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September 26, 1999

ICAN099907

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

Subject: Arkansas Nuclear One - Unit 1
Docket No. 50-313
License No. DPR-51
ANO-1 Relief Request For LPI/DHR Pump Casing Repair

Gentlemen:

On September 20, 1999, while performing a period pressure test on the "B" loop of the Arkansas Nuclear One-Unit One (ANO-1) decay heat removal system, a pin hole leak was detected on the casing of the decay heat removal (DHR)/ low pressure injection (LPI) pump. Evidence of the leak was in the form of a boric acid buildup on the pump casing with no measurable water leakage present.

The leak was believed to have originated from a shrinkage flaw created during original fabrication of the pump casing. Based on liquid penetrant testing and visual observation of the flawed areas and adjacent areas in the pump casing there was no sign of service induced defects. Efforts were undertaken to perform an ASME Code repair of the flaw. The area around and into the pin hole leak was excavated to determine the flaw extent. However, due to the location and the nature of the flaw, successful repairs in accordance with ANO-1's current 1992 ASME Code Edition for Section XI could not be reasonably performed without potentially causing additional damage to the casing. Entergy Operations has performed a structural flaw evaluation using the guidance of Section IWA-4422.2.2 (2) of the 1998 Edition of ASME Section XI and a weld repair. Therefore, ANO requests that an alternative be allowed in accordance with 10CFR50.55a (a)(3)(i) and (ii) as discussed in Enclosure 1. Enclosures 2 and 3 are the stress analysis and flaw evaluation summaries referenced in the enclosed alternative. The actual flaw analysis as specified by IWC-3134 will be provided in separate letter.

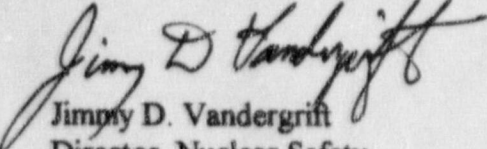
ANO is currently in refueling outage 15 (1R15). The fuel has been offloaded into the spent fuel pool and core reload is in progress. The ANO-1 technical specifications require that both decay heat pumps be operable prior to draining down the fuel transfer canal. Draindown is currently scheduled to begin on the evening of September 30, 1999. In order to return the pump to operable status to support the outage schedule, Entergy Operations requests NRC review and approval of the alternative on an expedited basis by September 30, 1999.

9910060242 990926
PDR ADOCK 05000313
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AD47/11

Please contact me if you have any questions.

Very truly yours,



Jimmy D. Vandergrift
Director, Nuclear Safety

JDV/sab
Attachments

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ENTERGY OPERATIONS, INC.

**ARKANSAS NUCLEAR ONE – UNIT 1
3rd TEN YEAR INTERVAL
REQUEST NO. 99-1-001, Revision 0**

**ENTERGY OPERATIONS, INC.
ARKANSAS NUCLEAR ONE – UNIT 1
3 rd TEN YEAR INTERVAL
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I. COMPONENT IDENTIFICATION

Code Class:	2
Examination Category:	C-H
Item No.:	C7.50
Examination Required:	VT-2 Inspection
Description:	Low Pressure Injection/Decay Heat Removal Pump
Component Number:	P-34B
References:	<ol style="list-style-type: none">1. ASME Section XI, 1992 Edition with portions of the 1993 Addenda as listed in the ISI program.2. Draft ASME Code For Pumps And Valves For Nuclear Power (1968)3. ASME Section XI, 1998 Edition, IWA-4422.2.2 (2) and IWA-4422.1(b)4. Letter AFD-99-068, "Stress Analysis for Decay Heat Removal Pump", 9/26/995. Letter AFD-99-069, "Evaluation of Flaw Remaining After Repair of Decay Heat Removal Pump P-34B", 9/26/99

II. REQUIREMENTS

In accordance with Reference 1 and Examination Category C-H, Class 2 pumps are required to receive a system leakage test once each inspection period. The test is performed in accordance with IWC-5220 with acceptance of the test results in accordance with IWC-3516. IWC-3516 is in the course of preparation with

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reference to IWB-3522 as an alternative. IWB-3522 requires leakage to be corrected to meet the requirements of IWB-3241 (IWC- 3130) and IWA-5250. IWC-3130 is generically written to apply to all inservice visual examinations and allows for acceptance of relevant conditions through various approaches including repair and reexamination. However, IWA-5250 specifically requires sources of leakage to be located and if it does not originate from a buried component or a mechanical connection, the source of leakage is to be repaired or replaced in accordance with IWA-4000.

When repair is the elected method for correcting the source of leakage, IWA-4170 requires the repair to be in accordance with the Original Construction Code with provisions to use later Editions of the Constructor Code or Section III. Reference 2 requires cast materials to be repaired by removal of the defect or by reduction of the defect to an acceptable size. The excavated area is required to be surface examined and the results compared to the acceptance criteria applicable to the product form. Once the defect is either removed or reduced to an acceptable size, repair by welding is permitted to restore the affected area to the required section thickness. The completed repair is then examined in accordance with the Code used in the repair process.

III. REQUESTED ALTERNATIVE

During performance of a scheduled Section XI pressure test in accordance with Reference 1, evidence of leakage was detected on the surface of the Arkansas Nuclear One – Unit 1 (ANO-1) low pressure injection (LPI)/ decay heat removal (DHR) pump. The leakage was located at approximately bottom dead center of the pump casing in an inside radius where the pump casing and pump casing volute intersect (See Attachment 1). From careful observation, weepage was identified from a rounded indication appearing as a pit. The pit or opening measured approximately 0.062 inches in diameter.

The component is a horizontal centrifugal pump manufactured by Babcock and Wilcox, Canada, and has been in service for approximately 25 years. The pump was designed and constructed to the requirements of Reference 2 and is manufactured from ASTM A-351 CF8 (304) material. During normal operation the pump is maintained in standby for ECCS function and its only active operation occurs during quarterly surveillance tests, 18 month system flow tests, refuel outages for decay heat removal, and once each period for the ASME Section XI pressure testing.

During the repair process described in Section II, it was determined that the flaw permitting the through wall leak could not be completely removed or reduced to an acceptable size as required by the Construction Code governing the repair. Alternatively, the flawed area was excavated from the outside surface to a depth

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of approximately 0.500 inches leaving a remaining ligament of approximately 1.250 inches. As the excavation gained depth the flaw changed from a rounded indication into a linear indication with a length of approximately 0.750 inches at the depth when excavation was ceased.

As an alternative to meeting the requirements described in Section II of this request, it is proposed that the repaired area including the remaining flaw be evaluated using the flaw evaluation provisions of ASME Section XI. With these provisions, a surface examination of the excavated area and removal of the flaw or reduction of the flaw size to meet the Construction Code is not required provided:

The defect removal area and any remaining portion of the defect is evaluated in accordance with the flaw evaluation provisions of ASME Section XI, or the design provisions of the Owner's Requirements and either the Construction Code or ASME Section III.

Under this process the repair described above, including welding of the excavated area, is acceptable and the component may be returned to service.

IV. BASIS FOR ALTERNATIVE

Pursuant to the provisions of 10 CFR 50.55a(a)(3)(i) and (ii) it is requested that the repair criteria contained in Reference 3 and described in Section III of this request be approved. Compliance with the repair rules as stated in Reference 2 and as described in Section II of this request, or replacement of the pump will result in hardship and unusual difficulty without a compensating increase in the level of quality and safety. Additionally, the proposed alternative does provide a level of quality and safety as demonstrated by analysis.

The option of complete or partial pump replacement was explored without success. A thorough search for a like-for-like replacement from appropriate pump manufacturers and other Owners determined that pumps meeting the design requirements for the ANO-1 application are not available. The one possible replacement required complete re-qualification and repairs to correct tolerance and out of round conditions within the pump. Other possible replacements would have resulted in a reduction in pump margin and performance or new pump procurement with corresponding long lead times for manufacture.

After a significant attempt to perform the repair as described in Section II, it was determined that the pump could be rendered unacceptable for continued service. Prior to performing repairs, ASME Section XI, IWA-4150 requires a suitability evaluation to ensure that the selected repair process will not be subject to the same degradation mechanism. To support this evaluation and prior to authorizing

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repairs, the pump was disassembled for evaluation. Areas in the vicinity of the leak were examined on the pump's outside surface and inside surface by liquid penetrant, visual, and radiography to the extent possible. All nondestructive evaluations concluded that there was no evidence of service induced degradation and that only flaws representative of manufacturing imperfections were identified. Additionally, the radiographs identified areas of casting shrink in the area noted on Attachment 2 which is directly behind the excavated cavity and in the same plane as the flaw causing the leakage. Because of the physical evidence and the following discussion, it is concluded that the leakage source resulted from a manufacturing flaw.

Pump Casing Flaw Characterization

Cast austenitic stainless steel is not generally susceptible to environmentally induced degradation in light water reactors. The presence of the duplex stainless steel microstructure provides excellent resistance to pitting, stress corrosion cracking, corrosion fatigue and flow assisted corrosion. This DHR pump is fabricated from an ASTM A351-CF8 casting with a carbon level of 0.07 wt % and a calculated ferrite number (FN) of 10.

The following identifies the potential degradation mechanisms that could result in a through-wall leak and discusses their likelihood of occurrence:

Fatigue:

The DHR pump casing is subjected to pressure and thermal stresses. The pressure stresses are expected to be quite low (due to pressure less than 450 psig), and would not lead to growth of flaws. Upon startup in the decay heat removal mode, reactor water at up to 280°F can hot shock the inside of the pump, producing a shock of about 210°F. This would have occurred on the order of 100 times. There are also quarterly surveillance tests, but these are at a lower pressure (less than about 200 psig) and entail no significant thermal shock.

The thermal shock is such that a compressive inside surface stress occurs. This type stress would not tend to initiate thermal fatigue cracking. In addition, the observed inside indications are not characteristic of thermal fatigue. Fatigue cracks tend to grow in both the depth and length directions. Thus, thermal fatigue is ruled out as a mechanism causing the leakage.

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Erosion-Corrosion:

High alloy steels are not susceptible to erosion-corrosion (flow assisted corrosion) due to the high alloy content. Even though there would be extremely high velocities locally at the pump outlet, there has been no history of this type of damage. This mechanism also does not lead to local through-wall leakage such as observed in the decay heat removal pump case. Additionally, this phenomenon would be detectable by visual observation during pump disassembly. There was no evidence of erosion-corrosion.

Cavitation-Corrosion:

This type of damage occurs when relatively low pressure water is pumped at high velocities. When the local pressure becomes less than the saturation pressure, vapor bubble formation and collapse causes work hardening and damage that can cause wall thinning. This is not expected at the exit of the DHR pump since the developed head is several hundred psi greater than the inlet pressure. Thus, any local damage should not be due to this mechanism. It does not lead to local through-wall leaks. Again, this phenomenon would be detectable by visual observation during pump disassembly. There was no evidence of cavitation-corrosion.

Stress Corrosion Cracking:

Intergranular stress corrosion cracking (IGSCC) in stainless steels is a well known phenomenon. In the presence of an oxygenated environment, tensile stress and a susceptible material, cracking at the grain boundaries can occur. IGSCC can lead to through-wall cracking, exhibiting crack-like indications at the inner surface and growing to the outside of the component. The fact that the water in the DHR pump contains oxygen makes IGSCC a possible cracking mechanism. Weld repairs (if present) or local casting shrinkage could produce some local residual stresses.

In NUREG 0313, Rev. 2, this phenomenon was addressed for boiling water reactors. Here, it is stated that cast stainless steels with FN greater than 7.5 are highly resistant to IGSCC even as welded. In the as cast and solution annealed condition, IGSCC is extremely unlikely. The FN for Heat A815, used for the pump casing, has a computed FN of 10, so the pump casing would be resistant to IGSCC, even if there had been weld repairs in the vicinity of the leak. Additionally, the pump casing was solution annealed after repairs. Thus, considering the condition of the cast pump, including no evidence of sensitization and the high ferrite level, IGSCC is not suspected to be a contributor.

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It is suspected that there may have been a sodium thiosulfate intrusion into portions of the decay heat removal system early in plant life. This material could have contributed to IGSCC cracking at the time, but its effect should have been seen much more in welds of wrought piping as it was seen in other systems. In addition, it would have been washed out of any defects in the DHR pump casing, so its contribution is rejected as a contributor to IGSCC at the leak.

Fabrication-Induced Flaws:

The DHR pump is a complex casting. At the intersection of the volute and the cylindrical casing, there is a discontinuity. In this area there is a structural connection between the two sides of the volute to withstand the pressure-induced stresses. This area could have been difficult to fill with molten material, and the cooling of the material could have resulted in local high stresses or some shrinkage-induced voids at the location of the flaw. In fact, there are some small but acceptable indications on the inside of the pump in the region of the leakage, and radiography did detect areas of shrinkage as shown in Attachment 2.

Pump Vibration:

Vibrational stresses in a large pump casing are generally not large, and would have been detected by pump vibration monitoring. Vibrational fatigue is generally seen in "cantilever" drain lines or similar small bore piping, that is excited (dynamically amplified) due to the pump or pump vane-passing frequency. This amplification cannot occur in the pump casing, where cyclic stresses would be due mainly to the pressure pulsations in the pump. These are expected to be small, such that pump vibration can be ruled out as a cause of the leak.

Based on the available evidence and the discussion above, it is believed that repair of a single isolated flaw is not possible. As the excavation began and advanced toward the area of complex geometry the flaw began to assume an appearance of cast shrinkage. Understanding this type casting imperfection and its location in the pump casing, it was concluded that any attempt to completely remove or reduce the flaw to an acceptable size would result in the removal of significant material from the pump casing. This type of excavation may result in a configuration that cannot be repaired by welding from inside the pump without major machining. Additionally, because shrink is inherent to the design of the casting mold, it is likely to be present in the same location around the pump casing. Attempting to chase indications being identified by the liquid penetrant method could eventually result in the complete destruction of the pump casing.

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However, the presence of shrink does not jeopardize the structural integrity of the pump.

As proposed by the alternative and described in Reference 3, an appropriate flaw evaluation has been performed demonstrating acceptability of the pump for continued service. A description of the evaluation and its results is provided below:

The geometry, materials and results of the stress analysis are described in Reference 4. Measurements taken during the cavity excavation and following the weld repair process show that the excavated cavity was 0.5 inches in depth as measured from the original outside surface in the region of the intersection between the pump casing and volute. In the finite element modeling, this region was modeled with a total diagonal thickness of 1.75 inches. This yields a flaw depth-to-thickness ratio (a/t) equal to 0.715. This is less than the maximum allowable size for flaws in austenitic stainless steel piping per Section XI IWB-3640 of $a/t = 0.75$.

During the cavity excavation, it was determined that there was a linear indication at the bottom of the cavity with length direction parallel to the volute/pump bowl casing intersection. During the excavation of the outside surface flaw, it appeared that the subsurface portion of the flaw was going in the direction of the pump impeller cavity, not toward the volute cavity.

Flaw Evaluation:

Flaw models do not specifically exist for evaluation of flaw geometry similar to that expected to remain under the repair cavity. Thus, conservative analysis was conducted to show that significant margin exists relative to that required by ASME Section XI. Section XI does not have specific evaluation criteria for pump casings, so the approach and philosophy for performing evaluations of austenitic stainless steel piping were conservatively applied.

Review of the stress analysis in Reference 4 shows that the stress in the vicinity of the path between the excavation and the inner pump bowl region (Path 2 of Reference 4) is approximately the same as that which exists in the pump casing just above the casing-to-volute transition region. Thus, to show that significant margin exists, the maximum principal membrane stress at Path 2 of Reference 4 was used in a fracture mechanics model representative of Path 3. This analysis will be bounding compared to analysis at Path 2. Since the stresses at Path 1 of reference 4 are much lower, it is also expected to be bounding for that location, should

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there potentially be any flaws between the outside of the pump and the volute region. The source equations of Appendix C of Section XI are used for the evaluation.

The decay heat removal pump is constructed of A351 Grade CF8 304 stainless steel. The allowable flow stress of the material is based on the maximum expected temperature conditions in the pump of 280°F. The flow stress is based on the average of the yield stress and the ultimate tensile strength, giving a value of 42.7 ksi, which is more conservative than the Class 1 piping allowable of 3Sm (60 ksi) in Appendix C.

For evaluating the allowable depth of a flaw running around the pump, the flaw was evaluated as a part through-wall flaw. The analysis was conducted using a membrane stress in the pump case due to the axial loading on the closure of 1.706 ksi derived from Path 2 as discussed above. Since the weld repair was made using the GTAW process, a Z-factor of 1.0 was assumed and no effects of thermal stresses or other secondary stresses were included. The bending stresses across the pump cross section are not significant. Since the loading is due to pressure and not due to pressure plus bending (as in the case of piping), a safety factor of 3.0 was used instead of 2.77 as in Appendix C. This analysis shows that a flaw depth of $a/t = 0.914$ would meet Section XI stress criteria for a part through-wall flaw extending completely around the pump. This is significantly greater than the actual flaw which remains.

Since the exact orientation of the flaw could not be determined using volumetric examination, similar analysis was conducted to evaluate potential axial flaws. The Appendix C model for allowable axial flaws was used. Based on the pump casing thickness in this region and pump discharge pressure, it was shown that a part-depth flaw with $a/t = 0.914$ would be acceptable for a flaw length of 4.4 inches. For $a/t = 0.75$, the allowable length would be 23 inches.

To show the flaw tolerance of the pump, a similar analysis was conducted using the Appendix C equations for a circumferential through-wall flaw in the pump casing. Using the same assumptions and stresses as for the part-through-wall flaw, the analysis shows that a through-wall flaw of slightly greater than 58 percent of the circumference would be acceptable. This flaw size is many times larger than the through-wall which led to detection of the leakage. This supports the argument that visual monitoring for leakage can be an effective approach for detecting any future through-wall defect prior to it affecting structural integrity of the decay heat removal pump.

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The introduction of hot water at up to 280°F into the pump results in a thermal shock that could potentially contribute to crack growth. The maximum observed thermal stress on the inner portion of the pump was 71.5 ksi compression, rapidly increasing up to 34.9 ksi tension on the outer portions of the pump. Using the Section XI, Appendix A model for an $a/t = 0.75$ flaw with aspect ratio of $a/l = 0.5$, and conservatively assuming a linear stress profile results in a deepest point stress intensity factor of $22.19 \text{ ksi-in}^{1/2}$. Using the Appendix C crack growth curve for air, multiplied by a factor of 2 to account for PWR water effects and $R = 0$ (since the stress intensity factor is negative), results in a crack growth rate of 4.5×10^{-6} inches per cycle. For an assumed 480 cycles (twice the design number of heatup/cool-down cycles), the resulting crack growth is computed to be 0.0043 inches. This is negligible such that the $a/t = 0.715$ flaw will never approach the Code allowable $a/t = 0.75$ flaw.

V. ALTERNATIVE EXAMINATIONS

In accordance with the ANO-1 ISI program and Reference 2, the pump is pressure tested and VT-2 visually inspected once each period. In addition to this test, Entergy proposes to also perform a VT-2 inspection during the surveillance tests that are conducted quarterly. The additional inspection will be limited to the area of the pump where the volute intersects the pump casing and will be performed for one complete operating cycle. If leakage is not identified, the augmented VT-2 inspections will be terminated and pressure testing will be performed once each period as described in Reference 2.

VI. WHY THE ALTERNATIVE SHOULD BE GRANTED

The flaw evaluation described in Section IV, demonstrates the extreme flaw tolerance of the LPI/DHR pump. The evaluation has conservatively assumed a crack-like flaw configuration and shows that a through-wall crack for 58% of the casing's circumference is acceptable. Also, the evaluation shows that a 90% through-wall crack for 100% of the casing circumference is also acceptable. Because the condition being evaluated is a result of casting imperfections, it could not be assured that components of the flaw did not also assume an axial direction. Therefore, the evaluation was extended to address axial flaw tolerance. In the axial direction for a 90% through-wall flaw, 4.4 linear inches was shown to be acceptable and for a 75% through-wall flaw, 23 linear inches is acceptable. Recognizing this evaluation conservatively bounds the behavior of imperfections caused by the manufacturing process, it is clearly demonstrated that obvious leakage would occur before any mechanism could progress to an extent that would challenge the pump's structural integrity.

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Observations of the leakage source identified a rounded opening approximately 0.062 inches in diameter. This condition is not indicative of a service induced flaw that would have propagated through the outer surface with linear characteristics. However, the leakage source is characteristic of a manufacturing imperfection, such as shrinkage. Over time the solution impurities from the casting process contained at the grain boundaries or within the flaws may have eventually given way to small mechanical stresses and allowed for the development of a tortuous leak path.

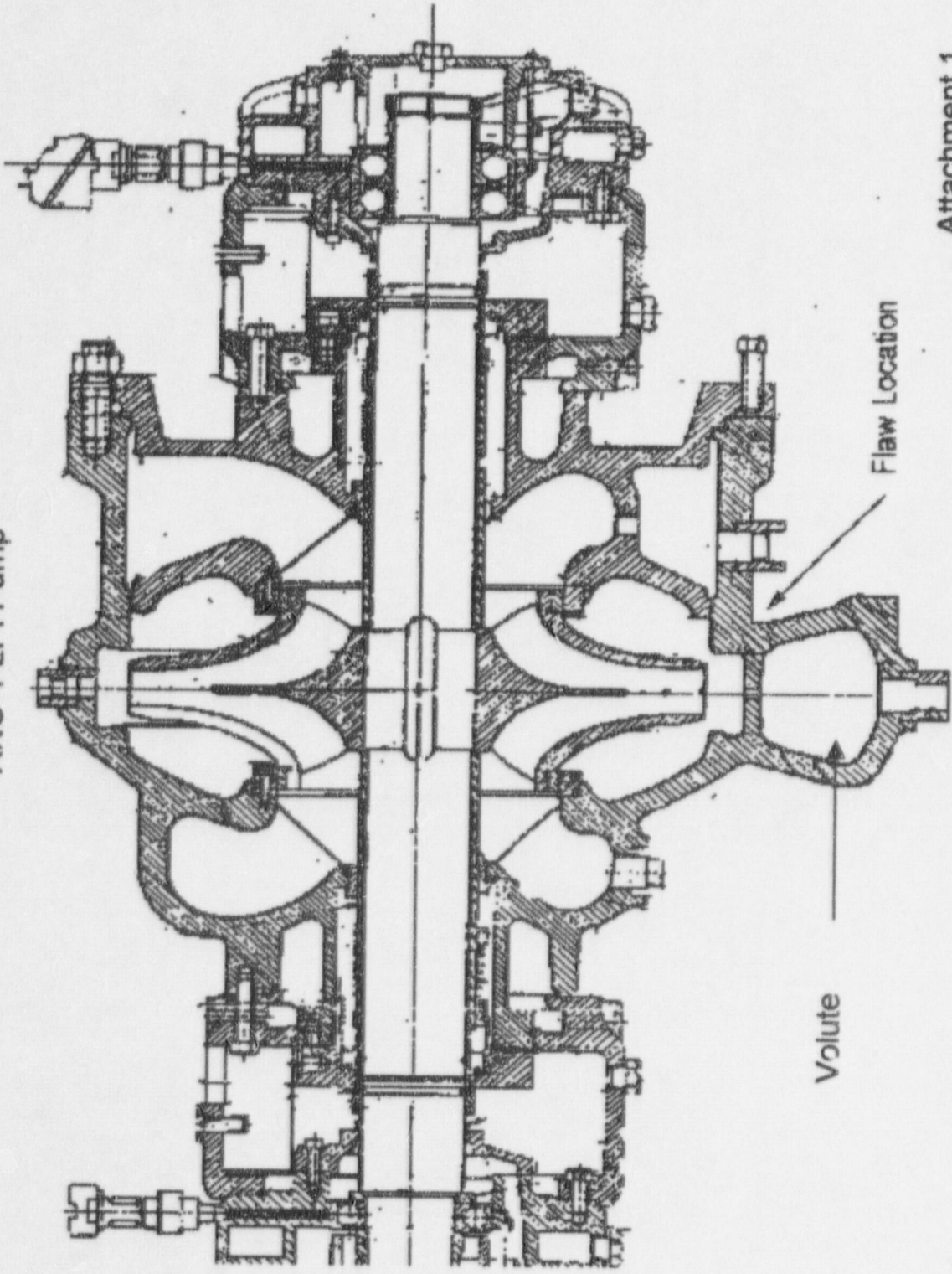
The remaining flaw in the repaired area is shown to meet the acceptance criteria of ASME Section XI and even with a projected flaw growth based on a number of cycles twice the total design life cycles, the resulting flaw size is also acceptable.

The repair and evaluations described within this request for the alternative have been performed to the guidance of ASME Section XI, 1998 Edition (Reference 3). Although this Edition is not yet endorsed by the NRC in 10 CFR 50.55a, it has been prepared and approved by the ASME with the support of technical authorities and a consensus process. It is believed by Entergy and the ASME that this approach provides an acceptable level of quality and safety.

In the event that the proposed alternative is not acceptable, the remaining option would require complete disassembly of the pump and removal of the pump casing from its foundation to allow for shop repair. Due to the extent of repair anticipated to achieve an acceptable liquid penetrant examination, it is likely that the casing would require solution heat treatment to prevent other degradation mechanisms. Because of the extreme heat from welding and heat treatment, the casing would then require a complete re-machining with possible re-welding to restore clearances and roundness. Repair to this extent would result in a pump casing of lesser quality than that currently in place with the casting imperfections and the local repair weld.

Therefore, Entergy Operations believes that the proposed alternative meets the criteria of 10 CFR 50.55a(a)(3)(i) and (ii).

ANO-1 LPI Pump

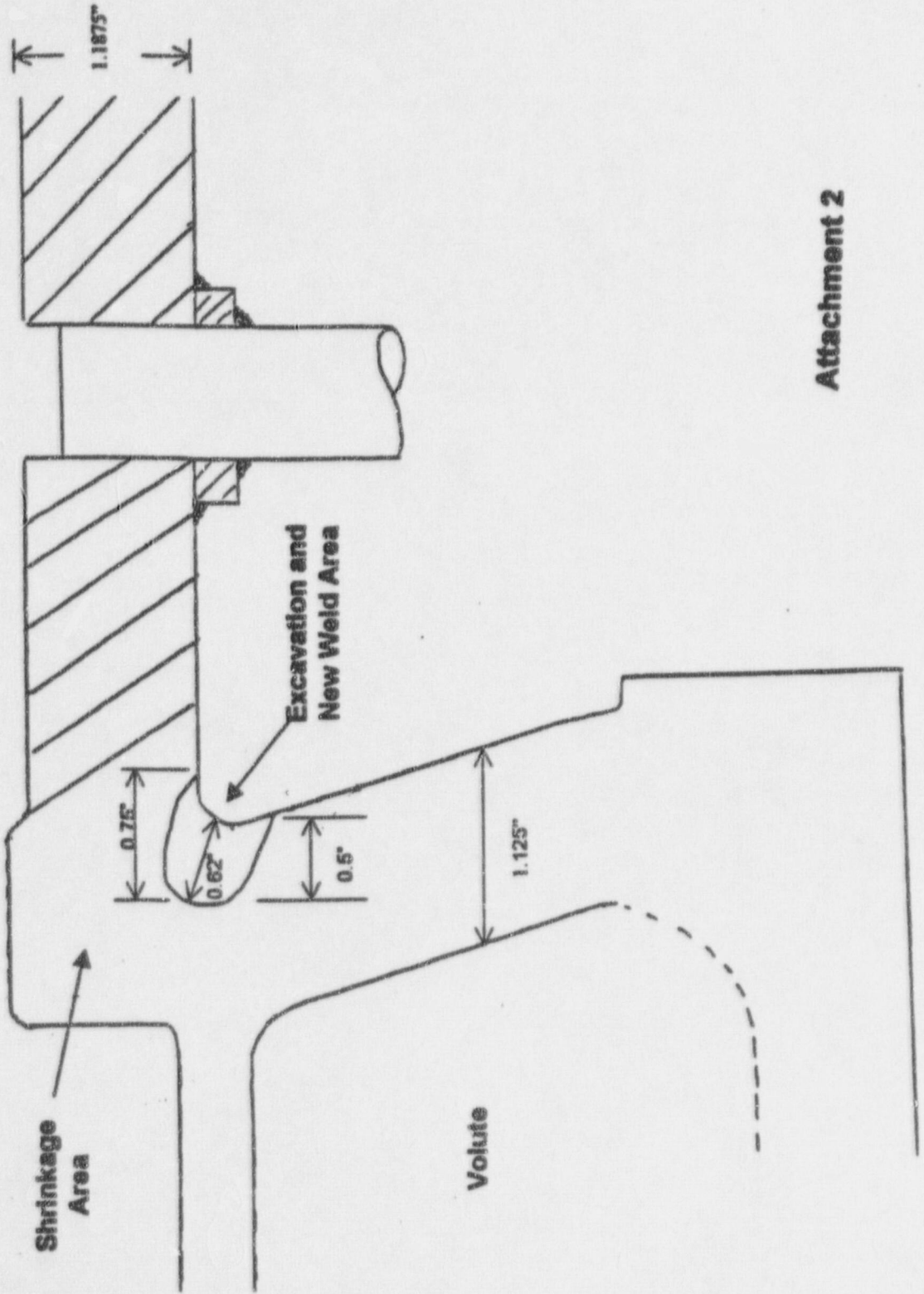


Volute

Flaw Location

Attachment 1

Excavation and Repair Depth of P34B Pump Casing Flaw



**Stress Analysis for
Decay Heat Removal Pump**

Structural Integrity Associates, Inc.

For Information Only



September 26, 1999
SIR-99-124
AFD-99-068

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Subject: Stress Analysis for Decay Heat Removal Pump

Dear Alan:

Stress analysis has been conducted for the P-34B decay heat removal pump. This letter summarizes the evaluations.

Geometry and Materials:

The geometry of the pump was taken from field measurements provided by Ken Panther. These are reflected in Figure 1. The general shape of the pump was taken from arrangement drawing 6600-MIH-39, Rev. 6 [1]. The material is A-351 CF8 304 stainless steel [1].

Finite Element Modeling:

A two dimensional axisymmetric finite element model, depicted in Figure 2, was constructed using the ANSYS finite element program (Version 5.3). Based on the available information, the model was contoured to match the arrangement drawing. The model assumed symmetry about the center of the pump impeller since the main interest was in the region of the intersection of the volute and the cylindrical pump casing. The boundary conditions allowed free radial movement at the symmetry line.

For mechanical loading, the inside surfaces of the model were loaded with pressure, for the load case of decay heat removal initiation. For the region at the pump outlet, a pressure of 445 psig was applied. This pressure is expected to be the maximum pressure at the pump outlet. The normal pressure is approximately 250 psig for initiation of decay heat removal [2]. The maximum pump developed shutoff head for a zero flow is 425 ft. (184 psid) while the normal developed head is 350 ft (152 psid)[3]. For the region exposed to the pump inlet pressure, a pressure of 250 psig was applied. An axial load was applied at the flange that accounted for

combined inlet and outlet pressures applied to the pump closure (stuffing box). The loadings due to weight, applied nozzle reactions and seismic loadings are expected to be insignificant compared to those from pressure at the bottom of the pump casing. (The nozzles are at the top of the pump and the supports for the pump are attached to the sides of the pump at mid-height.) Thus, the primary purpose of this model was to determine the pressure-induced stresses in the pump casing in the vicinity of the observed leakage for use in flaw acceptance evaluation.

The thermal loading applied to the model assumed a sudden thermal shock from 70°F to 280°F, the maximum temperature at initiation of decay heat removal with the pump at an initial temperature of 70°F. It is very conservative to assume the sudden load application since the actual response would occur as a ramp due to finite valve opening time and heat transfer between the fluid and the pipe wall between the reactor coolant loop piping and the pump. A conservatively high internal heat transfer coefficient of 10,000 Btu/hr-ft²-°F was assumed. This was applied on all internal surfaces of the model. A heat transfer coefficient of 1.0 Btu/hr-ft²-°F was assumed on the outside surfaces. The primary purpose of this analysis was to generate stresses for fatigue and/or crack growth assessment.

Results:

Figures 3 to 6 show the hoop, axial, and radial stresses and the stress intensity in the pump casing. Due to the thickness of the pump casing and the relatively low pressures, the stresses are very low, even at locations of local stress concentration. For the region of cracking, the most applicable stress for flaw evaluation is the stress perpendicular to the observed leakage path, which is the radial stress.

Table 1 shows the membrane, membrane plus bending and the total stress for a path from the outside leak location to a region inside the volute (See Figure 7). The stresses shown are those that would act across a flaw on the path. As shown, the membrane stresses are very low. For the volute area, the pressure loads are effectively supported by the volute structure, with very little of the loading being carried back into the pump casing. Table 2 shows the membrane, membrane plus bending and the total stress for a path from the outside leak location to a region inside the pump (See Figure 7). Again the stresses are very low, though greater than the previous path results. Table 3 shows the stresses in the lower portion of the pump case.

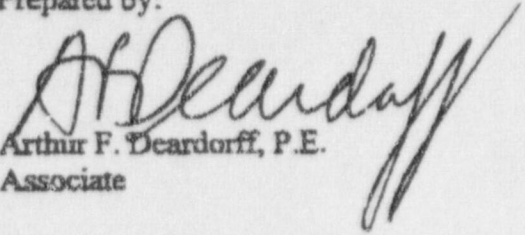
For the applied thermal shock, the surface stress intensity is compressive, and reaches a peak value of 84 ksi at the inner intersection of volute and the internal cross member. (This is across the volute wall from the location of the leak.) The peak stress intensity across from the leakage location inside the pump case is 50.2 ksi. These stresses are not especially significant from the standpoint of thermal fatigue in that more than 50,000 cycles would be required to produce a fatigue usage factor of 1.0, the Code allowable for Class I components.

These stresses will be utilized in the evaluation of allowable flaw sizes.

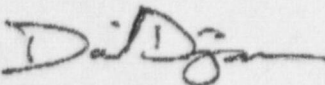


Please call if you have any questions.

Prepared by:


Arthur F. Deardorff, P.E.
Associate

Reviewed by:


David Dijamco
Engineering Analyst

ii

Attachments

cc: ANO-17Q-402

References:

1. Drawing 6600-M1H-39, "KSMK 10 x 12 x 12 Pump Sectional Arrangement," Rev. 6.
2. Plant Shutdown and Cooldown Procedure, 1102.010, Page 25 of 54, Change 050-01-0.
3. Pump Performance Curve from TD HL27.0020, Decay Heat Removal Pump Instruction Manual No. 713.3, PO 020967 LP, Contract 6668.



General dimensions
and shape taken from
DWG 6600-M1H-39

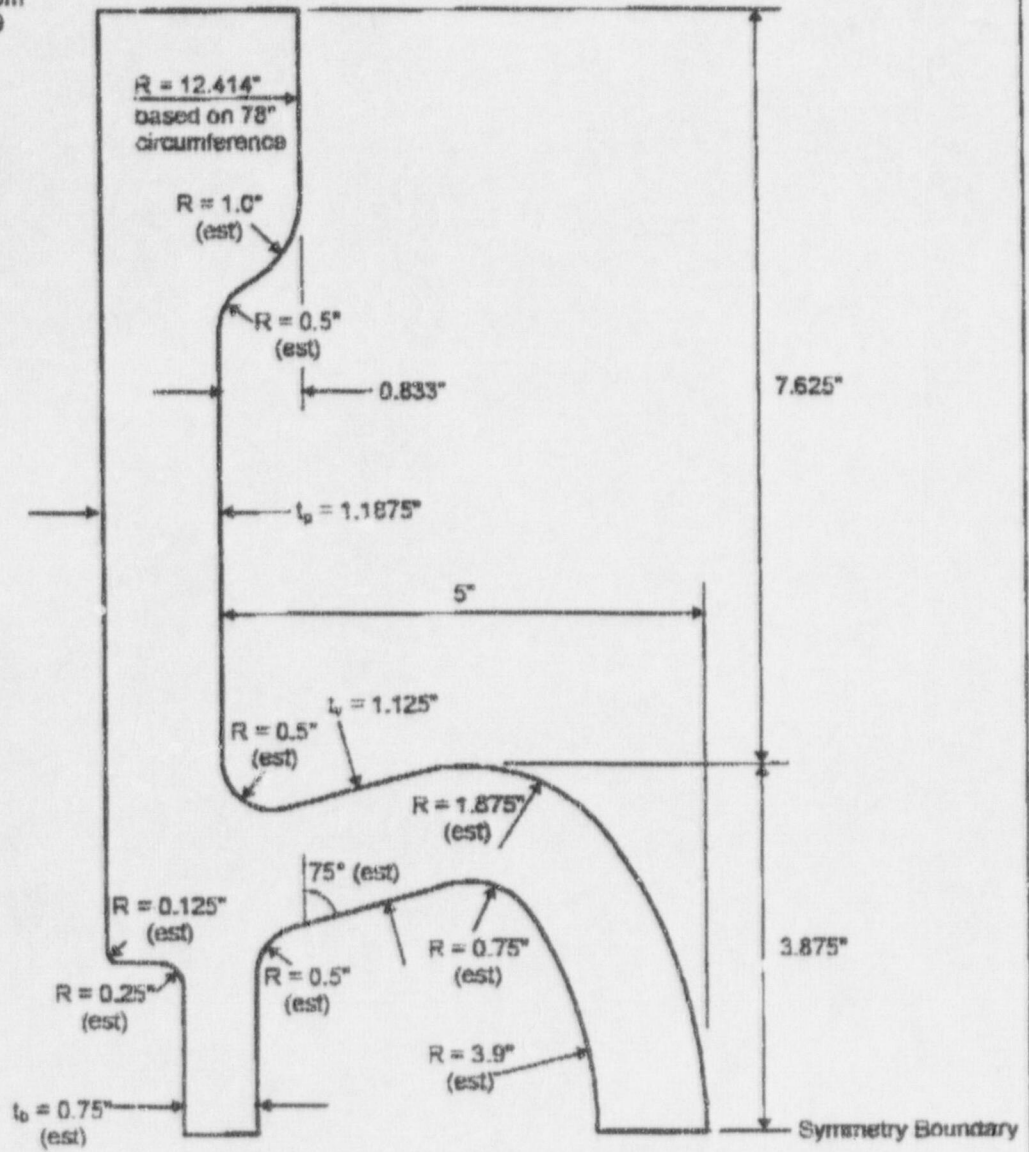
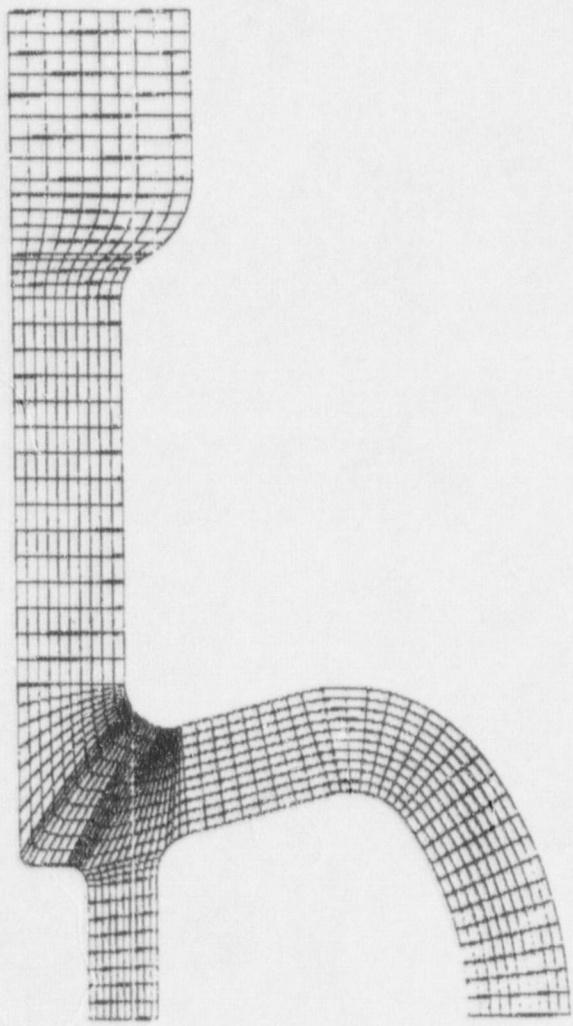


Figure 1. Geometry

1

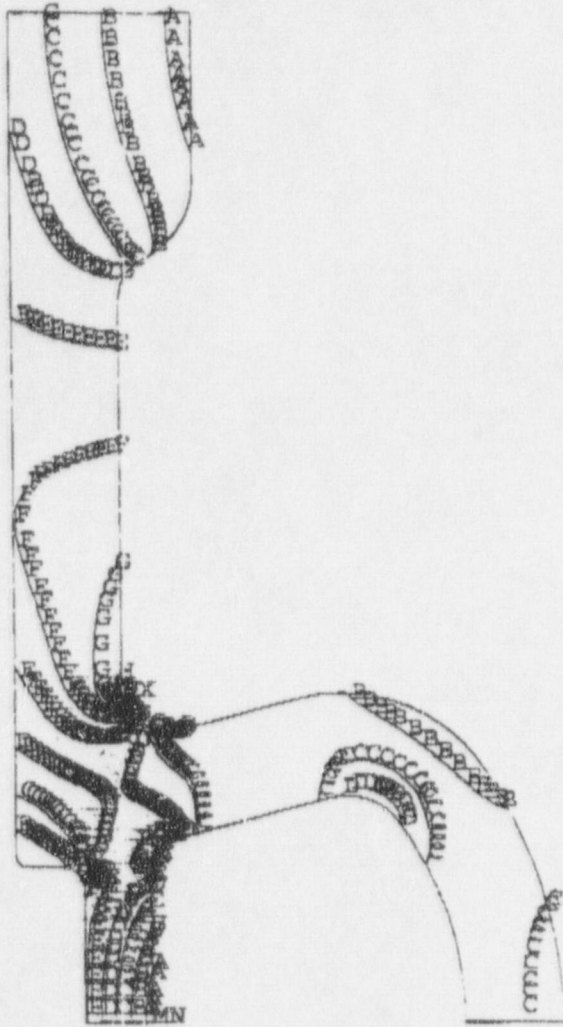


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SEP 24 1999
16:35:54
ELEMENTS
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XF =13.462
YF =-5.75
PRECISE HIDDEN
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Figure 2. Finite Element Model

1



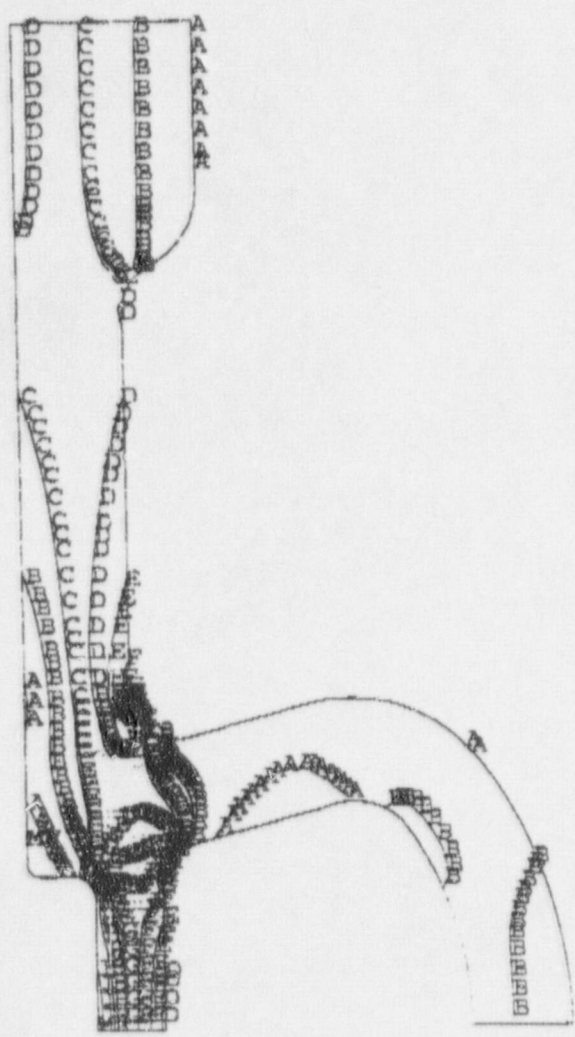
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SEP 26 1999
11:14:18
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SUB =1
TIME=1
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RSYS=0
DMX =.001063
SMN =738.714
SMNB=423.092
SMX =3762
SMXB=4075
A =906.664
B =1243
C =1578
D =1914
E =2250
F =2586
G =2922
H =3258
I =3594
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Hoop Stress (445 psi Outlet / 250 psi Inlet / 250F

Figure 3. Hoop Stress Due to Pressure



1

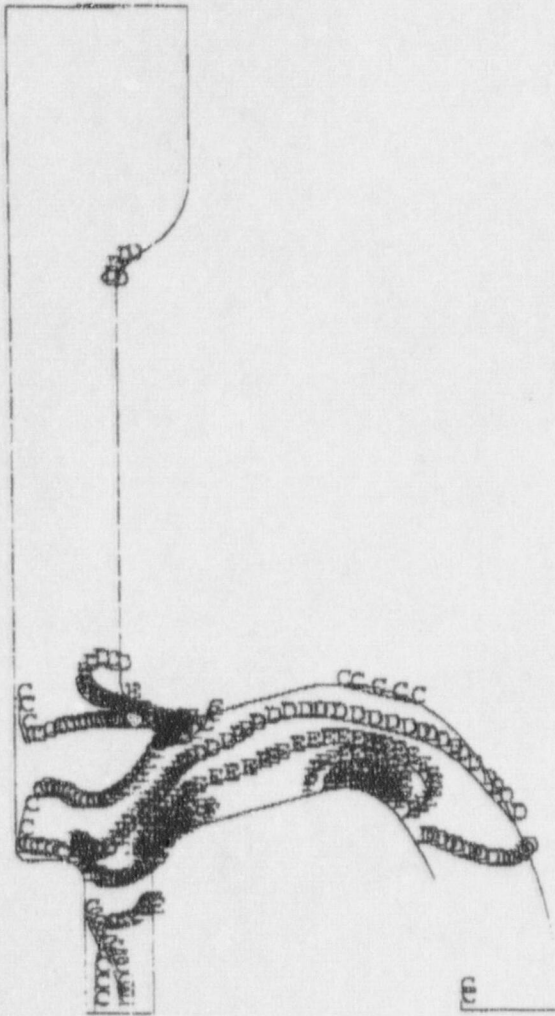


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TIME=1
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RSYS=0
DMX =.001063
SMN =-638.469
SMNB=-749.816
SMX =6497
SMXB=7131
A =-242.041
B =550.815
C =1344
D =2137
E =2929
F =3722
G =4515
H =5308
I =6101
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Axial Stress (445 psi Outlet/ 250 psi Inlet / 250F)

Figure 4. Axial Stress Due to Pressure

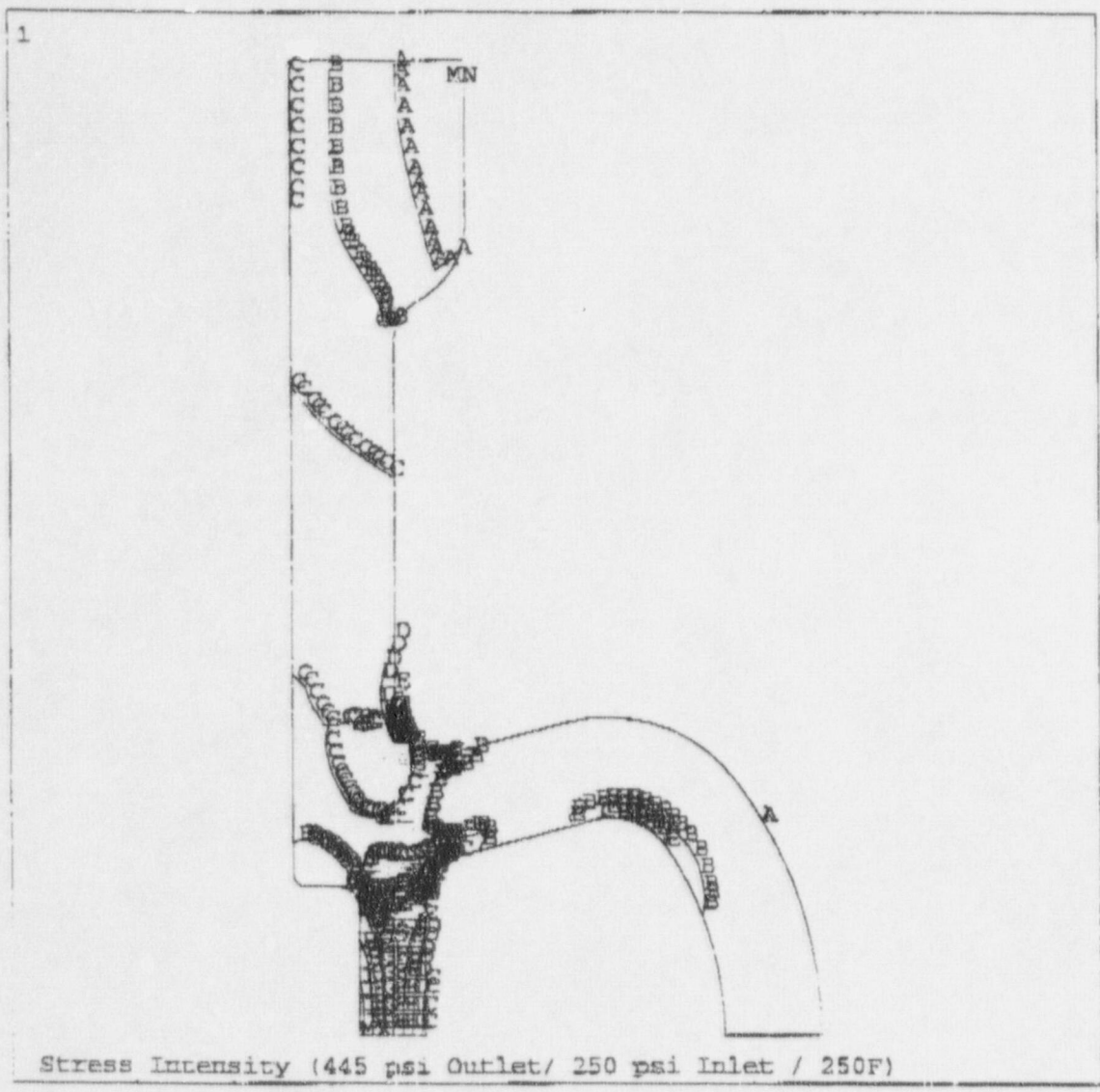
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SUB =1  
TIME=1  
SX (AVG)  
RSYS=0  
DMX =.001063  
SMN =-1785  
SMNB=-1999  
SMX =3083  
SMXB=3298  
A =-1514  
B =-973.315  
C =-432.47  
D =108.375  
E =649.219  
F =1190  
G =1731  
H =2272  
I =2813
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Radial Stress (445 psi Outlet/ 250 psi Inlet / 250F)

Figure 5. Radial Stress Due to Pressure

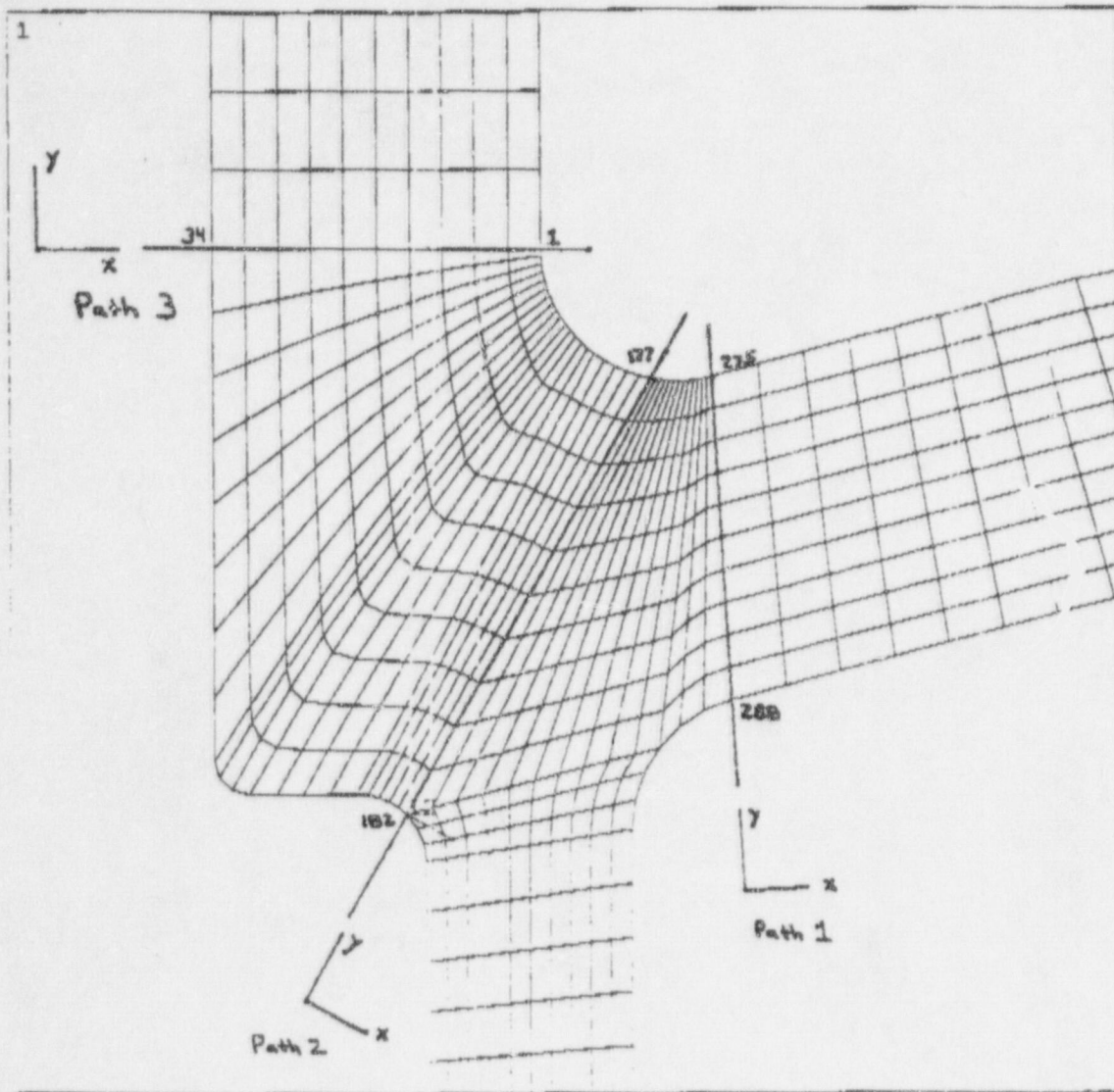


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NODAL SOLUTION
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SMN =889.952
SMNB=881.12
SMX =6947
SMXB=7792
A =1226
B =1899
C =2572
D =3245
E =3918
F =4591
G =5264
H =5937
I =6610

```

Figure 6. Stress Intensity Due to Pressure



ANSYS 5.3
 SEP 24 1999
 17:23:57
 ELEMENTS
 TYPE NUM

ZV =1
 *DIST=2.03
 *XF =11.683
 *YF =-8.842
 PRECISE HIDDEN

Figure 7. Path Definition for Stress Summary Tables

Table 1 - Path 1 Stress Results (See Figure 7)

Membrane Stresses (psi)										
	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	SINT
	286.8	299	1564	477.7	0	0	1564	770.6	-184.8	1749
Membrane Plus Bending Stresses (psi)										
Surface	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	SINT
Inside	1575	467.7	1780	1018	0	0	2180	1780	-137.1	2317
Center	286.8	299	1564	477.7	0	0	1564	770.6	-184.8	1749
Outside	-1001	130.2	1349	-82.26	0	0	1349	133.6	-1005	2353
Total Stresses (psi)										
Surface	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	SINT
Inside	1874	97.91	1766	1017	0	0	2338	1766	-364	2700
Center	270.8	456.2	1806	445.5	0	0	1806	818.5	-91.49	1698
Outside	-1288	-26.15	1212	-133.9	0	0	1212	12.09	-1302	2514

Table 2 - Path 2 Stress Results (See Figure 7)

Membrane Stresses (psi)										
	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	SINT
	497.8	904	1851	-1133	0	0	1852	1851	-450.1	2302
Membrane Plus Bending Stresses (psi)										
Surface	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	SINT
Inside	1351	1624	2062	-1498	0	0	2992	2062	-16.66	3008
Center	497.8	904	1851	-1133	0	0	1852	1851	-450.1	2302
Outside	-355.5	184.1	1541	-768	0	0	1841	728.3	-899.7	2540
Total Stresses (psi)										
Surface	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	SINT
Inside	2543	1125	2210	-1665	0	0	3644	2210	24.29	3620
Center	393.2	1214	1934	-1188	0	0	2061	1934	-453.9	2515
Outside	-1061	-277.1	1275	-748.1	0	0	1275	175.5	-1514	2789

Table 3 - Path 3 Stress Results (See Figure 7)

Membrane Stresses (psi)										
	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	SINT
	3,429	1706	2667	-180.9	0	0	2667	1725	-15.58	2682
Membrane Plus Bending Stresses (psi)										
Surface	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	SINT
Inside	-331.2	-529.2	2080	43.04	0	0	2080	-322.3	-538.1	2618
Center	3,429	1706	2667	-180.9	0	0	2667	1725	-15.58	2682
Outside	338.1	3941	3253	-404.9	0	0	3986	3253	293.1	3693
Total Stresses (psi)										
Surface	SX	SY	SZ	SXY	SYZ	SXZ	S1	S2	S3	SINT
Inside	-329	-337.5	2139	-17.38	0	0	2139	-315.3	-351.1	2490
Center	31.36	1533	2622	-143.6	0	0	2622	1547	17.76	2605
Outside	169.8	4831	3466	-375.7	0	0	4862	3466	139.7	4722

Enclosure 3 to
1CAN099907

**Evaluation of Flaw Remaining After Repair of
Decay Heat Removal Pump P-34B**

Structural Integrity Associates, Inc.

For Information Only



September 26, 1999
SIR-99-125
AFD-99-069

adcardor@structint.com

Mr. Alan B. Cox
Entergy Operations, Inc.
Arkansas Nuclear One
1448 S.R. 333
Russellville, AR 72801

Subject: Evaluation of Flaw Remaining After Repair of Decay Heat Removal Pump P-34B

Dear Alan:

This letter summarizes analysis conducted to evaluate a flaw left in place beneath the weld repair following discovery of leakage from Decay Heat Removal Pump P-34B during system pressure testing. This evaluation was conducted in accordance with the appropriate flaw evaluation provisions of Section XI of the ASME Code. It supports acceptance of the pump for continued service following a repair that did not remove all of a through-wall (leaking) flaw. As allowed by IWA-4422.1(b) of the 1998 Edition of Section XI, the flaw evaluation considers the remaining portion of an otherwise unacceptable through-wall defect.

The geometry, materials and results of the stress analysis are described in Reference 1. Measurements taken during the cavity excavation and following the weld repair process show that the excavated cavity was 0.5 inches in depth as measured from the original outside surface in the region of the intersection between the pump casing and volute [2]. In the finite element modeling, this region was modeled with a total diagonal thickness of 1.75 inches [1]. This yields a flaw depth-to-thickness ratio (a/t) equal to 0.715. This is less than the maximum allowable size for flaws in austenitic stainless steel piping per Section XI IWB-3640 of $a/t = 0.75$.

During the cavity excavation, it was determined that there was a linear indication at the bottom of the cavity with length direction parallel to the volute/pump bowl casing intersection [2]. During the excavation of the outside surface flaw, it appeared that the subsurface portion of the flaw was going in the direction of the region inside the pump cavity, not toward the volute cavity.

Evaluation:

Flaw models do not specifically exist for evaluation of flaw geometry similar to that expected to remain under the repair cavity. Thus, conservative analysis was conducted to show that significant margin exists relative to that required by ASME Section XI. Section XI does not have specific evaluation criteria for pump casings, so the approach and philosophy for performing evaluations of austenitic stainless steel piping were conservatively applied.

Review of the stress analysis in Reference 1 shows that the principal stress in the vicinity of the path between the excavation and the inner pump bowl region (Path 2 of Reference 1) is approximately the same as that which exists in the pump casing just above the casing-to-volute transition region. Thus, to show that significant margin exists, the maximum principal membrane stress at Path 2 of Reference 1 was used in a fracture mechanics model representative of Path 3. This analysis will be bounding as compared to analysis at Path 2. Since the stresses at Path 1 of Reference 1 are much lower, it is also expected to be bounding for that location, should there potentially be any flaws between the outside of the pump and the volute region. The source equations of Appendix C of Section XI are used for the evaluation.

The Decay Heat Removal Pump is constructed of A351 Grade CF8 304 stainless steel [1]. The allowable flow stress of the material is based on the maximum expected temperature conditions in the pump of 280°F. The flow stress is based on the average of the yield stress and the ultimate tensile strength, giving a value of 42.7 ksi, which is more conservative than the Class 1 piping allowable of $3S_m$ (60 ksi) in Appendix C. From the initial material test records [6], the computed ferrite content is 10 percent.

For evaluating the allowable depth of a flaw running around the pump, the flaw will be evaluated as a part through-wall flaw. The analysis was conducted using a membrane stress in the pump case due to the axial loading on the closure of 1.706 ksi derived from Path 2 as discussed above. Since the weld repair was made using the GTAW process [4], a Z-factor of 1.0 was assumed and no effects of thermal stresses or other secondary stresses were included. The bending stresses across the pump cross section are not significant. Since the loading is due to pressure and not due to pressure plus bending (as in the case of piping), a safety factor of 3.0 was used instead of 2.77 as in Appendix C. This analysis shows that a flaw depth of $a/t = 0.914$ would meet Section XI stress criteria for a part through-wall flaw extending completely around the pump. This is significantly greater than the actual flaw which remains.

Since the exact orientation of the flaw could not be determined using volumetric examination, similar analysis was conducted to evaluate potential axial flaws. The Appendix C model for allowable axial flaws was used. Based on the pump casing thickness in this region and pump discharge pressure, it was shown that a part-depth flaw with $a/t = 0.914$ would be acceptable for a flaw length of 4.4 inches. For $a/t = 0.75$, the allowable length would be 23 inches.



To show the flaw tolerance of the pump, a similar analysis was conducted using the Appendix C equations for a circumferential through-wall flaw in the pump casing. Using the same assumptions and stresses as for the part-through-wall flaw, the analysis shows that a through-wall flaw of slightly greater than 58 percent of the circumference would be acceptable. This flaw size is many times larger than the through-wall which led to detection of the leakage. This supports the argument that visual monitoring for leakage can be an effective approach for detecting any future through-wall defect prior to it affecting structural integrity of the decay heat removal pump.

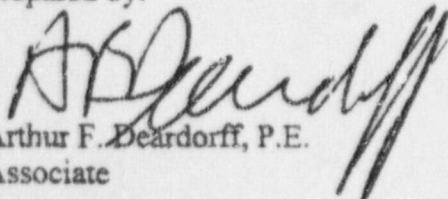
The introduction of hot water at up to 280°F into the pump results in a thermal shock that could potentially contribute to crack growth. The maximum observed thermal stress on the inner portion of the pump was 71.5 ksi compression, rapidly increasing up to 34.9 ksi tension on the outer portions of the pump. Using the Section XI, Appendix A model for an $a/t = 0.75$ flaw with aspect ratio of $a/l = 0.5$, and conservatively assuming a linear stress profile results in a deepest point stress intensity factor of $22.89 \text{ ksi-in}^{1/2}$. Using the Appendix C crack growth curve for air, multiplied by a factor of 2 to account for PWR water effects and $R = 0$ (since the stress intensity factor is negative), results in a crack growth rate of 4.5×10^{-6} inches per cycle. For an assumed 480 cycles (twice the design number of heatup/cooldown cycles from Reference 5), the resulting crack growth is computed to be 0.0043 inches. This is negligible such that the $a/t = 0.715$ flaw will never approach the Code allowable $a/t = 0.75$ flaw.

Summary

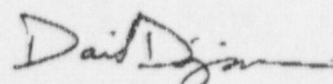
This evaluation, conducted using very conservative assumptions on flaw modeling, has shown that the size of the flaw remaining below the weld repair in the Decay Heat Removal Pump is acceptable per Section XI methods for evaluation. In addition, the effects of crack growth are negligible. This evaluation shows that the repair is qualified to the end of life.

Please call if you have any questions.

Prepared by:


Arthur F. Deardorff, P.E.
Associate

Reviewed by:


David Dijamco
Engineering Analyst

jj

Attachments

cc: ANO-17Q-403

References:

1. Letter AFD-99-068, "Stress Analysis for Decay Heat Removal Pump", 9/26/99.
2. "Report of Inspections of Leaking Area in P34B Pump Casing," Fax from Jerry Ray, 9/25/99
3. Plant Shutdown and Cooldown Procedure 1102.010, Change 050-001-0
4. Telecon with Steve Lewis (Entergy), 9/25/99
5. Functional Specification for Reactor Coolant System for Arkansas Nuclear One, 18-1173987-02
6. Wilmet Industries Inspection Report for Heat A815 (Pump P234B), 4/10/1970