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Revision 1
October 1982
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DESIGN REPORT
FOR
RECIRCULATION LINE
END CAP REPAIR
MONTICELLO
NUCLEAR GENERATING PLANT

Prepared for:
Northern States Power Company

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REVISION CONTROL SHEET

TITLE: Design Report for Recirculation Line End Cap Repair, Monticello Nuclear Generating Plant

REPORT NUMBER: NSP-81-103 Revision 1

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CERTIFICATION BY REGISTERED PROFESSIONAL ENGINEER

I hereby certify that this document and the calculations contained herein were prepared under my direct supervision, reviewed by me, and to the best of my knowledge are correct and complete. I am a duly Registered Professional Engineer under the laws of the States of Minnesota and California and am competent to review this document.

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Date 17 November 1982

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1.0 INTRODUCTION

This report summarizes evaluations performed by NUTECH to assess a weld overlay repair of the end cap to Loop A recirculation manifold weld at Northern States Power Company's Monticello Nuclear Generating Plant. The weld overlay has been applied to address ultrasonic and radiographic examination results believed to be indicative of intergranular stress corrosion cracking (IGSCC) in the vicinity of the weld. The purpose of the overlay is to arrest any further propagation of the cracking, and to restore original design safety margins to the weld.

The required design life of the weld overlay repair is at least one fuel cycle. The amount that the actual design life exceeds one fuel cycle will be established by a combination of future analysis and testing.

Three crack indications have been found in the end cap weld heat affected zone. Figure 1.1 shows the recirculation manifold in relation to the reactor pressure vessel (RPV) and other portions of the recirculation system. All three crack indications are located in the 12 o'clock position adjacent to the weld and all are axial. The largest crack indication is approximately 11 percent of the wall thickness and 1 inch long.

The existing pipe material is ASTM A358, Class 1, Type 304. The existing cap material is ASTM A403, Grade WP304.

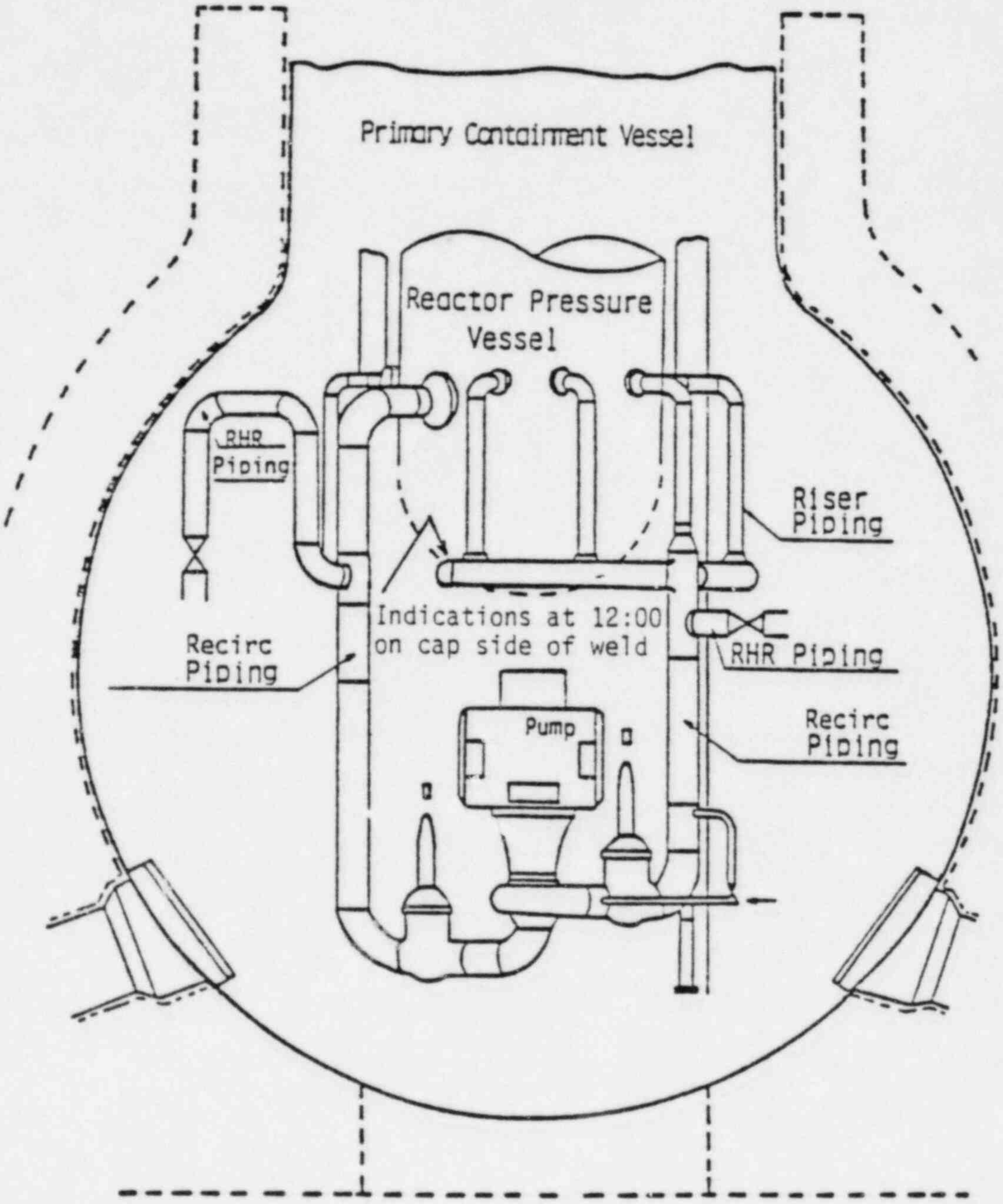

FIGURE 1.1

CONCEPTUAL DRAWING OF RECIRCULATION MANIFOLD

2.0 REPAIR DESCRIPTION

The longitudinal crack indications around and to both sides of the existing end cap weld heat affected zones have been repaired by establishing additional "cast-in-place" pipe wall thickness from weld metal deposited 360 degrees around and to either side of the existing weld, as shown in Figure 2.1. The weld deposited band over the longitudinal crack indications will increase the wall thickness to approximately 0.4 inch greater than that which exists in adjacent uncracked piping. In addition, the weld metal deposition will produce a favorable compressive residual stress pattern and the weld metal will be type 308L, which is resistant to propagation of IGSCC cracks.

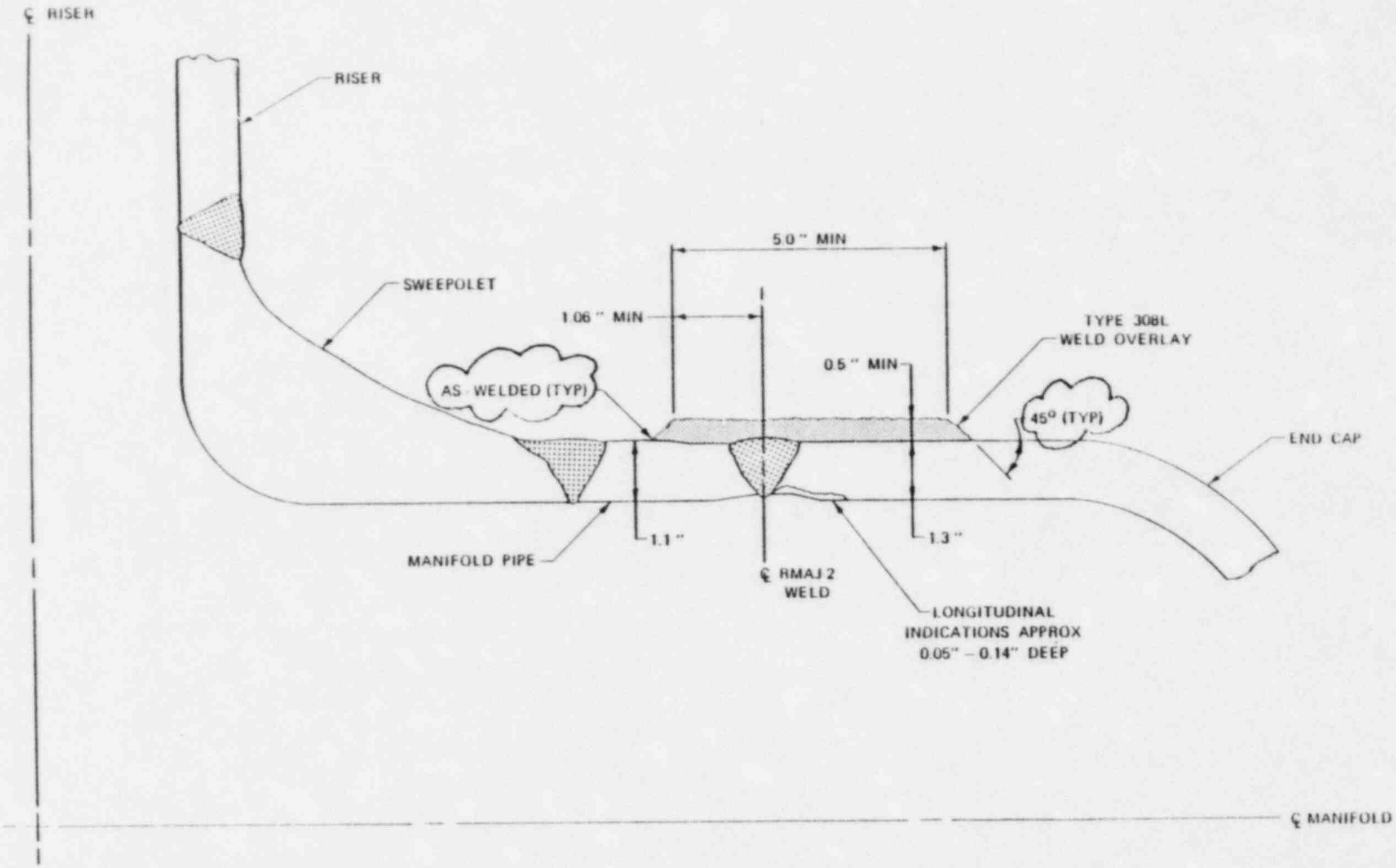

Figure 2.1
SCHEMATIC OF WELD OVERLAY

3.0 EVALUATION CRITERIA

This section describes the criteria that are applied in this report to evaluate the acceptability of the weld overlay described in Section 2.0. Because of the nature of this repair, the geometric configuration is not directly covered by Section III of the ASME Boiler and Pressure Vessel Code, which is intended for new construction. However, materials, fabrication procedures, and Quality Assurance requirements are in accordance with applicable sections of this Construction Code, and the intent of the design criteria described below is to demonstrate equivalent margins of safety on strength and fatigue considerations as provided in the ASME Section III Design Rules.

In addition, because of the IGSCC conditions that led to the need for repairs, IGSCC resistant materials have been selected for the weld overlay used in the repair. As a further means of ensuring structural adequacy, criteria are also provided below for fracture mechanics evaluation of the repair.

3.1 Strength Evaluation

Adequacy of the strength of the weld overlay with respect to applied mechanical loads is demonstrated with the following criteria:

1. An ASME Boiler and Pressure Vessel Code Section III Class 1 (Reference 1) analysis of the weld overlay was performed using worst case loads and using allowable stresses from the Power Piping Code USAS B31.1.0 (Reference 2).

2. The ultimate load capacity of the repair was calculated with a tearing modulus analyis. The ratio between failure load and applied loads was required to be greater than that required by Reference 1.

3.2 Fatigue Evaluation

The stress values obtained from the above strength evaluation were combined with thermal and other secondary stress conditions to demonstrate adequate fatigue resistance for the design life of the repair. The criteria for fatigue evaluation include:

1. The maximum range of primary plus secondary stress was compared to the secondary stress limits of Reference 1.

2. The peak alternating stress intensity, including all primary and secondary stress terms, as well as a fatigue strength reduction factor of 5.0 to account for the existing crack, was evaluated using conventional fatigue analysis techniques. The total fatigue usage factor, defined as the sum of the ratios of applied number of cycles to allowable number of cycles at each stress level, must be less than 1.0 for the design life of the repair. Allowable number of cycles was determined from the stainless steel fatigue curve of Reference 1.

3.3 Crack Growth Evaluation

Crack growth due to both fatigue (cyclic stress) and IGSCC (steady state stress) was calculated. The allowable crack depth was established based on net section limit load for the cracked pipe (Reference 3).

The design life of the repair was established as the minimum predicted time for the observed crack indication to grow to the allowable crack depth.

4.0 LOADS

The loads considered in the evaluation of the end cap weld overlay repair consist of mechanical loads, internal pressure, differential thermal expansion loads, and welding residual stresses. The mechanical loads and internal pressures used in the analysis are described in Section 4.1, and an explanation of the thermal transient conditions which cause differential thermal expansion loads is presented in Section 4.2. Welding residual stresses are considered in the crack growth analyses and are described in Section 5.2.2.

4.1 Mechanical and Internal Pressure Loads

The design pressure of 1248 psi for the recirculation system was obtained from Reference 4. Since the end cap is at the end of the recirculation manifold, there are no significant dead weight or seismic stresses applied to it. This is confirmed by the recent NUTECH analysis of the Monticello Reactor Recirculation System piping (Reference 5).

4.2 Thermal Loads

Since the end cap is at the end of the recirculation manifold, there are no gross section moments due to the thermal expansion applied to it, which is confirmed by Reference 5.

The only transient thermal condition defined in Reference 4 that occurs at the end cap is the normal startup and shutdown cycling. The maximum allowable heatup or cooldown rate is 100°F per hour.

An additional thermal transient was defined in the RPV Design Specification (Reference 6) to account for potential low pressure coolant injection (LPCI) into the recirculation system during a loss of coolant accident (LOCA). The thermal transient was very conservatively defined as a step change in water temperature from 546°F to 90°F at a flow velocity of 10 feet per second. One of these LPCI cycles is assumed to occur every five years (Reference 7). Also defined in Reference 7 is a thermal transient based on actual plant operation due to the initiation of shutdown cooling. The shutdown cooling transient is defined as a 50°F step change in water temperature and it occurs 10 times per year.

5.0 EVALUATION METHODS AND RESULTS

The evaluation of the weld overlay consists of a code stress analysis per References 1 and 2 and a fracture mechanics evaluation per Section XI (Reference 8).

5.1 Code Stress Analysis

The end cap region was assumed to be axisymmetric. That is, the axial crack was conservatively assumed to be 360 degrees around the pipe and the effect of the sweepolet was assumed to be negligible (based on a shell intersection analysis). The shrinkage of the weld overlay should therefore have a minimal effect on the sweepolet. A finite element model of the cracked and weld overlayed region was developed using the ANSYS (Reference 9) computer program. The crack depth was conservatively assumed to be 0.15 inch instead of the measured depth of approximately 0.12 inch. Figure 5.1 shows the model. The pressure stress profile for a design pressure of 1248 psi was calculated with this model. The results are shown in Figure 5.2.

The weld overlay thermal model was also taken to be axi-symmetrical (Figure 5.3). The exterior boundary was assumed to be insulated. The temperature distribution in the weld overlay subject to the thermal transients defined in Section 4.2 can be readily calculated using Charts 16 and 23 of Reference 10. The maximum through wall temperature difference was determined to be less than 2°F for the normal startup cycle, 40°F for the initiation of shutdown cooling, and 359°F for the LPCI transient.

The maximum thermal stress for use in the fatigue crack growth analysis was calculated as follows: (Reference 1)

$$s = \frac{EaWT_1}{2(1-n)} + \frac{EaWT_2}{1-n}$$

Where:

E	=	28.3×10^6 psi (Young's Modulus)
a	=	9.11×10^{-6} $°F^{-1}$ (Coefficient of Thermal Expansion)
WT_1	=	Equivalent Linear Temperature Difference
WT_2	=	Peak Temperature Difference

The values of WT_1, WT_2, and s are given in Table 5.1 for all three thermal transients.

The results of a code stress analysis per Reference 1 are given in Table 5.2. The allowable stress values for both References 1 and 2 are also given. The weld overlay repair satisfies the Reference 1 requirements even with the use of the more conservative Reference 2 allowable stress values.

A conservative fatigue analysis per Reference 1 was performed. In addition to the stress intensification factors required per Reference 1, an additional fatigue strength reduction factor of 5.0 was applied due to the crack. The fatigue usage factor was then calculated assuming 10 startups and shutdown cooling initiation cycles per year plus one LPCI injection every five years. The results are summarized in Table 5.2.

5.2 Fracture Mechanics Evaluation

Three types of fracture mechanics evaluations were performed. The allowable crack depth was calculated based on Reference 3. Crack growth due to both fatigue and IGSCC was calculated using the NUTECH computer program NUTCRAK (Reference 11) with material constants and methodology from References 12 and 13. Finally, the ultimate margin to failure for a crack assumed to propagate all the way through the original pipe material to the weld overlay was calculated per References 14 and 15.

5.2.1 Allowable Crack Depth

The allowable depth for a 1 inch long axial crack was determined using Reference 3. The dimensions of the unrepaired pipe were conservatively used. Thus, the ratio of applied primary stress to Code allowable stress (S_m) was calculated in the following manner:

$$\text{Stress Ratio} = \frac{PR/t}{Sm}$$

P = 1248 psi (Design Pressure)

R = 10.951 inches (Outside Radius of Pipe - before overlay)

t = .987 inch (Nominal Pipe Thickness - before overlay)

S_m = 14,427 psi (B31.1)

= 16,900 psi (Section III)

Substitution yields:

$$\text{Stress Ratio} = .96 \text{ (B31.1)}$$
$$= .82 \text{ (Section III)}$$

The average value of .89 was used. The nondimensional crack length was calculated in the following manner:

$$\text{Nondimensional Length} = \frac{L}{(Rt)^{1/2}}$$

L = 1 inch

R = 10.951 inches

t = .987 inch

Substitution yields:

Nondimensional Length = .3

Thus per Table IWB-3642-1 of Reference 3, the allowable crack depth is 70 percent of the wall thickness. To be conservative, the unrepaired pipe wall thickness was used. The allowable crack depth is then 0.69 inch.

5.2.2 Crack Growth

The existing 0.12 inch deep crack could grow due to both fatigue and stress corrosion. Fatigue crack growth due to the three types of thermal transients defined in Section 4.2 was calculated using material properties from Reference 13. The fatigue cycles considered are shown in Figure 5.4.

IGSCC growth depends on the total steady state stress. The steady state stresses can be postulated to be high due to the presence of weld residual stresses. The magnitude of weld residual stresses without the weld overlay is difficult to determine. Reference 16 gives a measurement of the residual stress through the thickness near a 26-inch butt weld. The weld overlay is expected to reduce the residual stresses, but the magnitude is not known. Future work at the Electric Power Research Institute (EPRI) is expected to increase our understanding of this reduction. To be conservative, another case with through wall bending residual stress equal to 30,000 psi was also considered. 30,000 psi is the ASME Code room temperature yield stress fo 304 stainless steel. Thus three residual stress distributions were used:

A) Zero stress; assuming the overlay process completely eliminates any tensile residual stresses due to the original butt weld.

B) The best estimate: measured residual stress for the original butt weld from Reference 16.

C) A worst case; upper bound residual stress distribution for conservative bounding crack growth calculations.

These distributions are presented in Figure 5.5.

Two IGSCC growth laws were also considered based on the data compiled in Reference 12. Thus, a total of six combinations of residual stress and crack growth law were investigated. The six cases are summarized in Table 5.3.

Cases A1, A2, B1 and B2 were analyzed using an infinite length flaw. Cases C1 and C2 (worst case residual stress) were analyzed using a finite size flaw of 2 inch length. The stress intensity factor (K) versus crack depth (a) is shown in Figure 5.6 for both infinite and finite length flaws for the Case C residual stress distribution.

Fatigue crack growth due to the cycles shown in Figure 5.4 for cases A1, A2, B1 and B2 assumed a worst case initial crack depth of 0.5 inch. The total fatigue crack growth was 0.02 inch. Fatigue crack growth due to the cycles shown in Figure 5.4 for cases C1 and C2 assumed a crack depth based on the finite size flaw (K versus a) curve in Figure 5.6. The maximum K occurs for a crack depth equal to 0.3. The total fatigue crack growth for five years of operation due to the cycles shown in Figure 5.4 for cases C1 and C2 with an initial crack of 0.3 was approximately 0.01 inch.

The predicted IGSCC and fatigue crack growths for all six cases for the next five years are presented in Figure 5.7. Cases A1, A2, B1 and B2, which are the most likely to occur, do not experience significant crack growth for at least five years. Even the most conservative cases (C1 and C2) with worst case residual stress do not grow to an unacceptable size during the first five years.

The initial crack sizes for cases A1, A2, B1 and B2 that would be necessary to grow (due to both fatigue and IGSCC) to a depth of 70 percent of the unreinforced pipe (.69 inch) in the next five years are shown in Figure 5.8. The time scales in Figures 5.7 and 5.8 are years of operation, not real time years. Thus, an initial crack depth of greater than 0.4 inch would be acceptable for at least 5 years using the most likely residual stress distributions.

The design life of the repair is thus clearly greater than five years, even considering the worst combinations of analytical conditions considered. A more precise determination of the actual design life of the repair will be possible after completion of the EPRI program to determine weld overlay residual stress reduction noted above.

5.2.3 Tearing Modulus

The largest size to which the existing crack could reasonably be expected to grow was postulated to be a 1 inch radius flaw. This assumes growth of the crack in the radial direction completely through the original pipe material to the overlay, even though such propagation is not predicted by the analysis of Section 5.2.2. After such propagation, the assumed crack would be completely surrounded by IGSCC resistant material: the weld between end cap and manifold, the weld overlay, and the annealed end cap. A tearing modulus evaluation was then performed for this postulated crack. The only applied load is pressure.

The evaluation was performed using the methodology of Reference 14 with material properties from Reference 15.

The postulated flaw and the results are shown in Figure 5.9. The upper dotted line represents the inherent material resistance to unstable fracture in terms of J-integral and Tearing Modulus, T. The line originating at the origin represents the applied loading. Increasing pressure results in applied J-T combination moving up this line, and unstable fracture is predicted at the intersection of this applied loading line with the material resistance line.

Figure 5.9 shows that the predicted burst pressure is in excess of 6500 psig. Thus, there is a safety factor on normal operating pressure of at least 6, which is well in excess of the safety factor inherent in the ASME Code, even in the presence of this worst case assumed crack.

PARAMETER	NORMAL STARTUP CYCLE (CYCLE 1)	INITIATION SHUTDOWN COOLING CYCLE (CYCLE 2)	LPCI CYCLE (CYCLE 3)
EQUIVALENT LINEAR TEMPERATURE ΔT_1	2^oF	32^oF	290^oF
PEAK TEMPERATURE ΔT_2	0	8^oF	69^oF
THROUGH WALL THERMAL STRESS σ	368 PSI	8839 PSI	78,817 PSI

Table 5.1

THERMAL STRESS RESULTS

CATEGORY	EQUATION NUMBER	ACTUAL STRESS OR THICKNESS	SECTION III NB ALLOWABLE	B31.1 ALLOWABLE
S		NA	S_m =16,900 PSI	S_h = 14.427 PSI S_c = 18,750 PSI
REQUIRED THICKNESS	(1)	1.308"	0.826"	0.952"
PRIMARY	(9)	5,470 PSI*	25,350 PSI	14,427 PSI
PRIMARY + SECONDARY	(10,	12,060 PSI	50,700 PSI	49,765 PSI
PEAK CYCLE 1 CYCLE 2 CYCLE 3	(11)	** (15,150)5 (27,484)5 (130,719)5	NA	NA
USAGE FACTOR (40 YR)		0.22		

* FINITE ELEMENT MODEL GIVES 9920 PSI FOR MAXIMUM STRESS INTENSITY. EQUATION (9) CALCULATES AXIAL STRESS WHICH IN THIS CASE IS NOT LIMITING AS MOMENTS ≃ 0.

** THE FACTOR OF 5 IS THE CONSERVATIVELY ASSUMED FATIGUE STRENGTH REDUCTION FACTOR.

Table 5.2

CODE STRESS ALLOWABLES 22" END CAP

CASE	RESIDUAL STRESS	GROWTH LAW $\frac{da}{dt}$
A1	A	$1.843 \times 10^{-12}\ K^{4.615}$*
A2	A	$4.116 \times 10^{-12}\ K^{4.615}$**
B1	B	$1.843 \times 10^{-12}\ K^{4.615}$
B2	B	$4.116 \times 10^{-12}\ K^{4.615}$
C1	C	$1.843 \times 10^{-12}\ K^{4.615}$
C2	C	$4.116 \times 10^{-12}\ K^{4.615}$

* BEST ESTIMATE EPRI NP 2423-LD JUNE 1982 0.2 ppm DATA.

** UPPER BOUND EPRI NP 2423-LD JUNE 1982 0.2 ppm DATA.

Table 5.3
CRACK GROWTH CASES

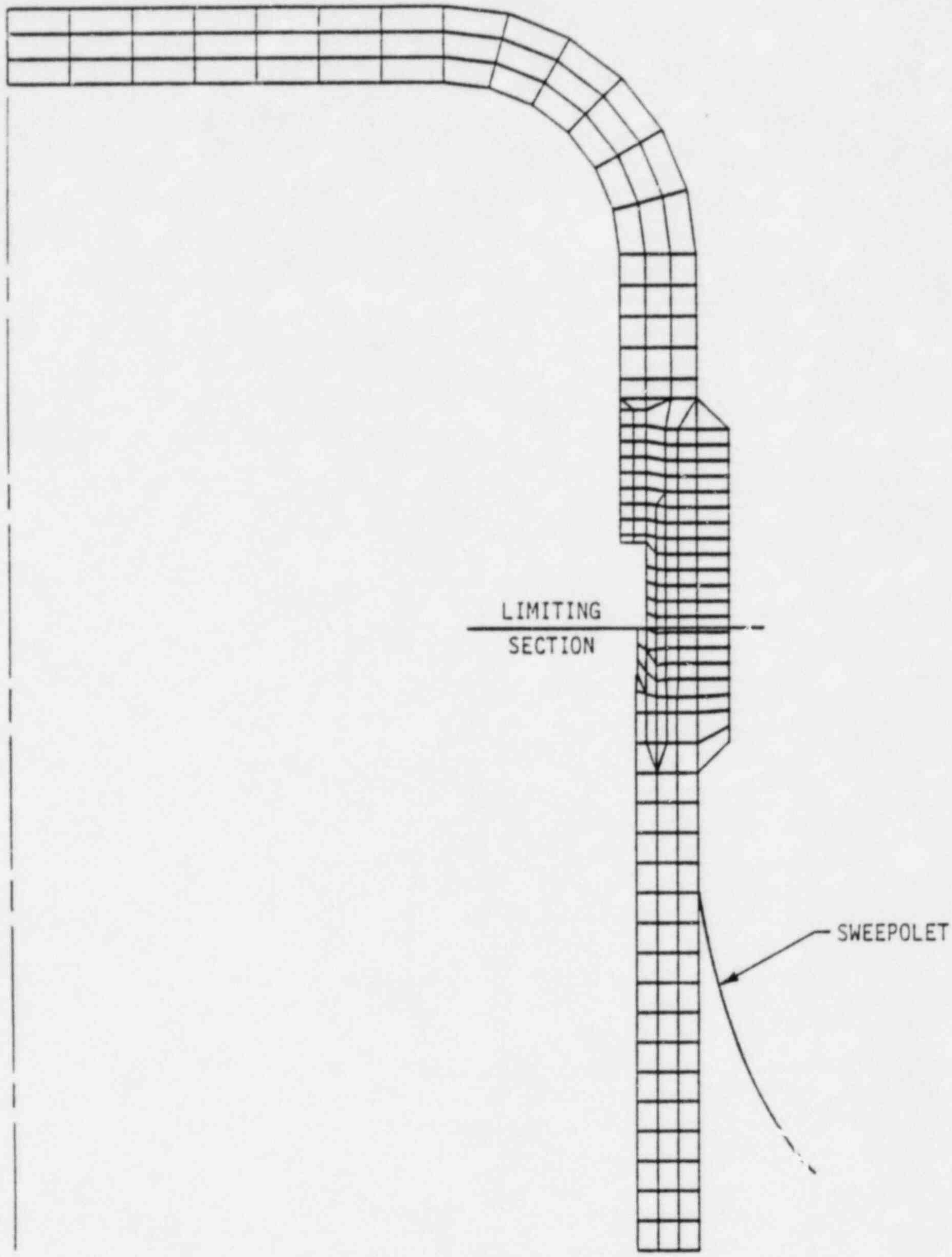

Figure 5.1

/PREP7

ANSYS MODEL OF 22" END CAP WELD OVERLAY

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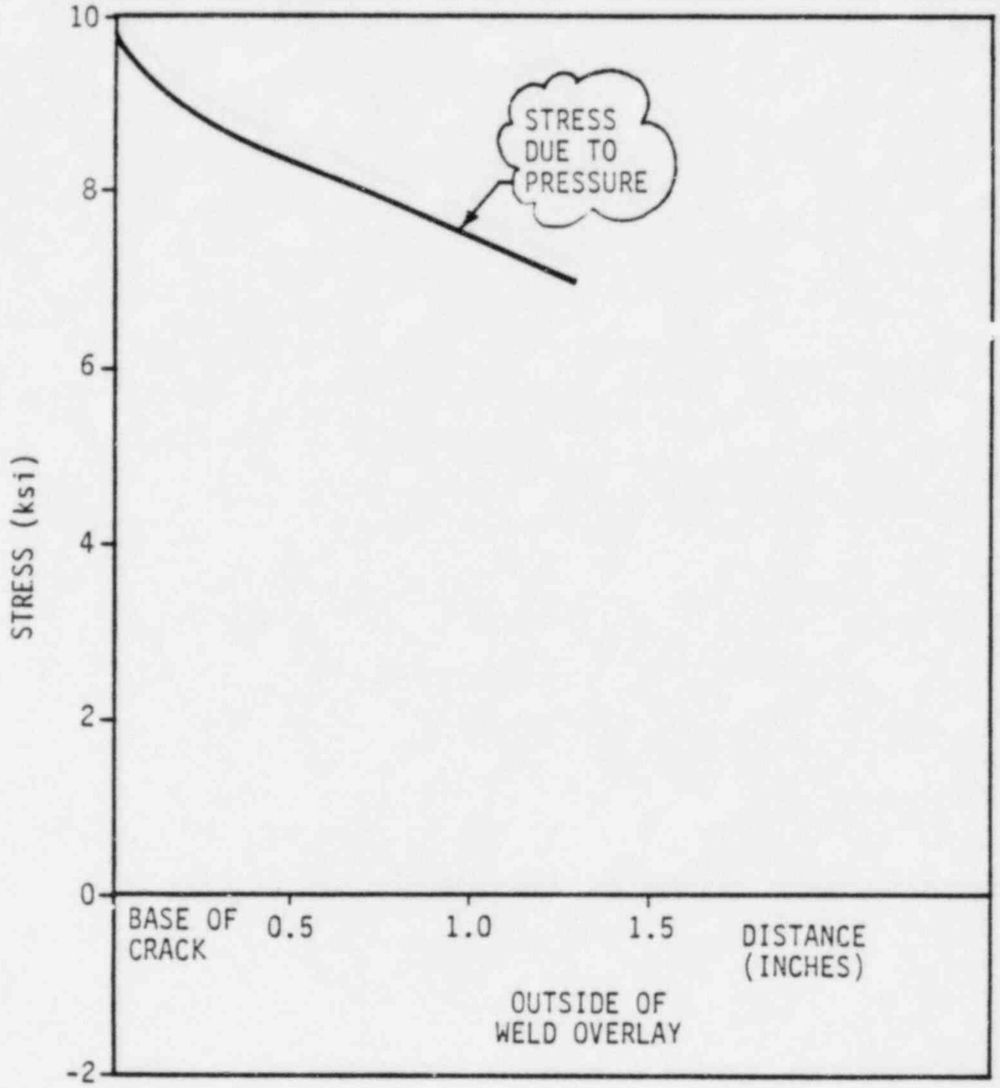
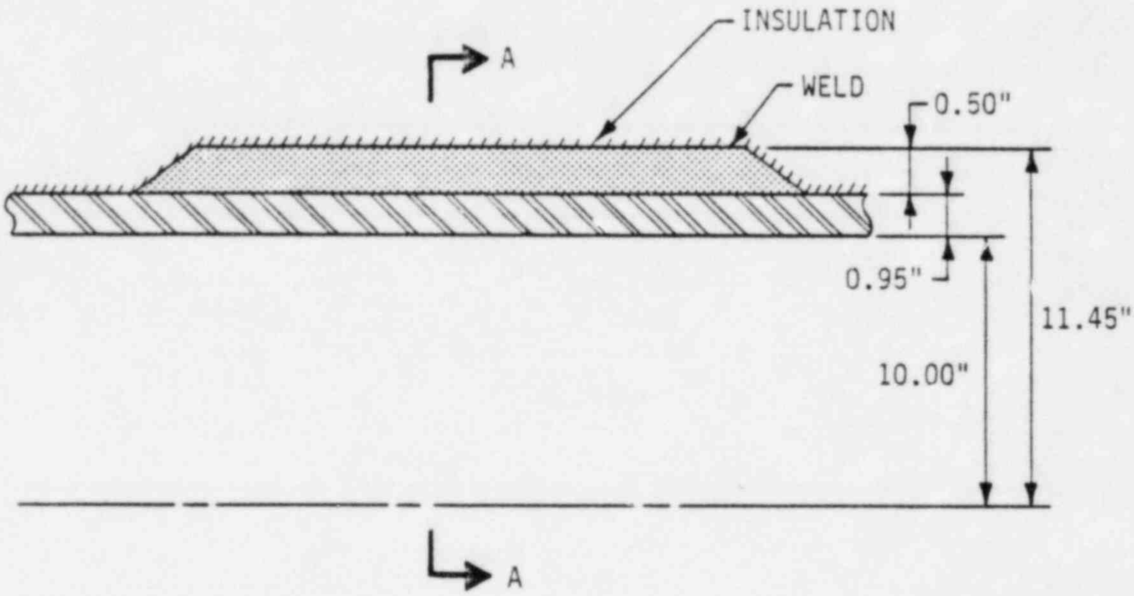
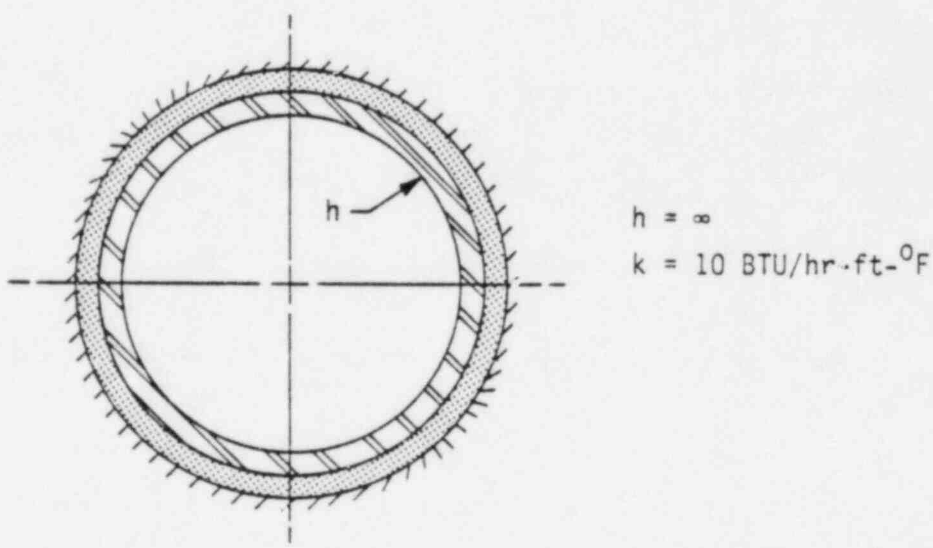


Figure 5.2

APPLIED STRESS PROFILE THROUGH
LIMITING SECTION 22" END CAP





SECTION A-A

Figure 5.3

WELD OVERLAY THERMAL MODEL

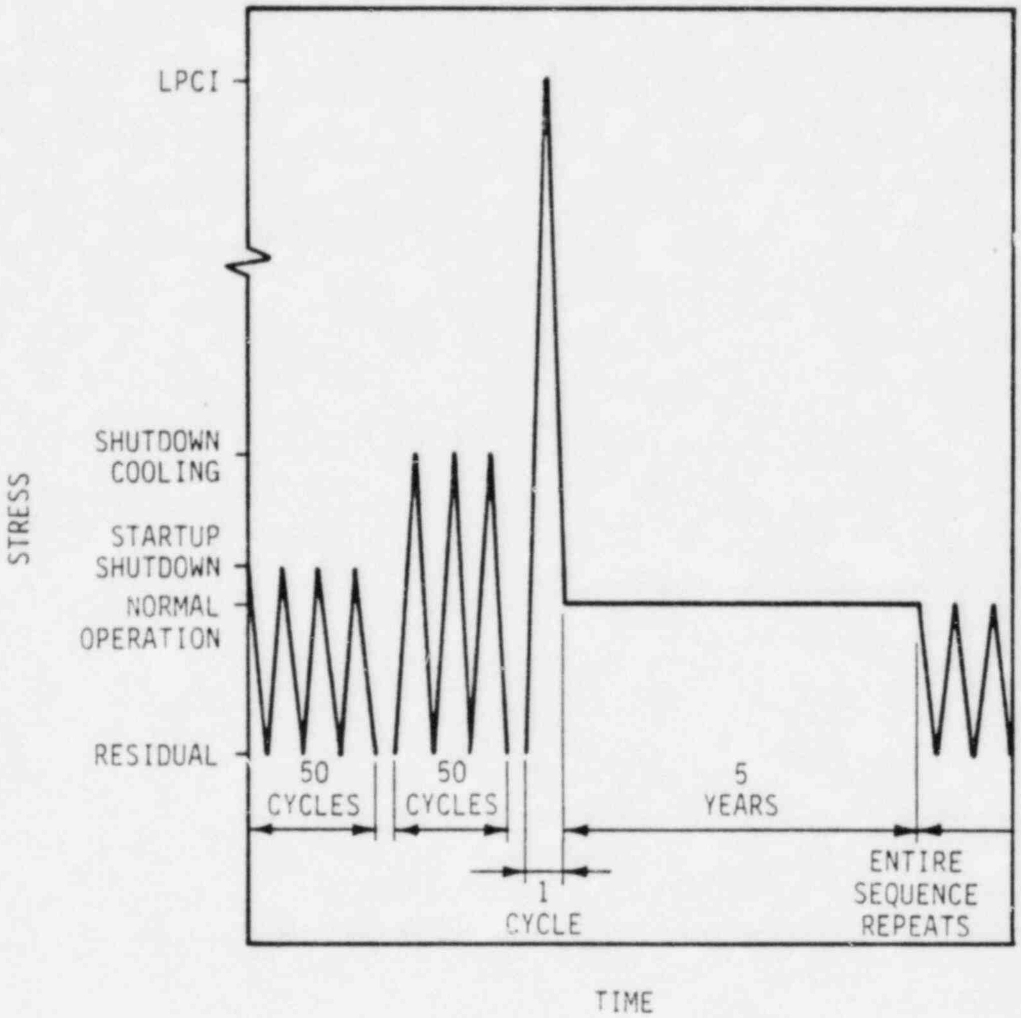


Figure 5.4
THERMAL TRANSIENTS

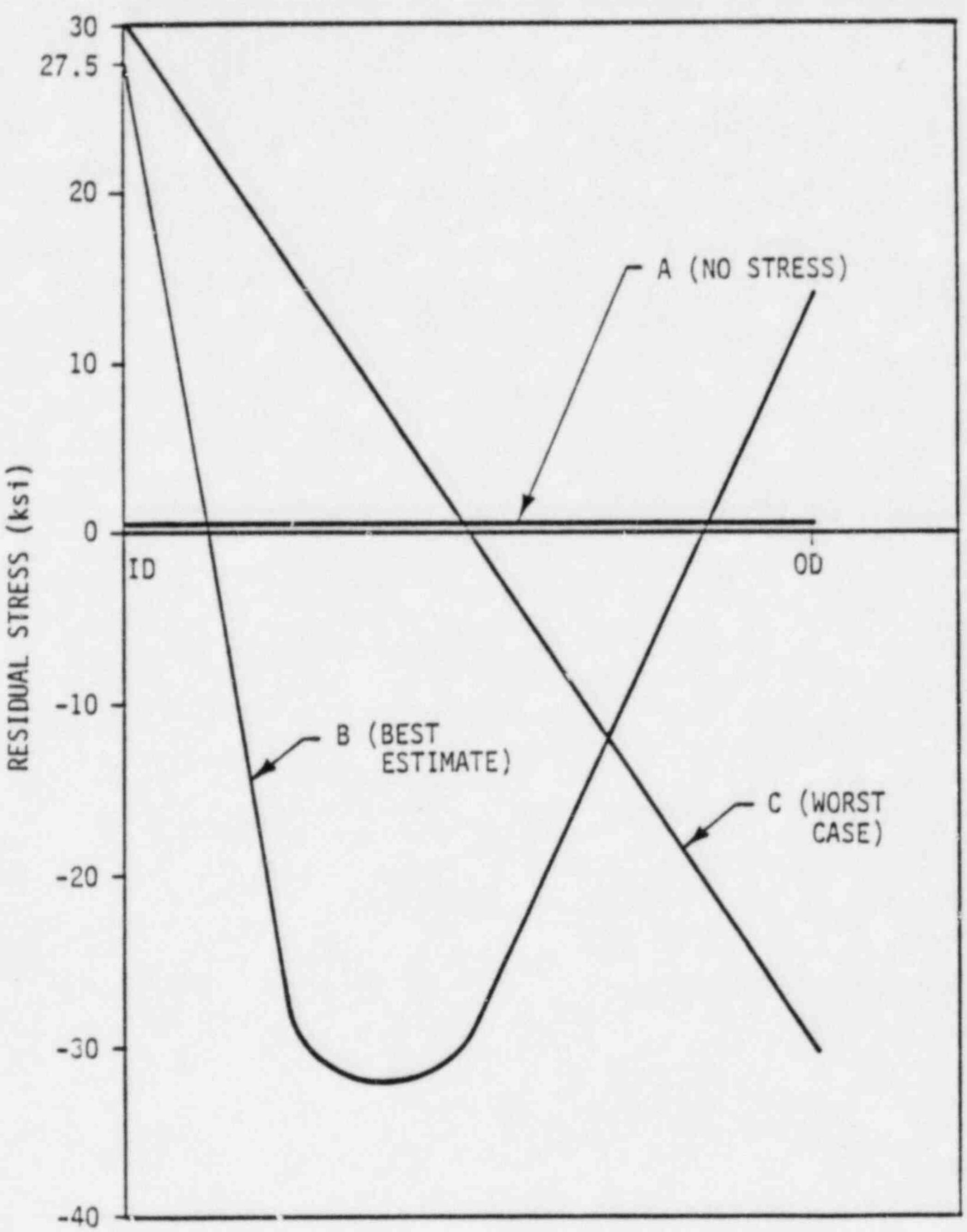


Figure 5.5

CRACK GROWTH RESIDUAL STRESS
22" END CAP

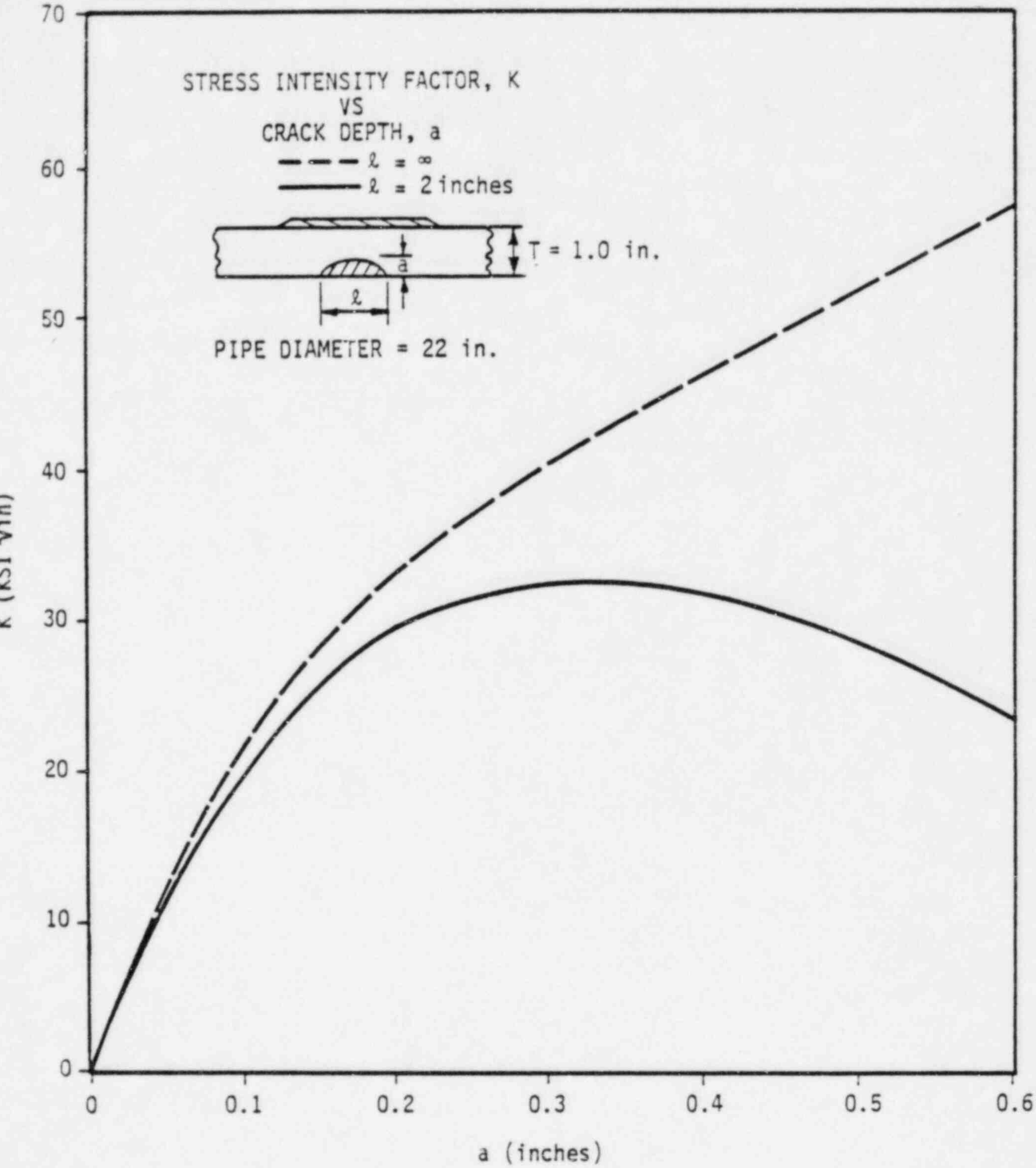
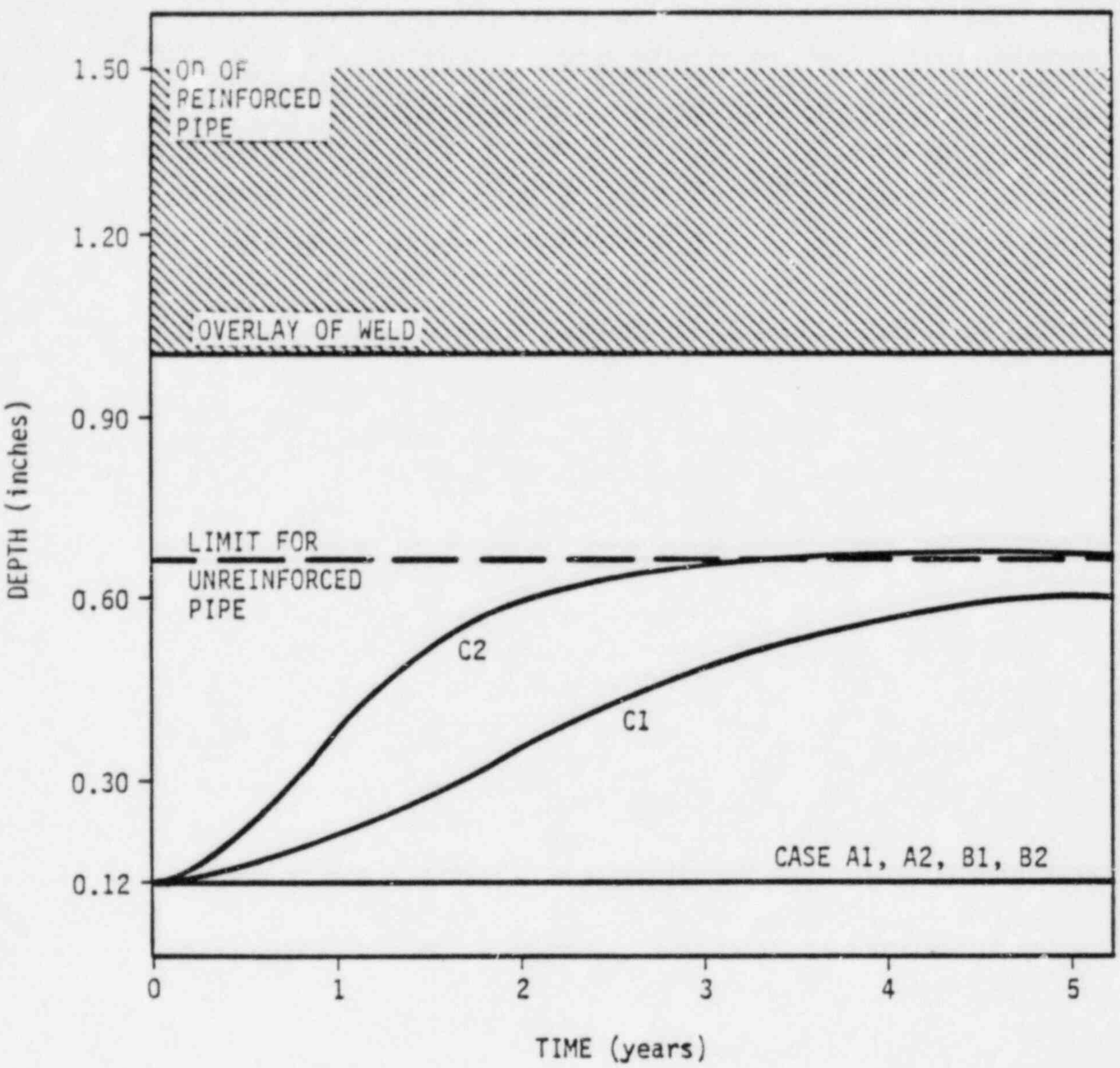

STRESS INTENSITY FACTOR, K
VS
CRACK DEPTH, a
ℓ = ∞
ℓ = 2 inches
T = 1.0 in.
a
ℓ
PIPE DIAMETER = 22 in.
70
60
50
40
30
20
10
0
K (KSI √in)
0
0.1
0.2
0.3
0.4
0.5
0.6
a (inches)

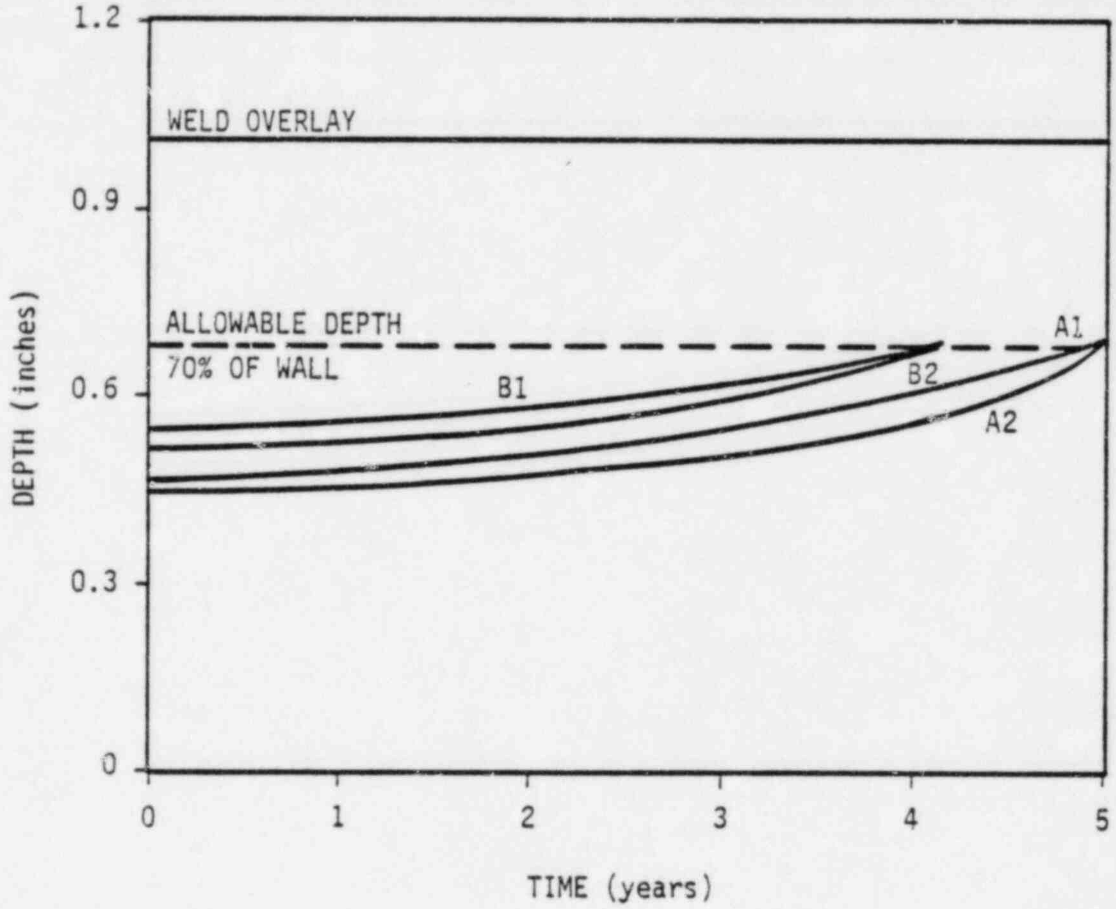
Figure 5.6



C1, C2 ARE RESPECTIVELY THE BEST ESTIMATE AND UPPER BOUND IGSCC CURVES FOR A FINITE LENGTH SEMI-ELLIPTICAL SURFACE CRACK. FATIGUE CRACK GROWTH OF 0.01 INCH IN 5 YEARS IS INCLUDED.

Figure 5.7

CRACK GROWTH 22" END CAP



INCLUDES 0.02 INCH OF FATIGUE CRACK GROWTH IN 5 YEARS.

Figure 5.8
ALLOWABLE CRACK DEPTH 22" END CAP

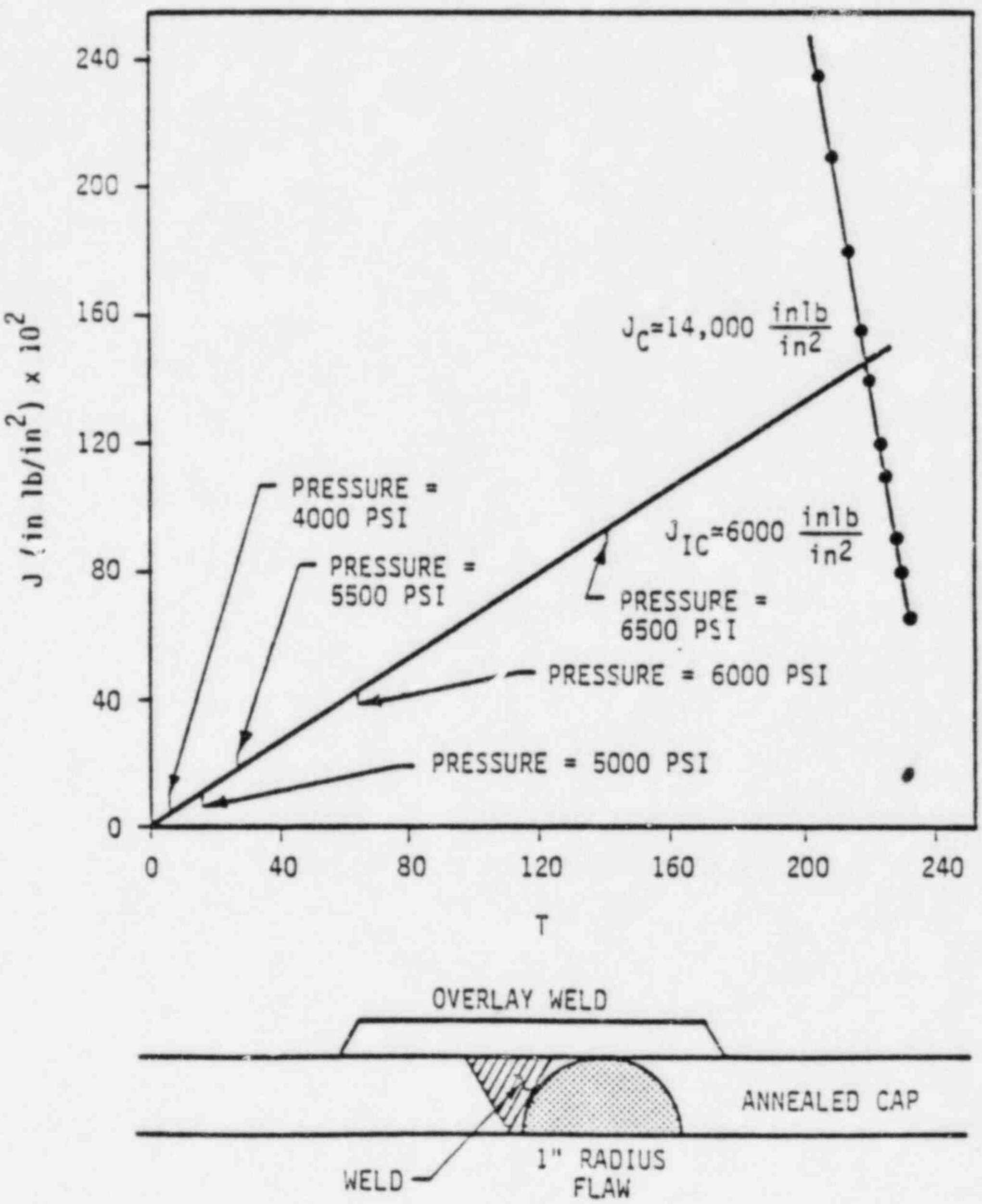


Figure 5.9

TEARING MODULUS 22" END CAP

6.0 SUMMARY AND CONCLUSIONS

The evaluation of the repairs to the recirculation end cap reported herein shows that the resulting stress levels are acceptable for all design conditions. The stress levels have been assessed from the standpoint of load capacity of the components, fatigue, and resistance to crack growth.

Acceptance criteria for the analysis have been established in Section 3.0 of this report which demonstrate that:

1. There is no loss of design safety margin over those provided by both the original Construction Code for the piping system (B31.1) or the current Code of Construction for Class 1 piping (ASME Section III).

2. During the design lifetime of the repair, the observed cracks will not grow to the point where the above safety margins would be exceeded.

Analyses have been performed and results are presented which demonstrate that the repaired weld satisfies these criteria by a large margin, and that the design life of the repair is at least five years.

7.0 REFERENCES

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16. EPRI-NP-1413, "Measurement of Residual Stresses in Type 304 Stainless Steel Piping Butt Weldments", June 1980.

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November 18, 1982
NSP-81-022

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Monticello, MN 55362

Subject: Leak-Before-Break Considerations for Recirculation System Stress Corrosion Cracks at the Monticello Nuclear Generating Plant

Reference: See Attachment F

Dear Mr. Hammer:

The purpose of this letter is to document the leak-before-break aspects of boiling water reactor (BWR) piping system intergranular stress corrosion cracking (IGSCC) which have led virtually all investigators to conclude that it represents an availability rather than a safety issue. The subject is investigated with particular reference to the recent IGSCC occurrences at Monticello, and it is determined that these occurrences do not alter this conclusion, nor do they reduce the design basis safety margin or increase the probability of an accident at the plant.

1.0 INTRODUCTION

Ultrasonic (UT) examination of recirculation piping system welds at the Monticello Nuclear Generating Plant have resulted in the detection of several intergranular stress corrosion cracks or crack-like indications in a number of welds. All welds containing such indications have been repaired using the weld overlay process as described and documented in References 1 and 2, and therefore restored to at least their original safety margin. However, considering uncertainties in the UT examination procedure, there is a reasonable chance that other, similar cracks may have gone undetected during the examination. This possibility raises the question of the potential effect of such cracking on the continued, safe operation of the plant.

IGSCC has occurred in numerous stainless steel piping welds in operating boiling water reactors since 1974. These occurrences were initially observed in 4-inch diameter recirculation bypass lines and 10-inch diameter core spray lines. Since that time, however, IGSCC has occurred in increasingly larger diameter piping systems, both in the U.S. and overseas, up through and including 12-inch and 28-inch main recirculation system piping. More than 400 cracked welds have been observed to date and recent cracking experience at Nine Mile Point, Unit 1 and Monticello will significantly increase this figure.

The cracking has been the subject of investigations by the Nuclear Regulatory Commission (References 3, 4, and 5), General Electric Company (Reference 6), and numerous studies sponsored by EPRI and a BWR Owners Group on the subject (References 7 and 8). The unanimous conclusion of all of these studies is that IGSCC in BWR piping, while undesirable from a plant reliability standpoint, does not represent a significant hazard to public health and safety. This conclusion is based primarily on the exceptional toughness and crack resistance of the austenitic stainless steel from which BWR piping is fabricated, and the distinct tendency for cracks which develop in such material to develop into small, detectable leaks before any significant reduction in the structural integrity of the piping (leak-before-break).

The purpose of this letter is to summarize the bases for this conclusion from References 3 through 8, and to confirm its validity and applicability to the current cracking situation at Monticello. This letter specifically addresses the potential for undetected cracks in welds other than those which have been repaired.

2.0 EFFECT OF IGSCC ON PIPING SYSTEM STRUCTURAL INTEGRITY

2.1 Net Section Collapse

The simplest way to determine the effect of IGSCC on the structural integrity of piping is through the use of a simple "strength of materials" approach to assess the load carrying capacity of a piping section after the cracked portion has been removed. Studies have shown (References 7 and 8) that this approach gives a conservative, lower-bound estimate of the loads which would cause unstable fracture of the cracked section. Typical results of such an analysis are indicated in Attachment A (from Reference 7). This figure defines the locus of limiting crack depths and lengths for circumferential cracks which are predicted to cause failure by the net section collapse method. Curves are presented for both typical piping system stresses and stress levels equal to ASME Code limits. Note that a very large

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percentage of pipe wall can be cracked before reaching these limits (40% to 60% of circumference for through-wall cracks, and 65% to 85% of wall thickness for 360° part-through cracks).

Also shown in Attachment A is a sampling of cracks which have been detected in service, either through UT examination or leakage. In each case there has been a comfortable margin between the size crack that was observed and that which would be predicted to cause failure under service loading conditions. Also, as discussed below, there is still considerable margin between these net section collapse limits and the actual cracks which would cause instability.

2.2 Tearing Modulus Analysis

Elastic-plastic fracture mechanics analyses are presented in Reference 8 which give a more accurate representation of the crack tolerance capacity of stainless steel piping than the net section collapse approach described above. Attachments B and C graphically depict the results of such an analysis from Reference 8. Through-wall circumferential defects of arc-length equal to 60° through 300° were assumed at various cross sections of a typical BWR recirculation system. Loads were applied to these sections of sufficient magnitude to produce net section limit load, and the resulting values of tearing modulus were compared to that required to cause unstable fracture (Attachment B). Note that in all cases there is substantial margin, indicating that the net section collapse limits of the previous section are not really failure limits. Attachment C summarizes the results of all such analyses performed for 60° through-wall cracks in terms of margin on tearing modulus for stability. The margin in all cases is substantial.

2.3 Leak Versus Break Flaw Configuration

Of perhaps more significance to the leak-before-break argument is the flaw configuration depicted in Attachment D. This configuration addresses the concerns raised by the occurrence of part-through flaws growing, with respect to the pipe circumference, before breaking through the outside surface to cause leakage. Attachment D presents typical size limitations on such flaws based on the conservative, net section collapse method of Section 2.1. Note that very large crack sizes are predicted. Also shown on this figure are typical detectability limits for short, through-wall flaws (which are amenable to leak detection) and long part-through flaws (which are amenable to detection by UT). The margins between the detectability limits, and the conservative, net section collapse failure limits are substantial. It is noteworthy that the likelihood of flaws developing which are characterized by the vertical axis shown in Attachment D (full 360° circumferential with no through-wall component) is so remote as to be considered impossible. Material and stress asymmetries always tend to propagate one portion of the crack faster than the bulk of the crack front, which will eventually result in "leak-before-break". This observation is born out by extensive field experience with BWR IGSCC.

2.4 Axial Cracks

The recent IGSCC occurrences at Monticello were predominantly short, axial cracks which grew through the wall but remained very short in the axial direction. This behavior is consistent with expectations for axial IGSCC since the presence of a sensitized weld heat-affected zone is necessary, and this heat-affected zone is limited to approximately 0.25 inch on either side of the weld. Since the major loadings in the above net section collapse analysis are bending moments on the cross section due to seismic loadings, and since these loads do not exist in the circumferential direction, the above leak-before-break arguments are even more persuasive for axially oriented cracks. There is no known mechanism for axial cracks to lengthen before growing through-wall and leaking, and the potential rupture loading on axial cracks is less than that on circumferential cracks.

2.5 Multiple Cracks

Recent analyses performed for EPRI (Reference 9) indicate that the occurrence of multiple cracks in a weld, or cracking in multiple welds in a single piping line do not invalidate the leak-before-break arguments discussed above.

3.0 CRACK DETECTION CAPABILITY

IGSCC in BWR piping is detected through two means: non-destructive examination (NDE) and leakage detection. Although neither is perfect, the two means complement one another well. This detection capability combined with the exceptional inherent toughness of stainless steel, results in essentially 100% probability that IGSCC would be detected before it significantly degraded the structural integrity of a BWR piping system.

3.1 Non-Destructive Examination

The primary means of non-destructive examination for IGSCC in BWR piping is ultrasonics (UT). This method has been the subject of considerable research and development in recent years, and significant improvements in its ability to detect IGSCC have been achieved. Nevertheless, recent UT experience at Monticello and elsewhere indicate that there is still considerable room for improvement, especially in the ability to distinguish cracks or crack-like indications from innocuous geometric conditions.

Attachment D, however, illustrates a significant aspect of UT detection capability with respect to leak-before-break. The types of cracking most likely to go undetected by UT are relatively short circumferential or axial cracks which are most amenable to detection by leakage. Conversely, as part-through cracks lengthen, and thus become more of a concern with respect to leak-before-break, they become readily detectable by UT, and are less likely to be misinterpreted as geometric conditions. This argument is further enhanced by the usual practice of supplementing the UT inspection with radiography (RT) when large, UT indications are observed. If a long UT indication is truly a geometric condition, it will be observable as density differences on the radiograph. If, on the other hand, no significant RT density differences are observed in the vicinity of the UT indication (or if the density differences are abrupt and crack-like), the observed indication is usually diagnosed as IGSCC.

3.2 Leakage Detection

Typical leakage detection capability for BWR reactor coolant system piping is through sump level and drywell activity monitoring. These systems have sensitivities on the order of 1.0 gallons per minute (GPM) of unidentified leakage (i.e. not from known sources such as valve packing or pump seals). Plant technical specification limits typically require investigation/corrective action at 5.0 GPM unidentified leakage.

Attachment E provides a tabulation of typical flaw sizes to cause 5.0 GPM leakage in various size piping (from Reference 7). Also shown on this table are the critical crack lengths for through wall cracks based on the net section collapse method of analysis discussed above. For conservatism, the leakage values are based on pressure stress only, while the critical crack lengths are based on the sum of all combined loads, including seismic. (Considering other normal operating loads in the leakage analysis would result in higher rates of leakage for a given crack size.) Note that there is considerable margin between the crack length to produce 5.0 GPM leakage and the critical crack length, and that this margin increases with increasing pipe size.

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3.3 Historical Experience

The above theories regarding crack detectability have been born out by experience. Indeed, of the approximately 400 IGSCC incidents to date in BWR piping, all have been detected by either UT or leakage, and none have even come close to violating the structural integrity of the piping.

4.0 CONCLUSION

On the basis of a large body of analytical and experimental work, (References 3 through 8) which is briefly summarized in this letter, it is concluded that the recent IGSCC experienced in the reactor recirculation system at Monticello does not increase the probability of a design basis pipe rupture at the plant. This conclusion expressly considers the nature of the cracking which has been repaired at Monticello, and the likelihood that other, similar cracking may have gone undetected. The conclusion is based primarily on the extremely high inherent toughness and ductility of the stainless steel piping material; the tendency of cracks in such piping to grow through-wall and leak before affecting its structural load carrying capacity (which indeed was the case in the defects observed at Monticello), and; the fact that as cracks lengthen and are less likely to "leak-before-break," they become more amenable to detection by other NDE techniques such as UT and RT.

Very truly yours,

Garrison Kost

for P. C. Riccardella, P.E.
Senior Director

PCR:lak

Attachments

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ATTACHMENT A

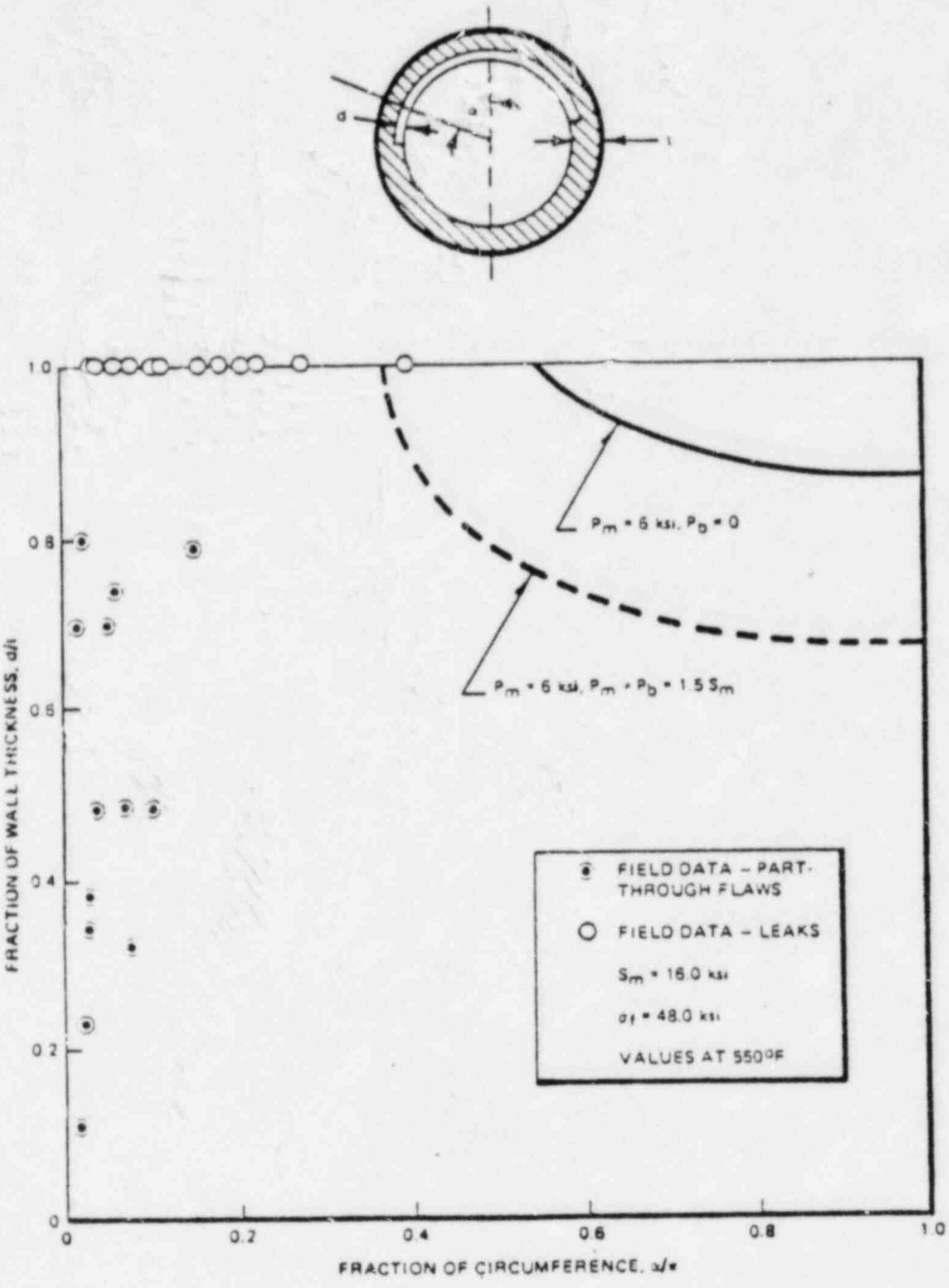

FIGURE 2-1
TYPICAL PIPE CRACK FAILURE LOCUS AND COMPARISON TO REPRESENTATIVE CRACKING EXPERIENCE IN OPERATING BWRs

ATTACHMENT B

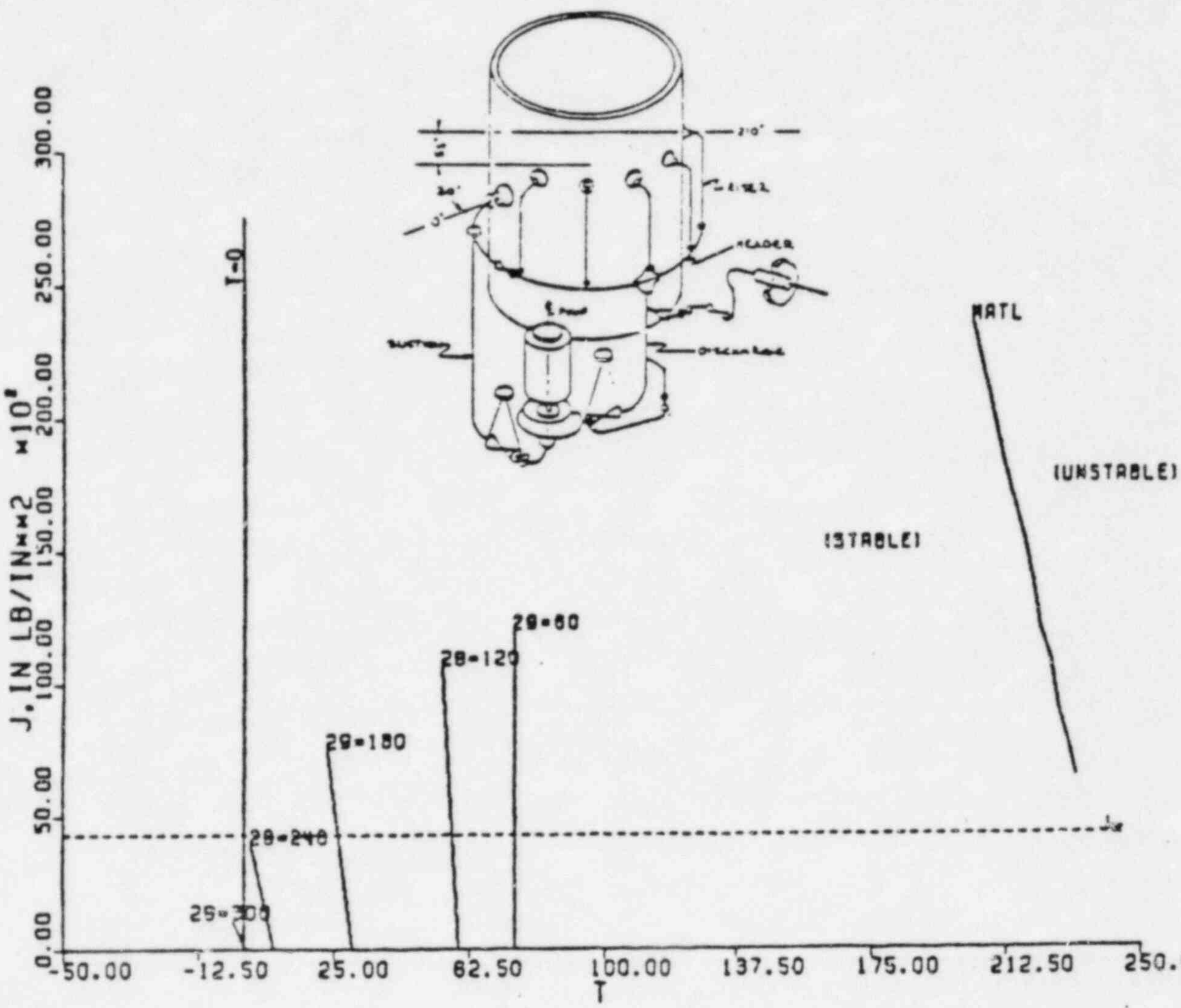

FIGURE 2-2

TEARING MODULUS STABILITY ANALYSIS FOR BWR RECIRCULATION SYSTEM (STAINLESS STEEL)

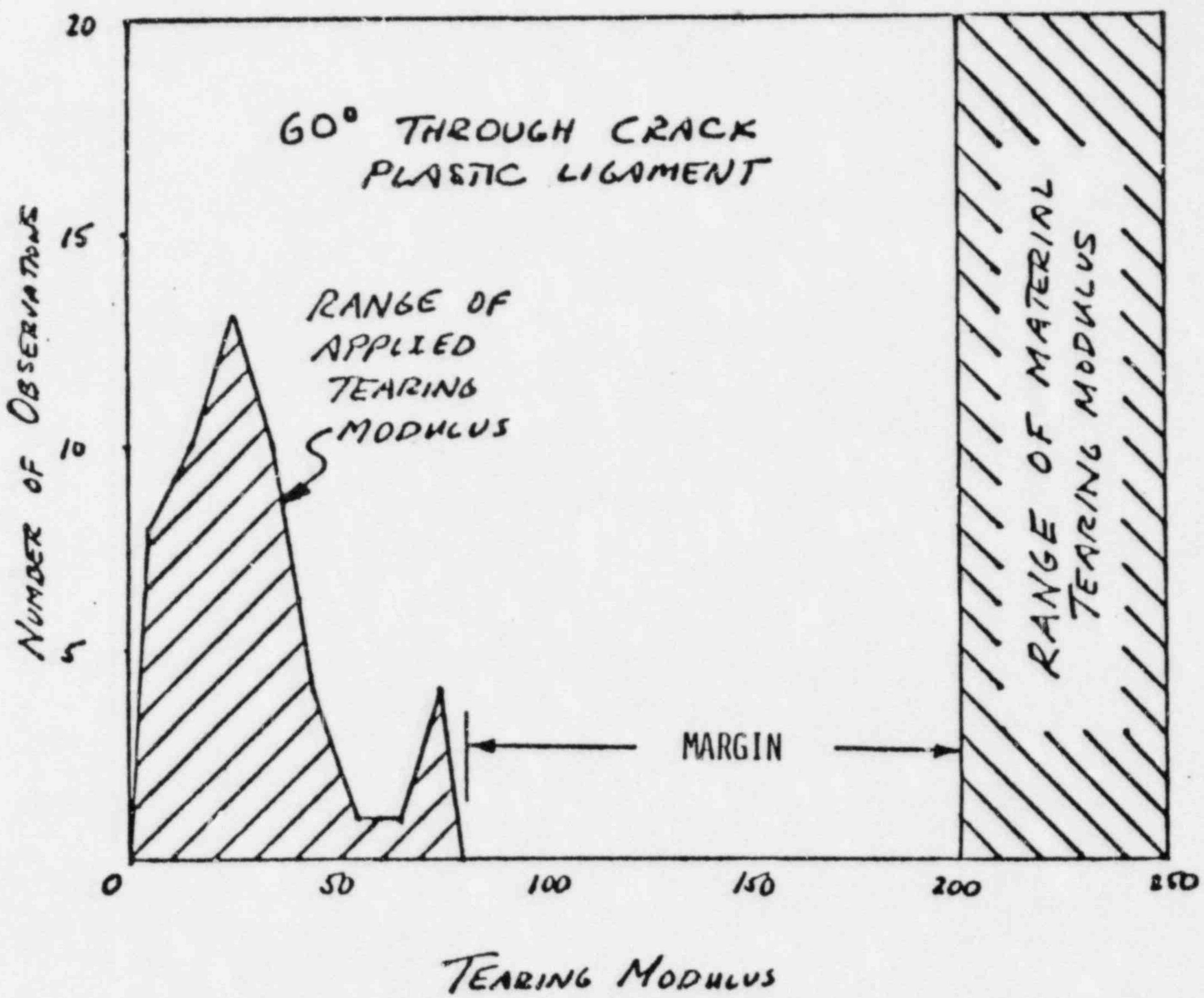

FIGURE 2-3
SUMMARY OF LEAK-BEFORE-BREAK ASSESSMENT
OF BWR RECIRCULATION SYSTEM

ATTACHMENT D

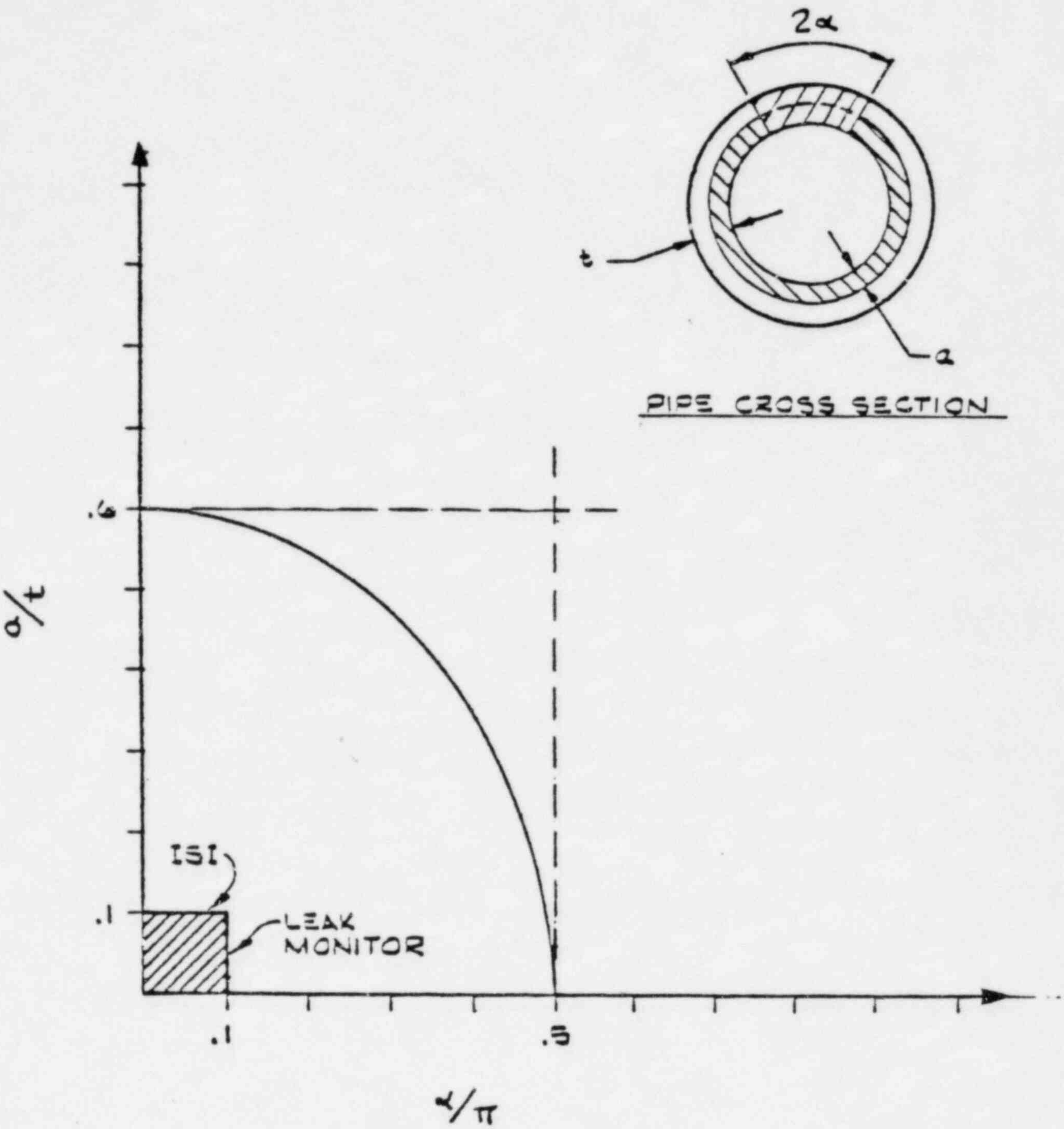

FIGURE 2-4

TYPICAL PIPE CRACK FAILURE LOCUS FOR COMBINED THROUGH-WALL PLUS 360° PART-THROUGH CRACK

TABLE 3-1

EFFECT OF PIPE SIZE ON THE RATIO OF THE
CRACK LENGTH FOR 5 GPM LEAK RATE AND THE CRITICAL CRACK LENGTH
(Assumed Stress $\sigma = S_m/2$)

Nominal Pipe Size	Crack Length for 5 GPM Leak (in.)	Critical Crack Length ℓ_c in.	ℓ/ℓ_c
4-in. Sch 80	4.50	6.54	0.688
10-in. Sch 80	4.86	15.95	0.305
24-in. Sch 80	4.97	35.79	0.139

ATTACHMENT F

LIST OF REFERENCES

1. "Design Report for Recirculation Line End Cap Repair, Monticello Nuclear Generating Plant," NUTECH Report NSP-81-103, Revision 1, November 1982.

2. "Design Report for Recirculation Line Safe End and Elbow Repairs, Monticello Nuclear Generating Plant," NUTECH Report NSP-81-105, Revision 0, November 1982.

3. "Investigation and Evaluation of Stress Corrosion Cracking in Piping of Light Water Reactor Plants," U. S. Nuclear Regulatory Commission, May 1979 (NUREG-0531).

4. "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping," U. S. Nuclear Regulatory Commission, July 1977 (NUREG-0313).

5. H. Tada, P. Paris, and R. Gamble, "Stability Analysis of Circumferential Cracks in Reactor Piping Systems," U. S. Nuclear Regulatory Commission, February 1979 (NUREG/CR0838).

6. H. H. Klepfer, et. al., "Cause of Cracking in Austenitic Stainless Steel Piping," General Electric Company, 1975 (NEDO-2100).

7. EPRI-NP-2472-SY, "The Growth and Stability of Stress Corrosion Cracks in Large-Diameter BWR Piping," General Electric Company, July 1982.

8. EPRI-NP-2261, "Application of Tearing Modulus Stability Concepts to Nuclear Piping," K. H. Cotter, et. al., November 1981.

9. Presentation by EPRI and BWR Owners Group to U.S. Nuclear Regulatory Commission, "Status of BWR IGSCC Development Program," October 15, 1982.

Attachment (6)
Director I&E, NRC
November 22, 1982

Monticello Nuclear Generating Plant

Determination of Reactor Coolant Leakage

The Monticello Nuclear Generating Plant is provided with redundant and diverse methods of detecting reactor coolant system pressure boundary leakage. These methods include:

1. Equipment and floor drain sump pump timers. An alarm is sounded when sump filling time is less than a preset time.

2. Equipment and floor drain sump level transmitters. Sump level is displayed and recorded on the control board. The plant process computer computes sump level rate of change and a computer alarm is generated when the preset setpoint is exceeded. These computer points provide rapid response to changes in leak rates.

3. Equipment and floor drain sump flow totalizers and flow recorders

4. Drywell pressure (13 - 17 psia narrow range)

5. Drywell temperature (seven points on multipoint recorder)

6. Drywell particulate monitoring and sampling system. A moving particulate filter and a beta scintillation detector provide an extremely sensitive and rapid means of detecting reactor coolant leakage. Leakage at very small rates can be detected. This is generally the earliest indicator of leakage.

Operating experience indicates the sump level monitoring system is capable of measuring leakage in the range of 0.1 gallons/minute. This system is also responsive to changes in leakage rate of about 0.1 gallons/minute or better.

The containment particulate radioactivity monitoring system is extremely sensitive. The system responds to leakage before such leakage can be physically identified. This system cannot easily quantify drywell leakage, but it provides a very early indication of changes in leakage. Response time is dependent on the leakage rate. Large leakage increases will cause the system to respond within minutes.