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ASME Code Case N-481
Evaluation of Arkansas Nuclear One Unit 1 Reactor Coolant Pumps

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Table of Contents

Section Page

1.0 INTRODUCTION 1-1
  1.1 Background 1-1
  1.2 Description of Pump Casings 1-1
  1.3 Objective and Organization 1-2

2.0 PREVIOUS INSPECTIONS 2-1
  2.1 1986 Inspection 2-1
  2.2 1988 Inspection 2-2
  2.3 1992 Inspection 2-4
  2.4 Disposition of Flaws 2-4

3.0 BACKGROUND ON ASME CODE CASE N-481 3-1

4.0 ASME CODE CASE N-481 EVALUATION 4-1
  4.1 Evaluation of Material Properties, Including Fracture Toughness ... 4-1
  4.2 Stress Analysis Results 4-5
  4.3 Review of Operating History of the Pumps 4-7
  4.4 Selection of Locations for Postulating Flaws 4-7
  4.5 Postulation of Flaws 4-9
  4.6 Determination of Stability of Postulated Flaws 4-10
  4.7 Effect of Thermal Embrittlement and Other Degradation Mechanisms that May Degrade Properties of the Pump Casing 4-14

5.0 SUMMARY AND CONCLUSIONS 5-1

6.0 REFERENCES 6-1

APPENDIX A ASME Code Case N-481

APPENDIX B **pc-CRACK** Output - Stress Intensity Factors

APPENDIX C **pc-CRACK** Output - Fatigue Crack Growth

List of Figures

Figure | Page

1-1 Typical Casing - Cross Section 1-3

1-2 Typical Casing - Horizontal Section 1-3

1-3 Schematic Drawing Showing Pump Casing Welds for ANO-1 Reactor Coolant Pump 1-4

2-1 Schematic Drawing of Weld Flaws in Arkansas Nuclear One "A" and "B" Reactor Coolant Pumps, Unit 1 2-5

2-2 Byron-Jackson Reactor Coolant Pump Weld and Base Material Thickness with Lower Scroll Weld Flaw Indication - ANO-1 "B" RCP - 1988 UT Exam 2-6

2-3 ANO-1 1988 UT Exam of "B" RCP Lower Scroll Weld Indication - Section View 2-7

2-4 ANO-1 1988 UT Exam of "B" RCP Lower Scroll Weld Indication - Plan View 2-8

2-5 Byron-Jackson Reactor Coolant Pump Weld and Base Material Thickness with Upper Scroll Weld Flaw Indication - ANO-1 "B" RCP - 1988 UT Exam 2-9

2-6 ANO-1 1988 UT Exam of "B" RCP Upper Scroll Weld Indication - Section View 2-10

2-7 ANO-1 1988 UT Exam of "B" RCP Upper Scroll Weld Indication - Plan View 2-11

4-1 Effect of Thermal Aging on Room Temperature Impact Energy of CF3, CF8 and CF8M Cast Stainless Steel 4-22

4-2 Solution Heat Treated Wrought Type 316 Stainless Steel 4-23

4-3 Solution Heat Treated Grade CF8 Stainless Steel Casting 4-23

4-4 Effect of Temperature on Charpy Transition Curves of CF3, CF8 and CF8M Steels Aged for 30,000 hours 4-24

List of Figures
(concluded)

Figure Page

4-5 Correlation Between Fracture Toughness (J_{Ic}) and Charpy Impact Energy for Unaged and Aged Cast Stainless Steels Tested at Room Temperature and 290-320°C 4-25

4-6 Axisymmetric Pump Case Model 4-26

4-7 Three-dimensional Element Map - Top 4-27

4-8 Three-dimensional Element Map - Bottom 4-28

4-9 Typical Section Cuts for Primary Plus Secondary Load Conditions 4-29

4-10 Pump Case Model - Top View 4-30

List of Tables

Table — Page

4-1 Properties of ASTM A351 Grade CF8M 4-15

4-2 Determination of Lower Bound Fracture Toughness of ANO-1 Pump Casings Considering Thermal Embrittlement 4-16

4-3 Stresses at Locations No. 1 and 2 4-17

4-4 Stresses at Location No. 3 4-17

4-5 Stresses at Location No. 4 4-18

4-6 Stresses at Location No. 5 4-19

4-7 Postulated Flaw Sizes and Locations 4-20

4-8 Comparison of Calculated and Allowable Stress Intensity Factors for Level A and B Conditions 4-20

4-9 Comparison of Calculated and Allowable Stress Intensity Factors for Level C and D Conditions 4-21

4-10 Results of Fatigue Crack Growth Analyses 4-21

1.0 INTRODUCTION

1.1 Background

During the 1992 Arkansas Nuclear One, Unit 1 (ANO-1) refueling outage (1R10), the "D" reactor coolant pump (RCP) was disassembled. The purpose of the disassembly was to inspect the RCP for damage due to a potential motor thrust bearing failure. One of the requirements in the safety evaluation performed by the Office of Nuclear Reactor Regulation (NRR) in April 1989 [1], following the 1988 refueling outage (1R8), is that single-wall radiography (RT) should be performed in the event that any RCPs are completely disassembled for maintenance, repair or examinations. The disassembly of the "D" pump was not a planned outage activity and, therefore, adequate plans had not been made to perform RT on this pump casing. Because of this, Entergy Operations submitted a letter to the NRC [2] to revise the commitment to perform single-wall RT of the pump casing, and instead conduct RCP casing structural integrity examinations and evaluations using the methodology contained in ASME Code Case N-481 [3]. Subsequently, the NRC requested the results of the VT-1 and VT-3 examinations of the "D" RCP. Prior to allowing ANO-1 to return to power operations, the NRC also requested a comparative analysis between the Code Case postulated flaw evaluation and the previous "A" and "B" RCP fracture mechanics and stress evaluations. The results of the VT-1 and VT-3 examinations and scoping evaluation of Code Case N-481 for the ANO-1 pump casing were provided to the NRC in Reference 4.

1.2 Description of Pump Casings

The four reactor coolant pumps at ANO-1 were manufactured by Byron-Jackson. All four pumps were fabricated from ASTM A351-69, Grade CF8M material. Figure 1-1 identifies the various portions of the pump casing. At the bottom of the pump casing is the suction nozzle whose axis of symmetry is an extension of the axis of rotation of the pump shaft. The lower flange occupies the upper end of the suction nozzle, and is marked by a series of internal steps as shown in Figure 1-1. The upper end of the lower flange blends into the diffuser. The diffuser consists of upper and lower rings separated by vanes. The upper diffuser ring blends into the upper flange. The scroll section is a relatively thin-walled section connecting the upper and lower flanges outside of the diffuser. The scroll forms a spiral around the diffuser as shown in Figure 1-2, starting at the crotch area and terminating at the discharge nozzle.

As shown in Figure 1-3, there are two horizontal welds on the scroll portion of the pump casing (one on the upper end and the other on the lower end). These two welds are joined together by a circumferential or vertical weld near the crotch region.

1.3 Objective and Organization

The objective of this document is to address the safety and serviceability requirements of ASME Code Case N-481 to assure that postulated flaws in the pump casings at critical locations will be stable, considering the operating stresses and material properties of the pump casings. Section 2 of this report discusses previous inspections that have been performed on the pump casings, and the inspection results. Section 3 discusses the background of Code Case N-481, the items covered by the ASME Code Case, and the safety factors used with this Code Case. Section 4 provides the specific evaluation performed using this Code Case. Section 5 presents the conclusions of the evaluation, and Section 6 provides the references used in the evaluation.

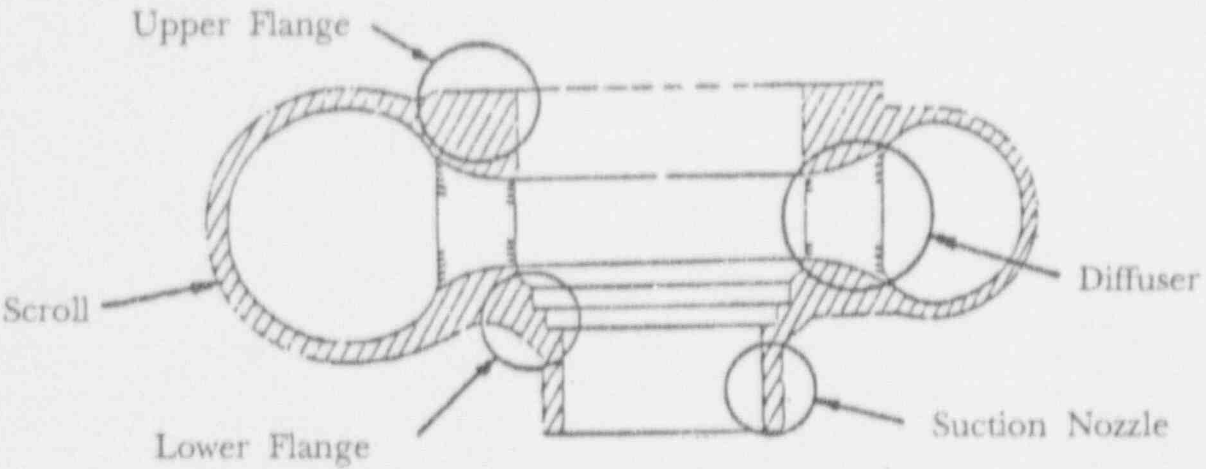


Figure 1-1. Typical Case - Cross Section

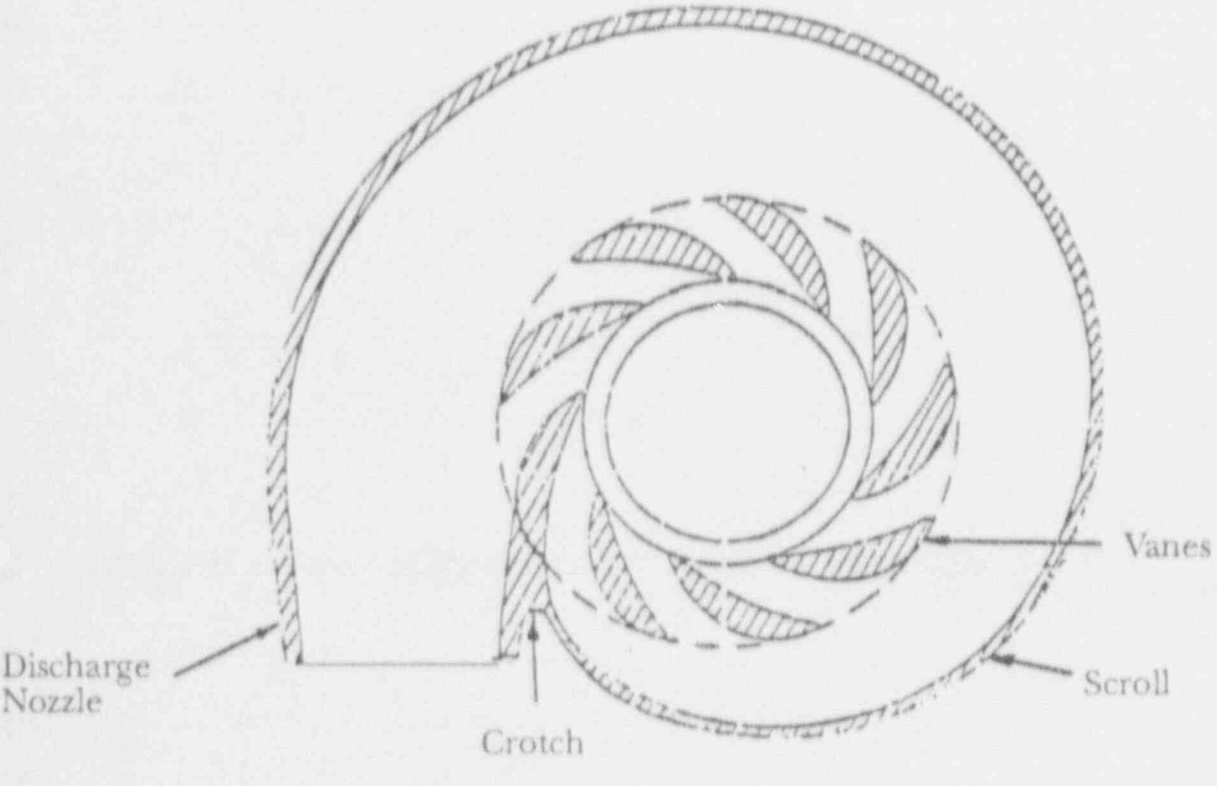


Figure 1-2. Typical Case - Horizontal Section

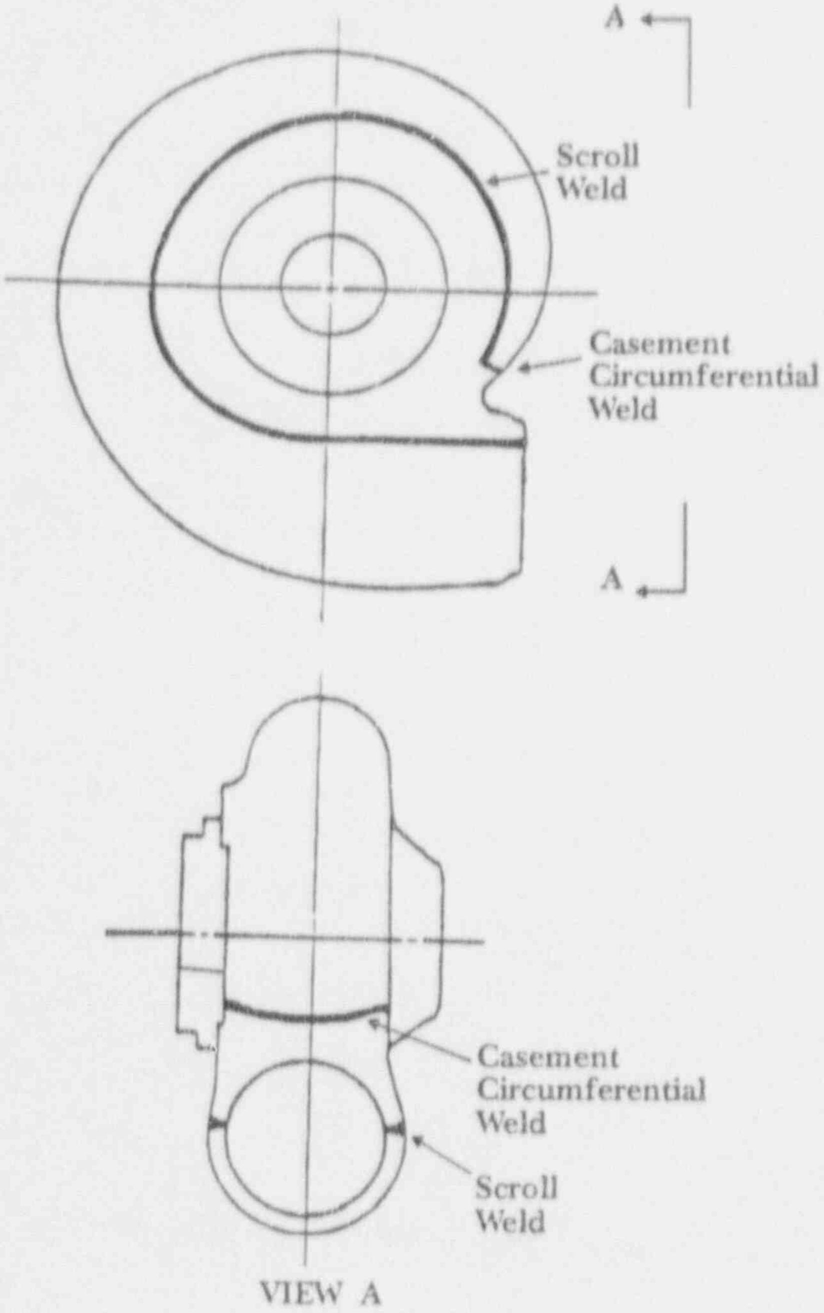


Figure 1-3. Schematic Drawing Showing Pump Casing Welds for ANO-1 Reactor Coolant Pump

2.0 PREVIOUS INSPECTIONS

2.1 1986 Inspection

During the 1986 refueling outage, a volumetric examination was performed on the "A" RCP welds, as required by the first 10-year ISI program (based on the requirements of the 1974 Edition through Summer 1975 Addenda of Section XI of the ASME Code), by performing RT examination of the pump casing welds. The RT examination indicated the presence of a flaw which exceeded the ASME Section XI allowable indication standards of IWB-3500 (1980 Edition through Winter 1981 Addenda). The indication is best described as a series of slag inclusions having an effective length (per ASME Section XI criteria) of 5.66 inches. The indication is located in the vertical weld which ties together the upper and lower scroll welds of the pump casing (see Figure 2-1).

Radiographic parallax techniques indicated that the top of the flaw is 1.5 inches below the outside surface of the weld. The weld is approximately 2.6 inches thick in this area. Application of special ultrasonic testing (UT) techniques indicated that the flaw indication does not extend to the internal diameter of the pump casing. Thus, the maximum through-wall dimension of the flaw indication is less than 1.1 inches.

To determine if any flaw existed at this location prior to service, the original construction radiographs were reviewed. The review found five small inclusions that are part of the identified flaw indication of 5.66 inches in length. These inclusions on the original radiograph were determined to be acceptable per the Code during the preservice examinations. Because of the quality of the preservice radiograph in the area of the indication, equipment was brought on-site to perform computer enhancement of the area of the flaw. This process allowed characterization of the flaw on the original film more clearly, and determined conclusively that the current flaw indication and the original flaw were identical.

The original construction radiographs for the remaining three pumps were then reviewed, searching for any preservice flaw indications or weak areas in film density. Identified areas were then computer enhanced in an attempt to identify any unacceptable flaws that were previously unidentified. Portions of approximately 20% of all preservice radiographs were computer enhanced. From this review, the "C" and "D" pumps were determined to have no unacceptable preservice flaw indications. However, the computer enhancement on the "B" pump did indicate an unacceptable flaw indication in the same general weld area as the "A" pump.

The flaw indication on the "B" pump through the computer enhancement process was shown as 1.5 inches in length. The original construction radiograph of this area shows a flaw of 0.625 inches in length which was acceptable per Code requirements at that time. The wall thickness in the area of the flaw indication is 3.1 inches. UT inspection was used in an attempt to better characterize the flaw indication. Due to the material of the pump casing (coarse grained, statically cast stainless steel) and the small size of the indication, UT was not able to specifically characterize the flaw. However, from these examinations, it was determined that the flaw size was no larger than 1.5 inches long by 1.5 inches deep.

2.2 1988 Inspection

Since the 1986 inspection, AP&L, with the assistance of Babcock and Wilcox (B&W), developed a UT procedure for the examination of the pump casing welds from the outside surface. The UT examination of the flaw indication in the "A" pump casing and the entire "B" pump casing welds were performed during the 1988 refueling outage, utilizing the B&W automated ultrasonic data acquisition and imaging system (ACCUSONEX).

A robot was used to perform the ACCUSONEX automated scanning and to provide coordinated data for the transducer location. Using threshold values that just exceeded the average noise level from the pump casing material for both straight beam and angle beam measurements, minimum detectable indications of approximately 1/8 inches wide (through-wall dimension) and 3/4 inches long through the maximum wall thickness can be detected. The fact that the previous slag indications could not be detected with UT most likely indicates that they are very small, occupy very little volume, and are below the limit of detection for present-day UT technology.

Also, during the 1988 refueling outage, a complete volumetric external surface examination of the "B" RCP casing welds, using double-wall RT and advanced ultrasonic techniques, was performed. The areas of the casing welds examined by RT showed no rejectable indications. Sections of the upper and lower scroll welds near the discharge end of the pump, which could not be successfully radiographed to meet ASME Code film density requirements, along with the remainder of the vertical weld, were examined by UT. In the lower scroll weld, several indications were detected (using ACCUSONEX) in an area bounded by a rectangle with a length of 4.1 inches and a through-wall dimension of 1.8 inches, at a depth of 0.9 inches below the outer weld surface in a region where the weld is 4.75 inches thick. These indications were considered to be slag inclusions located approximately 0.70 inches from the weld centerline. The upper scroll weld could not be examined with ACCUSONEX due to insufficient access for the robot; however, a manual scan was performed which identified three indications. The composite size was conservatively determined to be no larger than a 4.5 inch long by 1.25 inch through-wall dimension at a depth of 1.35 inches from the outside surface. The weld is also 4.75 inches thick in this region. These indications are located approximately on the weld centerline to 0.6 inches from the centerline. The composite indication is also considered to consist of slag inclusions resulting from the original construction welding process and not a service induced condition. Table IWB-3518-2 maximum allowable dimensions for an indication are 1.8 inches for the length and 0.30 inches for one-half the through-wall dimension within the weld. Figures 2-2 through 2-7 show the locations of the lower and upper scroll weld flaw indications found by the UT examinations. The "B" RCP factory radiographs for these areas and the low density radiographs of these areas taken during this outage were computer enhanced. The analysis of these enhanced radiographs showed no rejectable indications in the welds. It was thus concluded that these indications are small preservice slag inclusions.

2.3 1992 Inspection

During the 1992 refueling outage, the "D" RCP casing welds were inspected by visual means. A VT-1 examination was performed on the upper and lower scroll (horizontal) welds and torus (vertical) weld. No indications were identified. A VT-3 examination of the interior surface of the casing also identified no indications. Scratches were found during the VT-3 examination on the wear ring; however, this is not a concern since the wear ring does not function as a pressure boundary. A successful hydrostatic pressure test (and VT-2 examination) was performed on all four RCPs prior to returning the unit to power operation.

Enhanced UT examinations of the areas of interest on the "A" and "B" RCPs were also performed. No new indications were identified and there was no growth in the previously identified 1986 and 1988 flaws. In fact, due to better technology, the previously identified flaws in the "B" RCP have been sized smaller than were previously identified.

2.4 Disposition of Flaws

Conservative fracture mechanics and stress analyses were performed in 1986 and 1988 [5-9] to show that ASME Code Section XI safety margins were satisfied with the observed flaws. The evaluations were based on linear elastic fracture mechanics principles consistent with Appendix A of Section XI of the ASME Code.

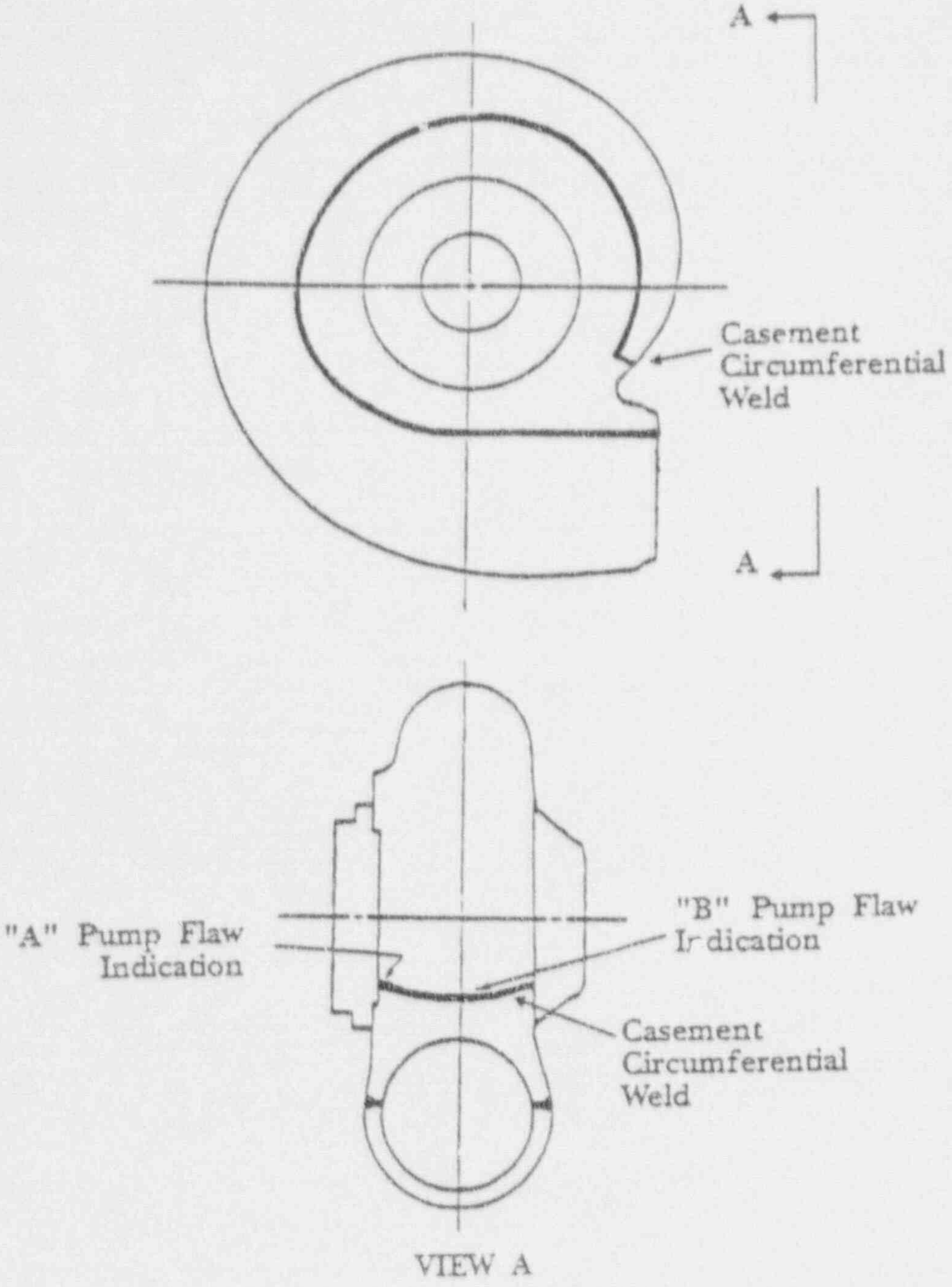


Figure 2-1. Schematic Drawing of Weld Flaws in Arkansas Nuclear One "A" and "B" Reactor Coolant Pumps, Unit 1

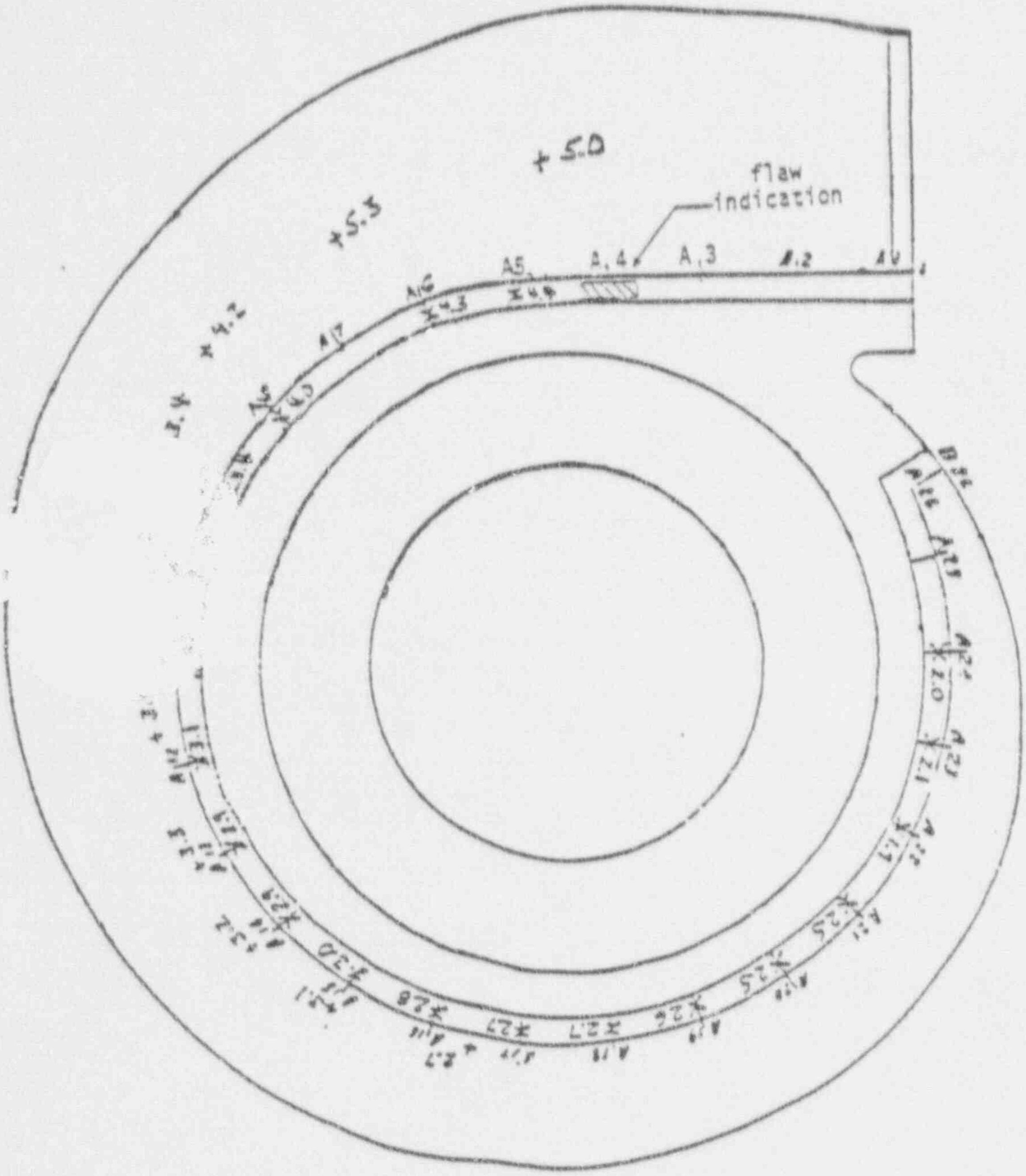
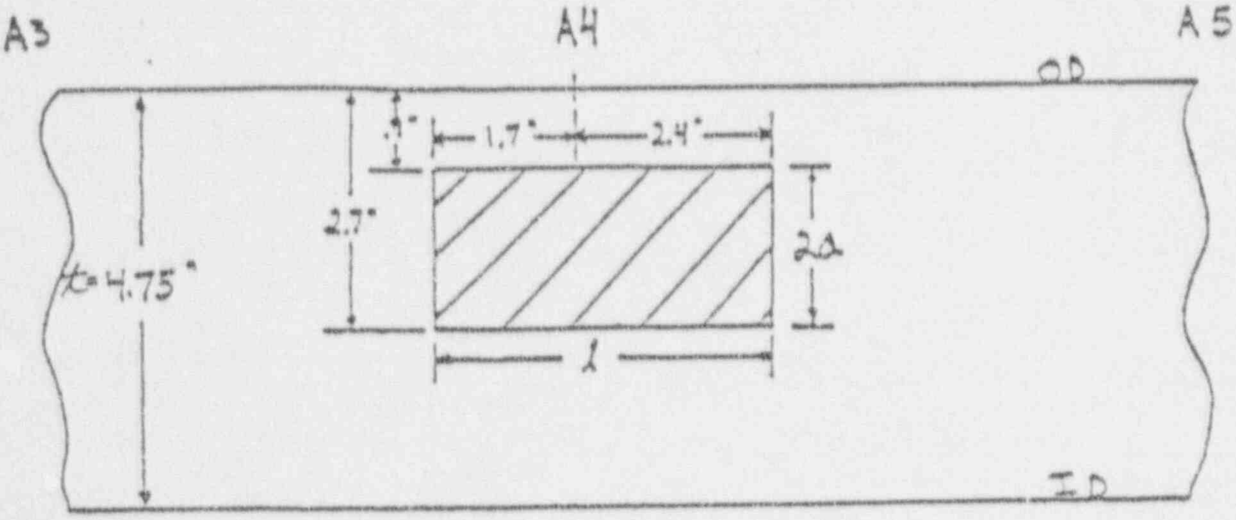


Figure 2-2. Byron-Jackson Reactor Coolant Pump Weld and Base Material Thickness with Lower Scroll Weld Flaw Indication - ANO-1 "B" RCP - 1988 UT Exam



l = 4.1"
2a= 1.8" (a= 0.90")
s = 0.90"

Figure 2-3. ANO-1 1988 UT Exam of "B" RCP Lower Scroll Weld Indication - Section View

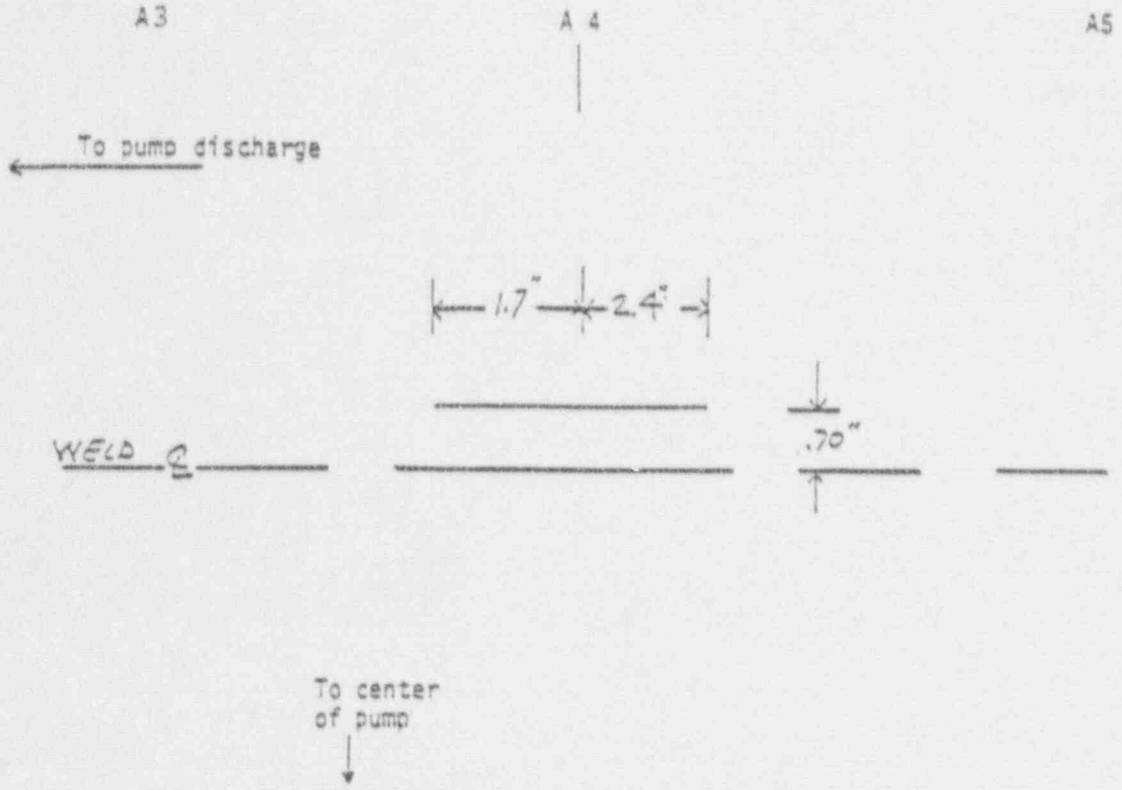


Figure 2-4. ANO-1 1988 UT Exam of "B" RCP Lower Scroll Weld Indication - Plan View

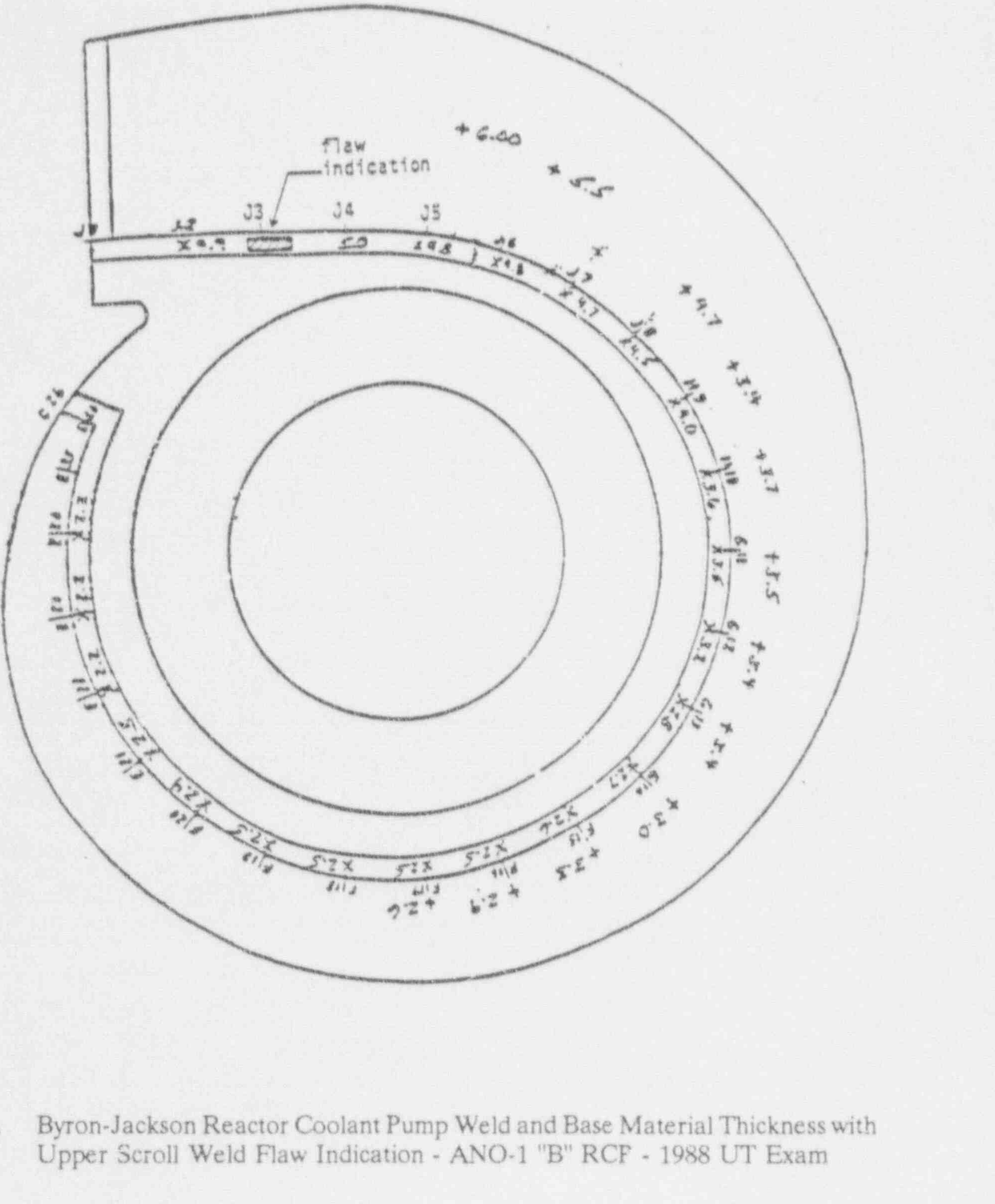
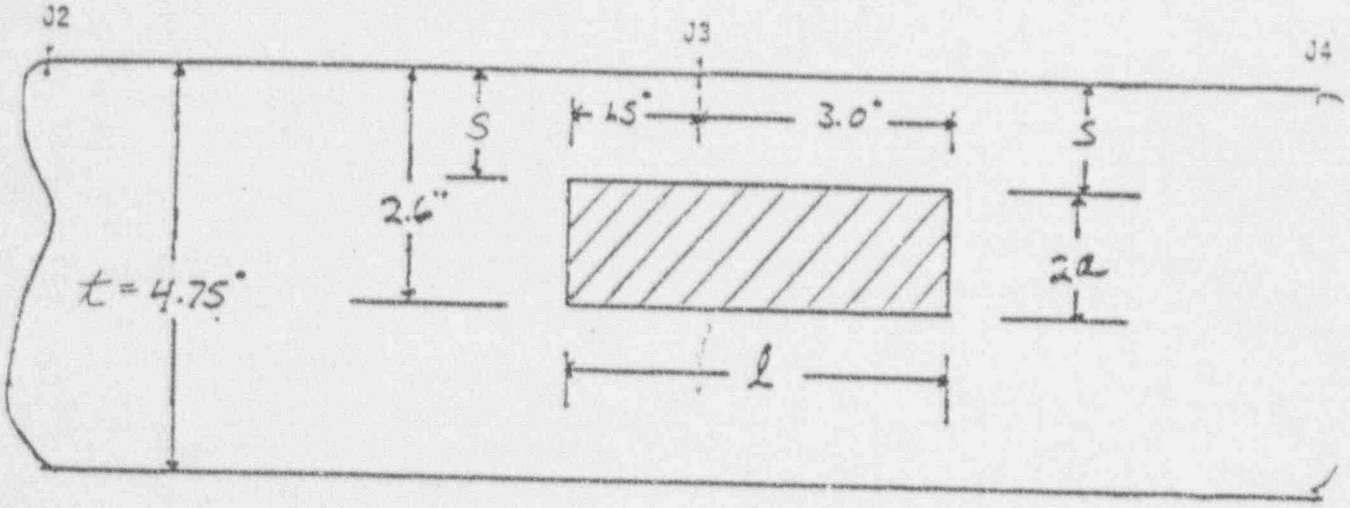


Figure 2-5. Byron-Jackson Reactor Coolant Pump Weld and Base Material Thickness with Upper Scroll Weld Flaw Indication - ANO-1 "B" RCF - 1988 UT Exam



l = 4.5"
2a = 1.25" (a = 0.625")
s = 1.35"

Figure 2-6. ANO-1 1988 UT Exam of "B" RCP Upper Scroll Weld Indication - Section View

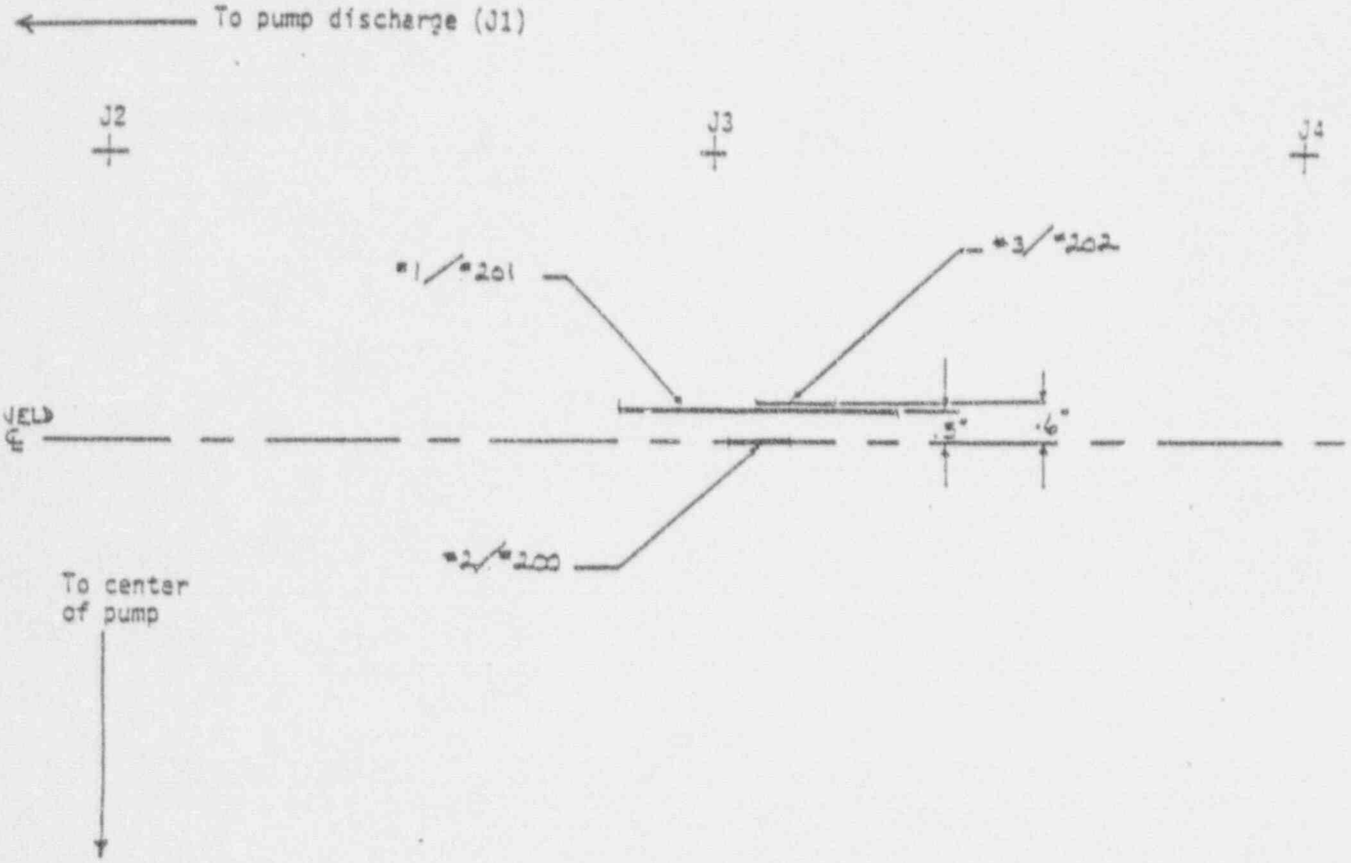


Figure 2-7. ANO-1 1988 UT Exam of "B" RCP Upper Scroll Weld Indication - Plan View

3.0 BACKGROUND ON ASME CODE CASE N-481

A review of data collected in EPRI's "Cast Austenitic Stainless Steel Sourcebook" [10] shows that slag inclusions and other fabrication defects, such as those identified during the inspections of the ANO-1 "A" and "B" pump casings, are not uncommon. However, whenever such flaws are identified by surface or volumetric inspection during fabrication, they are usually excavated and weld repaired. Examinations and repairs during the fabrication process are accomplished with relative ease, since they are performed in a shop environment.

Ultrasonic examination and radiography of pump casings, once in service, is very difficult and time consuming. As noted by the NRR in the 1989 Safety Evaluation [1], the disassembly of a reactor coolant pump for the sole purpose of performing a volumetric examination of the pump casing welds is not practical. There is considerable personnel exposure to radiation and significant outage time associated with removal of the pump shaft. The industry operating experience with cast stainless steel pressure components has been good, and furthermore, no detrimental service induced degradation of pump casing welds, detected with various inspection techniques, has been reported.

Because of difficulties associated with the examination of pump casing welds during service, ASME Code Case N-481, shown in Appendix A, addresses examinations and evaluations that may be performed in lieu of the volumetric examinations specified in Table IWB-2500-1 of Section XI, Division 1 of the ASME Code for Examination Category B-L-1. Examination Category B-L-1 relates to pressure retaining welds in pump casings; hence, the application of this code case is limited to the scroll welds, the vertical welds, and the adjacent base metal. Therefore, the vanes and their attachment welds, which are not pressure retaining, are excluded in this evaluation.

In addition to performing visual examinations (VT-1, VT-2 and VT-3), the code case outlines a seven-step evaluation procedure to demonstrate the safety and serviceability of the pump casings. Key to this procedure is the demonstration that an assumed quarter-thickness flaw, with length six times its depth, will remain stable, considering the stresses and material properties of the pump casings.

The ASME Code Case N-481 evaluation procedure is very similar to that in Appendix G of Sections III and XI of the ASME Code, which provides fracture toughness criteria for protection against failure of reactor pressure vessels, in that a similar postulated flaw is assumed for the analysis in both cases. The Code Case does not provide any guidance on safety factors to be used in the evaluation. Therefore, for the evaluation presented herein, safety factors consistent with Appendix G for similar evaluations of pressure vessels have been used.

Appendix G was first introduced into Section III of the ASME Code in the 1972 Edition, and has remained virtually unchanged through the current 1989 Edition. It was introduced into Section XI of the ASME Code in the 1986 edition with addenda through 1987. Therefore, even though ANO-1 is committed to the 1980 Edition with Winter 1981 Addenda of ASME Code Section XI, the use of the 1989 Edition of the ASME Code is acceptable for this evaluation.

Although Code Case N-481 does not specify that a fatigue crack growth evaluation must be done, and such analyses are not part of an Appendix G evaluation of the stability of a quarter thickness deep flaw, such calculations are done in this study for information purposes.

4.0 ASME CODE CASE N-481 EVALUATION

In this section, the seven items listed in the Code Case, to demonstrate the safety and serviceability of pump casings, are addressed in relation to ANO-1.

4.1 Evaluation of Material Properties, Including Fracture Toughness

The material of the pump casing is ASTM A351 Grade CF8M, an austenitic stainless steel casting specification. The mechanical and physical properties of this material, obtained from the ASME Code [11] used for the Stress Report, are shown in Table 4-1.

A review of the fabrication records indicates that the scroll and the vertical welds were fabricated using either the shielded metal arc welding (SMAW) or submerged arc welding (SAW) process. The records also show that several weld repairs were made during fabrication. After welding, the casings were solution heat treated at 1900-2050°F for ten hours at temperature, followed by quenching in agitated water to below 700°F within five minutes.

The most important material property pertinent to this evaluation is the fracture toughness. The fracture toughness of the base material and the weld metal are addressed separately, since they are affected by different mechanisms. Fatigue crack growth analyses are done for information only, since they are not specifically required to evaluate the large flaws postulated by the code case.

4.1.1 Fracture Toughness of ASTM A351 Grade CF8M

The fracture toughness of cast stainless steels has been the subject of significant research in the U.S. and elsewhere in recent years. Three grades of cast stainless steel frequently used in nuclear power plant applications (CF3, CF8 and CF8M) have all been studied extensively to determine the kinetics and material parameters that control the toughness of these materials. The major conclusion drawn from most of the work done on these castings is that initially cast, austenitic stainless steels have toughness that is relatively high; however, during service at 550°F they become embrittled with time, which results in a loss of toughness as shown in Figure 4-1.

The microstructure of stainless steel castings is significantly different from that of wrought products. Wrought products consist of a single phase, austenite (γ), as shown in Figure 4-2. Castings on the other hand exhibit a two-phase, or "duplex", microstructure of austenite (γ) and delta ferrite (δ) as shown in Figure 4-3. The ferrite phase in the duplex structure in these castings increases the tensile strength, improves the weldability and soundness of the casting, and increases the resistance to stress corrosion cracking. However, various carbide phases, intermetallic compounds such as sigma and chi phases, and a chromium rich bcc phase (α') can precipitate in the ferrite phase during service at elevated temperatures and lead to substantial degradation in toughness properties. Research performed at the Argonne National Laboratory (ANL) and elsewhere [12-23] has shown that the thermal embrittlement of cast stainless steel components will occur during the reactor lifetime of 40 years.

As a result of such thermal aging embrittlement, the Charpy transition curve shifts to higher temperatures as shown in Figure 4-4. For cast stainless steel of all grades, the extent of thermal embrittlement increases with an increase in ferrite content. The low-carbon CF3 grades are the most resistant and the molybdenum-bearing high carbon CF8M grades are the least resistant to thermal embrittlement.

The embrittlement of cast stainless steels results in brittle fracture associated with either the cleavage of the ferrite or separation of the ferrite/austenite phase boundaries. The degree of embrittlement is controlled by the amount of delta ferrite and the extent of ferrite/austenite phase boundaries. Brittle failure occurs when either the ferrite phase is continuous, such as the case with cast material with a high ferrite content, or the ferrite/austenite phase boundaries provide an easy path for crack propagation. Hence, the amount, size and distribution of the ferrite phase in the duplex microstructure and the presence of phase boundary carbides are important parameters in controlling the extent of thermal embrittlement.

The kinetics of thermal embrittlement have been explained in detail by Chopra, et al, [12-16]. The kinetics are controlled by several mechanisms that depend on material parameters and aging temperatures. During embrittlement, additional phases are precipitated in the ferrite matrix. These include the formation of a chromium (Cr) - rich α' phase by spinodal decomposition; nucleation and growth of α'; precipitation of nickel (Ni) - and Silicon (Si) - rich G phase, $M_{23}C_6$ carbide and γ_2 (austenite); and additional precipitation and/or growth of existing carbides at the ferrite/austenite phase boundaries.

The chemical composition of the casting and the ferrite morphology are important parameters to be considered during embrittlement. A procedure and correlations for predicting the fracture toughness of aged, cast stainless steels from known material information is provided by Chopra [24]. The only information required in these correlations is the chemical composition from the certified material test report (CMTR). A correlation for the extent of thermal embrittlement at "saturation" (the minimum impact energy that would be achieved for the material after long term aging) is given in terms of the chemical composition. The extent of thermal embrittlement as a function of time and temperature of reactor service is then estimated from the extent of embrittlement at saturation and from the correlations describing the kinetics of embrittlement, which are also given in terms of the chemical composition. In this evaluation, the fracture toughness associated with the minimum impact energy will be conservatively used.

Using the methodology of Reference 24, the chromium equivalent (Cr_{eq}) and nickel equivalent (Ni_{eq}) are determined from the chemical composition, based on Hull's equivalent factors [25]:

$$Cr_{eq} = (Cr) + 1.21\ (Mo) + 0.48\ (Si) - 4.99$$

$$Ni_{eq} = (Ni) + 0.11\ (Mn) - 0.0086\ (Mn)^2 + 18.4\ (N) + 24.5\ (C) + 2.77$$

where the chemical composition is in wt.%.

The ferrite content (δ_c) is then determined by the relationship:

$$\delta_c = 100.3\ (Cr_{eq}/Ni_{eq})^2 - 170.72\ (Cr_{eq}/Ni_{eq}) + 74.22$$

For CF8M cast stainless steel, the saturation (minimum) impact energy considering thermal embrittlement is given by:

$$\log_{10} Cv_{sat} = 7.28 - 0.011\ (\delta_c) - 0.185\ (Cr) - 0.369\ (Mo) - 0.451\ (Si) - 0.007\ (Ni) - 4.71\ (C + 0.4N)$$

Knowing the value of Cv_{sat}, a lower bound value of J_{Ic} can be determined using the correlation shown in Figure 4-5 [14]. The lower bound value of K_{Ic} used for linear elastic fracture mechanics analysis is determined from J_{Ic} using the relationship:

$$K_{Ic} = \sqrt{\frac{E\ J_{Ic}}{(1-\nu^2)}}$$

where E is the elastic modulus, and ν is Poisson's ratio.

The above methodology has been used to estimate the lower bound toughness value of the heats of the ANO-1 pump casings [26]. A summary of the results is presented in Table 4-2 and shows that for these CF8M pump casings, the range of J_{Ic} (including long-term aging effects (embrittlement)) is 817-1117 in-lb/in^2. This minimum value of 817 in-lb/in^2 translates into a K_{Ic} value of 152 $ksi\sqrt{in}$ at the operating temperature of 550° F.

4.1.2 Fracture Toughness of Pump Casing Weldments

As indicated earlier, the fabrication records indicate that the pump casing weldments were made using flux welding, either by submerged arc welding (SAW) or shielded metal arc welding (SMAW). Extensive work done on the toughness of austenitic stainless steel weldments in References 27 and 28 has shown that the toughness for SAW and SMAW weldments in the unaged condition are lower than for the base material. On the other hand, tungsten inert gas (TIG or GTAW) weldments have toughness more typical of the base metal. The lower toughness of SAW and SMAW weldments is due to nonmetallic inclusions in the weld metal that result from the flux welding process. Limited data from Reference 27 suggests that J_{Ic} values of 1168 and 973 in-lb/in² may be used for SMAW and SAW weldment fracture assessments, respectively, in the as-welded condition. Corresponding values for solution-annealed weldments are 968 and 1260 in-lb/in². Values of 990 and 650 in-lb/in² are suggested in Reference 29 for SMAW and SAW, respectively, based on the work done in Reference 28. Unlike the base cast materials, the fracture toughness of SMAW and SAW weld metals are virtually unaffected by long-term aging [30]. In the safety evaluation performed by NRR in 1989 [1], the lower bound value of 650 in-lb/in² for SAW weldments was recommended for use in any future fracture mechanics evaluations for the ANO-1 pumps. Hence, this lower bound value will be used in this evaluation.

In comparison with the fracture toughness of the ASTM A351 Grade CF8M material, it can be seen that the fracture toughness of the SAW weldment is controlling. The lower bound J_{Ic} value of 650 in-lb/in² translates into a K_{Ic} value of 135.5 $ksi\sqrt{in}$ at the operating temperature of 550° F.

4.2 Stress Analysis Results

A Stress Report [31] for the ANO Unit 1 RCPs was prepared in 1973 by the Byron-Jackson/Borg Warner Corporation to meet the requirements of the ASME Code Section III, 1968 [11]. Since the pumps are identical, this Stress Report covers all four pumps. In this

Stress Report, a significant portion of the pump casing was analyzed using a two-dimensional (2D) axisymmetric model. A small portion of the casing near the discharge nozzle was analyzed using a three-dimensional (3D) model. These models are shown in Figures 4-6 through 4-8. Stresses for various load combinations were reported at critical sections for the axisymmetric model, as shown in Figure 4-9.

A supplement to this Stress Report was provided by Babcock and Wilcox to address revised pipe loads [32]. In this analysis, a finite element model of the Byron-Jackson pump casing developed for Consumers Power Corporation's Midland plant in Reference 33 was used as shown in Figure 4-10. The ANO-1 RCPs were found to be sufficiently similar to those at Midland [34], thereby providing justification for the application of the Midland pump casing stress analysis to ANO Unit 1. This revised analysis showed that only very moderate centroidal and surface stresses are produced in the pump casing due to mechanical loadings. The only highly stressed areas for the Design Category loads are the vanes (especially the tips) and the suction and discharge nozzles. This observation suggests that the critical regions on the scroll welds are unaffected by this revised analysis and, therefore, stresses from the original Stress Report [31] are still valid for these locations.

In previous fracture mechanics analyses to disposition the flaws found in 1986 and 1988 [5-9], stress information from the Midland Stress Report was used. Conservative stresses at the flaw locations were used from this report. In the analyses presented herein, stress information contained in the original Byron-Jackson Stress Report, together with stresses at previous flaw locations provided in the Midland Stress Report, were used to perform the fracture mechanics analyses.

In addition to the applied stresses, weld residual stresses need to be addressed in this evaluation. In the evaluation of pressure vessels per ASME Code, Appendix G, residual stresses are not considered, because the vessel is postweld heat treated after welding to minimize the effect of residual stresses. Similarly, since the pump casings were solution heat treated subsequent to welding and weld repairs, residual stresses are expected to be minimal and are, therefore, not considered in this evaluation.

4.3 Review of Operating History of the Pumps

ANO-1 has been in commercial operation since December of 1974. The plant has undergone ninety-three (93) heatups and ninety-two (92) cooldowns. At this point in time, these numbers are slightly below the expected number of heatup/cooldown cycles considering the design number of heatup/cooldown cycles (240 for a 40-year plant life).

The four RCPs at ANO Unit 1 have experienced essentially the same operating history, since the cold legs are not isolable from the reactor vessel or the steam generators. The normal operating pressure and temperature for the RCPs are 2155 psig and 550°F, respectively. There have been short periods (on the order of 2 to 3 months) of only three pumps operation. These periods involved the "C" and "D" pumps not operating, and would have caused the temperatures through the respective cold legs to be somewhat elevated, but within the operating envelope. ANO is licensed for three pump operation. All other plant transients would have affected all the pumps and all the cold legs equally.

4.4 Selection of Locations for Postulating Flaws

Three criteria were used in selecting flaw locations for this evaluation:

1) Fracture Toughness
2) Previous Inspection Results
3) Stresses.

Since the fracture toughness of the weld material has been shown to be smaller than the base material, even when considering embrittlement, flaw locations were chosen at the welds. Along the welds, areas where slag inclusions have previously been found during inspections were selected. Hence, all the locations identified on the "A" and "B" RCP vertical and scroll welds in 1986 and 1988 were included in this evaluation. In addition, areas of maximum stress in the scroll welds were chosen. Considering the above criteria, five locations were chosen as described below. Stress and thickness information at these locations are also provided.

Location No. 1

This location corresponds to the location on the vertical weld of the "A" RCP where slag inclusions were identified in 1986. From Reference 5, the thickness of the pump casing at this location is 2.6 inches. The maximum tensile stresses occur for the combination of rapid cooldown, internal pressure, deadweight, preload and 15% thermal expansion load. The maximum compressive stresses occur for a load combination of heatup, internal pressure, deadweight, preload and 15% thermal expansion load. The stresses at this location are shown in Table 4-3. It should be noted that the assumed flaw would be on the inside surface since this is where the maximum tensile stress occurs.

Location No. 2

This location corresponds to the location on the vertical weld of the "B" RCP where slag inclusions were identified in 1986. From References 7 and 8, the thickness at this location is 3.1 inches. Stresses are identical to those at Location No. 1, and are shown in Table 4-3. Also, as at Location No. 1, the flaw was assumed on the inside surface. It should be noted that since stress results reported in References 5 and 6 are the same for both Locations No. 1 and 2, these will also envelope all other stresses in the vertical weld and, as such, further evaluation is not required for the vertical weld.

Location No. 3

This location corresponds to the area on the upper scroll weld on the "B" RCP where slag inclusions were identified in 1988. The thickness at this location was obtained from Reference 9 as 4.75 inches. Stresses at this location, also obtained from Reference 9, are shown in Table 4-4. The assumed flaw in this case would be on the outside surface, since the maximum tensile stress occurs at this surface.

Location No. 4

This location corresponds to the area on the lower scroll weld on the "B" RCP where slag inclusions were identified in 1988. The thickness at this location is also 4.75 inches [9]. Stresses at this location are provided in Table 4-5. Similar to Location No. 3, the assumed flaw will be on the outside surface.

Location No. 5

This location is chosen to correspond to the thickest portion of the horizontal scroll welds. From Reference 35, the maximum thickness of the scroll weld is 5.3 inches. At this location, the maximum stresses from the Stress Report [31] on the weld were used to perform a bounding evaluation. Stresses at this location, obtained from Reference 31, are shown in Table 4-6. The flaw is postulated on the inside surface for the fatigue evaluation.

4.5 Postulation of Flaws

As required by the Code Case, the postulated flaw is a quarter thickness semi-elliptical flaw with length six times the depth. A summary of the flaw dimensions at each location is provided in Table 4-7.

4.6 Determination of Stability of Postulated Flaws

To determine the stability of the postulated flaws, fracture mechanics evaluations are performed at each location to address the following:

1) Determination of applied stress intensity factors
2) Allowable stress intensity factor
3) Fatigue crack growth
4) Stress corrosion crack growth.

4.6.1 Determination of Applied Stress Intensity Factors

Even though austenitic stainless steels have been shown to be relatively ductile materials, linear elastic fracture mechanics (LEFM) techniques were conservatively used in lieu of elastic-plastic fracture mechanics (EPFM) techniques.

The stress intensity factors (K_I) associated with the applied stresses were conservatively determined using the flat plate model of ASME Code, Section XI, Appendix A [36]. The expression for K_I is given by:

$$K_I = \sigma_m M_m \sqrt{\pi}\ \sqrt{a/Q} + \sigma_b M_b \sqrt{\pi}\ \sqrt{a/Q}$$

where:

σ_m, σ_b = membrane and bending stresses
a = minor half-diameter of embedded flaw; flaw depth for surface flaw
Q = flaw shape parameter
M_m = correction factor for membrane stress
M_b = correction factor for bending stress

The above model is contained in the library of Structural Integrity's computer software **pc-CRACK** [37]. This software was, therefore, used to determine the stress intensity factors at the various locations, using the stress information contained in Tables 4-3 through 4-6. In order to use **pc-CRACK**, the through-thickness stresses are curve fit to a third degree polynomial to determine the membrane and the bending components. The **pc-CRACK** results for the stress intensity factor determination are provided in Appendix B.

4.6.2 Allowable Stress Intensity Factor

Stress intensity factors, for comparison to an allowable value, were calculated consistent with the safety factors provided in Appendix G of Section XI of the ASME Code. Paragraph G-2222 requires a safety factor of 2.0 on primary stresses and a safety factor of 1.0 on secondary stresses for Service Levels A and B.

The terms whose sum must be less than the allowable reference stress intensity factor (K_{IR}) for Levels A and B operating conditions (Service Levels A and B) are:

1) $2K_{Im}$ for primary membrane stress
2) $2K_{Ib}$ for primary bending stress
3) K_{Im} for secondary membrane stress
4) K_{Ib} for secondary bending stress.

No safety factors are specifically provided for Service Levels C and D, and it is recommended in Appendix G that each situation be studied on an individual case basis. In this evaluation, the safety factors used for Service Levels C and D were taken as $\sqrt{2}$ for primary stresses, and 1.0 for secondary stresses. The safety factor of $\sqrt{2}$ is conservatively taken as that used for flaw evaluations per Paragraph IWB-3610 of ASME Section XI, for ferritic materials.

Tables 4-8 and 4-9 provide the stress intensity factors with the appropriate safety factors for the various locations, and their comparison to the allowable K_{IR} value of 135.5 $ksi\sqrt{in}$. The analysis was performed using the postulated quarter thickness flaw depth. It should be noted that for Locations No. 1 through 4, a safety factor of 2 was conservatively used regardless of whether the stress is primary or secondary. It can be seen that the stress intensity factors at all locations are below the allowable values.

4.6.3 Fatigue Crack Growth

Even though the postulated flaw bounds the maximum expected flaw during the life of the component, fatigue crack growth analyses were performed to assure that crack growth is minimal compared to the postulated flaw. For postulated flaws on the outside surface, the analyses were performed using **pc-CRACK** and the ASME Section XI, Appendix C [36] crack growth law for austenitic stainless steel in an air environment and a temperature of 550°F. A fatigue crack growth law for a water environment is not currently in the ASME Section XI; however, per the recommendation of ASME Section XI Task Group for Flaw Evaluation [38], a factor of 2 was applied to the air environment law to account for the PWR water environment. The ASME Section XI fatigue crack growth law for air is given as:

$$\frac{da}{dN} = C_o(\Delta K_I)^n$$

where n equals 3.3, and

$$C_o = C(S)$$

where C is a scaling parameter to account for temperature, and is given by

$$C = 10^{[-10.009 + 8.12 x 10^{-4} T - 1.13 x 10^{-6} T^2 + 1.02 x 10^{-9} T^3]}$$

T is the metal temperature in °F ($T \leq 800$°F). S is a scaling parameter to account for the R ratio (K_{min}/K_{max}), and is given by:

$$\begin{aligned} S &= 1.0 && \text{when } R \leq 0 \\ &= 1.0 + 1.8R && \text{when } 0 < R \leq 0.79 \\ &= -43.35 + 57.97R && \text{when } 0.79 < R \leq 1.0 \end{aligned}$$

At a temperature of 550°F, and for $R \leq 0$ as in this case, C_o was calculated as 1.84×10^{-10} for an air environment. A value of C_o of 3.68×10^{-10} was, therefore, used for the PWR water environment to determine crack growth for flaws on the inside surface.

Fatigue crack growth analyses were performed for the five locations for a 40-year plant life (240 heatup and cooldown cycles) with an initial quarter thickness flaw. The **pc-CRACK** results for the fatigue crack growth analyses are presented in Appendix C and summarized in Table 4-10. The results show that in comparison to the large initial postulated flaw, fatigue crack growth is relatively small, except for Location No. 5. However, recent inspection results, documented in this report, show that initial fabrication defects in scroll welds have not grown since the start of service, indicating the very conservative nature of these fatigue predictions for large postulated defects.

4.6.4 Stress Corrosion Crack Growth

Stress corrosion cracking (SCC) in pressurized water reactors is not generally of concern, since the environment is not usually conducive to SCC. Moreover, stainless steel castings have been shown to have superior resistance to SCC when compared to wrought products. Because a wrought material consists of a single phase austenite (γ), when such a material is welded, the thermal cycles associated with the welding cause chromium carbides to be precipitated from solution and at austenite-austenite (γ-γ) grain boundaries. The diffusion of chromium from the austenite matrix results in a chromium depleted zone at the grain boundary, resulting in sensitization. On the other hand, when a stainless steel casting (a two-phase duplex microstructure) is exposed to the same thermal cycle, carbon and chromium also combine to form grain boundary carbides; however, these carbides form exclusively at the austenite-ferrite (γ-δ) boundaries, with the majority of the chromium diffusing from the delta ferrite side of the boundary (diffusion of chromium in the ferrite is approximately 1000 times faster than that in austenite at a temperature of 1100°F). Thus, the chromium content of the austenite is not reduced significantly, and corrosion resistance, even near the γ-δ grain boundary, is maintained. Crack growth due to SCC will, therefore, not be considered in this evaluation.

4.7 Effect of Thermal Embrittlement and Other Degradation Mechanisms that May Degrade Properties of the Pump Casing

Structural material degradation mechanisms for various components in light water reactors have been discussed extensively in Reference 39. Of all the degradation mechanisms addressed in this EPRI report, only thermal and irradiation embrittlement could potentially degrade the fracture toughness properties of the cast stainless steel pump casings. Thermal embrittlement effects have been included in the consideration of crack growth and fracture toughness (K_{IR}) properties in this study. Irradiation embrittlement is not of concern since the RCPs are far removed from the reactor core.

Table 4-1

Properties of ASTM A351 Grade CF8M

Temperature (°F)	$E \times 10^6$ (psi)	$\sigma_y \times 10^3$ (psi)	$S_m \times 10^3$ (psi)	$\alpha \times 10^{-6}$ (in/in/°F)
70	27.4	30.0	20.0	9.11
200	27.1	26.0	20.0	9.50
300	26.8	23.6	20.0	9.73
400	26.4	22.2	20.0	9.96
500	26.0	21.8	19.6	10.20
600	25.4	21.2	19.1	10.43
700	24.9	20.5	18.4	10.66

Table 4-2

Determination of Lower Bound Fracture Toughness of ANO-1 Pump Casings Considering Thermal Embrittlement

Material Composition	Heat Numbers			
	6426 Pump A	6415 Pump B	6441 Pump C	6395 Pump D
Cr	18.8	18.8	18.7	19.1
Si	0.76	0.82	0.71	0.92
Mo	2.23	2.26	2.15	2.19
Ni	9.4	9.4	9.3	9.4
C	0.04	0.04	0.07	0.04
Mn	0.91	0.98	0.8	1
N	0.047	0.07	0.068	0.055
Cr_{eq}	16.9	16.9	16.7	17.2
Ni_{eq}	14.1	14.5	15.1	14.3
Ferrite (δ_c)	13.5	11.5	7.9	14.2
Cv_{sat} (J/cm^2)	140	122	125	102
J_{Ic} (in-lb/in^2)	1117	975	1001	817

Table 4-3

Stresses at Locations No. 1 and 2

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Table 4-4

Stresses at Location No. 3

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Table 4-5

Stresses at Location No. 4

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Table 4-6

Stresses at Location No. 5[1]

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Table 4-7

Postulated Flaw Sizes and Locations

Location	Location of Flaw	Weld Thickness (in.)	Flaw Depth (in.)	Flaw Length (in.)
1	Inside	2.60	0.65	3.9
2	Inside	3.10	0.775	4.65
3	Outside	4.75	1.1875	7.125
4	Outside	4.75	1.1875	7.125
5	Inside	5.30	1.325	7.95

Table 4-8

Comparison of Calculated and Allowable Stress Intensity Factors for Level A and B Conditions for Quarter Thickness Surface Flaws

Location	Calculated Stress Intensity Factor ($ksi\sqrt{in}$)	Allowable Stress Intensity Factor ($ksi\sqrt{in}$)
1	47.7	135.5
2	52.1	135.5
3	129.0	135.5
4	128.7	135.5
5 (2D)	99.4	135.5
(3D)	128.4	135.5

Table 4-9

Comparison of Calculated and Allowable Stress Intensity Factors for Level C and D Conditions for Quarter Thickness Surface Flaws

Location	Calculated Stress Intensity Factor ($ksi\sqrt{in}$)	Allowable Stress Intensity Factor ($ksi\sqrt{in}$)
1	38.9	135.5
2	42.5	135.5
3	106.3	135.5
4	106.3	135.5
5 (2D)	109.0	135.5
(3D)	110.1	135.5

Table 4-10

Results of Fatigue Crack Growth Analyses for Quarter Thickness Surface Flaws

Location	Initial Flaw Depth (in.)	Crack Growth (in.)
1	0.65	0.0389
2	0.775	0.0523
3	1.1875	0.0655
4	1.1875	0.0662
5 (2D)	1.325	0.5870
(3D)	1.325	0.2908

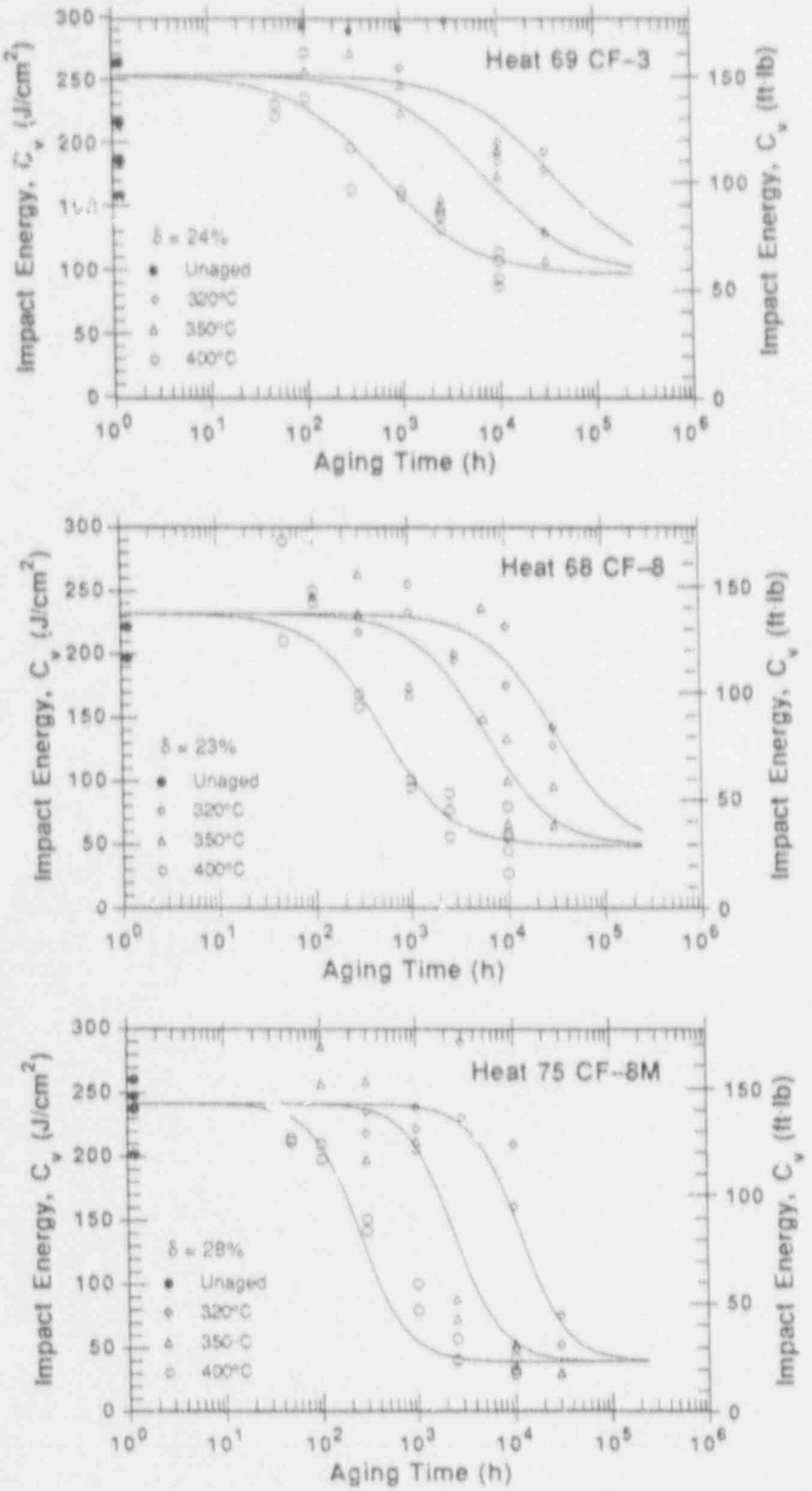

Figure 4-1. Effect of Thermal Aging on Room Temperature Impact Energy of CF3, CF8 and CF8M Cast Stainless Steel [15]

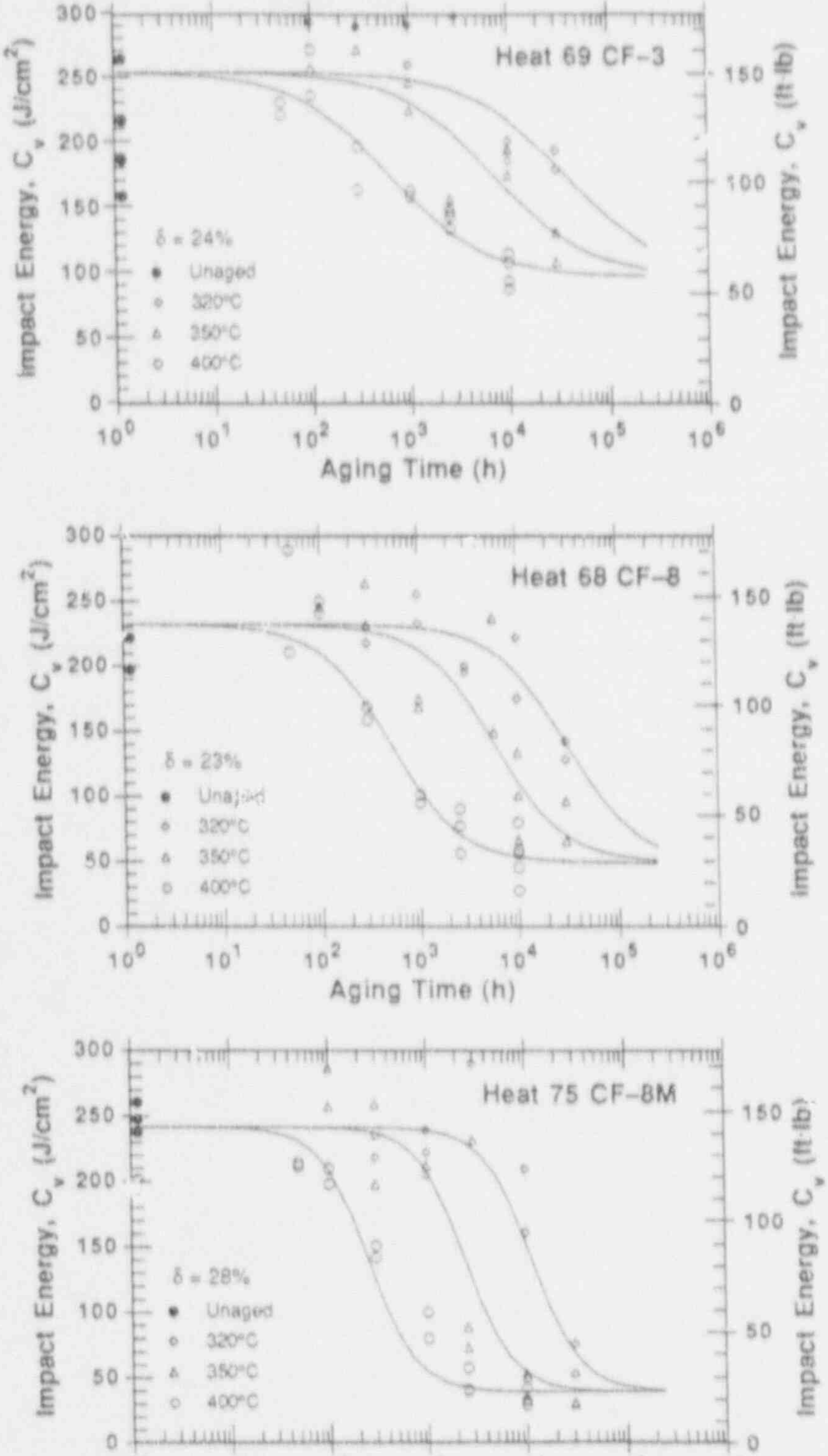

Figure 4-1. Effect of Thermal Aging on Room Temperature Impact Energy of CF3, CF8 and CF8M Cast Stainless Steel [15]

Figure 4-2. Solution Heat Treated Wrought Type 316 Stainless Steel

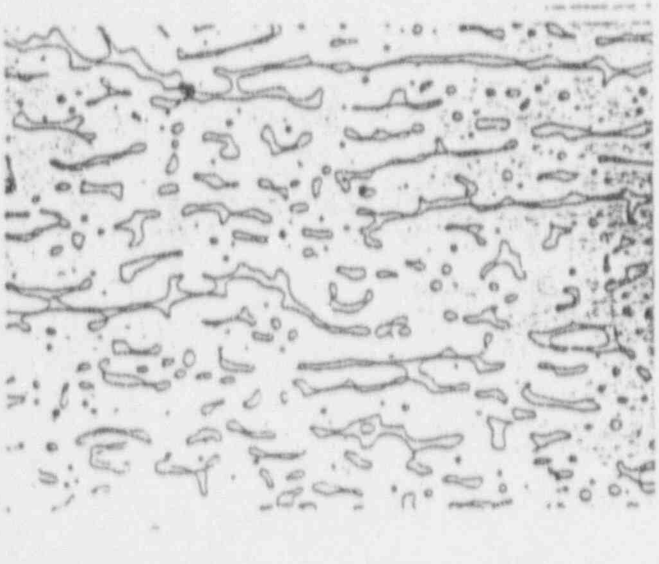

Figure 4-3. Solution Heat Treated Grade CF8 Stainless Steel Casting

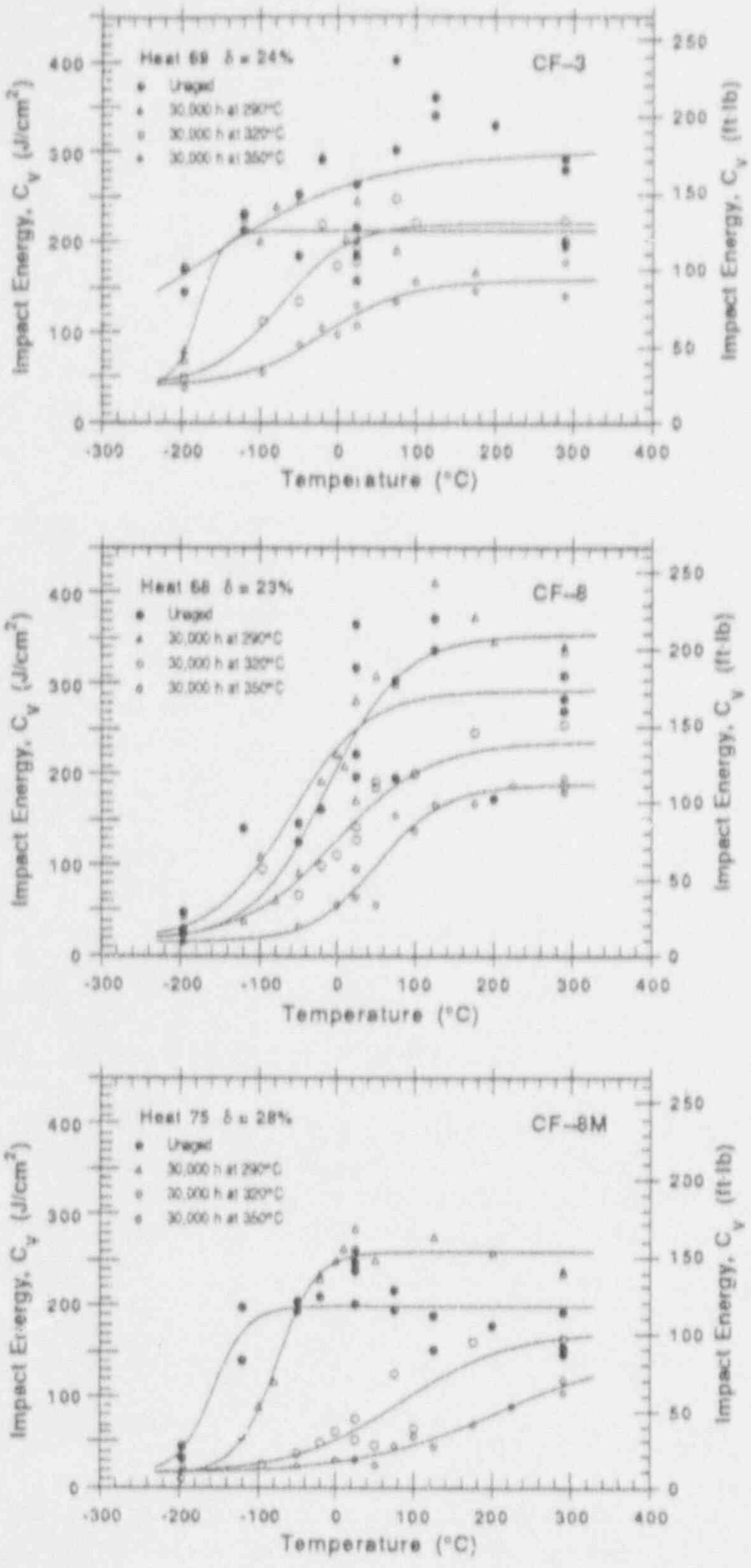

Figure 4-4. Effect of Temperature on Charpy Transition Curves of CF3, CF8 and CF8M Steels Aged for 30,000 hours [15]

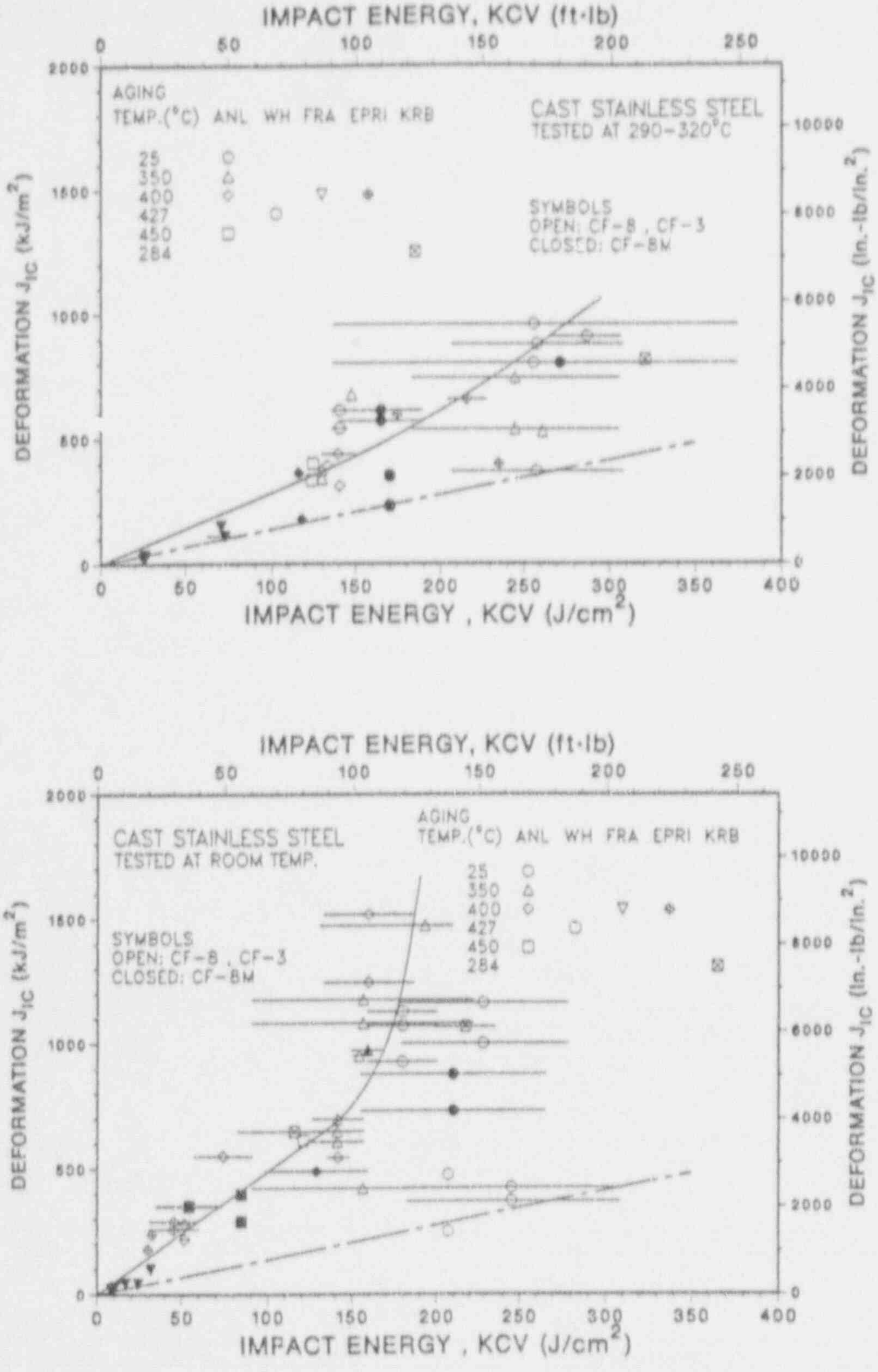

Figure 4-5. Correlation Between Fracture Toughness (J_{Ic}) and Charpy Impact Energy for Unaged and Aged Cast Stainless Steels Tested at Room Temperature and 290-320°C [14]

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Figure 4-7. Three-dimensional Element Map - Top [31]

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Figure 4-8. Three-dimensional Element Map - Bottom [31]

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Figure 4-9. Typical Section Cuts for Primary Plus Secondary Load Conditions [31]

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Figure 4-10. Pump Case Model - Top View [6]

5.0 SUMMARY AND CONCLUSIONS

The evaluations contained in this report have demonstrated that the ANO-1 reactor coolant pump casings meet the safety and serviceability requirements of ASME Code Case N-481.

The fracture toughness of the base metal stainless steel, A351 Grade CF8M casting, and the weld metal were addressed, including the consideration of thermal embrittlement. The lower bound fracture toughness value of these materials was used in the analysis.

Five critical flaw locations were selected for the evaluation, considering areas where fabrication defects have previously been identified. In addition, the maximum stress locations were also included in the analysis.

Consistent with similar evaluations for pressure vessels with postulated large flaws, per Appendix G of ASME Section III, safety factors of 2 for primary and 1 for secondary loads were used for Service Levels A and B conditions. Safety factors of $\sqrt{2}$ and 1 were used for primary and secondary loads, respectively, for Service Levels C and D conditions. At all locations, the applied stress intensity factors were below the allowable values.

Fatigue crack growth analyses were performed for information purposes, conservatively considering the 40-year plant life to show that crack growth for even the boundary postulated flaws are relatively small.

The analyses included a number of conservatisms as noted below:

- The lower bound toughness of the weld metal was used in all cases to determine the allowable stress intensity factor.

- Even though cast stainless steel components and their weldments are relatively ductile, a linear elastic fracture mechanics approach was used for the analysis, in lieu of elastic-plastic fracture mechanics techniques.

- A flat plate model was used to calculate the stress intensity factors, even though the pump casings, for the most part, have circular cross sections. The use of a more representative model would have reduced the stress intensity factors.

- At Locations No. 1 through 4, because available documentation provided only a combination of primary and secondary stresses, a safety factor of 2 was applied on both the primary and secondary stresses. A safety factor of 1 on the secondary stresses, as required by Appendix G of Sections III and XI of the ASME Code, would have resulted in lower applied stress intensity factors at these locations.

- At Location No. 5 the maximum stresses along the weld were applied at the thickest section, resulting in conservative stress intensity factors. Also at this location, stresses were classified as primary if they could not be conveniently separated into primary and secondary components. In addition, stresses were classified as membrane if it could not be determined whether they are membrane or bending.

6.0 REFERENCES

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24. O. K. Chopra, "Estimation of Mechanical Properties of Cast Stainless Steels During Thermal Aging in LWR Systems", NUREG/CP-0119, Vol. 2, pp. 151-178, Proceedings of the U.S. Nuclear Regulatory Commission, 19th Water Reactor Safety Information Meeting held at Bethesda, MD, October 28-30, 1991, published April 1992.

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26. Babcock & Wilcox P. O. No. 805502, Contract No. 620-0008, Byron-Jackson Pumps.

27. EPRI Report NP-4668, "Evaluation of the Toughness of Austenitic Stainless Steel Pipe Weldments", June 1986.

28. EPRI Report NP-4768, "Toughness of Austenitic Stainless Steel Pipe Welds", October 1986.

29. EPRI Report NP-4690-SR, "Evaluation of Flaws in Austenitic Steel Piping", July 1986.

30. Private Communication between Nathaniel G. Cofie (Structural Integrity Associates) and O. K. Chopra (Argonne National Laboratory), April 24, 1992.

31. Byron-Jackson Report TCF-1014-STR, Vol. 1, Rev. 0, "33 x 33 x 38 DFSS Primary Coolant Pump Arkansas Power & Light Co.", dated 12/21/73, (B&W Document 32-0232-00) NSS-8 (AP&L - Calc. #83-S-00020-05).

32. B&W Document No. 32-1169053-00, "Stress Analysis of Revised Nozzle Loads", dated November 16, 1987.

33. Byron-Jackson Report TCF-1023-STR, Vol. 2, Rev. C, "Pump Case Analysis for Consumers Power Midland Plant Unit I and Unit II", dated June 19, 1980 (B&W Document 33-0210-03, dated July 29, 1980) NSS-12/13.

34. Telecopy from F. Marrujo (Byron-Jackson) to Bill Jones (B&W) dated October 21, 1986.

35. Duke Power Company, Radiographic Inspection Report/Technique, ANO Unit 1, Item Number B12-10-1, ID Number 43-001-UPPER, dated October 20, 1986.

36. ASME Boiler and Pressure Vessel Code, Section XI, 1989 Edition.

37. **pc-CRACK** Computer Software, Version 2.1, Structural Integrity Associates, May 1992.

38. Section XI Task Group for Piping Flaw Evaluation, ASME Code, "Evaluation of Flaws in Austenitic Steel Piping", Journal of Pressure Vessel Technology, Vol. 108, August 1986.

39. EPRI Report No. NP-5461, "Component Life Estimation: LWR Structural Material Degradation Mechanisms", September 1987, prepared by Structural Integrity Associates.

APPENDIX A

ASME Code Case N-481

Approval Date: March 5, 1990

*See Numerical Index for expiration
and any reaffirmation dates.*

Case N-481
Alternate Examination Requirements for Cast Austenitic Pump Casings
Section XI, Division 1

Inquiry: When conducting examination of cast austenitic pump casings in accordance with Section XI, Division 1, what examinations may be performed in lieu of the volumetric examinations specified in Table IWB-2500-1, Examination Category B-L-1, Item B12.10?

Reply: It is the opinion of the Committee that the following requirements shall be met in lieu of performing the volumetric examination specified in Table IWB-2500-1, Examination Category B-L-1, Item B12.10:

(a) Perform a VT-2 visual examination of the exerior of all pumps during the hydrostatic pressure test required by Table IWB-2500-1, Category B-P.

(b) Perform a VT-1 visual examination of the external surfaces of the weld of one pump casing.

ternal surfaces of the weld of one pump casing.

(c) Perform a VT-3 visual examination of the internal surfaces whenever a pump is disassembled for maintenance.

(d) Perform an evaluation to demonstrate the safety and serviceability of the pump casing. The evaluation shall include the following:

(1) evaluating material properties, including fracture toughness values;

(2) performing a stress analysis of the pump casing;

(3) reviewing the operating history of the pump;

(4) selecting locations for postulating flaws;

(5) postulating one-quarter thickness reference flaw with a length six times its depth;

(6) establishing the stability of the selected flaw under the governing stress conditions;

(7) considering thermal aging embrittlement and any other processes that may degrade the properties of the pump casing during service.

(e) A report of this evaluation shall be submitted to the regulatory and enforcement authorities having jurisdiction at the plant sit for review.

APPENDIX B

pc-CRACK Output - Stress Intensity Factors

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                                   tm
                            pc-CRACK
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              STRUCTURAL INTEGRITY ASSOCIATES, INC.
                  SAN JOSE, CA (408)978-8200
                         VERSION 2.1

Date: 27-May-1992
Time: 10:51:31.57

                 LINEAR ELASTIC FRACTURE MECHANICS EVALUATION


ANO-1 CODE CASE N-481 EVALUATION - LOCATION NO. 1


crack model:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSES

WALL THICKNESS (t)=     2.6000
YIELD STRESS=    21.5000
CRACK ASPECT RATIO (a/L)=     0.1667


              STRESS COEFFICIENTS:
    CASE ID           C0          C1
   COOLDOWN      15.8833     -2.5000
     HEATUP     -19.0167      3.8077
  EMERGENCY      19.6833     -6.9615


     CRACK ----------------STRESS INTENSITY FACTOR----------------
     SIZE           CASE         CASE         CASE
                 COOLDOWN       HEATUP   EMERGENCY

    0.0260         4.663       -5.302        5.861
    0.0520         6.587       -7.485        8.254
    0.0780         8.059       -9.151       10.067
    0.1040         9.295      -10.548       11.576
    0.1300        10.380      -11.771       12.888
    0.1560        11.357      -12.871       14.058
    0.1820        12.253      -13.877       15.120
    0.2080        13.084      -14.808       16.095
    0.2340        13.861      -15.678       16.998
    0.2600        14.594      -16.496       17.841
    0.2860        15.340      -17.324       18.673
    0.3120        16.058      -18.118       19.464
    0.3380        16.750      -18.882       20.217
    0.3640        17.420      -19.620       20.937
    0.3900        18.071      -20.335       21.627
    0.4160        18.705      -21.029       22.290
    0.4420        19.322      -21.705       22.929
    0.4680        19.926      -22.363       23.545
    0.4940        20.516      -23.005       24.139
    0.5200        21.094      -23.633       24.715
    0.5460        21.665      -24.257       25.302
```

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pc-CRACK  VERSION 2.1                                                       PAGE    2

     0.5720       22.226      -24.868       25.873
     0.5980       22.777      -25.468       26.430
     0.6240       23.320      -26.058       26.973
     0.6500       23.855      -26.639       27.503
     0.6760       24.382      -27.210       28.021
     0.7020       24.903      -27.774       28.528
     0.7280       25.417      -28.329       29.024
     0.7540       25.926      -28.877       29.510
     0.7800       26.428      -29.418       29.986
     0.8060       27.069      -30.106       30.587
     0.8320       27.709      -30.793       31.183
     0.8580       28.349      -31.479       31.774
     0.8840       28.989      -32.164       32.362
     0.9100       29.628      -32.848       32.946
     0.9360       30.268      -33.532       33.526
     0.9620       30.908      -34.216       34.103
     0.9880       31.549      -34.899       34.677
     1.0140       32.190      -35.581       35.247
     1.0400       32.832      -36.264       35.815
     1.0660       33.578      -37.070       36.534
     1.0920       34.328      -37.879       37.254
     1.1180       35.081      -38.691       37.973
     1.1440       35.837      -39.506       38.697
     1.1700       36.597      -40.325       39.421
     1.1960       37.360      -41.147       40.146
     1.2220       38.126      -41.972       40.873
     1.2480       38.896      -42.800       41.601
     1.2740       39.669      -43.632       42.332
     1.3000       40.446      -44.467       43.063

                                        END OF pc-CRACK
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                                    tm
                              pc-CRACK
                    (C) COPYRIGHT 1984, 1990
             STRUCTURAL INTEGRITY ASSOCIATES, INC.
                  SAN JOSE, CA (408)978-8200
                         VERSION 2.1

Date: 23-May-1992
Time: 11: 5:10.18

          LINEAR ELASTIC FRACTURE MECHANICS EVALUATION


ANO-1 CODE CASE N-461 EVALUATION - LOCATION NO. 2


crack model:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSES

WALL THICKNESS (t)=    3.1000
YIELD STRESS=   21.5000
CRACK ASPECT RATIO (a/L)=     0.1667


              STRESS COEFFICIENTS:
     CASE ID           C0          C1
    COOLDOWN     15.8833     -2.0968
      HEATUP    -19.0167      3.1935
   EMERGENCY     19.6833     -5.8387


      CRACK ---------------STRESS INTENSITY FACTOR---------------
      SIZE         CASE         CASE        CASE
               COOLDOWN       HEATUP   EMERGENCY

     0.0310       5.092       -5.790       6.400
     0.0620       7.193       -8.173       9.013
     0.0930       8.800       -9.992      10.993
     0.1240      10.149      -11.517      12.640
     0.1550      11.334      -12.853      14.072
     0.1860      12.401      -14.055      15.350
     0.2170      13.379      -15.153      16.510
     0.2480      14.287      -16.170      17.575
     0.2790      15.136      -17.119      18.561
     0.3100      15.936      -18.012      19.481
     0.3410      16.750      -18.916      20.390
     0.3720      17.534      -19.783      21.253
     0.4030      18.290      -20.618      22.075
     0.4340      19.022      -21.424      22.861
     0.4650      19.732      -22.205      23.615
     0.4960      20.424      -22.963      24.339
     0.5270      21.098      -23.700      25.036
     0.5580      21.757      -24.419      25.709
     0.5890      22.402      -25.120      26.359
     0.6200      23.034      -25.806      26.987
     0.6510      23.657      -26.487      27.628
```

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pc-CRACK  VERSION 2.1                                                      PAGE    2

        0.6820       24.269      -27.154       28.251
        0.7130       24.871      -27.810       28.859
        0.7440       25.464      -28.454       29.452
        0.7750       26.048      -29.088       30.031
        0.8060       26.624      -29.712       30.597
        0.8370       27.193      -30.327       31.151
        0.8680       27.754      -30.933       31.692
        0.8990       28.309      -31.531       32.223
        0.9300       28.858      -32.122       32.743
        0.9610       29.557      -32.874       33.399
        0.9920       30.256      -33.624       34.049
        1.0230       30.955      -34.373       34.695
        1.0540       31.654      -35.121       35.337
        1.0850       32.352      -35.868       35.974
        1.1160       33.051      -36.615       36.608
        1.1470       33.750      -37.361       37.238
        1.1780       34.449      -38.107       37.864
        1.2090       35.149      -38.852       38.488
        1.2400       35.850      -39.598       39.108
        1.2710       36.665      -40.478       39.892
        1.3020       37.483      -41.361       40.678
        1.3330       38.306      -42.248       41.465
        1.3640       39.131      -43.138       42.254
        1.3950       39.961      -44.032       43.045
        1.4260       40.794      -44.929       43.837
        1.4570       41.631      -45.830       44.630
        1.4880       42.472      -46.735       45.426
        1.5190       43.316      -47.643       46.223
        1.5500       44.164      -48.555       47.022

                                         END OF pc-CRACK
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                                        tm
                                pc-CRACK
                        (C) COPYRIGHT 1984, 1990
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                      SAN JOSE, CA (408)978-8200
                             VERSION 2.1

Date: 23-M..  992
Time: 11:36..2.10

                LINEAR ELASTIC FRACTURE MECHANICS EVALUATION


ANO-1 CODE CASE N-481 EVALUATION - LOCATION NO.3


crack model:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSES

WALL THICKNESS (t)=     4.7500
YIELD STRESS=   21.5000
CRACK ASPECT RATIO (a/L)=     0.1467


               STRESS COEFFICIENTS:
   CASE ID          CO          C1
   TRANS-A      37.0000    -10.6526
   TRANS-B      -8.8000      5.5579
 EMERGENCY      38.3000     -6.4000


     CRACK ---------------STRESS INTENSITY FACTOR----------------
     SIZE          CASE        CASE        CASE
                 TRANS-A     TRANS-B   EMERGENCY

    0.0475       14.946      -3.143      15.662
    0.0950       20.993      -4.369      22.074
    0.1425       25.533      -5.257      26.943
    0.1900       29.279      -5.963      31.004
    0.2375       32.505      -6.547      34.544
    0.2850       35.357      -7.040      37.711
    0.3325       37.919      -7.462      40.591
    0.3800       40.248      -7.825      43.242
    0.4275       42.382      -8.138      45.705
    0.4750       44.351      -8.408      48.009
    0.5225       46.234      -8.611      50.303
    0.5700       47.995      -8.778      52.489
    0.6175       49.649      -8.911      54.580
    0.6650       51.205      -9.014      56.585
    0.7125       52.673      -9.089      58.515
    0.7600       54.061      -9.137      60.375
    0.8075       55.374      -9.161      62.173
    0.8550       56.619      -9.162      63.913
    0.9025       57.801      -9.141      65.601
    0.9500       58.922      -9.099      67.240
    0.9975       60.120      -9.112      68.894
```

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       1.0450       61.272       -9.110       70.509
       1.0925       62.380       -9.093       72.087
       1.1400       63.447       -9.063       73.631
       1.1875       64.475       -9.019       75.143
       1.2350       65.466       -8.962       76.624
       1.2825       66.422       -8.893       78.076
       1.3300       67.344       -8.812       79.502
       1.3775       68.234       -8.719       80.902
       1.4250       69.093       -8.615       82.278
       1.4725       70.157       -8.464       84.018
       1.5200       71.199       -8.300       85.749
       1.5675       72.222       -8.126       87.471
       1.6150       73.226       -7.940       89.185
       1.6625       74.211       -7.744       90.892
       1.7100       75.179       -7.537       92.591
       1.7575       76.130       -7.320       94.284
       1.8050       77.065       -7.093       95.971
       1.8525       77.984       -6.856       97.652
       1.9000       78.888       -6.610       99.328
       1.9475       80.218       -6.487      101.394
       1.9950       81.545       -6.359      103.465
       2.0425       82.869       -6.224      105.542
       2.0900       84.190       -6.084      107.624
       2.1375       85.508       -5.938      109.711
       2.1850       86.824       -5.787      111.805
       2.2325       88.138       -5.630      113.904
       2.2800       89.449       -5.468      116.010
       2.3275       90.759       -5.301      118.122
       2.3750       92.068       -5.129      120.240

                                        END OF pc-CRACK
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                                        tm
                                 pc-CRACK
                        (C) COPYRIGHT 1984, 1990
                 STRUCTURAL INTEGRITY ASSOCIATES, INC.
                      SAN JOSE, CA (408)978-8200
                               VERSION 2.1

Date: 23-May-1992
Time: 12:17:44.78

               LINEAR ELASTIC FRACTURE MECHANICS EVALUATION

ANO-1 CODE CASE N-481 EVALUATION - LOCATION NO.4

crack model:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSES

WALL THICKNESS (t)=    4.7500
YIELD STRESS=   21.5000
CRACK ASPECT RATIO (a/L)=     0.1667

               STRESS COEFFICIENTS:
    CASE ID           C0          C1
    TRANS-A      36.9000    -10.6105
    TRANS-B      -9.3000      5.9368
  EMERGENCY      38.3000     -6.4000

     CRACK ----------------STRESS INTENSITY FACTOR----------------
     SIZE           CASE         CASE         CASE
                  TRANS-A      TRANS-B    EMERGENCY

    0.0475       14.907       -3.319       15.662
    0.0950       20.937       -4.613       22.074
    0.1425       25.466       -5.550       26.943
    0.1900       2[illegible].201       -6.293       31.004
    0.2375       32.420       -6.907       34.544
    0.2850       35.265       -7.426       37.711
    0.3325       37.821       -7.869       40.591
    0.3800       40.144       -8.249       43.242
    0.4275       42.273       -8.577       45.705
    0.4750       44.237       -8.859       48.009
    0.5225       46.116       -9.070       50.303
    0.5700       47.874       -9.242       52.489
    0.6175       49.524       -9.378       54.580
    0.6650       51.077       -9.482       56.385
    0.7125       52.542       -9.555       58.515
    0.7600       53.927       -9.601       60.375
    0.8075       55.239       -9.621       62.173
    0.8550       56.482       -9.616       63.913
    0.9025       57.661       -9.588       65.601
    0.9500       58.781       -9.538       67.240
    0.9975       59.977       -9.547       68.894
```

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        1.0450       61.127       -9.539       70.509
        1.0925       62.233       -9.516       72.087
        [illegible]  63.299       -9.478       73.631
        1.1875       64.325       -9.426       75.143
        1.2350       65.315       -9.360       76.624
        1.2825       66.269       -9.281       78.076
        1.3300       67.190       -9.190       79.502
        1.3775       68.079       -9.086       80.902
        1.4250       68.937       -8.970       82.278
        1.4725       70.000       -8.802       84.018
        1.5200       71.041       -8.621       85.749
        1.5675       72.063       -8.[illegible]29 87.471
        1.6150       73.066       -8.224       89.185
        1.6625       74.051       -8.008       90.892
        1.7100       75.018       -7.781       92.591
        1.7575       75.969       -7.542       94.284
        1.8050       76.903       -7.293       95.971
        1.8525       77.822       -7.034       97.652
        1.9000       78.725       -6.764       99.328
        1.9475       80.054       -6.626      101.394
        1.9950       81.379       -6.481      [illegible]65
        2.0425       82.702       -6.331      105.542
        2.0900       84.021       -6.174      107.624
        2.1375       85.338       -6.010      109.711
        2.1850       86.652       -5.841      111.805
        2.2325       87.965       -5.667      113.904
        2.2800       89.275       -5.486      116.010
        2.3275       90.584       -5.300      118.122
        2.3750       91.891       -5.108      120.240

                                        END OF pc-CRACK
```

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                                    tm
                            pc-CRACK
                    (C) COPYRIGHT 1984, 1990
           STRUCTURAL INTEGRITY ASSOCIATES, INC.
                 SAN JOSE, CA (408)978-8200
                        VERSION 2.1

Date:  5-Jun-1992
Time: 13:10:30.25

                LINEAR ELASTIC FRACTURE MECHANICS EVALUATION


ANO-1 CODE CASE N-481 EVALUATION - LOCATION NO. 5 (2-D MODEL)


crack model:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSES

WALL THICKNESS (t)=     5.3000
YIELD STRESS=   21.5000
CRACK ASPECT RATIO (a/L)=     0.1667


                STRESS COEFFICIENTS:
    CASE ID           C0          C1
  NORMAL-PRI     11.0000      0.0000
  NORMAL-SEC     27.0000     -6.7925
    EMER-PRI     14.0000     -0.0000
    EMER-SEC     34.4000     -8.6415
  NORMAL-RNG     58.0000    -14.3396


     CRACK ----------------STRESS INTENSITY FACTOR----------------
     SIZE          CASE        CASE        CASE        CASE        CASE
              NORMAL-PRI  NORMAL-SEC    EMER-PRI    EMER-SEC  NORMAL-RNG

    0.0530       4.531      11.529       5.859      14.690      24.779
    0.1060       6.416      16.197       8.296      20.637      34.815
    0.1590       7.867      19.704      10.173      25.106      42.361
    0.2120       9.095      22.599      11.761      28.796      48.592
    0.2650      10.181      25.096      13.165      31.977      53.967
    0.3180      11.166      27.303      14.439      34.790      58.723
    0.3710      12.075      29.288      15.614      37.320      63.002
    0.4240      12.924      31.094      16.712      39.621      66.896
    0.4770      13.725      32.750      17.747      41.732      70.470
    0.5300      14.484      34.280      18.730      43.682      73.773
    0.5830      15.273      35.747      19.750      45.552      76.946
    0.6360      16.038      37.121      20.739      47.303      79.920
    0.6890      16.782      38.412      21.700      48.950      82.719
    0.7420      17.508      39.629      22.639      50.507      85.359
    0.7950      18.218      40.779      23.557      51.968      87.855
    0.8480      18.914      41.867      24.457      53.356      90.220
    0.9010      19.598      42.899      25.342      54.672      92.465
    0.9540      20.271      43.879      26.212      55.922      94.599
    1.0070      20.934      44.810      27.069      57.110      96.629
```

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pc-CRACK  VERSION 2.1                                                          PAGE    2

    1.0600       21.588       45.696       27.915       58.240        98.562
    1.1130       22.221       46.638       28.735       59.441       100.612
    1.1660       22.847       47.544       29.544       60.598       102.586
    1.2190       23.466       48.418       30.344       61.712       104.490
    1.2720       24.078       49.260       31.135       62.786       106.327
    1.3250       24.684       50.072       31.919       63.822       108.100
    1.3780       25.285       50.856       32.696       64.823       109.814
    1.4310       25.880       51.613       33.466       65.789       111.470
    1.4840       26.471       52.345       34.230       66.723       113.072
    1.5370       27.058       53.052       34.989       67.626       114.622
    1.5900       27.641       53.736       35.742       68.499       116.123
    1.6430       28.388       54.584       36.708       69.581       117.986
    1.6960       29.137       55.417       37.676       70.644       119.816
    1.7490       29.888       56.235       38.648       71.688       121.615
    1.8020       30.641       57.038       39.622       72.714       123.385
    1.8550       31.396       57.829       40.599       73.723       125.126
    1.9080       32.154       58.606       41.579       74.715       126.840
    1.9610       32.915       59.370       42.562       75.692       128.528
    2.0140       33.678       60.123       43.549       76.653       130.190
    2.0670       34.443       60.864       44.539       77.599       131.829
    2.1200       35.212       61.593       45.532       78.531       133.444
    2.1730       36.070       62.649       46.643       79.879       135.756
    2.2260       36.934       63.703       47.759       81.224       138.065
    2.2790       37.803       64.755       48.883       82.566       140.369
    2.3320       38.676       65.805       50.012       83.906       142.671
    2.3850       39.555       66.853       51.148       85.244       144.969
    2.4380       40.438       67.900       52.290       86.580       147.265
    2.4910       41.326       68.945       53.439       87.914       149.558
    2.5440       42.220       69.990       54.594       89.247       151.849
    2.5970       43.118       71.033       55.756       90.579       154.139
    2.6500       44.021       72.075       56.923       91.909       156.427

                                    END OF pc-CRACK
```

```
                                        tm
                                  pc-CRACK
                         (C) COPYRIGHT 1984, 1990
                    STRUCTURAL INTEGRITY ASSOCIATES, INC.
                         SAN JOSE, CA (408)978-8200
                                VERSION 2.1

Date:  5-Jun-1992
Time: 12:32:51.43

                 LINEAR ELASTIC FRACTURE MECHANICS EVALUATION


AND-1 CODE CASE N-481 EVALUATION - LOCATION NO. 5 (3-D MODEL)


crack model:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSES

WALL THICKNESS (t)=     5.3000
YIELD STRESS=   21.5000
CRACK ASPECT RATIO (a/L)=     0.1667


                STRESS COEFFICIENTS:
     CASE ID           C0           C1
  NORMAL-PRI     18.0000       0.0000
  NORMAL-SEC     28.0000     -10.5660
    EMER-PRI     19.0000       0.0000
    EMER-SEC     29.6000     -11.1700
  NORMAL-RNG     48.0000     -11.3208


      CRACK ---------------STRESS INTENSITY FACTOR----------------
      SIZE         CASE         CASE         CASE         CASE         CASE
             NORMAL-PRI NORMAL-SEC    EMER-PRI    EMER-SEC NORMAL-RNG

     0.0530       7.709       11.785        8.195       12.459       20.534
     0.1060      10.916       16.488       1[illegible].604       17.430       28.861
     0.1590      13.385       19.974       14.229       21.116       35.129
     0.2120      15.474       22.811       16.450       24.114       40.311
     0.2650      17.322       25.221       18.414       26.662       44.787
     0.3180      18.998       27.318       20.196       28.879       48.753
     0.3710      20.545       29.172       21.840       30.838       52.326
     0.4240      21.990       30.828       23.377       32.589       55.582
     0.4770      23.352       32.318       24.824       34.165       58.576
     0.5300      24.644       33.666       26.198       35.590       61.346
     0.5830      25.986       34.877       27.625       36.870       64.020
     0.6360      27.287       35.976       29.008       38.032       66.532
     0.6890      28.553       36.976       30.354       39.088       68.900
     0.7420      29.788       37.884       31.667       40.048       71.140
     0.7950      30.996       38.709       32.951       40.921       73.263
     0.8480      32.181       39.457       34.210       41.712       75.280
     0.9010      33.344       40.134       35.447       42.427       77.198
     0.9540      34.489       40.745       36.664       43.073       79.027
     1.0070      35.617       41.294       37.863       43.653       80.772
```

```
      1.0600      36.730      41.784      39.047      44.171      82.438
      1.1130      37.808      42.389      40.193      44.811      84.192
      1.1660      38.873      42.950      41.325      45.404      85.885
      1.2190      39.926      43.469      42.444      45.952      87.521
      1.2720      40.967      43.948      43.551      46.458      89.102
      1.3250      41.998      44.388      44.647      46.924      90.632
      1.3780      43.020      44.793      45.733      47.352      92.114
      1.4310      44.034      45.163      46.811      47.743      93.549
      1.4840      45.039      45.499      47.880      48.098      94.940
      1.5370      46.037      45.803      48.941      48.420      96.290
      1.5900      47.029      46.076      49.995      48.708      97.599
      1.6430      48.300      46.382      51.346      49.031      99.230
      1.6960      49.574      46.660      52.700      49.326     100.836
      1.7490      50.852      46.913      54.059      49.593     102.417
      1.8020      52.133      47.141      55.421      49.834     103.975
      1.8550      53.419      47.345      56.788      50.049     105.512
      1.9080      54.708      47.525      58.159      50.239     107.027
      1.9610      56.002      47.682      59.534      50.406     108.523
      2.0140      57.300      47.817      60.914      50.548     109.999
      2.0670      58.603      47.930      62.299      50.668     111.456
      2.1200      59.910      48.023      63.688      50.766     112.896
      2.1730      61.371      48.500      65.242      51.270     114.906
      2.2260      62.841      48.967      66.804      51.764     116.913
      2.2790      64.319      49.424      68.375      52.247     118.919
      2.3320      65.805      49.872      69.955      52.721     120.923
      2.3850      67.300      50.310      71.544      53.184     122.926
      2.4380      68.803      50.740      73.142      53.639     124.927
      2.4910      70.314      51.160      74.749      54.083     126.928
      2.5440      71.834      51.573      76.364      54.518     128.928
      2.5970      73.362      51.977      77.989      54.945     130.928
      2.6500      74.899      52.372      79.622      55.364     132.928

                                 END OF pc-CRACK
```

APPENDIX C

pc-CRACK Output - Fatigue Crack Growth

```
                                                               tm
                                                   pc-CRACK
                                        (C) COPYRIGHT 1984, 1990
                              STRUCTURAL INTEGRITY ASSOCIATES, INC.
                                       SAN JOSE, CA (408)978-8200
                                                  VERSION 2.1

Date:  5-Jun-1992
Time: 13:28:47.16

                                     FATIGUE CRACK GROWTH ANALYSIS


ANO-1 CODE CASE N-481 EVALUATION - LOCATION NO. 1

INITIAL CRACK SIZE=  0.6500
WALL THICKNESS=  2.6000
MAX CRACK SIZE FOR FCG=  1.3000

PARIS CRACK GROWTH LAW:
   da/dN = C * (dK)^n
where
       dK = Kmax - Kmin
       dK > dKthres
    Kmax < K1c

CURRENT
LAWS:           LAW ID              C               n        dKthres           K1c
            PWR WATER   3.680E-10             3.300           0.000        135.500


                                       STRESS COEFFICIENTS
    CASE ID                 C0              C1              C2              C3
   COOLDOWN          15.8833         -2.5000          0.0000          0.0000
      HEATUP        -19.0167          3.8077          0.0000          0.0000
  EMERGENCY          19.6833         -6.9615          0.0000          0.0000



NUMBER OF CYCLE BLOCKS=                                    240
PRINT INCREMENT OF CYCLE BLOCK=                              6

                       NUMBER OF         CALCULATION                  PRINT           FCG
   SUBBLOCK                CYCLES           INCREMENT           INCREMENT           LAW ID
           1                    1                    1                    1  PWR WATER

                            Kmax                                      Kmin
SUBBLOCK        CASE ID     SCALE FACTOR             CASE ID      SCALE FACTOR
          1    COOLDOWN          1.0000               HEATUP          1.0000

crack model:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSES

       CRACK ---------------------STRESS INTENSITY FACTOR-------------------
       SIZE             CASE            CASE            CASE
                    COOLDOWN          HEATUP   EMERGENCY
```

```
  0.0260        4.663       -5.302        5.861
  0.0520        6.587       -7.485        8.254
  0.0780        8.059       -9.151       10.067
  0.1040        9.295      -10.548       11.576
  0.1300       10.380      -11.771       12.888
  0.1560       11.357      -12.871       14.058
  0.1820       12.253      -13.877       15.120
  0.2080       13.084      -14.808       16.095
  0.2340       13.861      -15.678       16.998
  0.2600       14.594      -16.496       17.841
  0.2860       15.340      -17.324       18.673
  0.3120       16.058      -18.118       19.464
  0.3380       16.750      -18.882       20.217
  0.3640       17.420      -19.620       20.937
  0.3900       18.071      -20.335       21.627
  0.4160       18.705      -21.029       22.290
  0.4420       19.322      -21.705       22.929
  0.4680       19.926      -22.363       23.545
  0.4940       20.516      -23.005       24.139
  0.5200       21.094      -23.633       24.715
  0.5460       21.665      -24.257       25.302
  0.5720       22.226      -24.868       25.873
  0.5980       22.777      -25.468       26.430
  0.6240       23.320      -26.058       26.973
  0.6500       23.855      -26.639       27.503
  0.6760       24.382      -27.210       28.021
  0.7020       24.903      -27.774       28.528
  0.7280       25.417      -28.329       29.024
  0.7540       25.926      -28.877       29.510
  0.7800       26.428      -29.418       29.986
  0.8060       27.069      -30.106       30.587
  0.8320       27.709      -30.793       31.183
  0.8580       28.349      -31.479       31.774
  0.8840       28.989      -32.164       32.362
  0.9100       29.628      -32.848       32.946
  0.9360       30.268      -33.532       33.526
  0.9620       30.908      -34.216       34.103
  0.9880       31.549      -34.899       34.677
  1.0140       32.190      -35.581       35.247
  1.0400       32.832      -36.264       35.815
  1.0660       33.578      -37.070       36.534
  1.0920       34.328      -37.879       37.254
  1.1180       35.081      -38.691       37.975
  1.1440       35.837      -39.506       38.697
  1.1700       36.597      -40.325       39.421
  1.1960       37.360      -41.147       40.146
  1.2220       38.126      -41.972       40.873
  1.2480       38.896      -42.800       41.601
  1.2740       39.669      -43.632       42.332
  1.3000       40.446      -44.467       43.063
```

```
 TOTAL SUBBLOCK
 CYCLE   CYCLE       KMAX      KMIN   DELTAK      R     DADN     DA          A  A/T

BLOCK   6
      6       1     23.87    -26.66    50.53 -1.12  1.5E-04 0.0002   0.6509 0.25

BLOCK  12
     12       1     23.89    -26.68    50.57 -1.12  1.5E-04 0.0002   0.6518 0.25

BLOCK  18
     18       1     23.91    -26.70    50.60 -1.12  1.5E-04 0.0002   0.6528 0.25

BLOCK  24
     24       1     23.93    -26.72    50.64 -1.12  1.6E-04 0.0002   0.6537 0.25

BLOCK  30
     30       1     23.95    -26.74    50.68 -1.12  1.6E-04 0.0002   0.6546 0.25

BLOCK  36
     36       1     23.96    -26.76    50.72 -1.12  1.6E-04 0.0002   0.6556 0.25

BLOCK  42
     42       1     23.98    -26.78    50.76 -1.12  1.6E-04 0.0002   0.6565 0.25

BLOCK  48
     48       1     24.00    -26.80    50.80 -1.12  1.6E-04 0.0002   0.6574 0.25

BLOCK  54
     54       1     24.02    -26.82    50.84 -1.12  1.6E-04 0.0002   0.6584 0.25

BLOCK  60
     60       1     24.04    -26.84    50.88 -1.12  1.6E-04 0.0002   0.6593 0.25

BLOCK  66
     66       1     24.06    -26.86    50.92 -1.12  1.6E-04 0.0002   0.6603 0.25

BLOCK  72
     72       1     24.08    -26.88    50.96 -1.12  1.6E-04 0.0002   0.6612 0.25

BLOCK  78
```

```
pc-CRACK  VERSION 2.1                                                      PAGE    4
     78        1     24.10    -26.90     51.00 -1.12  1.6E-04 0.0002   0.6622 0.25

BLOCK  84
     84        1     24.12    -26.92     51.04 -1.12  1.6E-04 0.0002   0.6631 0.26

BLOCK  90
     90        1     24.14    -26.95     51.08 -1.12  1.6E-04 0.0002   0.6641 0.26

BLOCK  96
     96        1     24.16    -26.97     51.12 -1.12  1.6E-04 0.0002   0.6651 0.26

BLOCK  102
    102        1     24.18    -26.99     51.16 -1.12  1.6E-04 0.0002   0.6660 0.26

BLOCK  108
    108        1     24.20    -27.01     51.20 -1.12  1.6E-04 0.0002   0.6670 0.26

BLOCK  114
    114        1     24.22    -27.03     51.25 -1.12  1.6E-04 0.0002   0.6679 0.26

BLOCK  120
    120        1     24.24    -27.05     51.29 -1.12  1.6E-04 0.0002   0.6689 0.26

BLOCK  126
    126        1     24.26    -27.07     51.33 -1.12  1.6E-04 0.0002   0.6699 0.26

BLOCK  132
    132        1     24.27    -27.09     51.37 -1.12  1.6E-04 0.0002   0.6709 0.26

BLOCK  138
    138        1     24.29    -27.12     51.41 -1.12  1.6E-04 0.0002   0.6718 0.26

BLOCK  144
    144        1     24.31    -27.14     51.45 -1.12  1.6E-04 0.0002   0.6728 0.26

BLOCK  150
    150        1     24.33    -27.16     51.49 -1.12  1.6E-04 0.0002   0.6738 0.26

BLOCK  156
    156        1     24.35    -27.18     51.53 -1.12  1.6E-04 0.0002   0.6748 0.26
```

```
BLOCK  162
    162         1      24.37    -27.20     51.58 -1.12  1.6E-04 0.0002    0.6758 0.26

BLOCK  168
    168         1      24.39    -27.22     51.62 -1.12  1.7E-04 0.0002    0.6768 0.26

BLOCK  174
    174         1      24.41    -27.24     51.66 -1.12  1.7E-04 0.0002    0.6778 0.26

BLOCK  180
    180         1      24.43    -27.27     51.70 -1.12  1.7E-04 0.0002    0.6788 0.26

BLOCK  186
    186         1      24.45    -27.29     51.74 -1.12  1.7E-04 0.0002    0.6798 0.26

BLOCK  192
    192         1      24.47    -27.31     51.78 -1.12  1.7E-04 0.0002    0.6808 0.26

BLOCK  198
    198         1      24.49    -27.33     51.83 -1.12  1.7E-04 0.0002    0.6818 0.26

BLOCK  204
    204         1      24.51    -27.35     51.87 -1.12  1.7E-04 0.0002    0.6828 0.26

BLOCK  210
    210         1      24.53    -27.38     51.91 -1.12  1.7E-04 0.0002    0.6838 0.26

BLOCK  216
    216         1      24.56    -27.40     51.95 -1.12  1.7E-04 0.0002    0.6848 0.26

BLOCK  222
    222         1      24.58    -27.42     51.99 -1.12  1.7E-04 0.0002    0.6858 0.26

BLOCK  228
    228         1      24.60    -27.44     52.04 -1.12  1.7E-04 0.0002    0.6868 0.26

BLOCK  234
    234         1      24.62    -27.46     52.08 -1.12  1.7E-04 0.0002    0.6878 0.26

BLOCK  240
```

```
    240        1    24.64   -27.49    52.12 -1.12  1.7E-04 0.0002   0.6889 0.26

                             END OF pc-CRACK
```

```
                                           tm
                                   pc-CRACK
                         (C) COPYRIGHT 1984, 1990
                  STRUCTURAL INTEGRITY ASSOCIATES, INC.
                        SAN JOSE, CA (408)978-8200
                               VERSION 2.1

Date:  5-Jun-1992
Time: 13:37:31.76

                      FATIGUE CRACK GROWTH ANALYSIS


AND-1 CODE CASE N-481 EVALUATION - LOCATION NO. 2

INITIAL CRACK SIZE=  0.7750
WALL THICKNESS=  3.1000
MAX CRACK SIZE FOR FCG=  1.5500

PARIS CRACK GROWTH LAW:
  da/dN = C * (dK)^n
where
      dK = Kmax - Kmin
      dK > dKthres
    Kmax < K1c

CURRENT
LAWS:        LAW ID          C            n       dKthres      K1c
         PWR WATER  3.680E-10       3.300       0.000    135.500


                            STRESS COEFFICIENTS
   CASE ID           C0           C1           C2           C3
  COOLDOWN     15.8833      -2.0968       0.0000       0.0000
    HEATUP    -19.0167       3.1935       0.0000       0.0000
 EMERGENCY     19.6833      -5.8387       0.0000       0.0000



NUMBER OF CYCLE BLOCKS=                    240
PRINT INCREMENT OF CYCLE BLOCK=              6

                   NUMBER OF     CALCULATION          PRINT       FCG
  SUBBLOCK           CYCLES       INCREMENT        INCREMENT      LAW ID
         1                1               1                1  PWR WATER

                     Kmax                             Kmin
SUBBLOCK     CASE ID   SCALE FACTOR       CASE ID   SCALE FACTOR
       1    COOLDOWN      1.0000          HEATUP      1.0000

crack model:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSES

      CRACK ---------------STRESS INTENSITY FACTOR----------------
      SIZE          CASE         CASE         CASE
                COOLDOWN       HEATUP    EMERGENCY
```

```
pc-CRACK  VERSION 2.1                                                  PAGE    2

      0.0310        5.092       -5.790        6.400
      0.0620        7.193       -8.173        9.013
      0.0930        8.800       -9.992       10.993
      0.1240       10.149      -11.517       12.640
      0.1550       11.334      -12.853       14.072
      0.1860       12.401      -14.055       15.350
      0.2170       13.379      -15.153       16.510
      0.2480       14.287      -16.170       17.575
      0.2790       15.136      -17.119       18.561
      0.3100       15.936      -18.012       19.481
      0.3410       16.750      -18.916       20.390
      0.3720       17.534      -19.783       21.253
      0.4030       18.290      -20.618       22.075
      0.4340       19.022      -21.424       22.861
      0.4650       19.732      -22.205       23.615
      0.4960       20.424      -22.963       24.339
      0.5270       21.098      -23.700       25.036
      0.5580       21.757      -24.419       25.709
      0.5890       22.402      -25.120       26.359
      0.6200       23.034      -25.806       26.987
      0.6510       23.657      -26.487       27.628
      0.6820       24.269      -27.154       28.251
      0.7130       24.871      -27.810       28.859
      0.7440       25.464      -28.454       29.452
      0.7750       26.048      -29.088       30.031
      0.8060       26.624      -29.712       30.597
      0.8370       27.193      -30.327       31.151
      0.8680       27.754      -30.933       31.692
      0.8990       28.309      -31.531       32.223
      0.9300       28.858      -32.122       32.743
      0.9610       29.557      -32.874       33.399
      0.9920       30.256      -33.624       34.049
      1.0230       30.955      -34.373       34.695
      1.0540       31.654      -35.121       35.337
      1.0850       32.352      -35.868       35.974
      1.1160       33.051      -36.615       36.608
      1.1470       33.750      -37.361       37.238
      1.1780       34.449      -38.107       37.864
      1.2090       35.149      -38.852       38.488
      1.2400       35.850      -39.598       39.108
      1.2710       36.665      -40.478       39.892
      1.3020       37.483      -41.361       40.678
      1.3330       38.306      -42.248       41.465
      1.3640       39.131      -43.138       42.234
      1.3950       39.961      -44.032       43.045
      1.4260       40.794      -44.929       43.837
      1.4570       41.631      -45.830       44.630
      1.4880       42.472      -46.735       45.426
      1.5190       43.316      -47.643       46.223
      1.5500       44.164      -48.555       47.022
```

```
pc-CRACK  VERSION 2.1                                                    PAGE    3

  TOTAL  SUBBLOCK
  CYCLE   CYCLE       KMAX       KMIN    DELTAK      R     DADN      DA          A   A/T

BLOCK   6
      6         1      26.07    -29.11     55.18 -1.12  2.1E-04 0.0002    0.7762 0.25

BLOCK   12
     12         1      26.09    -29.13     55.22 -1.12  2.1E-04 0.0002    0.7775 0.25

BLOCK   18
     18         1      26.11    -29.16     55.27 -1.12  2.1E-04 0.0002    0.7787 0.25

BLOCK   24
     24         1      26.14    -29.18     55.32 -1.12  2.1E-04 0.0002    0.7800 0.25

BLOCK   30
     30         1      26.16    -29.21     55.37 -1.12  2.1E-04 0.0002    0.7812 0.25

BLOCK   36
     36         1      26.18    -29.23     55.42 -1.12  2.1E-04 0.0002    0.7825 0.25

BLOCK   42
     42         1      26.21    -29.26     55.46 -1.12  2.1E-04 0.0002    0.7837 0.25

BLOCK   48
     48         1      26.23    -29.28     55.51 -1.12  2.1E-04 0.0002    0.7850 0.25

BLOCK   54
     54         1      26.25    -29.31     55.56 -1.12  2.1E-04 0.0002    0.7862 0.25

BLOCK   60
     60         1      26.28    -29.34     55.61 -1.12  2.1E-04 0.0002    0.7875 0.25

BLOCK   66
     66         1      26.30    -29.36     55.66 -1.12  2.1E-04 0.0002    0.7888 0.25

BLOCK   72
     72         1      26.32    -29.39     55.71 -1.12  2.1E-04 0.0002    0.7900 0.25

BLOCK   78
```

```
      78        1     26.35    -29.41      55.76 -1.12  2.1E-04 0.0002   0.7913 0.26

BLOCK  84
      84        1     26.37    -29.44      55.81 -1.12  2.1E-04 0.0002   0.7926 0.26

BLOCK  90
      90        1     26.39    -29.46      55.86 -1.12  2.1E-04 0.0002   0.7939 0.26

BLOCK  96
      96        1     26.42    -29.49      55.91 -1.12  2.2E-04 0.0002   0.7952 0.26

BLOCK  102
     102        1     26.44    -29.52      55.96 -1.12  2.2E-04 0.0002   0.7965 0.26

BLOCK  108
     108        1     26.47    -29.54      56.01 -1.12  2.2E-04 0.0002   0.7978 0.26

BLOCK  114
     114        1     26.49    -29.57      56.06 -1.12  2.2E-04 0.0002   0.7991 0.26

BLOCK  120
     120        1     26.52    -29.59      56.11 -1.12  2.2E-04 0.0002   0.8004 0.26

BLOCK  126
     126        1     26.54    -29.62      56.16 -1.12  2.2E-04 0.0002   0.8017 0.26

BLOCK  132
     132        1     26.56    -29.65      56.21 -1.12  2.2E-04 0.0002   0.8030 0.26

BLOCK  138
     138        1     26.59    -29.67      56.26 -1.12  2.2E-04 0.0002   0.8043 0.26

BLOCK  144
     144        1     26.61    -29.70      56.31 -1.12  2.2E-04 0.0002   0.8056 0.26

BLOCK  150
     150        1     26.64    -29.73      56.36 -1.12  2.2E-04 0.0002   0.8069 0.26

BLOCK  156
     156        1     26.66    -29.75      56.41 -1.12  2.2E-04 0.0002   0.8083 0.26
```

```
BLOCK  162
    162         1     26.69    -29.78     56.46 -1.12  2.2E-04 0.0002   0.8096 0.26

BLOCK  168
    168         1     26.71    -29.81     56.52 -1.12  2.2E-04 0.0002   0.8109 0.26

BLOCK  174
    174         1     26.74    -29.83     56.57 -1.12  2.2E-04 0.0002   0.8123 0.26

BLOCK  180
    180         1     26.76    -29.86     56.62 -1.12  2.2E-04 0.0002   0.8136 0.26

BLOCK  186
    186         1     26.78    -29.89     56.67 -1.12  2.2E-04 0.0002   0.8150 0.26

BLOCK  192
    192         1     26.81    -29.91     56.72 -1.12  2.3E-04 0.0002   0.8163 0.26

BLOCK  198
    198         1     26.83    -29.94     56.77 -1.12  2.3E-04 0.0002   0.8177 0.26

BLOCK  204
    204         1     26.86    -29.97     56.82 -1.12  2.3E-04 0.0002   0.8190 0.26

BLOCK  210
    210         1     26.88    -29.99     56.88 -1.12  2.3E-04 0.0002   0.8204 0.26

BLOCK  216
    216         1     26.91    -30.02     56.93 -1.12  2.3E-04 0.0002   0.8218 0.27

BLOCK  222
    222         1     26.93    -30.05     56.98 -1.12  2.3E-04 0.0002   0.8231 0.27

BLOCK  228
    228         1     26.96    -30.07     57.03 -1.12  2.3E-04 0.0002   0.8245 0.27

BLOCK  234
    234         1     26.98    -30.10     57.09 -1.12  2.3E-04 0.0002   0.8259 0.27

BLOCK  240
```

```
pc-CRACK  VERSION 2.1                                                    PAGE    6

    240       1    27.01    -30.13    57.14 -1.12  2.3E-04 0.0002   0.8273 0.27

                              END OF pc-CRACK
```

```
                                           tm
                                   pc-CRACK
                           (C) COPYRIGHT 1984, 1990
                    STRUCTURAL INTEGRITY ASSOCIATES, INC.
                           SAN JOSE, CA (408)978-8200
                                  VERSION 2.1

Date: 23-May-1992
Time: 11:50:18.99

                           FATIGUE CRACK GROWTH ANALYSIS


ANO-1 CODE CASE N-481 EVALUATION - LOCATION NO.3

INITIAL CRACK SIZE=  1.1875
WALL THICKNESS=  4.7500
MAX CRACK SIZE FOR FCG=  2.3750
TEMPERATURE=    550.0

      ASME SECTION XI: AUSTENITIC STEEL WITH AIR ENVIRONMENT

                  da/dN = C * 10^F * S * dK^3.3
where
            S =   1.0                  for R < 0
              =   1.0  +  1.8  * R     for 0 < R < 0.79
              = -43.35 + 57.97 * R     for 0.79 < R < 1
            F = code specified function of temperature
                        dK = Kmax - Kmin
                         R = Kmin / Kmax

WHERE:
    C * 10^F =  1.84033E-10
IS FOR THE CURRENTLY ASSUMED UNITS OF:
   FORCE: kips   LENGTH: inches   TEMPERATURE: Fahrenheit


                           STRESS COEFFICIENTS
   CASE ID          C0          C1          C2          C3
   TRANS-A    37.0000    -10.6526      0.0000      0.0000
   TRANS-B    -8.8000      5.5579      0.0000      0.0000
 EMERGENCY    38.3000     -6.4000      0.0000      0.0000


 NUMBER OF CYCLE BLOCKS=                     240
 PRINT INCREMENT OF CYCLE BLOCK=               6

                 NUMBER OF    CALCULATION          PRINT       FCG
  SUBBLOCK          CYCLES      INCREMENT      INCREMENT     LAW ID
         1               1              1              1 SECT XI AUSTENITIC/AIR

                    Kmax                            Kmin
 SUBBLOCK     CASE ID   SCALE FACTOR      CASE ID   SCALE FACTOR
        1     TRANS-A      1.0000         TRANS-B      1.0000
```

```
pc-CRACK  VERSION 2.1                                                    PAGE    2

crack model:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSES

    CRACK ------------ --STRESS INTENSITY FACTOR---------------
    SIZE         CASE        CASE       CASE
               TRANS-A     TRANS-B  EMERGENCY

   0.0475       14.946      -3.143     15.662
   0.0950       20.993      -4.369     22.074
   0.1425       25.533      -5.257     26.943
   0.1900       29.279      -5.963     31.004
   0.2375       32.505      -6.547     34.544
   0.2850       35.357      -7.040     37.711
   0.3325       37.919      -7.462     40.591
   0.3800       40.248      -7.825     43.242
   0.4275       42.382      -8.138     45.705
   0.4750       44.351      -8.408     48.009
   0.5225       46.234      -8.611     50.303
   0.5700       47.995      -8.778     52.489
   0.6175       49.649      -8.911     54.580
   0.6650       51.205      -9.014     56.585
   0.7125       52.673      -9.089     58.515
   0.7600       54.061      -9.137     60.375
   0.8075       55.374      -9.161     62.173
   0.8550       56.619      -9.162     63.913
   0.9025       57.801      -9.141     65.601
   0.9500       58.922      -9.099     67.240
   0.9975       60.120      -9.112     68.894
   1.0450       61.272      -9.110     70.509
   1.0925       62.380      -9.093     72.087
   1.1400       63.447      -9.063     73.631
   1.1875       64.475      -9.019     75.143
   1.2350       65.466      -8.962     76.624
   1.2825       66.422      -8.893     78.076
   1.3300       67.344      -8.812     79.502
   1.3775       68.234      -8.719     80.902
   1.4250       69.093      -8.615     82.278
   1.4725       70.157      -8.464     84.018
   1.5200       71.199      -8.300     85.749
   1.5675       72.222      -8.126     87.471
   1.6150       73.226      -7.940     89.185
   1.6625       74.211      -7.744     90.892
   1.7100       75.179      -7.537     92.591
   1.7575       76.130      -7.320     94.284
   1.8050       77.065      -7.093     95.971
   1.8525       77.984      -6.856     97.652
   1.9000       78.888      -6.610     99.328
   1.9475       80.218      -6.487    101.394
   1.9950       81.545      -6.359    103.465
   2.0425       82.869      -6.224    105.542
   2.0900       84.190      -6.084    107.624
   2.1375       85.508      -5.938    109.711
   2.1850       86.824      -5.787    111.805
   2.2325       88.138      -5.630    113.904
```

```
    2.2800       89.449      -5.468     116.010
    2.3275       90.759      -5.301     118.122
    2.3750       92.068      -5.129     120.240



  TOTAL SUBBLOCK
  CYCLE   CYCLE       KMAX       KMIN    DELTAK      R     DADN      DA          A   A/T

 BLOCK  6
       6        1     64.50     -9.02     73.52 -0.14  2.7E-04 0.0003    1.1891 0.25

 BLOCK  12
      12        1     64.54     -9.02     73.55 -0.14  2.7E-04 0.0003    1.1907 0.25

 BLOCK  18
      18        1     64.57     -9.01     73.58 -0.14  2.7E-04 0.0003    1.1923 0.25

 BLOCK  24
      24        1     64.60     -9.01     73.61 -0.14  2.7E-04 0.0003    1.1939 0.25

 BLOCK  30
      30        1     64.64     -9.01     73.65 -0.14  2.7E-04 0.0003    1.1955 0.25

 BLOCK  36
      36        1     64.67     -9.01     73.68 -0.14  2.7E-04 0.0003    1.1971 0.25

 BLOCK  42
      42        1     64.70     -9.01     73.71 -0.14  2.7E-04 0.0003    1.1987 0.25

 BLOCK  48
      48        1     64.74     -9.00     73.74 -0.14  2.7E-04 0.0003    1.2003 0.25

 BLOCK  54
      54        1     64.77     -9.00     73.77 -0.14  2.7E-04 0.0003    1.2019 0.25

 BLOCK  60
      60        1     64.80     -9.00     73.80 -0.14  2.7E-04 0.0003    1.2035 0.25

 BLOCK  66
      66        1     64.84     -9.00     73.84 -0.14  2.7E-04 0.0003    1.2051 0.25
```

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pc-CRACK  VERSION 2.1                                                        PAGE    4

BLOCK  72
     72         1    64.87     -9.00     73.87 -0.14  2.7E-04 0.0003   1.2068 0.25

BLOCK  78
     78         1    64.90     -8.99     73.90 -0.14  2.7E-04 0.0003   1.2084 0.25

BLOCK  84
     84         1    64.94     -8.99     73.93 -0.14  2.7E-04 0.0003   1.2100 0.25

BLOCK  90
     90         1    64.97     -8.99     73.96 -0.14  2.7E-04 0.0003   1.2116 0.26

BLOCK  96
     96         1    65.01     -8.99     73.99 -0.14  2.7E-04 0.0003   1.2132 0.26

BLOCK  102
    102         1    65.04     -8.99     74.03 -0.14  2.7E-04 0.0003   1.2149 0.26

BLOCK  108
    108         1    65.07     -8.98     74.06 -0.14  2.7E-04 0.0003   1.2165 0.26

BLOCK  114
    114         1    65.11     -8.98     74.09 -0.14  2.7E-04 0.0003   1.2181 0.26

BLOCK  120
    120         1    65.14     -8.98     74.12 -0.14  2.7E-04 0.0003   1.2198 0.26

BLOCK  126
    126         1    65.18     -8.98     74.16 -0.14  2.7E-04 0.0003   1.2214 0.26

BLOCK  132
    132         1    65.21     -8.98     74.19 -0.14  2.7E-04 0.0003   1.2230 0.26

BLOCK  138
    138         1    65.25     -8.97     74.22 -0.14  2.7E-04 0.0003   1.2247 0.26

BLOCK  144
    144         1    65.28     -8.97     74.25 -0.14  2.7E-04 0.0003   1.2263 0.26

BLOCK  150
```

```
      150         1     65.31     -8.97     74.28 -0.14  2.7E-04 0.0003    1.2280 0.26

   BLOCK  156
      156         1     65.35     -8.97     74.32 -0.14  2.8E-04 0.0003    1.2296 0.26

   BLOCK  162
      162         1     65.38     -8.97     74.35 -0.14  2.8E-04 0.0003    1.2313 0.26

   BLOCK  168
      168         1     65.42     -8.96     74.38 -0.14  2.8E-04 0.0003    1.2329 0.26

   BLOCK  174
      174         1     65.45     -8.96     74.41 -0.14  2.8E-04 0.0003    1.2346 0.26

   BLOCK  180
      180         1     65.49     -8.96     74.45 -0.14  2.8E-04 0.0003    1.2363 0.26

   BLOCK  186
      186         1     65.52     -8.96     74.48 -0.14  2.8E-04 0.0003    1.2379 0.26

   BLOCK  192
      192         1     65.55     -8.96     74.51 -0.14  2.8E-04 0.0003    1.2396 0.26

   BLOCK  198
      198         1     65.59     -8.95     74.54 -0.14  2.8E-04 0.0003    1.2412 0.26

   BLOCK  204
      204         1     65.62     -8.95     74.57 -0.14  2.8E-04 0.0003    1.2429 0.26

   BLOCK  210
      210         1     65.65     -8.95     74.60 -0.14  2.8E-04 0.0003    1.2446 0.26

   BLOCK  216
      216         1     65.69     -8.95     74.63 -0.14  2.8E-04 0.0003    1.2463 0.26

   BLOCK  222
      222         1     65.72     -8.94     74.66 -0.14  2.8E-04 0.0003    1.2479 0.26

   BLOCK  228
      228         1     65.75     -8.94     74.70 -0.14  2.8E-04 0.0003    1.2496 0.26
```

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pc-CRACK  VERSION 2.1                                                  PAGE    6

BLOCK  234
     234        1     65.79     -8.94     74.73 -0.14  2.8E-04 0.0003   1.2513 0.26

BLOCK  240
     240        1     65.82     -8.94     74.76 -0.14  2.8E-04 0.0003   1.2530 0.26

                              END OF pc-CRACK
```

```
                                        tm
                                 pc-CRACK
                         (C) COPYRIGHT 1984, 1990
                 STRUCTURAL INTEGRITY ASSOCIATES, INC.
                      SAN JOSE, CA (408)978-8200
                               VERSION 2.1

Date: 23-May-1992
Time: 12:20: 9.40

                        FATIGUE CRACK GROWTH ANALYSIS


ANO-1 CODE CASE N-481 EVALUATION - LOCATION NO. 4

INITIAL CRACK SIZE=  1.1875
WALL THICKNESS=  4.7500
MAX CRACK SIZE FOR FCG=  2.3750
TEMPERATURE=   550.0

     ASME SECTION XI: AUSTENITIC STEEL WITH AIR ENVIRONMENT

                da/dN = C * 10^F * S * dK^3.3
where
             S =   1.0                 for R < 0
               =   1.0  +  1.8  * R    for 0 < R < 0.79
               = -43.35 + 57.97 * R    for 0.79 < R < 1
             F = code specified function of temperature
                         dK = Kmax - Kmin
                          R = Kmin / Kmax


WHERE:
    C * 10^F =  1.84033E-10
IS FOR THE CURRENTLY ASSUMED UNITS OF:
    FORCE: kips    LENGTH: inches    TEMPERATURE: Fahrenheit


                          STRESS COEFFICIENTS
   CASE ID           C0          C1           C2           C3
   TRANS-A      36.9000    -10.6105       0.0000       0.0000
   TRANS-B      -9.3000      5.9368       0.0000       0.0000
 EMERGENCY      38.3000     -6.4000       0.0000       0.0000



 NUMBER OF CYCLE BLOCKS=                   240
 PRINT INCREMENT OF CYCLE BLOCK=             6

                NUMBER OF    CALCULATION          PRINT      FCG
  SUBBLOCK         CYCLES      INCREMENT      INCREMENT     LAW ID
         1              1              1              1 SECT XI AUSTENITIC/AIR

                  Kmax                            Kmin
 SUBBLOCK    CASE ID   SCALE FACTOR      CASE ID   SCALE FACTOR
        1    TRANS-A      1.0000         TRANS-B      1.0000
```

```
pc-CRACK  VERSION 2.1                                                  PAGE    2

crack model:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSES

      CRACK ----------------STRESS INTENSITY FACTOR----------------
      SIZE        CASE        CASE        CASE
                TRANS-A     TRANS-B   EMERGENCY

     0.0475     14.907      -3.319      15.662
     0.0950     20.937      -4.613      22.074
     0.1425     25.466      -5.550      26.943
     0.1900     29.201      -6.293      31.004
     0.2375     32.420      -6.907      34.544
     0.2850     35.265      -7.426      37.711
     0.3325     37.821      -7.869      40.591
     0.3800     40.144      -8.249      43.242
     0.4275     42.273      -8.577      45.705
     0.4750     44.237      -8.859      48.009
     0.5225     46.116      -9.070      50.303
     0.5700     47.874      -9.242      52.489
     0.6175     49.524      -9.378      54.580
     0.6650     51.077      -9.482      56.585
     0.7125     52.542      -9.555      58.515
     0.7600     53.927      -9.601      60.375
     0.8075     55.239      -9.621      62.173
     0.8550     56.482      -9.616      63.913
     0.9025     57.661      -9.588      65.601
     0.9500     58.761      -9.538      67.240
     0.9975     59.977      -9.547      68.894
     1.0450     61.127      -9.539      70.509
     1.0925     62.233      -9.516      72.087
     1.1400     63.299      -9.478      73.631
     1.1875     64.325      -9.426      75.143
     1.2350     65.315      -9.360      76.624
     1.2825     66.269      -9.281      78.076
     1.3300     67.190      -9.190      79.502
     1.3775     68.079      -9.086      80.902
     1.4250     68.937      -8.970      82.278
     1.4725     70.000      -8.802      84.018
     1.5200     71.041      -8.621      85.749
     1.5675     72.063      -8.429      87.471
     1.6150     73.066      -8.224      89.185
     1.6625     74.051      -8.008      90.892
     1.7100     75.018      -7.781      92.591
     1.7575     75.969      -7.542      94.284
     1.8050     76.903      -7.293      95.971
     1.8525     77.822      -7.034      97.652
     1.9000     78.725      -6.764      99.328
     1.9475     80.054      -6.626     101.394
     1.9950     81.379      -6.481     103.465
     2.0425     82.702      -6.331     105.542
     2.0900     84.021      -6.174     107.624
     2.1375     85.338      -6.010     109.711
     2.1850     86.652      -5.841     111.805
     2.2325     87.965      -5.667     113.904
```

```
pc-CRACK  VERSION 2.1                                                                    PAGE    3

     2.2800      89.275       -5.486      116.010
     2.3275      90.584       -5 300      118.122
     2.3750      91.891       -5.108      120.240



   TOTAL  SUBBLOCK
   CYCLE    CYCLE          KMAX       KMIN    DELTAK       R      DADN       DA           A   A/T
 BLOCK   6
        6          1      64.35      -9.42     73.78 -0.15   2.7E-04 0.0003     1.1891 0.25

 BLOCK   12
       12          1      64.39      -9.42     73.81 -0.15   2.7E-04 0.0003     1.1907 0.25

 BLOCK   18
       18          1      64.42      -9.42     73.84 -0.15   2.7E-04 0.0003     1.1923 0.25

 BLOCK   24
       24          1      64.45      -9.42     73.87 -0.15   2.7E-04 0.0003     1.1940 0.25

 BLOCK   30
       30          1      64.49      -9.42     73.90 -0.15   2.7E-04 0.0003     1.1956 0.25

 BLOCK   36
       36          1      64.52      -9.41     73.93 -0.15   2.7E-04 0.0003     1.1972 0.25

 BLOCK   42
       42          1      64.56      -9.41     73.97 -0.15   2.7E-04 0.0003     1.1988 0.25

 BLOCK   48
       48          1      64.59      -9.41     74.00 -0.15   2.7E-04 0.0003     1.2004 0.25

 BLOCK   54
       54          1      64.62      -9.41     74.03 -0.15   2.7E-04 0.0003     1.2021 0.25

 BLOCK   60
       60          1      64.66      -9.40     74.06 -0.15   2.7E-04 0.0003     1.2037 0.25

 BLOCK   66
       66          1      64.69      -9.40     74.09 -0.15   2.7E-04 0.0003     1.2053 0.25
```

```
BLOCK  72
     72        1     64.73     -9.40     74.12 -0.15  2.7E-04 0.0003   1.2070 0.25

BLOCK  78
     78        1     64.76     -9.40     74.16 -0.15  2.7E-04 0.0003   1.2086 0.25

BLOCK  84
     84        1     64.79     -9.40     74.19 -0.14  2.7E-04 0.0003   1.2103 0.25

BLOCK  90
     90        1     64.83     -9.39     74.22 -0.14  2.7E-04 0.0003   1.2119 0.26

BLOCK  96
     96        1     64.86     -9.39     74.25 -0.14  2.7E-04 0.0003   1.2135 0.26

BLOCK  102
    102        1     6 .90     -9.39     74.28 -0.14  2.7E-04 0.0003   1.2152 0.26

BLOCK  108
    108        1     64.93     -9.39     74.32 -0.14  2.8E-04 0.0003   1.2168 0.26

BLOCK  114
    114        1     64.96     -9.38     74.35 -0.14  2.8E-04 0.0003   1.2185 0.26

BLOCK  120
    120        1     65.00     -9.38     74.38 -0.14  2.8E-04 0.0003   1.2201 0.26

BLOCK  126
    126        1     65.03     -9.38     74.41 -0.14  2.8E-04 0.0003   1.2218 0.26

BLOCK  132
    132        1     65.07     -9.38     74.45 -0.14  2.8E-04 0.0003   1.2235 0.26

BLOCK  138
    138        1     65.10     -9.37     74.48 -0.14  2.8E-04 0.0003   1.2251 0.26

BLOCK  144
    144        1     65.14     -9.37     74.51 -0.14  2.8E-04 0.0003   1.2268 0.26

BLOCK  150
```

```
     150        1     65.17     -9.37     74.54 -0.14  2.8E-04 0.0003    1.2285 0.26

BLOCK  156
     156        1     65.21     -9.37     74.57 -0.14  2.8E-04 0.0003    1.2301 0.26

BLOCK  162
     162        1     65.24     -9.37     74.61 -0.14  2.8E-04 0.0003    1.2318 0.26

BLOCK  168
     168        1     65.28     -9.36     74.64 -0.14  2.8E-04 0.0003    1.2335 0.26

BLOCK  174
     174        1     65.31     -9.36     74.67 -0.14  2.8E-04 0.0003    1.2351 0.26

BLOCK  180
     180        1     65.35     -9.36     74.70 -0.14  2.8E-04 0.0003    1.2368 0.26

BLOCK  186
     186        1     65.38     -9.36     74.73 -0.14  2.8E-04 0.0003    1.2385 0.26

BLOCK  192
     192        1     65.41     -9.35     74.77 -0.14  2.8E-04 0.0003    1.2402 0.26

BLOCK  198
     198        1     65.45     -9.35     74.80 -0.14  2.8E-04 0.0003    1.2419 0.26

BLOCK  204
     204        1     65.48     -9.35     74.83 -0.14  2.8E-04 0.0003    1.2436 0.26

BLOCK  210
     210        1     65.51     -9.34     74.86 -0.14  2.8E-04 0.0003    1.2452 0.26

BLOCK  216
     216        1     65.55     -9.34     74.89 -0.14  2.8E-04 0.0003    1.2469 0.26

BLOCK  222
     222        1     65.58     -9.34     74.92 -0.14  2.8E-04 0.0003    1.2486 0.26

BLOCK  228
     228        1     65.62     -9.34     74.95 -0.14  2.8E-04 0.0003    1.2503 0.26
```

```
pc-CRACK  VERSION 2.1                                                PAGE    6

BLOCK  234
    234         1    65.65     -9.33     74.98 -0.14  2.8E-04 0.0003   1.2520 0.26

BLOCK  240
    240         1    65.69     -9.33     75.01 -0.14  2.8E-04 0.0003   1.2537 0.26

                              END OF pc-CRACK
```

```
                                    tm
                              pc-CRACK
                      (C) COPYRIGHT 1984, 1990
               STRUCTURAL INTEGRITY ASSOCIATES, INC.
                   SAN JOSE, CA (408)978-8200
                            VERSION 2.1

Date:  5-Jun-1992
Time: 13:14:52.95

                    FATIGUE CRACK GROWTH ANALYSIS


ANO-1 CODE CASE N-481 EVALUATION - LOCATION NO. 5 (2-D MODEL)

INITIAL CRACK SIZE=  1.3250
WALL THICKNESS=  5.3000
MAX CRACK SIZE FOR FCG=  2.6500

PARIS CRACK GROWTH LAW:
  da/dN = C * (dK)^n
where
      dK = Kmax - Kmin
      dK > dKthres
   Kmax < Klc

CURRENT
LAWS:       LAW ID         C            n       dKthres       Klc
        PWR WATER  3.680E-10      3.300       0.000     135.500


                            STRESS COEFFICIENTS
   CASE ID           C0           C1           C2           C3
NORMAL-PRI     11.0000       0.0000       0.0000       0.0000
NORMAL-SEC     27.0000      -6.7925       0.0000       0.0000
  EMER-PRI     14.0000      -0.0000       0.0000       0.0000
  EMER-SEC     34.4000      -8.6415       0.0000       0.0000
NORMAL-RNG     58.0000     -14.3396       0.0000       0.0000



NUMBER OF CYCLE BLOCKS=                    240
PRINT INCREMENT OF CYCLE BLOCK=              6

                NUMBER OF    CALCULATION          PRINT        FCG
  SUBBLOCK         CYCLES      INCREMENT      INCREMENT     LAW ID
         1              1              1              1  PWR WATER

                 Kmax                               Kmin
SUBBLOCK    CASE ID   SCALE FACTOR       CASE ID   SCALE FACTOR
       1 NORMAL-RNG      1.0000       NORMAL-RNG      0.0000

crack model:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSES

     CRACK ---------------STRESS INTENSITY FACTOR----------------
```

```
pc-CRACK  VERSION 2.1                                                        PAGE    2

     SIZE          CASE         CASE          CASE          CASE         CASE
             NORMAL-PRI  NORMAL-SEC      EMER-PRI      EMER-SEC  NORMAL-RNG

   0.0530         4.531       11.529         5.859        14.690       24.779
   0.1060         6.416       16.197         8.296        20.637       34.815
   0.1590         7.867       19.704        10.173        25.106       42.361
   0.2120         9.095       22.599        11.761        28.796       48.592
   0.2650        10.181       25.096        13.165        31.977       53.967
   0.3180        11.166       27.303        14.439        34.790       58.723
   0.3710        12.075       29.288        15.614        37.320       63.002
   0.4240        12.924       31.094        16.712        39.621       66.896
   0.4770        13.725       32.750        17.747        41.732       70.470
   0.5300        14.484       34.280        18.730        43.682       73.773
   0.5830        15.273       35.747        19.750        45.552       76.946
   0.6360        16.038       37.121        20.739        47.303       79.920
   0.6890        16.782       38.412        21.700        48.950       82.719
   0.7420        17.508       39.629        22.639        50.502       85.359
   0.7950        18.218       40.779        23.557        51.968       87.855
   0.8480        18.914       41.867        24.457        53.356       90.220
   0.9010        19.598       42.899        25.342        54.672       92.465
   0.9540        20.271       43.879        26.212        55.922       94.599
   1.0070        20.934       44.810        27.069        57.110       96.629
   1.0600        21.588       45.696        27.915        58.240       98.562
   1.1130        22.221       46.638        28.735        59.441      100.612
   1.1660        22.847       47.544        29.544        60.598      102.586
   1.2190        23.466       48.418        30.344        61.712      104.490
   1.2720        24.078       49.260        31.135        62.786      106.327
   1.3250        24.684       50.072        31.919        63.822      108.100
   1.3780        25.285       50.856        32.696        64.823      109.814
   1.4310        25.880       51.613        33.466        65.789      111.470
   1.4840        26.471       52.345        34.230        66.723      113.072
   1.5370        27.058       53.052        34.989        67.626      114.622
   1.5900        27.641       53.736        35.742        68.499      116.123
   1.6430        28.388       54.584        36.708        69.581      117.986
   1.6960        29.137       55.417        37.676        70.644      119.816
   1.7490        29.888       56.235        38.648        71.688      121.615
   1.8020        30.641       57.038        39.622        72.714      123.385
   1.8550        31.396       57.829        40.599        73.723      125.126
   1.9080        32.154       58.606        41.579        74.715      126.840
   1.9610        32.915       59.370        42.562        75.692      128.528
   2.0140        33.678       60.123        43.549        76.653      130.190
   2.0670        34.443       60.864        44.539        77.599      131.829
   2.1200        35.212       61.593        45.532        78.531      133.444
   2.1730        36.070       62.649        46.643        79.879      135.756
   2.2260        36.934       63.703        47.759        81.224      138.065
   2.2790        37.803       64.755        48.883        82.566      140.369
   2.3320        38.676       65.805        50.012        83.906      142.671
   2.3850        39.555       66.853        51.148        85.244      144.969
   2.4380        40.438       67.900        52.290        86.580      147.265
   2.4910        41.326       68.945        53.439        87.914      149.558
   2.5440        42.220       69.990        54.594        89.247      151.849
   2.5970        43.118       71.037        55.756        90.579      154.139
   2.6500        44.021       72.075        56.923        91.909      156.427
```

```
  TOTAL SUBBLOCK
  CYCLE   CYCLE      KMAX       KMIN     DELTAK      R     DADN      DA          A   A/T

BLOCK  6
      6        1    108.41      0.00    108.41   0.00  1.9E-03 0.0019     1.3364 0.25

BLOCK  12
     12        1    108.78      0.00    108.78   0.00  1.9E-03 0.0019     1.3480 0.25

BLOCK  18
     18        1    109.16      0.00    109.16   0.00  2.0E-03 0.0020     1.3597 0.26

BLOCK  24
     24        1    109.54      0.00    109.54   0.00  2.0E-03 0.0020     1.3715 0.26

BLOCK  30
     30        1    109.92      0.00    109.92   0.00  2.0E-03 0.0020     1.3834 0.26

BLOCK  36
     36        1    110.30      0.00    110.30   0.00  2.0E-03 0.0020     1.3955 0.26

BLOCK  42
     42        1    110.68      0.00    110.68   0.00  2.0E-03 0.0020     1.4077 0.27

BLOCK  48
     48        1    111.07      0.00    111.07   0.00  2.1E-03 0.0021     1.4201 0.27

BLOCK  54
     54        1    111.46      0.00    111.46   0.00  2.1E-03 0.0021     1.4326 0.27

BLOCK  60
     60        1    111.84      0.00    111.84   0.00  2.1E-03 0.0021     1.4453 0.27

BLOCK  66
     66        1    112.22      0.00    112.22   0.00  2.1E-03 0.0021     1.4581 0.28

BLOCK  72
     72        1    112.61      0.00    112.61   0.00  2.2E-03 0.0022     1.4710 0.28
```

```
BLOCK  78
     78        1    113.01      0.00    113.01   0.00  2.2E-03 0.0022    1.4841 0.28

BLOCK  84
     84        1    113.40      0.00    113.40   0.00  2.2E-03 0.0022    1.4974 0.28

BLOCK  90
     90        1    113.79      0.00    113.79   0.00  2.2E-03 0.0022    1.5108 0.29

BLOCK  96
     96        1    114.19      0.00    114.19   0.00  2.3E-03 0.0023    1.5243 0.29

BLOCK  102
    102        1    114.59      0.00    114.59   0.00  2.3E-03 0.0023    1.5380 0.29

BLOCK  108
    108        1    114.98      0.00    114.98   0.00  2.3E-03 0.0023    1.5519 0.29

BLOCK  114
    114        1    115.37      0.00    115.37   0.00  2.3E-03 0.0023    1.5659 0.30

BLOCK  120
    120        1    115.78      0.00    115.78   0.00  2.4E-03 0.0024    1.5801 0.30

BLOCK  126
    126        1    116.20      0.00    116.20   0.00  2.4E-03 0.0024    1.5945 0.30

BLOCK  132
    132        1    116.71      0.00    116.71   0.00  2.4E-03 0.0024    1.6090 0.30

BLOCK  138
    138        1    117.22      0.00    117.22   0.00  2.5E-03 0.0025    1.6238 0.31

BLOCK  144
    144        1    117.75      0.00    117.75   0.00  2.5E-03 0.0025    1.6387 0.31

BLOCK  150
    150        1    118.28      0.00    118.28   0.00  2.5E-03 0.0025    1.6540 0.31

BLOCK  156
```

```
     156        1   118.81      0.00   118.81  0.00  2.6E-03 0.0026   1.6694 0.31

BLOCK  162
     162        1   119.35      0.00   119.35  0.00  2.6E-03 0.0026   1.6850 0.32

BLOCK  168
     168        1   119.89      0.00   119.89  0.00  2.7E-03 0.0027   1.7009 0.32

BLOCK  174
     174        1   120.44      0.00   120.44  0.00  2.7E-03 0.0027   1.7171 0.32

BLOCK  180
     180        1   120.99      0.00   120.99  0.00  2.7E-03 0.0027   1.7335 0.33

BLOCK  186
     186        1   121.56      0.00   121.56  0.00  2.8E-03 0.0028   1.7501 0.33

BLOCK  192
     192        1   122.12      0.00   122.12  0.00  2.8E-03 0.0028   1.7670 0.33

BLOCK  198
     198        1   122.69      0.00   122.69  0.00  2.9E-03 0.0029   1.7841 0.34

BLOCK  204
     204        1   123.27      0.00   123.27  0.00  2.9E-03 0.0029   1.8016 0.34

BLOCK  210
     210        1   123.85      0.00   123.85  0.00  3.0E-03 0.0030   1.8192 0.34

BLOCK  216
     216        1   124.44      0.00   124.44  0.00  3.0E-03 0.0030   1.8372 0.35

BLOCK  222
     222        1   125.04      0.00   125.04  0.00  3.1E-03 0.0031   1.8555 0.35

BLOCK  228
     228        1   125.64      0.00   125.64  0.00  3.1E-03 0.0031   1.8740 0.35

BLOCK  234
     234        1   126.25      0.00   126.25  0.00  3.2E-03 0.0032   1.8929 0.36
```

```
pc-CRACK  VERSION 2.1                                                       PAGE     6

BLOCK  240
    240        1   126.87      0.00    126.87  0.00  3.2E-03 0.0032   1.9120 0.26

                                END OF pc-CRACK
```

```
                                        tm
                                 pc-CRACK
                        (C) COPYRIGHT 1984, 1990
                  STRUCTURAL INTEGRITY ASSOCIATES, INC.
                      SAN JOSE, CA (408)978-8200
                              VERSION 2.1

Date:  5-Jun-1992
Time: 12:52:10.75

                         FATIGUE CRACK GROWTH ANALYSIS


ANO-1 CODE CASE N-481 EVALUATION - LOCATION NO.5 (3-D MODEL)

INITIAL CRACK SIZE=  1.3250
WALL THICKNESS=  5.3000
MAX CRACK SIZE FOR FCG=  2.6500

PARIS CRACK GROWTH LAW:
  da/dN = C * (dK)^n
where
      dK = Kmax - Kmin
      dK > dKthres
   Kmax < Kic

CURRENT
LAWS:        LAW ID        C           n      dKthres      Kic
         PWR WATER  3.680E-10      3.300      0.000    135.500


                             STRESS COEFFICIENTS
   CASE ID          CO          C1          C2          C3
NORMAL-PRI    18.0000      0.0000      0.0000      0.0000
NORMAL-SEC    28.0000    -10.5660      0.0000      0.0000
  EMER-PRI    19.0000      0.0000      0.0000      0.0000
  EMER-SEC    29.6000    -11.1700      0.0000      0.0000
NORMAL-RNG    48.0000    -11.3208      0.0000      0.0000


NUMBER OF CYCLE BLOCKS=                    240
PRINT INCREMENT OF CYCLE BLOCK=              6

                NUMBER OF    CALCULATION          PRINT      FCG
  SUBBLOCK         CYCLES      INCREMENT      INCREMENT     LAW ID
         1              1              1              1  PWR WATER

                 Kmax                              Kmin
SUBBLOCK     CASE ID   SCALE FACTOR       CASE ID   SCALE FACTOR
       1 NORMAL-RNG      1.0000        NORMAL-RNG      0.0000

crack model:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSE

     CRACK ----------------STRESS INTENSITY FACTOR----------------
```

```
       SIZE          CASE          CASE          CASE          CASE          CASE
               NORMAL-PRI   NORMAL-SEC     EMER-PRI      EMER-SEC   NORMAL-RNG

     0.0530         7.709        11.785         8.195        12.459        20.354
     0.1060        10.916        16.488        11.604        17.430        28.861
     0.1590        13.385        19.974        14.229        21.116        35.129
     0.2120        15.474        22.811        16.450        24.114        40.311
     0.2650        17.322        25.221        18.414        26.662        44.787
     0.3180        18.998        27.318        20.196        28.879        48.753
     0.3710        20.545        29.172        21.840        30.838        52.326
     0.4240        21.990        30.828        23.377        32.589        55.582
     0.4770        23.352        32.318        24.824        34.165        58.576
     0.5300        24.644        33.366        26.198        35.590        61.346
     0.5830        25.986        34.877        27.625        36.870        64.020
     0.6360        27.287        35.976        29.008        38.032        66.532
     0.6890        28.553        36.976        30.354        39.088        68.900
     0.7420        29.788        37.884        31.667        40.048        71.140
     0.7950        30.996        38.709        32.951        40.921        73.263
     0.8480        32.181        39.457        34.210        41.712        75.280
     0.9010        33.344        40.134        35.447        42.427        77.198
     0.9540        34.489        40.745        36.664        43.073        79.027
     1.0070        35.617        41.294        37.863        43.653        80.772
     1.0600        36.730        41.784        39.047        44.171        82.438
     1.1130        37.808        42.389        40.193        44.811        84.192
     1.1660        38.873        42.950        41.325        45.404        85.885
     1.2190        39.926        43.469        42.444        45.952        87.521
     1.2720        40.967        43.948        43.551        46.458        89.102
     1.3250        41.998        44.388        44.647        46.924        90.632
     1.3780        43.020        44.793        45.733        47.352        92.114
     1.4310        44.034        45.163        46.81[illegible]        47.743        93.549
     1.4840        45.039        45.499        47.880        48.098        94.940
     1.5370        46.037        45.803        48.941        48.420        96.290
     1.5900        47.029        46.076        49.995        48.708        97.599
     1.6430        48.300        46.382        51.346        49.031        99.230
     1.6960        49.574        46.660        52.700        49.326       100.836
     1.7490        50.852        46.913        54.059        49.593       102.417
     1.8020        52.133        47.141        55.421        49.834       103.975
     1.8550        53.419        47.345        56.788        50.049       105.512
     1.9080        54.708        47.525        58.159        50.239       107.027
     1.9610        56.002        47.682        59.534        50.406       108.523
     2.0140        57.300        47.817        60.914        50.548       109.999
     2.0670        58.[illegible]03        47.930        62.299        50.668       111.456
     2.1200        59.910        48.023        63.688        50.766       112.896
     2.1730        61.371        48.500        65.242        51.270       114.906
     2.2260        62.841        48.967        66.804        51.764       116.913
     2.2790        64.319        49.424        68.375        52.247       118.919
     2.3320        65.805        49.872        69.955        52.721       120.923
     2.3850        67.300        50.310        71.544        53.184       122.926
     2.4380        68.803        50.740        73.142        53.638       124.927
     2.4910        70.314        51.160        74.749        54.083       126.928
     2.5440        71.834        51.573        76.364        54.518       128.928
     2.5970        73.362        51.977        77.989        54.945       130.9[illegible]9
     2.6500        74.899        52.372        79.622        55.364       132.9[illegible]
```

```
  TOTAL SUBBLOCK
  CYCLE   CYCLE        KMAX       KMIN    DELTAK      R     DADN      DA          A   A/T
BLOCK  6
      6       1       90.78       0.00     90.78   0.00  1.1E-03 0.0011     1.3314 0.25

BLOCK  12
     12       1       90.96       0.00     90.96   0.00  1.1E-03 0.0011     1.3378 0.25

BLOCK  18
     18       1       91.14       0.00     91.14   0.00  1.1E-03 0.0011     1.3442 0.25

BLOCK  24
     24       1       91.32       0.00     91.32   0.00  1.1E-03 0.0011     1.3507 0.25

BLOCK  30
     30       1       91.50       0.00     91.50   0.00  1.1E-03 0.0011     1.3573 0.26

BLOCK  36
     36       1       91.69       0.00     91.69   0.00  1.1E-03 0.0011     1.3639 0.26

BLOCK  42
     42       1       91.87       0.00     91.87   0.00  1.1E-03 0.0011     1.3705 0.26

BLOCK  48
     48       1       92.06       0.00     92.06   0.00  1.1E-03 0.0011     1.3772 0.26

BLOCK  54
     54       1       92.24       0.00     92.24   0.00  1.1E-03 0.0011     1.3839 0.26

BLOCK  60
     60       1       92.43       0.00     92.43   0.00  1.1E-03 0.0011     1.3906 0.26

BLOCK  66
     66       1       92.61       0.00     92.61   0.00  1.1E-03 0.0011     1.3974 0.26

BLOCK  72
     72       1       92.79       0.00     92.79   0.00  1.1E-03 0.0011     1.4043 0.26
```

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pc-CRACK  VERSION 2.1                                                           PAGE    4

BLOCK  78
     78        1     92.98      0.00      92.98  0.00  1.2E-03 0.0012    1.4112 0.27

BLOCK  84
     84        1     93.17      0.00      93.17  0.00  1.2E-03 0.0012    1.4181 0.27

BLOCK  90
     90        1     93.36      0.00      93.36  0.00  1.2E-03 0.0012    1.4251 0.27

BLOCK  96
     96        1     93.55      0.00      93.55  0.00  1.2E-03 0.0012    1.4321 0.27

BLOCK  102
    102        1     93.73      0.00      93.73  0.00  1.2E-03 0.0012    1.4392 0.27

BLOCK  108
    108        1     93.92      0.00      93.92  0.00  1.2E-03 0.0012    1.4463 0.27

BLOCK  114
    114        1     94.11      0.00      94.11  0.00  1.2E-03 0.0012    1.4535 0.27

BLOCK  120
    120        1     94.30      0.00      94.30  0.00  1.2E-03 0.0012    1.4607 0.28

BLOCK  126
    126        1     94.49      0.00      94.49  0.00  1.2E-03 0.0012    1.4680 0.28

BLOCK  132
    132        1     94.68      0.00      94.68  0.00  1.2E-03 0.0012    1.4753 0.28

BLOCK  138
    138        1     94.87      0.00      94.87  0.00  1.2E-03 0.0012    1.4827 0.28

BLOCK  144
    144        1     95.06      0.00      95.06  0.00  1.2E-03 0.0012    1.4901 0.28

BLOCK  150
    150        1     95.25      0.00      95.25  0.00  1.2E-03 0.0012    1.4976 0.28

BLOCK  156
```

```
     156        1     95.45      0.00      95.45  0.00  1.3E-03 0.0013   1.5051 0.28

BLOCK  162
     162        1     95.64      0.00      95.64  0.00  1.3E-03 0.0013   1.5127 0.29

BLOCK  168
     168        1     95.83      0.00      95.83  0.00  1.3E-03 0.0013   1.5203 0.29

BLOCK  174
     174        1     96.03      0.00      96.03  0.00  1.3E-03 0.0013   1.5280 0.29

BLOCK  180
     180        1     96.22      0.00      96.22  0.00  1.3E-03 0.0013   1.5357 0.29

BLOCK  186
     186        1     96.42      0.00      96.42  0.00  1.3E-03 0.0013   1.5434 0.29

BLOCK  192
     192        1     96.61      0.00      96.61  0.00  1.3E-03 0.0013   1.5513 0.29

BLOCK  198
     198        1     96.80      0.00      96.80  0.00  1.3E-03 0.0013   1.5591 0.29

BLOCK  204
     204        1     97.00      0.00      97.00  0.00  1.3E-03 0.0013   1.5671 0.30

BLOCK  210
     210        1     97.20      0.00      97.20  0.00  1.3E-03 0.0013   1.5750 0.30

BLOCK  216
     216        1     97.40      0.00      97.40  0.00  1.3E-03 0.0013   1.5831 0.30

BLOCK  222
     222        1     97.59      0.00      97.59  0.00  1.4E-03 0.0014   1.5912 0.30

BLOCK  228
     228        1     97.84      0.00      97.84  0.00  1.4E-03 0.0014   1.5993 0.30

BLOCK  234
     234        1     98.10      0.00      98.10  0.00  1.4E-03 0.0014   1.6075 0.30
```

```
pc-CRACK  VERSION 2.1                                                          PAGE    6

BLOCK  240
    240        1     98.35      0.00      98.35  0.00  1.4E-03 0.0014    1.6158 0.30

                                   END OF pc-CRACK
```