SUMMARY TECHNICAL REPORT

EVALUATION OF FLAW INDICATION(S) IN THE PERRY FEEDWATER NOZZLE TO SAFE-END WELDS EXTRAPOLATED BEYOND RFO-3

Revision 0: February 3, 1992

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OBJECTIVES

1. To perform bounding fracture mechanics analyses for the subject feedwater nozzle safe-end weld flaws; using various assumed flaw sizes, Crack Growth Rates (CGR's) and other pertinent parameter combinations; to determine permissible operational hours for Cycle 4.

2. The analyses of #1 shall include the piping reactions onto the nozzles due to feedwater snubber reduction analyses, including use of response spectra generated utilizing ASME Code Case N-411-1 damping values (reference PY-CEI/NRR-1374L dated October 18, 1991). Note: Feedwater snubber reduction is concurrently planned for RFO-3 implementation.

3. The analyses are being performed prior to RFO-3 and provided to the NRC for information, such that expedited resolution of nozzle flaws (as resized in RFO-3) may be facilitated by both CEI and the NRC.

ABSTRACT

Referring to the CEI/Perry letter to the NRC (PY-CEI/NRR-1337L, March 25, 1991), Perry's Inservice Inspection (ISI) Program detected an indication in each of two feedwater nozzles (N4C and N4E) during RFO-2. These indications were determined to be fully acceptable for the full duration of Operational Cycle 3.

Pending inspection of the feedwater nozzles during RFO-3, certain assumptions have been made concerning indication sizes that may be detected during RFO-3. Using these assumptions, various flaw size and growth rate scenarios have been evaluated. For flaw sizes that require CGR analyses to be performed, the computer program PC-Crack[1] was used to determine the associated flaw size tolerance level for permissible Cycle 4 operating hours.

Per NUREG 0313, Revision 2, flaws less than or equal to 30% of the component thickness (a/t) and 10% of the component circumference ($L/2\pi r$) are considered to be fully mitigated by stress improvement. Therefore, if RFO-3 inspection indicates the flaws on these two nozzles remained within this envelope, MSIP will be applied without the need for additional supporting analyses.

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(1) PC-CRACK is a computer program developed by Structural Integrity Associates, Inc.

ABSTRACT

(continued)

For flaws that may exist outside the 30%-10% envelope, but within 30% (a/t) and 25% (L/2πr) envelope, stress improvement (MSIP) is assumed to be effective in mitigating the growth of the flaw. It is felt that for shallow flaws (<30%) with flaw lengths that are up to one quarter of the pipe circumference, MSIP is effective. Supporting technical documentation, that demonstrates a fully effective MSIP mitigation envelope of a/t = 40% and (L/2πr) = 33%, is provided by AEA O'Donnell, Inc. as Attachment #1 hereto. Thus, a 30%-25% mitigation envelope, being still slightly more conservative, is considered technically justifiable. Nevertheless, crack growth analyses in this region can be generated by CEI if considered necessary by the NRC.

For flaws outside of the 30%(a/t) and 25% (L/2πr) envelope, CGR analyses have been performed. The method of ASME Section XI (1986) Appendix C was used to establish the flaw acceptance limit, with the maximum a/t limit set at 60% by the ASME.

Due to concerns for a viable crack growth rate (EPRI variable CGR) and residual stress profile, several scenarios incorporating various combinations of these items and applied loads from the feedwater piping (GE Report 23A6987 Revision 1 including the snubber reduction effects) were analyzed.

ABSTRACT

(continued)

For the case of the constant crack growth (5×10^{-5} in/hr) scenario flaw growth is independent of loading conditions except for the case when K_I (ksi $\sqrt{in}$) is negative. K_I would be negative (compressive) for any flaws which are within the 30%(a/t) and 25% ($L/2\pi r$) envelope at the beginning of Operating Cycle 4, and to which MSIP has been applied which would inhibit flaw growth.

The results of the CGR analyses are presented in Figure 2, and discussed in the Conclusions Section of this report.

STRESS FIELD DISCUSSION

No supporting analysis is necessary for flaws in the region a/t <= 30% since MSIP will be applied for flaws in this envelope, thus introducing compressive stresses which prevent further flaw growth. Growth of any flaw that may exist within the envelope a/t <= 30% and ($L/2\pi r$) <= 25% is assumed to be fully mitigated by application of MSIP as discussed previously.

The two feedwater nozzle safe-ends are loaded by the feedwater pipe which was analyzed in GE Report 23A6987, Revision 1. The GE steady state analysis results were used and included the effects of snubber reduction and provide axial, bending and thermal expansion effects on the nozzle safe-end. The GE generated piping reaction loads were common to all scenarios investigated.

The stress profile was considered alternately with and without as-welded residual stress. For those scenarios that incorporated the as-welded residual stress, the profile used was obtained from NUREG 0313, Revision 2. Conservatively, only the results for the scenarios neglecting the benefit of as-welded residual stress are presented in Figure 2 of this report. Also, conservatively, MSIP compressive residual stresses are neglected for flaws assumed beyond the a/t = 30% envelope. The negative stress intensity (K_I) induced by the MSIP residual stress would actually aid in curtailing flaw growth in the range 30% <a/t <= 40%, as well as for a/t <= 30%.

ACCEPTANCE CRITERIA

The flaws in the safe ends are at or close to the Inconel 182 buttering and SA 508 Class 1 interface. Figure IWB-3641-1 in ASME Section XI indicates flaws in the proximity of the weld are considered to be in the weld. The affected welds were made by the SMAW process which dictates using ASME Section XI, Paragraph C3320 (c) for the acceptance criteria for the flaw.

The equations found there are based on a relationship between the collapse load and flaw size at incipient plastic collapse. The acceptance level a/t (flaw depth to thickness) is set at a maximum 60% by the ASME so that any calculated allowable values of a/t greater than 60% default to this value, while a/t values calculated to be less than 60% retain their calculated values. The horizontal a/t acceptance line in Figure 2 herein for all flaw lengths illustrates that all calculated values of allowable a/t, from ($L/2\pi r$) = 0% to 100%, exceed the 60% limit and defaulted to the a/t = 60% limit.

Figure 2 shows the acceptance envelope for all service levels, since emergency and faulted conditions produce negligible effects on the final projected flaw depth. The acceptance envelope is based on the combination of Primary Membrane Stress (P_m), Primary Bending Stress (P_b) and Thermal Expansion Stress (P_e), including seismic loadings obtained from the feedwater piping analysis. Included in these stresses are the effects of snubber reduction analyses performed by GE on the feedwater piping.

CRACK GROWTH DISCUSSION

The two initial flaws detected during RFO-2 were both 0.15 inches deep and oriented circumferentially on the inside surface of the nozzle safe end. To extrapolate the possible growth behavior of these flaws from assumed sizes that may be detected during RFO-3, several CGR's, stress profiles and flaw size combinations were analyzed to determine the effect of these various combinations on permissible Cycle 4 operating time duration. MSIP is assumed to be effective and curtails flaw growth inside the envelope $a/t <= 30\%$ and $(L/2\pi r) <= 25\%$, so the majority of this report addresses those flaws that may exceed this envelope.

Two crack growth rate methods have been utilized for the Operational Cycle 4 period: (1) one CGR is obtained from EPRI Report RP 1930-1, Amendment 22 (October, 1990). This CGR is variable and dependent on K_I as shown in Figure 1; (2) the second CGR method (suggested by the NRC) is a constant value equal to 5×10^{-5} in/hr. The constant CGR is independent of piping applied load stress and all residual stress, except in the case when residual stress causes a net compressive stress. The net compressive stress occurs inside the envelope $a/t =$ 30% and $(L/2\pi r) = 25\%$ when MSIP is applied, thus producing a negative stress intensity K_I so that flaws in this region would not continue to grow.

CRACK GROWTH DISCUSSION

(continued)

Residual stresses (as-welded and MSIP) were addressed in the analyses of all assumed flaw depths outside the envelope a/t = 30%, but conservatively were ignored in the results subsequently reported in Figure 2 even though MS.P demonstrated mitigations of CGR up to a/t = 40%. Without residual stresses considered, the assumed flaws that are initially outside of the envelope a/t <= 30% and ($L/2\pi r$) <= 25% at the start of Cycle 4 were shown analytically to grow unimpeded to the limit a/t = 60%, within the number of hours shown in Figure 2.

Shown on Figure 2 are various assumed starting crack depths that may be detected during RFO-3. These are shown as percentages of a/t. In addition, this figure presents the operational hours that could be tolerated considering the two CGR's analyzed; i.e., constant CGR = 5 X 10^{-5} in/hr and EPRI's variable CGR. The full planned operating time for Cycle 4 is approximately 12,000 hours as shown on the right side of Figure 2 (under EPRI-CGR-12,000 hours).

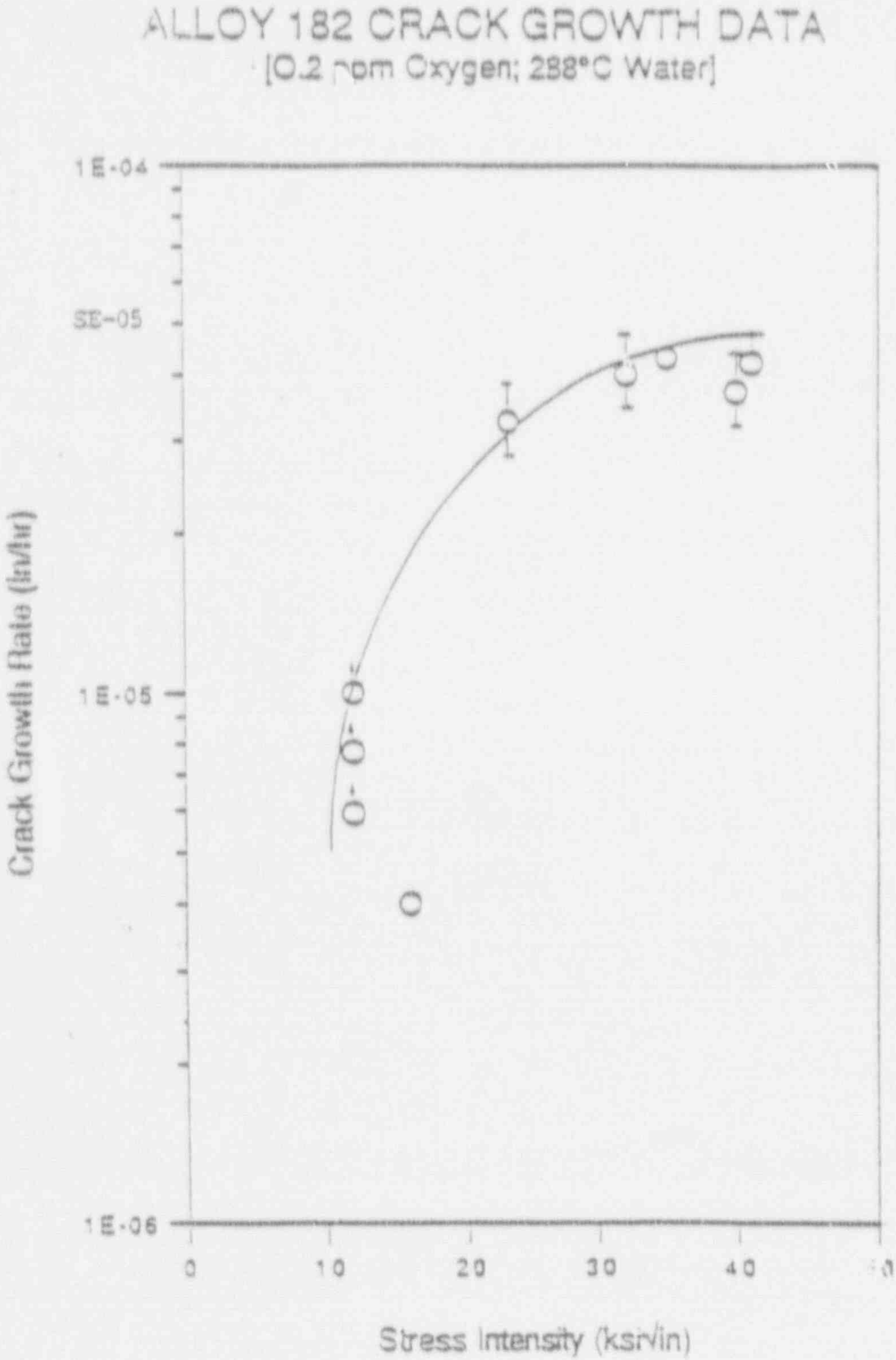

Figure 1 Alloy 182 Crack Growth Rate Stress Dependency
Reference: EPRI Project #RP 1930-1
Amendment 22, October, 1990

CONCLUSIONS

Evaluations were conducted for multiple assumed RFO-3 and Operating Cycle 4 parameters to develop time-operating envelopes for Cycle 4. The most restrictive of the conditions evaluated was the constant CGR equal to 5 X 10^{-5} in/hr and the flaw depth initiating at an assumed 40% of the pipe wall thickness. For this worst case combination, 4800 hours of Cycle 4 operation was demonstrated within the tolerance limit of a/t = 60%. Considering the EPRI variable CGR and a flaw initiating at an assumed 34% of wall thickness and no residual stress considered, the plant could operate for 12,000 hours which is the current projected duration of Operating Cycle 4.

It is felt the use of the constant CGR assumption is overly conservative, particularly at the lower K_I values. Several tests at various laboratories indicate that CGR is influenced by K_I; i.e., lower CGR's at lower K_I values. The use of variable CGR's (per EPRI data) is considered more realistic, yet retaining sufficient margin of safety.

With regard to the previously stated objectives, the following conclusions are presented:

1. The bounding fracture mechanics analyses, with respect to permissible Cycle 4 run times and considering multiple assumed scenarios, are presented in Figure 2.
2. The fracture mechanics analyses include full consideration of snubber reduction effects as appropriate.
3. Timely dispositioning of safe-end weld flaws, as resized by RFO-3 inspections, may be performed by CEI/NRC utilizing Figure 2 as a basis, thus helping to ensure restart from RFO-3 as scheduled.

FLAW ACCEPTANCE CRITERIA
CIRCUMFERENTIAL FLAW IN SMAW

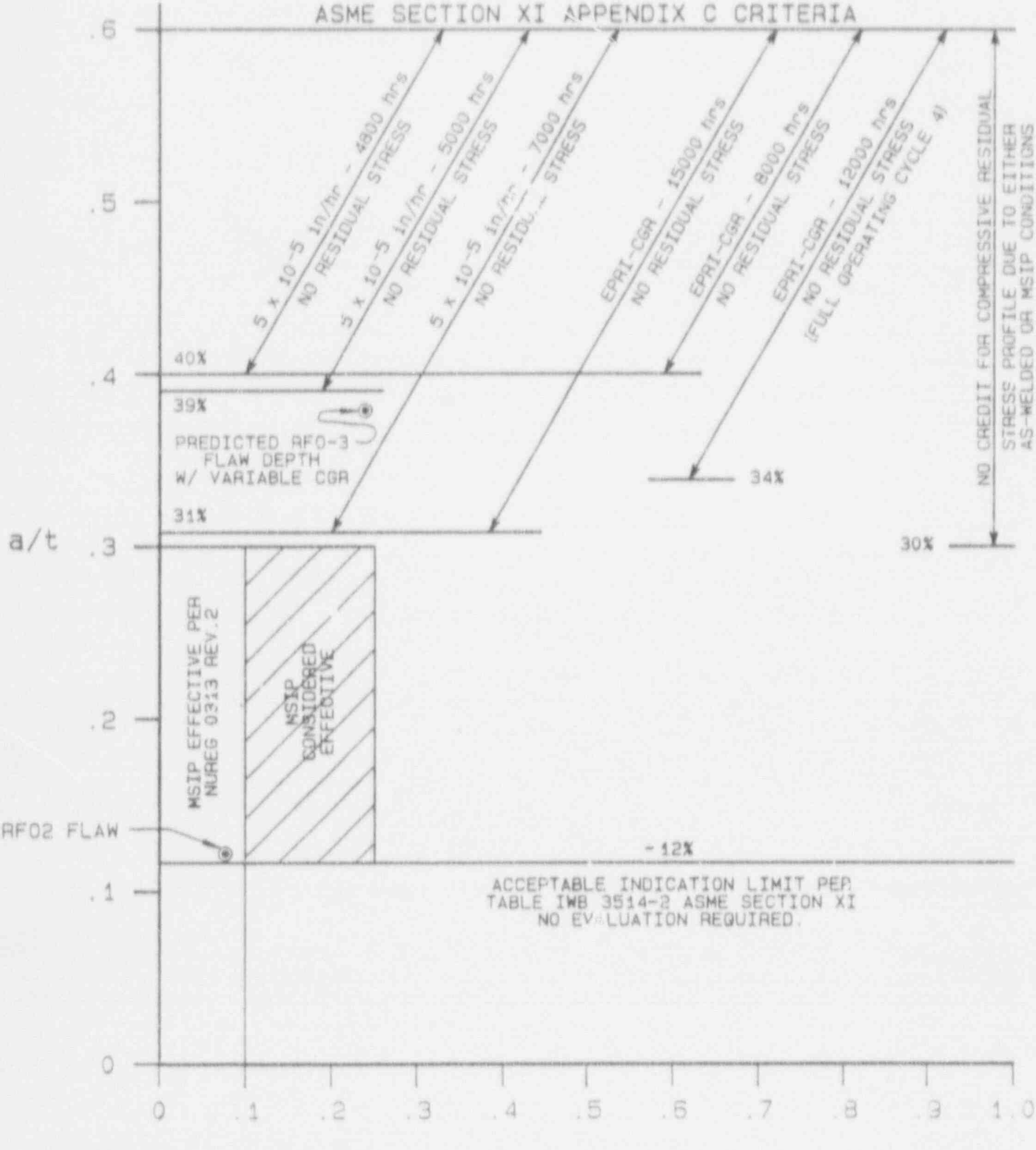

FIGURE 2

MSIP CRACK MITIGATION CRITERIA PROPOSED FOR NRC CONSIDERATION

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January 1992

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MSIP CRACK MITIGATION CRITERIA
PROPOSED FOR NRC CONSIDERATION

INTRODUCTION

IGSCC in BWR piping weldments is a recognized problem. The three contributors, which in combination cause IGSCC, are: significant tensile stress, sensitized material and an aggressive environment. The NRC Staff recommends that improvements in all three of these elements should be pursued. Accordingly, mitigation processes such as Stress Improvement (SI), modified weld technologies and new nuclear grade materials, as well as water chemistry control, have become an integral part of the solution to the IGSCC problem.

MSIP is a stress-related mitigation method that prevents IGSCC by removing tension and generating high compressive stresses on the inside surface of the weld, HAZ and adjacent piping in both the axial and hoop directions. MSIP is a proven SI technology recognized in NUREG-0313, Rev. 2 which provides the NRC guidelines and recommendations for preventing and/or mitigating IGSCC in BWR piping weldments. The NRC has also issued Generic Letter 88-01 which provides the Staff Positions regarding the IGSCC problem.

For most types of weldme: : MSIP has been applied and continues to be applied as a preventive measure. However, since MSIP imposes only monotonic compressive strains during application, its use is also well-suited for weldments with pre-existing cracks and those with geometrical or material discontinuities. New criteria for the application and use of MSIP on weldments with cracks to prevent further growth are proposed herein for NRC consideration.

CURRENT NRC POSITION ON SI OF CRACKED WELDMENTS

The current Staff position in NUREG-0313, Rev. 2 is that Stress Improvement is considered to be an effective mitigation process when applied to weldments with short or shallow cracks. Specifically, welds with cracks that are no longer than 10% of the circumference, and are no deeper than 30% of the wall thickness are considered to be mitigated by SI.

MSIP CRACK MITIGATION CRITERIA PROPOSED FOR NRC CONSIDERATION

It is proposed for NRC's consideration that MSIP be approved as an effective measure in mitigating crack growth when applied to weldments with circumferential cracks that meet the following criteria:

crack depth ≤ 40% of the wall thickness
crack length ≤ 33% of pipe circumference

JUSTIFICATION FOR PROPOSED CRITERIA

1. Fracture Mechanics evaluations with the typical operating stresses superposed on the residual compressive axial stresses generated by MSIP show that cracks meeting the proposed criteria are arrested.

2. Cracks meeting the proposed criteria remain in the stable regime when treated by MSIP as shown by a crack stability analysis based on ASME Section XI. Figures 1a and 1b show the typical failure analysis diagrams for the Feedwater Nozzle at Perry. It can be seen that there is substantial margin between the proposed criteria and the failure curves. *Even for a through-wall crack, the corresponding length exceeds the proposed length criteria, i.e., 33% of circumference.*

3. The proposed length criterion is consistent with the recommendations of NUREG-1061 which can be accepted without repair. NUREG-1061 recommends that flaw evaluation criteria should limit the lengths of cracks accepted for continued operation without repair. The limiting recommendation for the acceptable crack length is primarily a result of the lack of confidence in flaw depth sizing capability, and is intended to ensure leak-before-break conditions. Also NUREG-1061 calculations indicate that the maximum crack length acceptable without repair will be approximately 25% to 30% of the pipe circumference. With MSIP the inside half of the wall thickness is put in compression for the complete circumference, i.e., 360°.

4. Analysis and independent tests by ANL (for NRC) and EPRI have shown that the axial stress generated by MSIP is compressive through the inner half of the wall thickness. Moreover this post-MSIP stress distribution is

independent of the 'as-welded' initial residual stress distribution and variations in material properties. Thus, the proposed depth criteria leaves sufficient margin to allow for any uncertainty in accurately sizing the depth of the defect, meets the ASME Code limits and does not compromise plant safety.

5. Actual field experience has demonstrated that MSIP is successful in arresting long circumferential cracks. Figure 2 shows the geometry of the circumferential crack in the 10 inch pipe-to-elbow weldment treated by MSIP. UT inspections before and after application of the Process verified that there was no change in the crack size. Moreover, after one year of operation, the UT examination confirmed that the crack was arrested. It has now been more that three years of operation since the weldment was treated with MSIP.

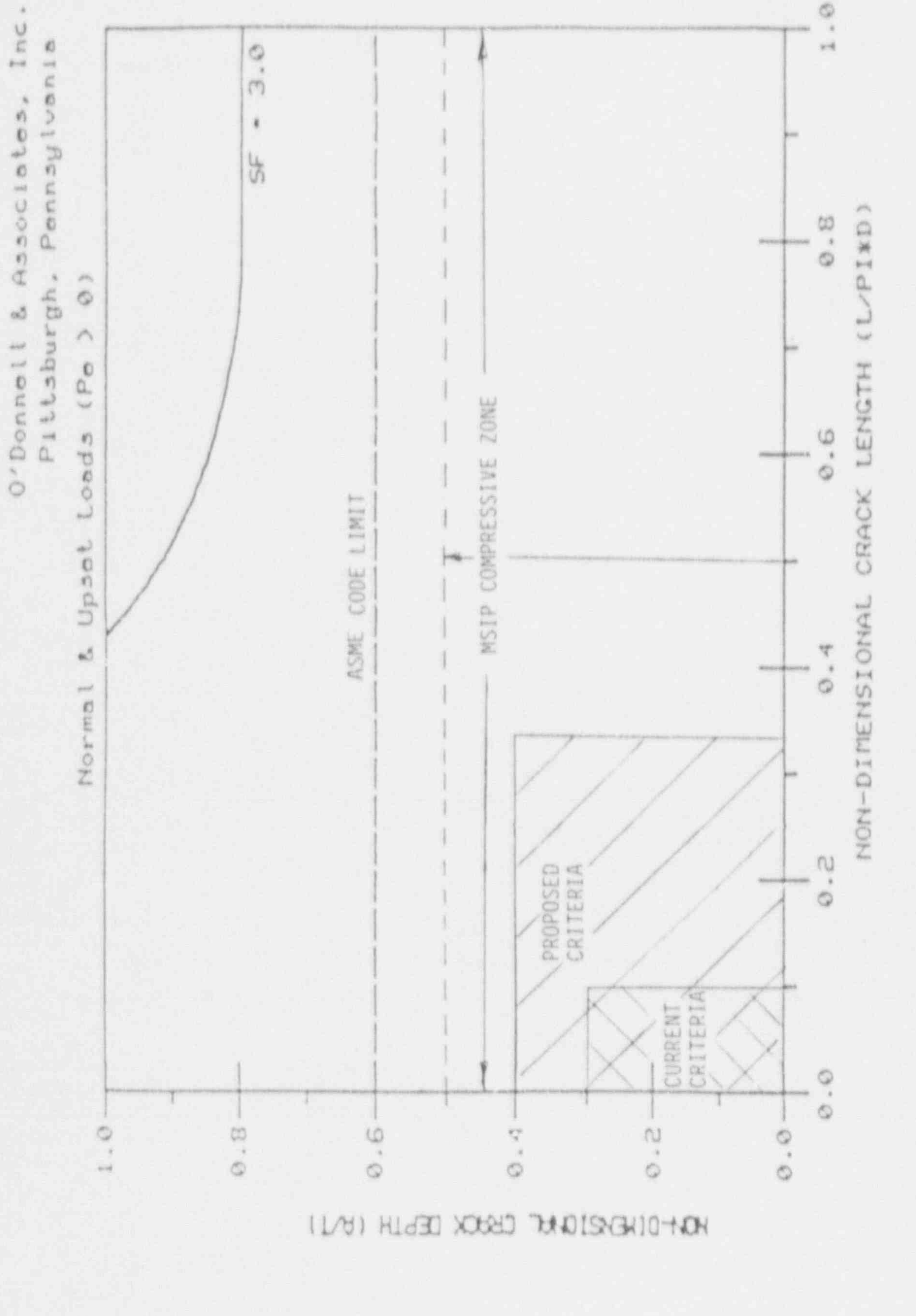

FIGURE 1a STABILITY DIAGRAM FOR UPSET LOADING

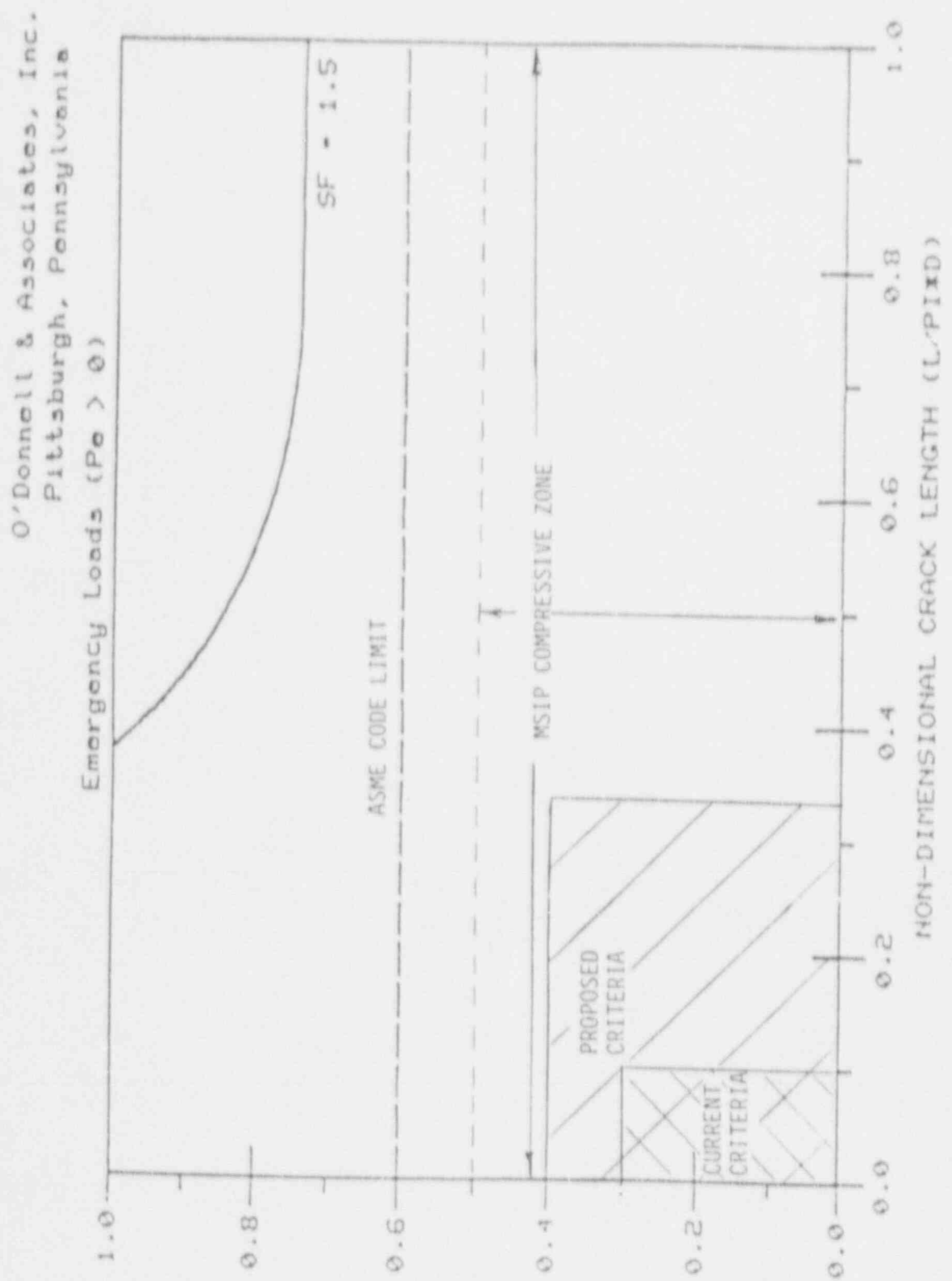

FIGURE 1b STABILITY DIAGRAM FOR EMERGENCY LOADING

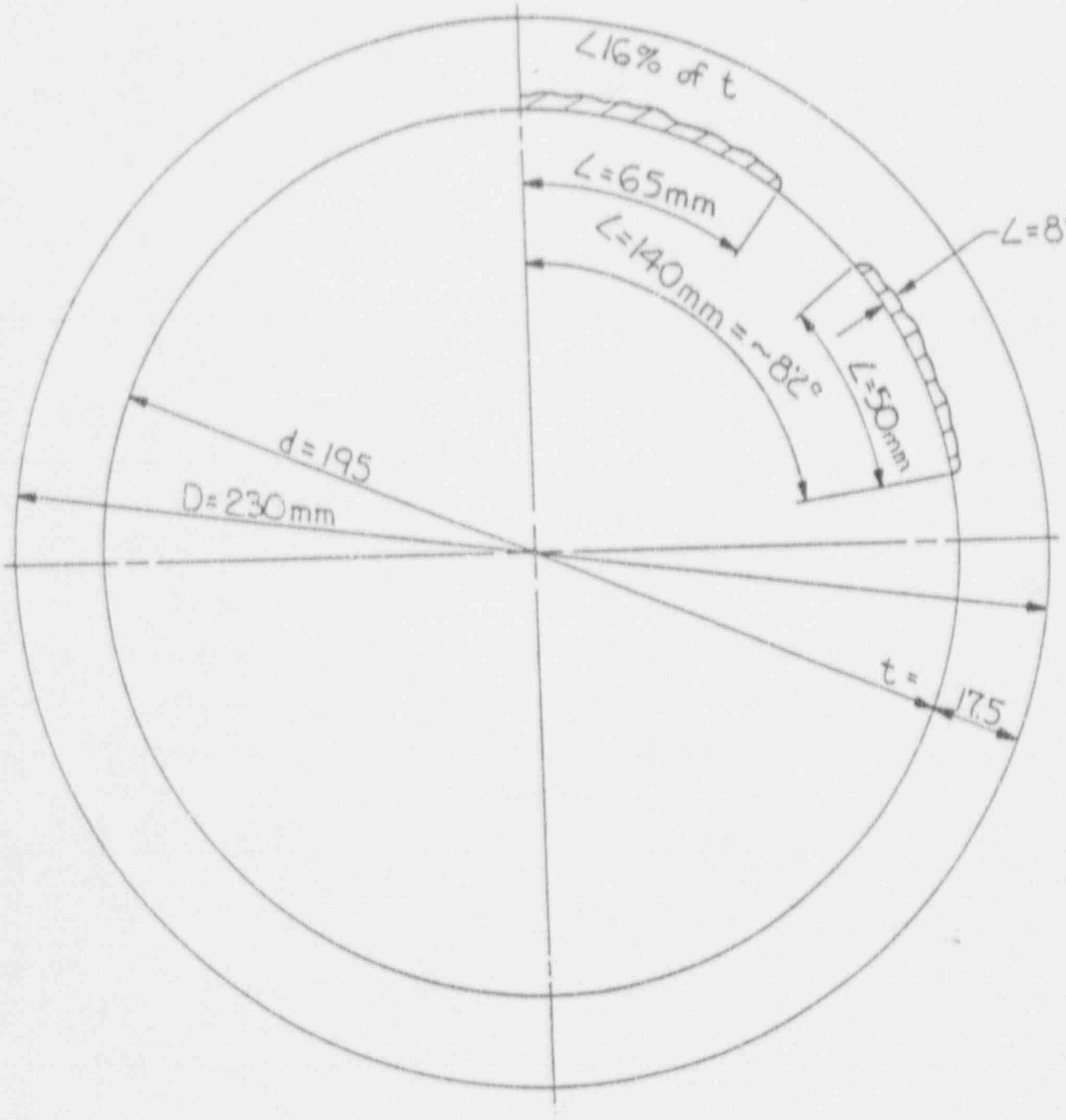

FIGURE 2 CIRCUMFERENTIAL CRACK TREATED BY MSIP