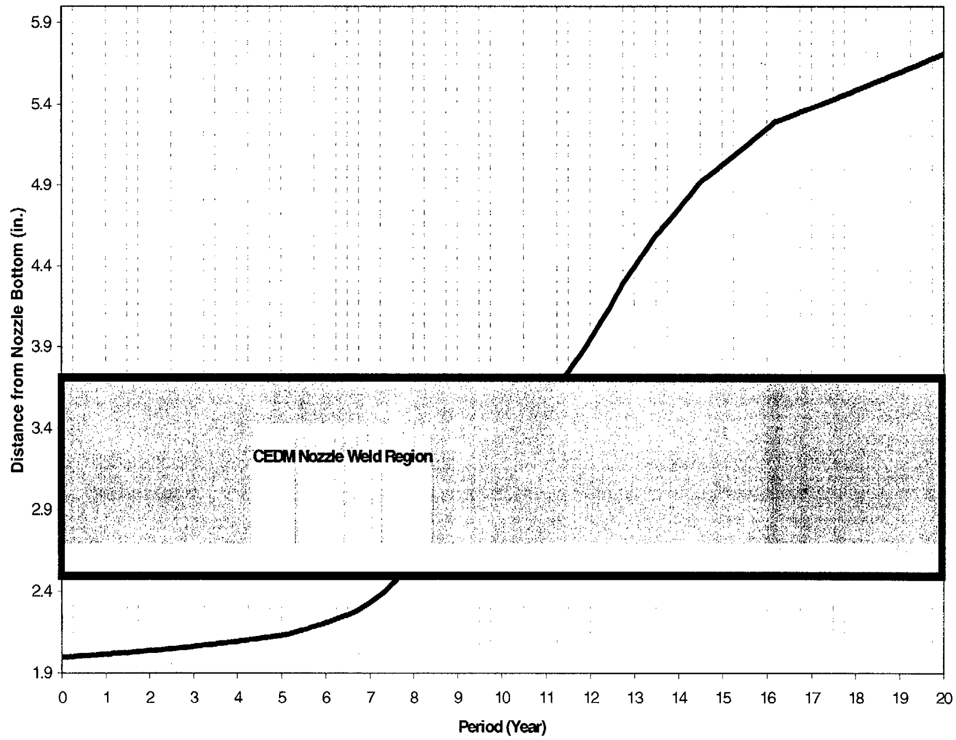


Figure D-17 Through-Wall Axial Flaws Located in the 49.7 Degree Row of Penetrations, Downhill Side - Crack Growth Predictions

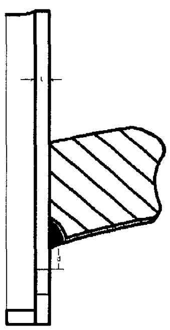
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______ " Below Weld	Uphill	55.3°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



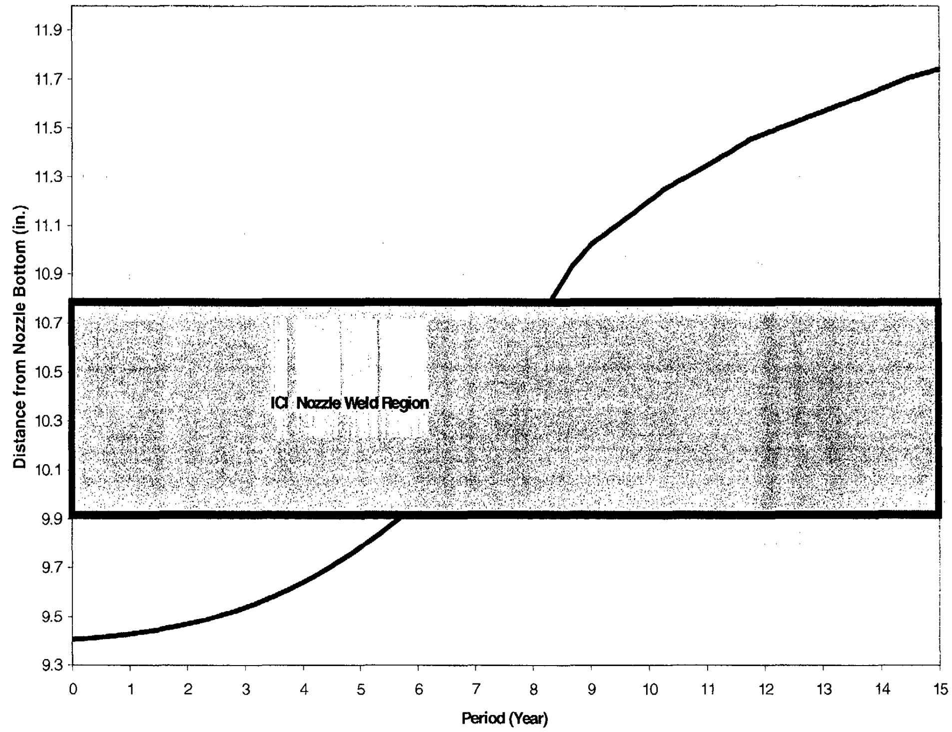


Figure D-18 Through-Wall Axial Flaws Located in the 55.3 Degree Row of Penetrations, Uphill Side - Crack Growth Predictions

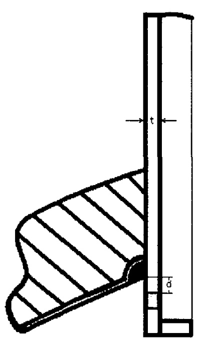
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Axial – Through Wall	______" Below Weld	Downhill	55.3°						

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



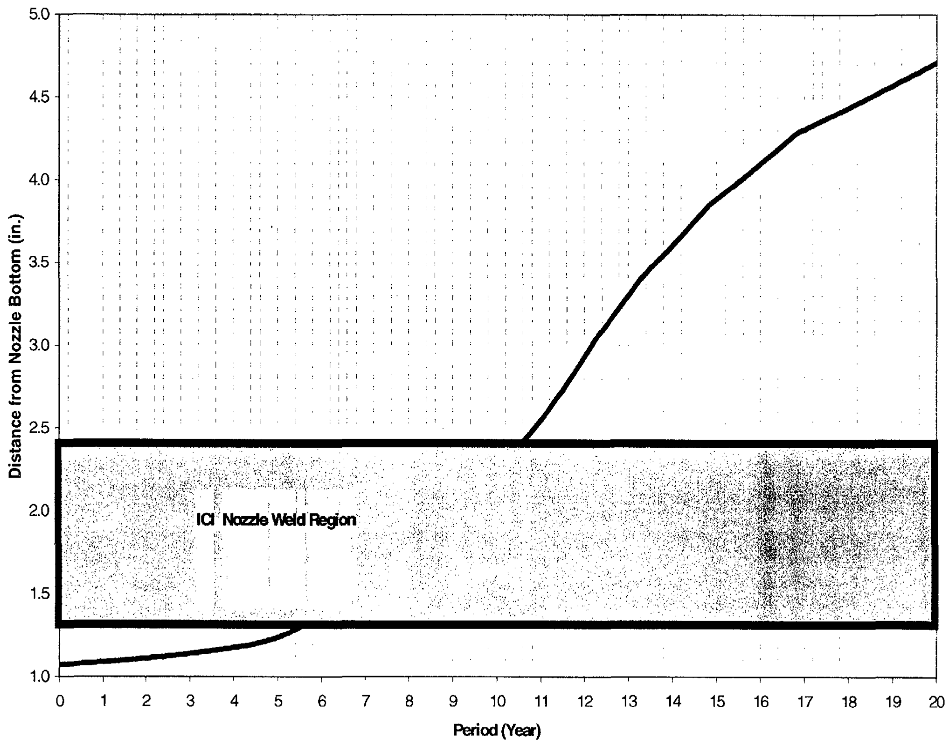


Figure D-19 Through-Wall Axial Flaws Located in the 55.3 Degree Row of Penetrations, Downhill Side - Crack Growth Predictions

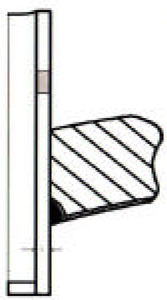
Orientation	Crack Tip Location	Circum. Location	Pen No.	Length (2c)	Depth (a)	Penetration Angle	a/t	Asp. Ratio	Wall Thick. (t)
Circum. – Through Wall	Above Weld	Uphill / Downhill							

Acceptance Criteria (Table 6-1)

Location	Axial	
	a_f	l

Locality Angles (Table 1-1)

Nozzle No.	Type	Angle



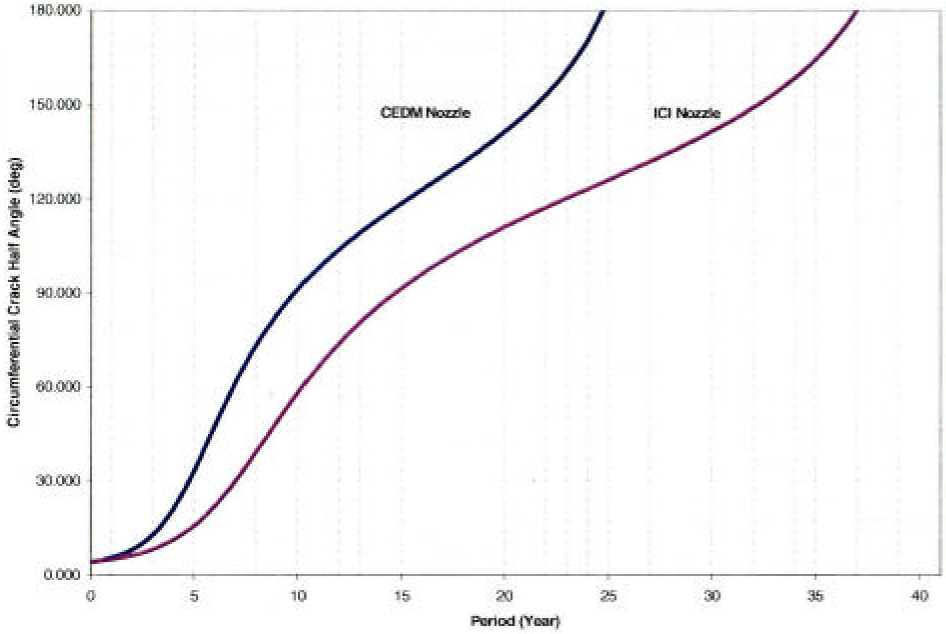


Figure D-20 Through-Wall Circumferential Flaws Near the Top of the Attachment Weld for CEDM and ICI Nozzles - Crack Growth Predictions (MRP Factor of 2.0 Included)

C15

APPENDIX E

CEDM NOZZLE HOOP STRESS VS DISTANCE FROM BOTTOM OF WELD PLOTS

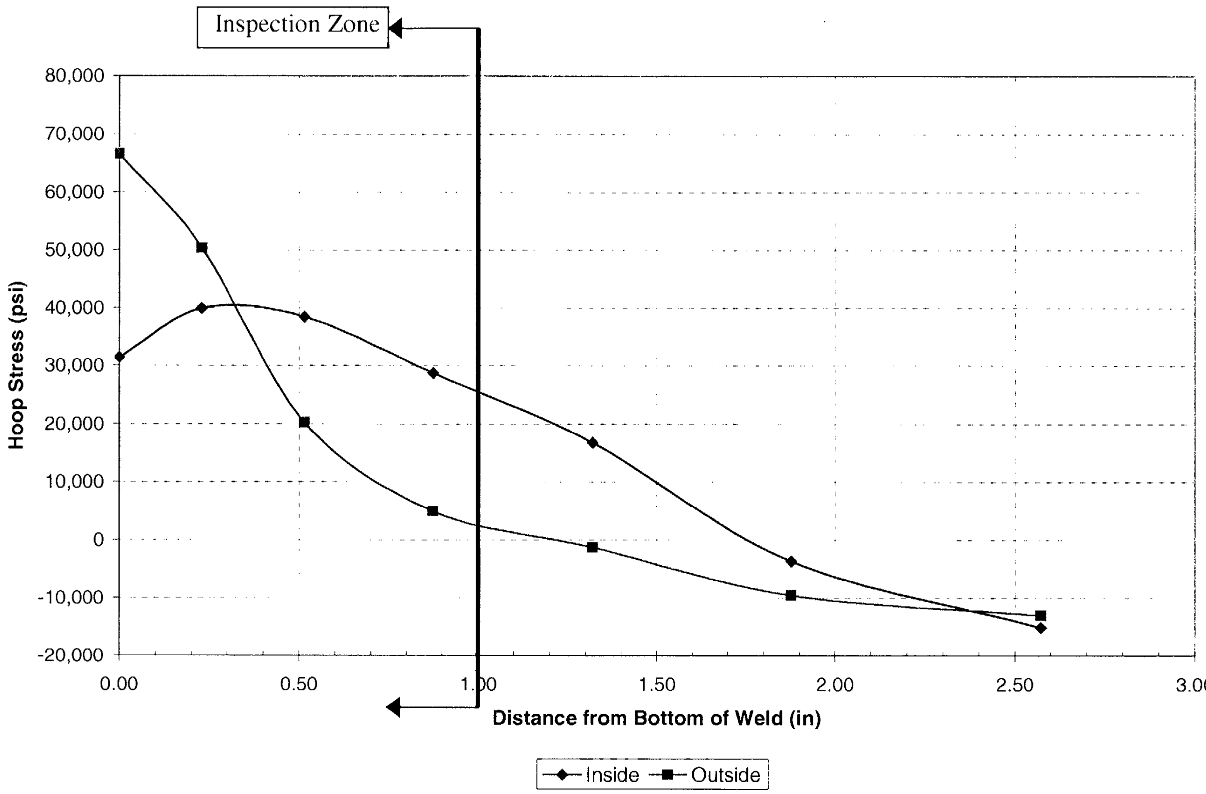


Figure E-1 Hoop Stress Vs Distance from Bottom of Weld Plot for the Center CEDM Penetration

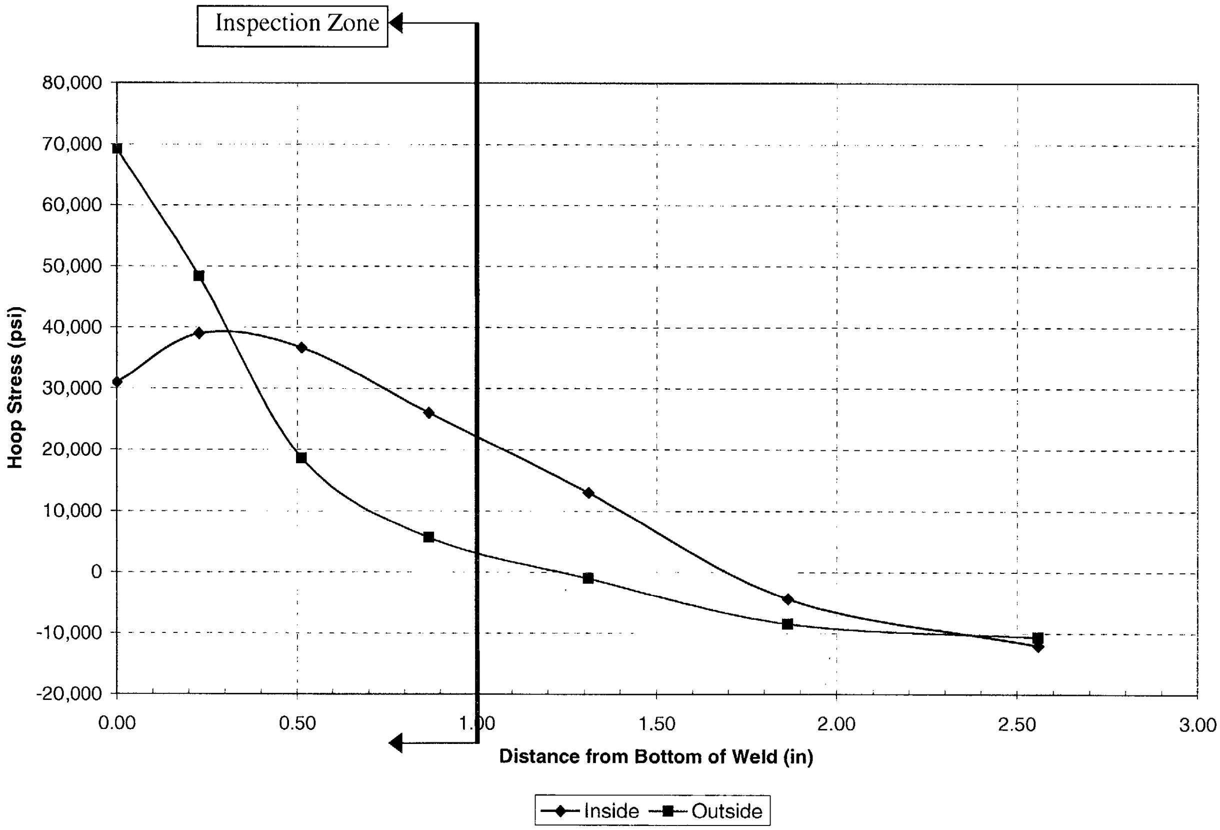


Figure E-2 Hoop Stress Vs Distance from Bottom of Weld Plot for the 7.8 Degrees Row of Penetration, Downhill Side

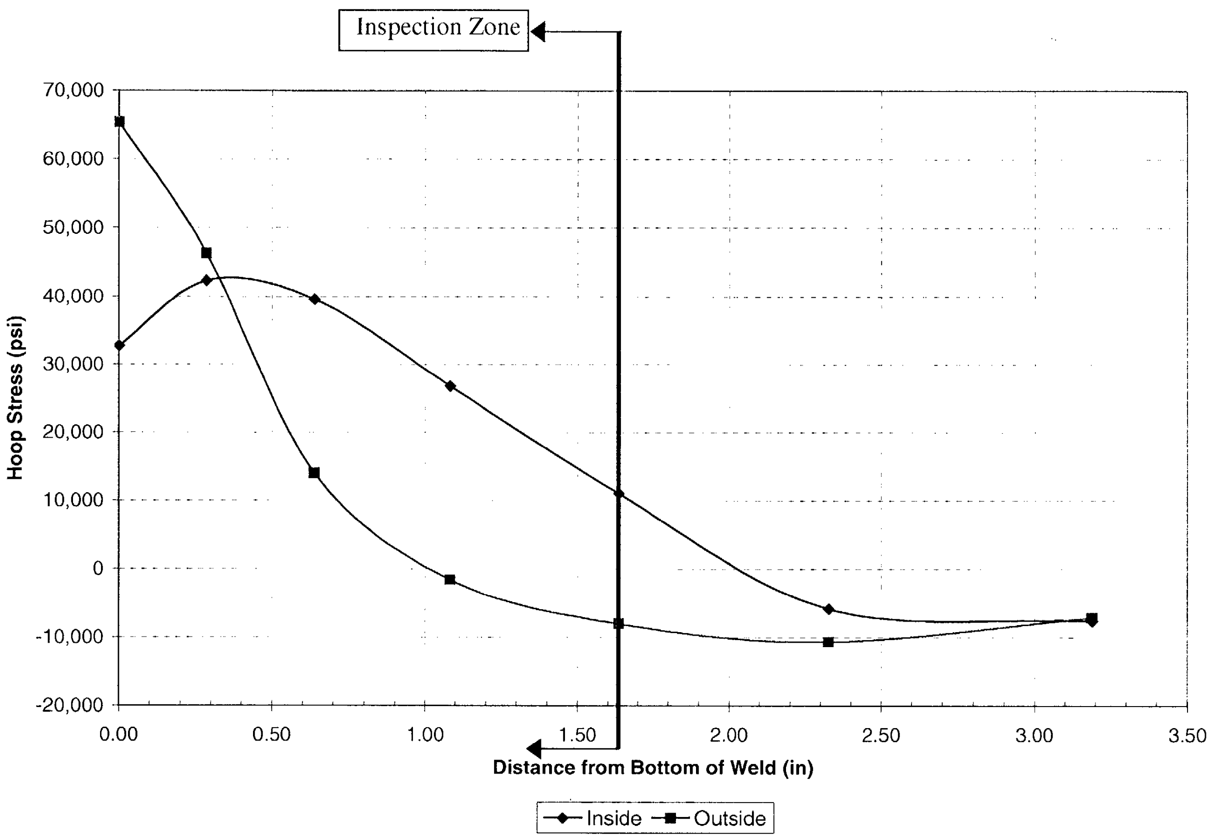


Figure E-3 Hoop Stress Vs Distance from Bottom of Weld Plot for the 7.8 Degrees Row of Penetration, Uphill Side

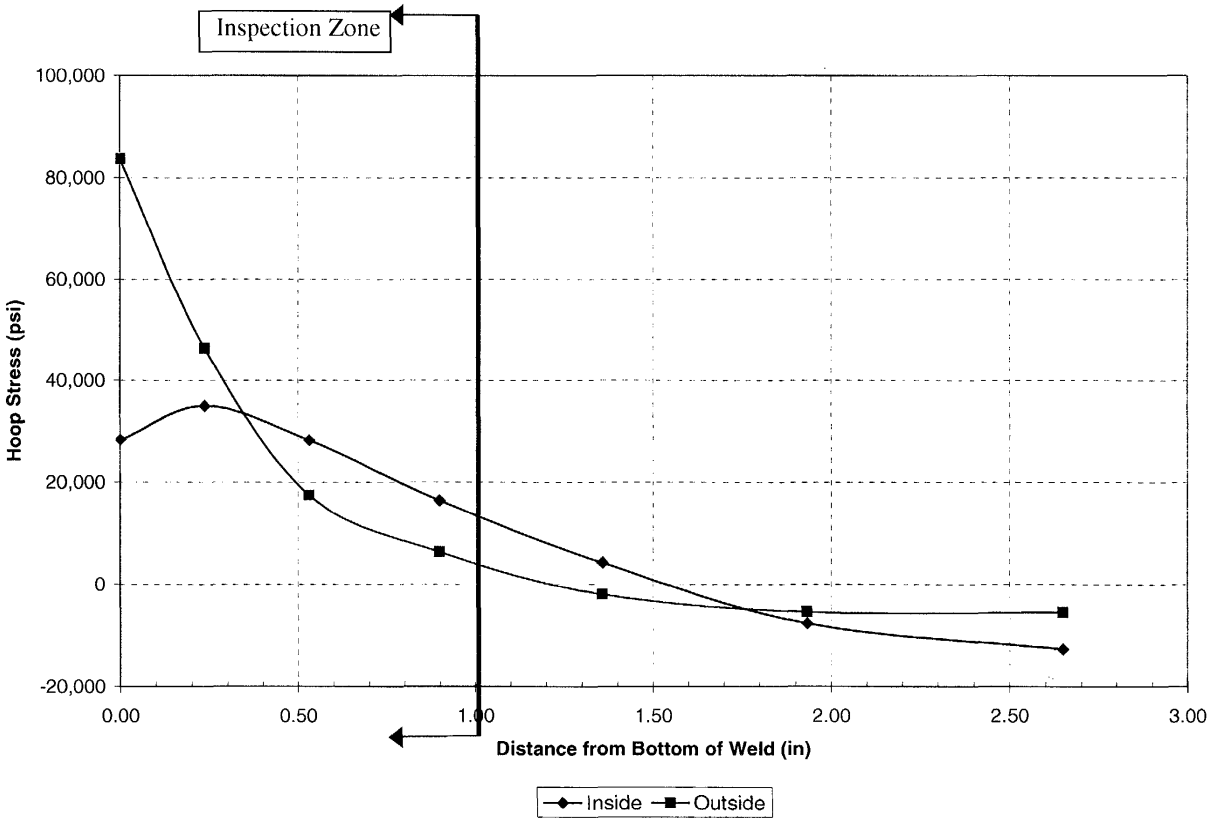


Figure E-4 Hoop Stress Vs Distance from Bottom of Weld Plot for the 29.1 Degrees Row of Penetration, Downhill Side

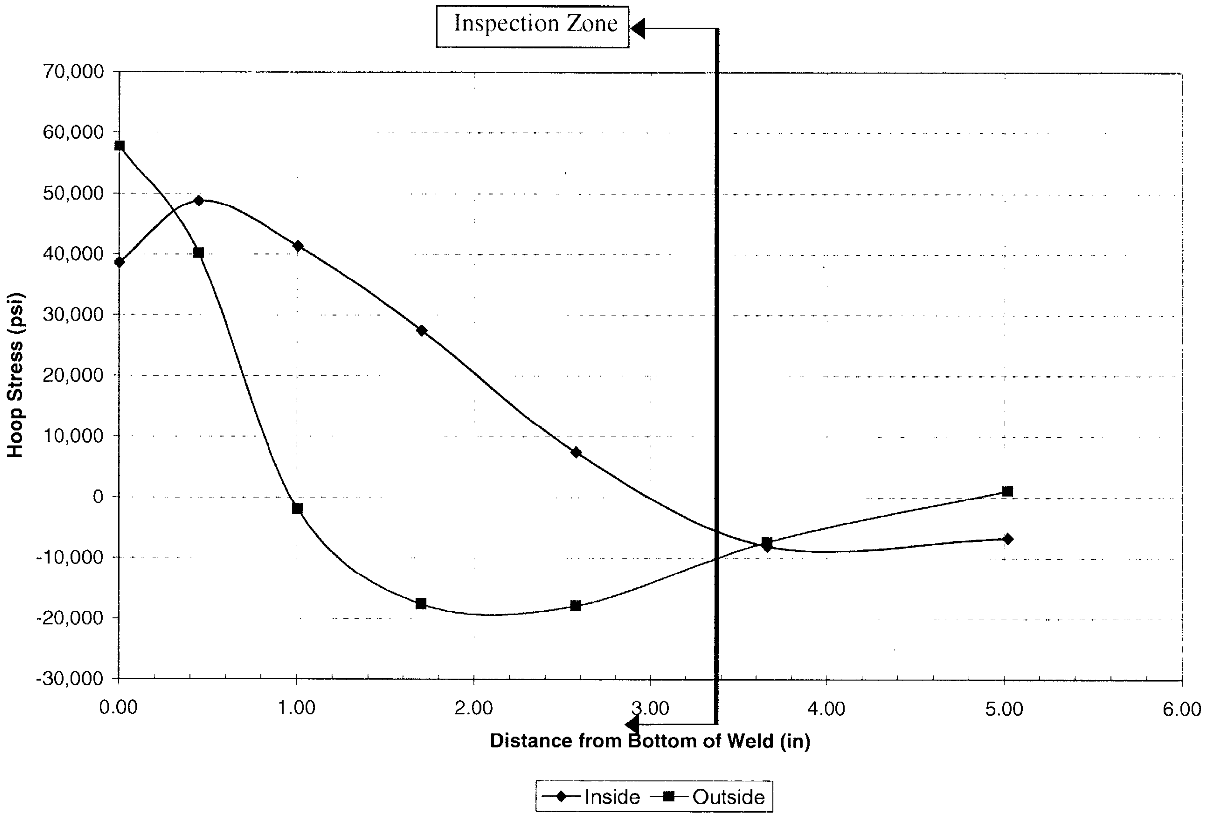


Figure E-5 Hoop Stress Vs Distance from Bottom of Weld Plot for the 29.1 Degrees Row of Penetration, Uphill Side

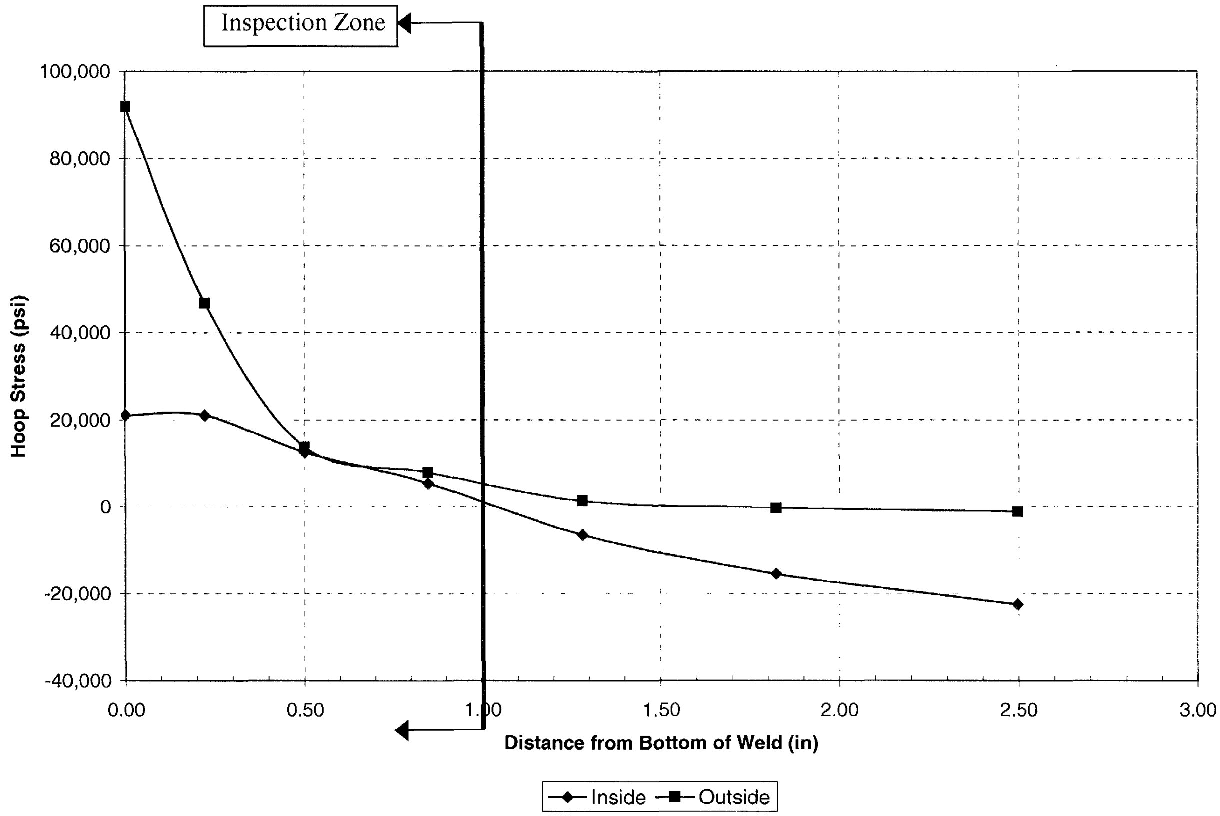


Figure E-6 Hoop Stress Vs Distance from Bottom of Weld Plot for the 49.7 Degrees Row of Penetration, Downhill Side

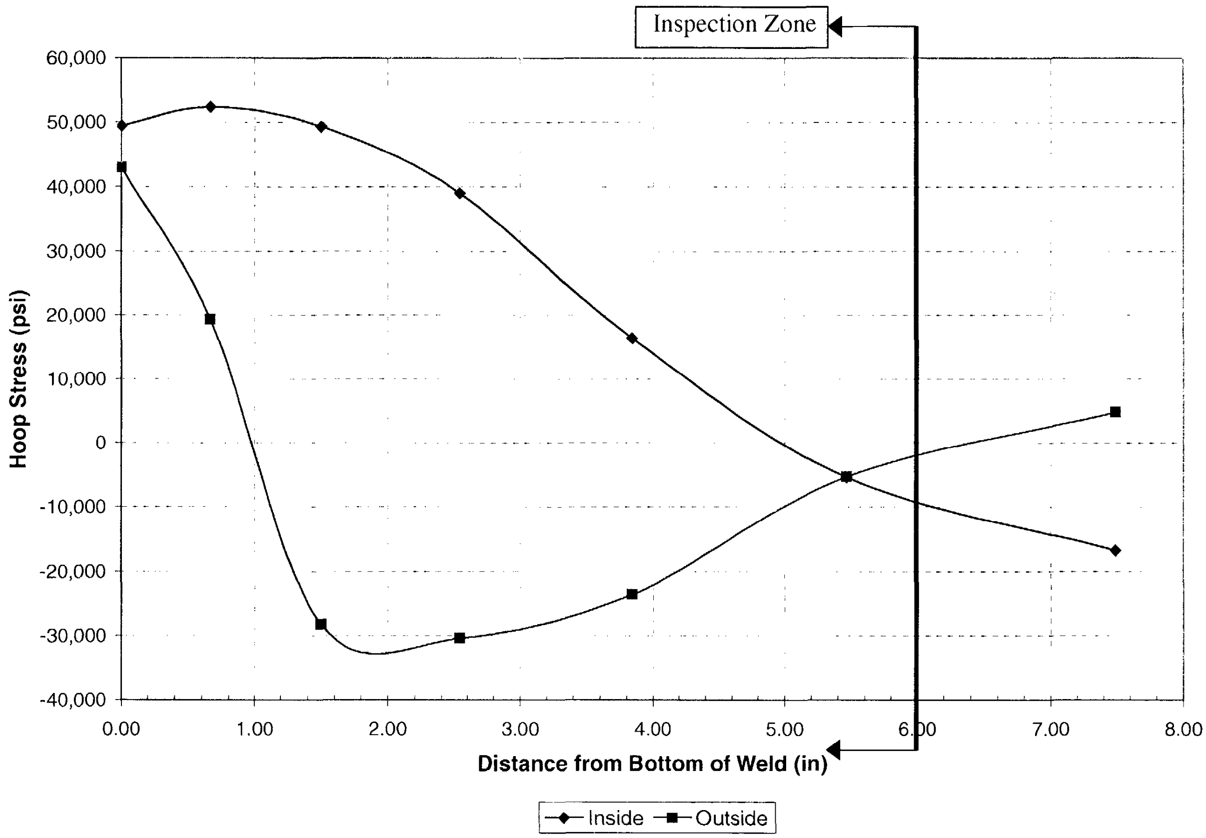


Figure E-7 Hoop Stress Vs Distance from Bottom of Weld Plot for the 49.7 Degrees Row of Penetration, Uphill Side