VIRGINIA ELECTRIC AND POWER COMPANY
RICHMOND, VIRGINIA 23261

March 22, 2024

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

Serial No. 24-142
NRA/JHH R0
Docket No. 50-338
License No. NPF-4

VIRGINIA ELECTRIC AND POWER COMPANY
NORTH ANNA POWER STATION UNIT 1
REQUEST FOR APPROVAL OF ALTERNATIVE REQUEST N1-I5-NDE-007
TO DEFER ADDITIONAL REQUIRED REACTOR COOLANT PUMP CASING INSPECTION

Pursuant to 10 CFR 50.55a(z)(2), Virginia Electric and Power Company (Dominion Energy Virginia) requests Nuclear Regulatory Commission (NRC) approval to defer inspection of an additional Reactor Coolant Pump (RCP) Casing for one refueling cycle at North Anna Power Station (NAPS) Unit 1. During visual examination of the Unit 1 "A" RCP casing on March 16, 2024, which was performed concurrent with replacement of the "A" RCP, relevant indications were identified that were conservatively estimated to exceed the acceptance standards of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (BPV) Code Section XI. The subsequent engineering evaluation was not able to confirm that there are no additional parts or components subject to the same service conditions that caused the relevant indications, requiring an examination of an additional reactor coolant pump in accordance with ASME Section XI during the current outage.

Dominion Energy Virginia requests to perform the additional examination during the next scheduled Unit 1 refueling outage when one of the remaining two reactor coolant pumps will be removed and replaced. The process for complete disassembly and removal of an RCP to allow complete inspection of the pump casing during the current ongoing refueling outage presents a hardship without a compensating increase in quality and safety because of a significant increase in outage duration, dose, effects on critical equipment, and challenges to nuclear and personnel safety.

Specifically, verbal approval is requested by March 26, 2024 to support startup of NAPS Unit 1. The basis for this alternative is provided in Attachment 1 to this letter. Attachment 2 provides an engineering evaluation of the casing condition.

Should you have any questions regarding this submittal, please contact Julie Hough at (804) 273-3586.

Sincerely,

James E. Holloway
Vice President Nuclear Engineering & Fleet Support

Attachment:

1) Proposed Alternative in Accordance with 10 CFR 50.55a(z)(2), Hardship or Unusual Difficulty without Compensating Increase in Level of Quality or Safety
2) Excerpts from Engineering Evaluation, ETE-NA-2024-0033, "1-RC-P-1A Casing Indication Evaluation"

Commitments made in this letter: None

cc: U. S. Nuclear Regulatory Commission, Region II
Marquis One Tower
245 Peachtree Center Avenue, NE, Suite 1200
Atlanta, Georgia 30303-1257

Mr. G. E. Miller
NRC Senior Project Manager - North Anna Power Station
U. S. Nuclear Regulatory Commission
One White Flint North
Mail Stop 9E3
11555 Rockville Pike
Rockville, Maryland 20852-2738

NRC Senior Resident Inspector
North Anna Power Station

Serial No. 24-142
Docket No. 50-338

Attachment 1

Proposed Alternative in Accordance with 10 CFR 50.55a(z)(2) Hardship or Unusual Difficulty without Compensating Increase in Level of Quality or Safety

Virginia Electric and Power Company (Dominion)
North Anna Power Station Unit 1

Proposed Alternative in Accordance with 10 CFR 50.55a(z)(2)
Hardship or Unusual Difficulty without Compensating Increase in Level of Quality or Safety

N1-I5-NDE-007

1.0 ASME CODE COMPONENT AFFECTED

The affected components are the North Anna Power Station (NAPS) Unit 1 reactor coolant pump casings. The following American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (BPV) Code Section XI examination category and item number cover examination of the reactor coolant pump casings:

Examination Category	Item No.	Description
B-L-2	B12.20	Pump Casings

The examination category and item number are from IWB-2500 and Table IWB-2500-1 of the ASME BPV, Code Section XI.

2.0 APPLICABLE CODE EDITION AND ADDENDA

The ASME BPV Code (ASME Code) of record for the North Anna Power Station Unit 1 5th 10-Year Inservice Inspection (ISI) interval is the 2013 Edition of Section XI.

3.0 APPLICABLE CODE REQUIREMENTS

IWB-2430, Additional Examinations, requires examinations that reveal flaws or relevant conditions exceeding the acceptance standards of Table IWB-3410-1 be extended to include additional examinations during the current outage.

4.0 REASON FOR REQUEST

An alternative is requested from the requirements of IWB-2430, Additional Examinations, associated with relevant indications found during the Category B-L-2, Item B12.20, VT-3 visual examination of the Reactor Coolant Pump (RCP) casing. The examination was performed on March 16, 2024, during NAPS Unit 1 R30 refueling outage as part of a pump replacement activity. This examination is only required when the pump is disassembled for maintenance or repair, and is an examination of the internal pressure boundary including all pressure boundary surfaces made accessible for examination by disassembly. The 1-RC-P-1A RCP is being replaced with a refurbished pump as part of the North Anna Subsequent License Renewal Project.

The required VT-3 Visual Examination was performed to identify (a) corrosion or erosion that reduces the pressure retaining wall thickness by more than 10%; (b) wear of mating surfaces that may lead to loss of function or leakage; or (c) crack-like surface flaws developed in service or grown in size beyond that recorded during preservice visual examination. During the remote visual examination, multiple instances of

Proposed Alternative in Accordance with 10 CFR 50.55a(a)(3)(ii)
Hardship or Unusual Difficulty without Compensating Increase in Level of Quality or Safety

structural deformation were identified near the bottom of the casing. The deformations appear to be impressions in the casing made by loose parts from the degraded cap screws used to attach the diffuser adapter to the turning vane diffuser. Based on visual inspections by a Non-Destructive Examination Level III qualified individual, and overall dimensions of the cap screws, the limiting depth of the indentations in the pump casing are conservatively estimated to exceed the limiting flaw depth of 0.3" in the acceptance standards of ASME Section XI, Table 3519-2.2.

IWB-2430 requires additional examinations during the current outage for examinations that reveal flaws or relevant conditions exceeding the acceptance standards. However, the process for complete disassembly and removal of a RCP to allow complete inspection of the pump casing presents a hardship without a compensating increase in quality and safety because of significant increase in outage duration, dose, effects on critical equipment, and challenges to nuclear and personnel safety. Based on the previous RCP pump refurbishment projects (2-RC-P-1A in Fall 2023, 1-RC-P-1A Spring 2024), the expected dose associated with this evolution averages 5.5 REM. The removal of an RCP would also require the use of critical spare parts such as seal faces (currently in an industry-wide parts shortage due to closure of primary manufacturing facility), seal package soft goods, and pump main flange gaskets. Removing an RCP safely requires specialty tools and equipment, some of which Dominion does not own. Removal of a pump without this specialty equipment (such as the contaminated pump cask and shield plug) runs a high risk of unnecessary radioactive contamination of the plant and unnecessary dose exposure for personnel. Emergent and unplanned removal of an RCP is a high risk activity since it is a critical heavy lift, and also requires a special strongback to rig the pump cask for safe removal.

Dominion concludes that performing the additional examination of an RCP casing during the current outage in accordance with IWA-2430(a)(1)(a) presents a hardship without compensating increase in quality or safety. Dominion also concludes that performing the additional examination of an RCP casing as required by IWA-2430(a)(1)(a) during the next refueling outage provides an acceptable alternative.

5.0 PROPOSED ALTERNATIVES AND BASIS FOR USE

This request proposes an alternative to performing the additional examination of an RCP casing during the current outage in accordance with IWB-2430(a)(1)(a) to performing the additional examination of an RCP casing during the next refueling outage. The next scheduled pump replacement is currently planned for the next refueling outage, N1R31 (Fall 2025).

The limiting depth of the indentations in the pump casing are conservatively estimated to exceed the limiting flaw depth of 0.3" in the acceptance standards of ASME Section XI, Table 3519-2.2. An analytical evaluation has been performed in

accordance with IWB-3142.4 to demonstrate acceptability for continued service. The evaluation for 1-RC-P-1A is included in Attachment 2. Vendor proprietary material has been redacted but can be found in the cited references.

The conservative evaluation in Attachment 2 can be applied to 1-RC-P-1B and 1-RC-P-1C. Although the cause evaluation is not complete, the likely cause of the defects in 1-RC-P-1A pump casing is cap screw fragment migration into the gap between the diffuser adaptor and casing and long-term fretting. Cap screw impression of half the width was a conservative assumption considering the gap dimensions and the lack of a large static load to implant debris. The only reasonable mechanism to cause a deeper flaw than analyzed is fretting, which does not involve plastic deformation. The conservative approach in Attachment 2 is to assume a single, excessive static load that would initiate plastic deformation and cracking, which was still found to be acceptable. The bounding nature of the analysis covers potential conditions in all three RCPs that have similar age and operating time. This approach provides reasonable assurance that the other pump casings would have structural integrity, supporting the proposed extension of performing the additional examination to a future refueling outage.

6.0 DURATION OF PROPOSED ALTERNATIVE

The proposed alternative is requested to complete the additional examination of an RCP casing as required by IWB-2430 during the fall 2025 refueling outage, which is before the end of the current 5th ISI Interval, which ends on April 30, 2029.

7.0 PRECEDENTS

None.

Serial No. 24-142
Docket No. 50-338

Attachment 2

Excerpts from Engineering Evaluation ETE-NA-2024-0033, 1-RC-P-1A Casing Indication Evaluation

Attachments not relevant to the structural analysis, vendor proprietary information, and Dominion personnel information have been omitted from the evaluation.

Virginia Electric and Power Company (Dominion)
North Anna Power Station Unit 1

Source Document

CR1253801-Structural Deformation Identified on Pump Casing- 1-RC-P-1A

Purpose

The purpose of this ETE is to evaluate the indications observed in the 1-RC-P-1A casing for structural integrity and impact to pump hydraulics.

The purpose satisfies Step 2.5.a in CM-AA-ETE-101, Rev. 16. This is a Level 2 ETE that documents a technical basis where more rigorous documentation is required to support the disposition AND implementation of resolution (or acceptance of a Use-As-Is condition) is required. The engineering evaluations in this ETE support a use as-is determination for the indications identified in CR1253801 and the NDE report (Reference 17). FSRC approval is being pursued as part of closure for the Mode 6 hold on CA12378356.

Risk was evaluated per CM-AA-RSK-1001, Rev. 26, and this ETE was determined to be Medium. Risk mitigation measures include: 1) a Fleet Engineering Challenge Review using CM-AA-ECR-1001, Rev. 14, on the analytical methodology that was conducted on March 19, 2024; 2) use of Framatome pump experts to support the in-house evaluation of pump hydraulics (see Attachment 4); 3) Independent Third Party Review by Westinghouse (the OEM) for both the structural analysis and RCP performance evaluation (through participation in the Challenge Review on 3/19/2024 and the review of a post-QA product); 4) Second Engineering Challenge Review on 3/21/2024.

Design Inputs and Assumptions

North Anna Unit 1 and Unit 2 RCP Model: Westinghouse 93A

Casing Material-

Diffuser Adapter Cap Screw Material:

New RCP:
I

Removed RCP:

Methodology

Pump hydraulic evaluation was performed using pump design, operating flow path, pump operational principles, and pump dimensional/general arrangement analysis. Structural evaluation was performed using fracture mechanics and use of WCAP-13045 guidance.

Discussion

As part of the North Anna Subsequent License Renewal Project, 1-RC-P-1A is being replaced with a refurbished pump under work package 59203368795. As part of this evolution, the existing 1-RC-P-1A

was removed from the pump casing and shipped to Framatome for overhaul. Following the removal of the 1-RC-P-1A pump assembly, it was identified that the diffuser adapter had broken off and remained within the casing- reference CR1253557. The diffuser adapter is installed on the bottom of the pump turning vane assembly via twelve (12) 3/4" cap crews in a 42" bolt circle. The susceptibility of these bolts to degrade and break has become a known industry issue since installation of these bolts at North Anna in 1982. As noted in the industry OE of Technical Bulletin NSD-TB-83-01 and Infogram 95008A, these original SS cap screws have been known to break at North Anna Unit 1 on 1-RC-P-1A in 1982. Per Licensee Event Report 82-056, 1-RC-P-1A had 7 of 12 diffuser adapter cap screws broken due to stress corrosion cracking while working on pump removal under work package N1-82-07231815. The diffuser adapter cap screws in all 3 Unit 1 RCPs were replaced in 1982 IAW EWR-82-421 and EWR 82-464 per Westinghouse recommendations. The new reactor coolant pumps being installed into North Anna have diffuser adapter cap screw upgrades as part of the design change (DC NA-22-00076 for 1-RC-P-1A). The upgraded material is and is not known to be susceptible to stress corrosion cracking and is material recommended in the OEM's (WEC) latest Infogram 95008A regarding reactor coolant pump diffuser adapter cap screws and provides reasonable assurance that diffuser adapter cap screw failure will not occur in the future due to SCC. The current SLR RCP replacement schedule projects the final RCP refurbishment to be completed in 2028, but could be earlier pending evaluations being performed under CA12331144. It should be noted that 2-RC-P-1A was replaced in Fall 2023 under work package 59203404236 and the removed pump (currently being installed into 1-RC-P-1A as noted above) had no failed diffuser adapter cap screws or a dropped diffuser adapter. Based on conversations with Framatome, Westinghouse, and the PWROG RCP WG, other than North Anna 1-RC-P-1A (1982, 2024) there are no domestic plants that have had a dropped diffuser adapter. Regardless of whether original bolts or upgraded bolts are in use per WEC IG95008A, several foreign plants have experienced failure of the original bolts similar to the 1982 failures at North Anna. It should also be noted that 1-RC-P-1B and 1-RC-P-1C were removed from their casings in 1982 following the identification of the broken diffuser cap screws on 1-RC-P-1A and none of the cap screws on either pump had failed but were replaced as a precaution IAW with Westinghouse Recommendations (reference EWR's 82-464 and 82-421).

Section 1-Pump Hydraulic Performance Impact Evaluation

The North Anna Reactor Coolant Pumps are Westinghouse Model 93A single stage, seven vane, single suction centrifugal pumps. These pumps consist of 3 general areas: the hydraulics, the seals, and the motor. The hydraulic parts primarily consist of an impeller, turning vane diffuser, diffuser adapter, and casing. The casing is permanently welded into the reactor coolant system. Attached to the bottom of the shaft is the impeller which is the primary mover of the coolant. The coolant flows into the suction eye of the impeller and a velocity head is imparted to the fluid. The pump casing is a SST casting with a height of 101 inches and a maximum radial distance from casing centerline to the centerline of the mounting feet of 44 inches. The casing has a total weight of approximately 38,000 lbs. The North Anna RCP casing dimensions are shown in station drawings 11715/12050-2.31-30A Sheets 1 and 2. The area of the casing that had indications identified in CR1253801 are highlighted in Figure 1 below. Figure 1 also depicts the orientation of the diffuser adapter in the pump casing.

Figure 1- 93A RCP Case to Diffuser Adapter Interface

The diffuser adapter is made of

. The diffuser adapter limits reactor coolant recirculation flow from the impeller discharge back to the impeller suction via the close clearances designed into these areas. Without a diffuser adapter, excess recirculation flow would likely exist due to reduced ability to maintain the tight clearances around the impeller that are provided by the diffuser adapter.

As detailed in CR1253801 the casing VT-3 examination revealed multiple instances of structural deformation at the bottom of the casing near where the 'A' intermediate leg enters the pump. If looking downstream with the 'A' Cold Leg at 12:00, the area with the most significant impressions are at 9:00. The deformation appears to be impressions in the casing made by loose parts (i.e. bolts). The indications in question are shown below in Figures 2, 3, 4, and 5. The specific location of these indications is highlighted above in Figure 1 and is at the diffuser adapter to casing interface. By design, the diffuser adapter has a minimum diametral clearance of 0.050" and a maximum clearance of 0.060" to the casing wall. Based on a review of the as built drawing for 1-RC-P-1A (reference ETE-NA-2023-0031 Revision 1 Attachment 3), the clearance of the new pump to casing is estimated to be 0.048". This is tighter than the original design requirements which has no impact on the diffuser adapter function. The interior of the casing, including the areas where all of the indications were found, does not participate in a measurable way in the hydraulic performance of the pump. The only clearances that are important to hydraulic performance are the labyrinth clearance between the diffuser adapter and the impeller suction ring and, to a lesser extent, the clearance between the diffuser adapter and impeller at the discharge of the impeller.

There are several ~3-4 indications on the ID of the casing at the adapter interface. These indications do have potential to impact the adapter functionality by allowing flow around the impeller (or adapter due to opened clearances) and into the ID of the casing. As stated above, in 1982, 1-RC-P-1A was removed from its casing to support suction splitter plate removal. Upon removal of the pump assembly, it was identified that 7 of the 12 adapter cap screws had failed. From a review of LER 82-056 (Attachment 3), Westinghouse evaluated the condition and determined that even if all of the adapter socket head cap screws had failed, significant operation degradation of the reactor coolant pump would not have resulted. A loose adapter would initially drop loop flow about 0.2% which is much less than the existing flow margin of approximately 5% above core thermal design flow. In addition, the automatic low flow reactor trip would prevent operation below core thermal design flow. Based on a review of current 1-PT-27 trends, the total RCS flow rate on Unit 1 is 313,904.4 gpm which has considerable margin above the Technical Specification LCO 3.4.1 requirements of 295,000 gpm. This supports the fact that with the diffuser adapter in the dropped condition on 1-RC-P-1A, there is no impact on the pumps ability to adequately cool the core. Given that the impact of a loose diffuser adapter is an anticipated drop in flow

of 0.2%, the minor indications observed at the ID of the casing at the diffuser adapter OD interface will have no noticeable impact on pump hydraulics or performance as is. This is further supported by the design and operational flow path of the coolant through the pump (through suction eye, into turning vane, out the discharge). There is no interface between the coolant and the casing wall in this location that would impact pump functionality.

The installation of a refurbished pump with a new rotating element and the attached diffuser adapter is anticipated to increase loop flows compared to the existing 1-PT-27 trends. The only indications of interest to hydraulic performance would be those in the bore of the casing where the diffuser adapter fits into it with the .048 - .060 clearance on diameter. These indications will have no measurable impact on performance. Additionally, the upper fits between the turning vane diffuser/casing turning vane/diffuser adapter and the lower fit between the diffuser adapter/casing effectively seal the casing annulus in the location of the indications from any potential leakage from the RCS. Reference Framatome disposition in Attachment 4.

Once the pump is in the assembled condition, this location of the casing does not participate in the hydraulics. In summary, there is no expected impact on 1-RC-P-1A hydraulic performance due to the casing indications identified in CR1253801.

Figure 2- 1-RC-P-1A Casing Indications- Partial Plan View

Figure 3- 1-RC-P-1A Casing Indications- Partial Elevation View

Figure 4- 1-RC-P-1A Casing Indications- Partial Elevation View

Figure 5- 1-RC-P-1A Casing Indications- Partial Plan View

Note that the indications shown on the inner bore of the casing at the diffuser adapter interface (Figures 3,4, and 5 above) are believed to be induced during the maintenance evolution. Upon the retrieval attempt of the diffuser adapter, it was identified that the component was “stuck” and required mechanical methods to be removed from the case. This indicates that there was interference between the casing bore and the diffuser adapter, likely due to the small fragments of the failed cap screws becoming lodged within the clearance between the casing the diffuser adapter. Upon separation of the two parts, the forces applied caused small pieces of the casing to shear off which created these indications. This is supported by the visually rough surface of these indications as compared to the clear indications in the upper cavity induced by the fastener caps/threads. As such, the indications on the inner bore of the casing ID at the diffuser adapter interface are a result of the maintenance activity and are not service related/induced and there are no degradation mode concerns.

Section 2- Structural Integrity Evaluation

Evaluation of areas of surface compressive deformation due to diffuser bolting cap screws being partially pressed into the pump casing.

Except for fatigue crack growth in a primary water environment, which is directly considered in WCAP-13045 (Reference 10), no active pump casing degradation mechanisms are known to exist. However, it is also possible that fretting degradation caused the observed degradation in the pump casing based on OE from Salem Station. However, based on the visual appearance of the surface degradation it was considered possible that the damage was caused by a onetime load application, and fretting wear would not introduce any physical characteristics that would be more severe, thus a static load application is being considered in this evaluation.

The pump casing material is a SS Casting, , which is an Austenitic Stainless Steel material that is very flaw tolerant. A Leak Before Break (LBB) analysis of the pump casing was performed in WCAP-11517 (Reference 26) and demonstrates that a postulated through-wall crack in the pump casing remains stable based on a detailed fracture mechanics evaluation and demonstrates that a gross failure of the casing is not feasible. If such a through-wall crack did exist, it would be detected based on the leakage detection capability and the plant would safely come down to a safe shutdown condition. The LBB evaluation was performed as part of a Westinghouse Owners Group program for Westinghouse pumps and included the North Anna specific pump Model 93A as well. The goal of the LBB evaluation for the pump casings performed in WCAP-11517 was to demonstrate the structural integrity of the pump casing since the grain structure of material posed hardship in performing cost-effective volumetric inspection.

Based on visual inspections and overall dimensions of the cap screws the limiting depth of the indentations in the pump casing is conservatively estimated to be 1.125/2 = 0.5625”, which exceeds the limiting flaw depth of 0.3” in the acceptance standards of ASME Section XI, Table IWB-3519.2-2 (Ref. 9 and 17). The noted degradation has effectively changed the surface profile locally in this area and it is considered the new casing surface in this area. Therefore, the evaluation considers the effects of this new surface profile on the ASME Class 1 Stress Report (EM-4771) along with potential impact of this new surface profile being created by partially pressing the bolting material into the surface of the pump casing. Based on provisions of IWB-3142.4, Acceptance by Analytical Evaluation, the surface degradation is evaluated considering that a crack like flaw may be present at or just below the surface of the more heavily deformed areas. For the current Licensing period the allowance for performing only visual examinations at North Anna is based on NRC approval of the Code Case N-481 evaluations performed by Westinghouse, as documented in LR-1017/LR-2017 (WCAP-15555), Reference 27, which is based on the generic industry analysis performed in WCAP-13045 (Reference 10). Based on a review of WCAP-13045 the global stress field in this area of the pump casing is relatively low compared to the postulated flaw locations evaluated (Ref. Figures 8-12, 8-13 and 8-14 of Ref. 10). During the event which resulted in the postulated plastic deformation at the pump casing surface the material at or just below the surface of the indentations would have been subject to out of plane tensile stress in the hoop and axial directions of the pump casing. Although no indications of actual surface cracking could be seen in the photos and video of the affected area, since the compressive stresses required to generate the observed surface profile would have exceeded the yield strength of the material it is conservatively postulated that the resulting out of plane tensile stresses in the surface and underlying material could have resulted in minor cracking at or just below the surface. Given that the surface indentations are limited in depth to 0.5625” or less it is considered reasonable to postulate that a maximum resulting flaw size during the postulated deformation of the subsurface material would not exceed approximately 50% of the depth of these local surface depressions, or 0.2813”, given a typical extent of influence for localized loading effects. Thus, the maximum postulated initial flaw size of 0.3” used in the analysis performed in WCAP-13045, which has been approved by

the NRC as reconciled in WCAP-15555 specifically for North Anna, and in subsequent evaluations performed in support of Subsequent License Renewal documented in Ref. 11 and 28 would still be considered bounding.

The assumption of cracking being limited to 50% of the depth of the indentation is supported by industry technical research performed in Reference 8 regarding the estimated size of the plastic zone below a cylindrical depression. The plastic zone depth below the deformed area for the worst-case cap screw head indentation was calculated using the equation below to be less than 0.1" considering an average calculated load of 25,000 lbf, which is less than the assumed initial flaw size used in the crack growth/fracture analysis. Even considering higher point loads based on uneven distribution of the various bolting material, 1.5x25,000 lbf = 37,500 lbf, the maximum predicted plastic zone depth would be less than 0.2", and still less than the initial flaw size assumed in the analysis performed in Ref. 10. The equation for the radius, c, of the plastic zone which is based on the Johnsons Cavity Model (See Appendix 1 and References 8, 15 & 16) is given by:

$$P = \pi a^2 \left[\frac{2}{3} + 2\ln\left(\frac{c}{a}\right)\right]\sigma_y$$

, where a = 0.5625", P = the applied load, and σ_y = 30,000 psi

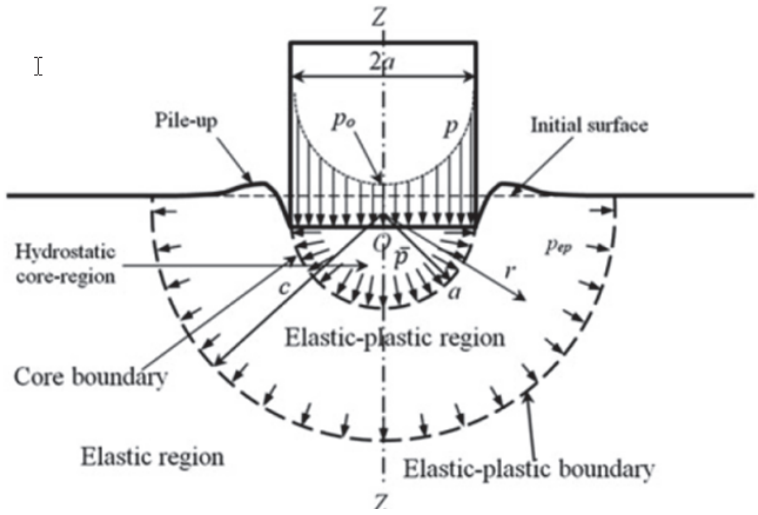
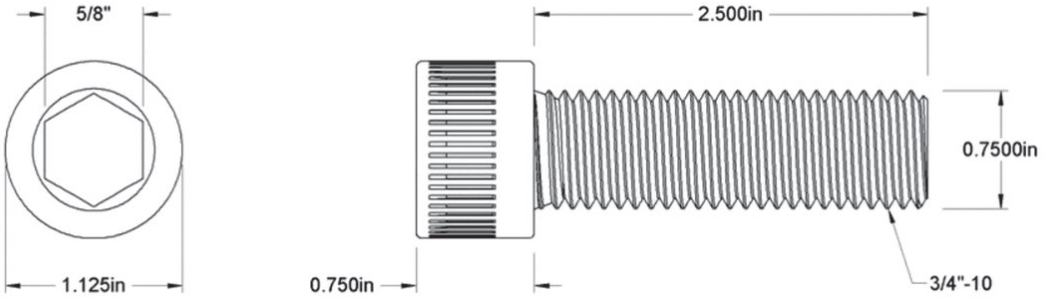


Figure 6- Johnson's Cavity Model

Note that the presence of multiple postulated cracks is considered. The worst case was judged to be two adjacent indentations from cap screw heads, aligned to form a single flaw of 0.3" depth and an estimated 1.5" length (1.5" = 0.75"x2), or (a/l) = 0.3/1.5 = 1/5 which is bounded by the aspect ratio of 6:1 assumed in the analysis performed in Ref. 10. Based on the majority of the areas of deformation being shallow compared to the worst-case assumption, no other combined flaws are postulated based on the proximity rules of IWA-3330-1, which would limit the need to consider indentations separated by more than half of the depth of the deepest adjacent indentation.
The dimensions of the cap screws are shown below for reference.



Although some residual elastic tensile stress may exist near the boundary of any plastically deformed material, it would be very localized and would not have a significant effect on overall crack growth rates, and the crack growth and fracture mechanics analysis performed in Reference 10 would remain bounding based on the relatively low global stresses in the area of deformation. ASME Section III stress limits would not be challenged by these local areas of increased stress and the governing locations identified in the stress report remain governing. Based on a review of WCAP-13045 the area where the deformation has occurred would be bounded, with significant margin, by fracture mechanics evaluations performed for paths 2 and 3 in Figure 9-2 below. Path 2 is considered most representative of the global stresses in the actual area of deformation.

LOCATION OF FLAWS POSTULATED IN THE MODEL 93A PUMP CASING

Given the relatively low global stress levels in this area of the pump casing the actual crack driving force is below the limiting material fracture toughness, J_{IC} = 750 in-lbf/in^2, as shown by comparison of Table 11-7 results below, and stress fields for the actual location compared to the path 2 location in Figures 8-12, 8-13 and 8-14 of WCAP-13045.

TABLE 11-7

STABILITY RESULTS OBTAINED USING THE ASME CODE PROPERTIES FOR THE MODEL 93A PUMP CASINGS

While the actual cause of this new local surface profile is unknown, a conservative estimate can be made regarding the amount of load required to effectively press the bolting material into the pump casing to generate the bounding level of deformation being postulated here. Based on the bolt size and number of depressions noted a value of 500,000 lbf can be estimated for the net load given the bolt size and assuming an approximate flow stress for the cast Stainless Steel Material = (30 ksi + 70 ksi)/2 = 50 ksi to account for strain hardening effects. Note that room temperature material properties are used given the postulated onetime event occurring either immediately following pump internals removal or during prior pump internals installation.

Assuming that the average width of an impression is 1/2”
Assuming the average length of the impression is 1”
Assuming that the local stress in the pump casing was effectively at the flow stress of 50 ksi during the deformation process.

The required load to cause *one* impression is conservatively estimated to be (50,000 psi) x (1/2”)(1”) = 25000 lbs.

Assuming there were 20 of these impressions in the pump casing (based on a review of examination photographs) the estimated total load would have been 20x(25000 lbf) = 500,000 pounds. The only source capable of producing this magnitude of load would be the pump main flange bolting. Thus, this load would have been reacted internal to the pump casing, not affecting any NSSS supports or piping. Based on a conservative assumption that the area of the pump where the indentations are located is 1/8 of the circumference of the pump casing (based on review of photos and video) it can be assumed that the entire load was reacted in this small section of pump casing. A simple check of tensile and shear stress can be made using the minimum wall thickness in this area of the pump casing of 4.5” and a limiting criteria of 0.9Sy for tension, and 0.9(0.4Sy) for shear.
The inside diameter at this location is 34” and would be the minimum in the load path. Thus a limiting cross sectional area would be (4.5”)(π)(34”)/8 = 60 in^2. Then the through thickness tensile and shear stress would be 500,000 lbf/60 in^2 = 8333 psi < 0.9(0.4Sy) = 10,800 psi.

Appendix 1:

The plastic zone ($a < r < c$) can be estimated by Johnson's cavity model (see Figure 7) [8], where a spherical core of radius a, representing the contact area, is assumed to be under hydrostatic pressure, p_m, as a result of the indentation load P. The elastic-plastic boundary of radius c as defined by the yield criteria is given by [9, 10]

$$p_m = \left[\frac{2}{3} + 2\ln\left(\frac{c}{a}\right)\right]\sigma_Y$$

where σ_Y = 30,000 psi is the yield strength of the material, the contact radius a is set to a = 0.5625". With an estimated pressure of 25,000 psi, the estimated plastic zone depth is less than 0.1". When c is set to 0.8625" (0.5625" + 0.3"), the estimated hydrostatic pressure would be 45,000 psi, which exceeds the estimated load for the worst-case scenario. Therefore, a subsurface flaw as a result of indentation is bounded by the 0.3" initial flaw depth used in Reference 10.

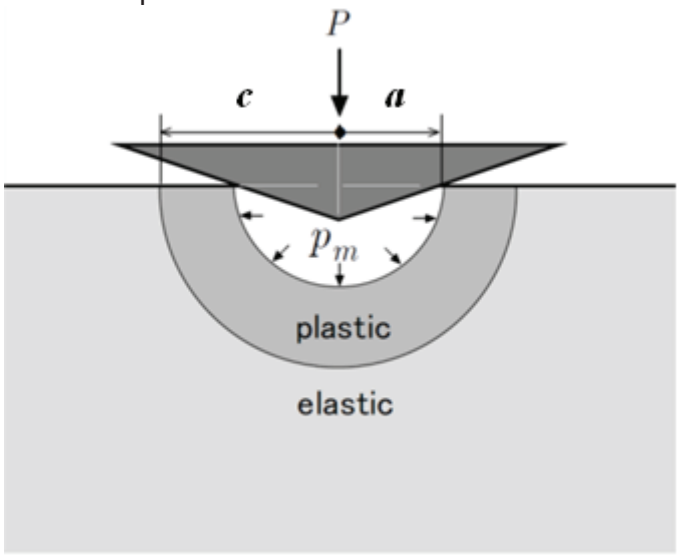


Figure 7- Cavity model of an elastoplastic indentation contact by a cone; the model comprises a hemispherical cavity of radius a with internal hydrostatic contact pressure $p_m = P/\pi a^2$. The cavity is surrounded by a plastic core with radius b embedded in an elastic half space [8].

Section 3- Foreign Material Concerns

As required by the detailed assignment CA12378356, this evaluation must address any foreign material concerns. Based on the detailed inspection of the casing after the shield plug was removed and Engineering eSOMS Narrative log on 3/20/2024 at 04:07, there were two (2) areas of concern with regards to raised metal on the inner bore of the casing at the diffuser adapter clearance. Reference CR1254049. These burrs posed a threat to become foreign material during pump installation as the pump diffuser adapter could contact the burrs and chip off and enter the intermediate loop below. Due to the concern, these burrs were filed down flush with the casing ID and are no longer a concern. An FME retrieval plan was generated due to CR1253557 and CR1254091 and is being documented in CA12375685 which will include retrieval and accounting for the cap screws and any other fragments generated from the cap screw failures. This start up CA will address any existing or potential foreign material introduction issues prior to core onload. Based on the final material condition inspections performed on 3/20/2024 of the casing indications and the fact that the FM retrieval plan is accounting for any loose debris within the pump/intermediate loop cavities, there is no concern with foreign material introduction because of the casing indications identified in CR1253801.

Conclusions

In conclusion, the indications identified on the 1-RC-P-1A casing in CR1253801 have no impact on the pump hydraulics, ASME Code Section III compliance, or structural integrity based on the discussion and evaluations above. The refurbished pump is equipped with upgraded diffuser adapter cap screws not known to be susceptible to stress corrosion cracking, which is the likely cause of the fastener failure on the removed pump. Given the new pump will have an attached diffuser adapter with upgraded bolting, it is expected that the diffuser adapter will not “drop” in the future and create the service condition on the casing identified in CR1253801. Additionally, given the failed diffuser adapter cap screws have been removed from the casing along with the dropped diffuser adapter, and burrs have been removed, the degradation mechanisms that induced the imprinting on the 1-RC-P-1A casing have been removed as the contact between these parts is the likely cause of the imprinting identified on the casing. Based on the evaluations performed above, there are no issues with accepting the 1-RC-P-1A casing “as-is” with no further maintenance or inspections required.

This conservative evaluation can be applied to 1-RC-P-1B and 1-RC-P-1C. Although the cause evaluation is not complete, the likely cause of the defects in 1-RC-P-1A is cap screw fragment migration into the gap between the diffuser adaptor and casing and long-term fretting. Cap screw implantation of half the width was a conservative assumption considering the gap dimensions and the lack of a large static load to implant debris. The only reasonable mechanism to cause a deeper flaw than analyzed is fretting, which does not involve plastic deformation. The conservative approach in this evaluation is to assume a single, excessive static load that would initiate plastic deformation and cracking, which was still found to be acceptable. The bounding nature of the analysis covers potential conditions in all three RCPs that have similar age and operating time. This approach provides reasonable assurance that the other pump casings would have structural integrity.

Design Effects and Considerations

ASME Section XI & In-Service Inspection (ISI):

The Reactor Coolant Pump Casing is an RCS pressure boundary surface within the scope of ASME Section XI. CA12378359 documents ISI review of the as found casing conditions and identification of any required follow on action.

North Anna 08/23/2011 Seismic Event & RCP Dynamic Requirements:

As concluded above, the as-found RCP pump casing impressions do not affect the structural integrity of the casing. As a result, there is no adverse effect on the ability of the pump casing to withstand a North Anna licensing basis seismic event or any other licensing basis loading condition acting on the casing (e.g. Large Break LOCA). Discussed with Corporate Engineering Mechanics (B. Derreberry).

Impact To Other Unit, Affect A Direct/Indirect Path To The Core, Special Process Qualifications (Visual Inspection) , Input From Engineering Mechanics, & Potential For Corrosion Related Material Degradation (per DNES-AA-GN-1003 Att. 1 Design Attribute Review Checklist); and Mechanical & Structural Discipline Reviews, ASME Code/ISI/IST, Other Stakeholders/ISI Engineering/Other/, Framatome/Westinghouse SMEs , Foreign Material, Seismic Qualification/Review, Material Compatibility, Nuclear Fuels/Reactor Engineering (foreign material in the core), & Licensing [per DNES-AA-GN-1003 Att. 2 Industry Design Attribute Review Checklist]:

These considerations are addressed in the body of the ETE, in other specific Design Effects & Consideration discussions, or in the 50.59 Program review for this ETE.

Required Actions

Reference DRUL (Attachment 1).

Recommendations

None.

References

1. Westinghouse NSD-TB-83-01- Diffuser Adapter Cap Screws – contained in Reference 4
2. Licensee Event Report 82-056
3. Station Drawings 11715/12050-2.31-30A Sheets 1 and 2 Revision 1
4. VTM 59-W893-00044 Revision 19 - Westinghouse Reactor Coolant Pump Manual
5. ETE-NA-2023-0031 Revision 1- RCP Case Machining
6. DC NA-22-00076 Revision 1- Reactor Coolant Pump Refurbishment (1-RC-P-1A)
7. Purchase Order 70357668
8. Zhong Hu, Kevin Lynne, and Fereidoon Delfanian, “Characterization of Materials Elasticity and Yield Strength Through Micro-Nana Indentation Testing With a Cylindrical Flat Tip Indenter”, Department of Mechanical Engineering, South Dakota State University, January 2015
9. ASME Boiler and Pressure Vessel Code, Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components”, 2013 Edition
10. WCAP-13045, “Compliance to ASME Code Case N-481 of the Primary Loop Pump Casing of Westinghouse Type Nuclear Steam Supply Systems”, Westinghouse, September 1991
11. PWROG 17033, “Update for Subsequent License Renewal: WCAP-13045 “Compliance to ASME Code Case N-481 of the Primary Loop Pump Casing of Westinghouse Type Nuclear Steam Supply Systems”, Westinghouse, November 2019
12. CR1253801, “Structural Deformation Identified on Pump Casing” including:

a. CA12378362, “CA To Eng - SLR to capture any lessons learned or extent concerns in applicable forums.”
b. CA12378359, “CA to Inns-Eng to review for ISI/IST program concerns and determine / initiate any needed actions - STARTUP (PRIOR TO CORE ONLOAD)”
c. CR1253801, “CA to Inns-Eng to disposition structural deformation on the pump casing, including any possible FM concerns - STARTUP (PRIOR TO CORE ONLOAD)”

13. Work Package N1-82-07231815
14. Code Case N-481, “Alternative Examination Requirements for Cast Austenitic Pump Casings,” Section XI, Division 1, Approval Date: March 5, 1990.
15. M. Sakai, Indentation Contact Mechanics, Revised Edition, 2020
16. F. F. Ling, Introduction to Contact Mechanics, Second Edition, 2010
17. NDE Report, VT-24-063, Dated 3/19/24
18. NRC Inspection Report Numbers 50-338-82-28/50-339-82-28 & 50-338-83-9/50-339.83-9 (these reports detail NRC inspection results for the 1982 RCP diffuser bolting event. Inspection closeout report 50-338-83-9/50-339-83-9 concluded that the cap screws were made of 303SS material, that failure resulted from a combination of mechanisms including fatigue, stress corrosion cracking combined with ductile rupture. In addition the report concludes that the parts in question were subjected to a large bending and tensile stresses and, the accepted mitigation recommendation was to replace with different type of material.)
19. Westinghouse Infogram 95008A- Kori 3 Reactor Coolant Pump Diffuser Adapter Cap Screws (part of Westinghouse Letter VRA-95-129 attached to VTM 59-W893-00044 Addenda 28).
20. CR1253557, “1-RC-P-1A Pump Diffuser Adapter remains inside pump casing” including:

a. CA12375702, “DTI to Maintenance, as program owners, to review this issue for any necessary improvements to current FME requirements”
b. CA12375701, “CA to Eng SLR Evaluate the extent of condition of the diffuser assemblies and bolts on 1-RC-P-1B, 1-RC-P-1C"
c. CA12375685, “STARTUP (PRIOR TO CORE ONLOAD - Eng SLR to develop a FM Retrieval plan to remove the diffuser adapter”
21. Westinghouse RCP Design Report EM-4771, December 8th 1975
22. CR1254049, “1-RC-P-1A - Two Casing Internal Surface Irregularities Identified”
23. EWR 82-464 Dated 9-17-1982
24. EWR 82-421 Dated 8-24-1982
25. NAPS UFSAR Revision 59.03 Section 5.1.1- Reactor Coolant System Components
26. WCAP-11517, “Leak Before Break Analyses for the Primary Loop Pump Casings and Isolation Valve Bodies of Westinghouse Type Pressurized Water Reactors,” July 1987. Witt, F. J., et. al. [Westinghouse Proprietary]
27. Technical Report LR-1017/LR-2017, License Renewal Project Time Limited Aging Analysis Ewview, Westinghouse Report – A Demonstration of Applicability of Code Case N-481 to the Primary Loop Pump Casings of North Anna and Surry Units 1 and 2 for the License Renewal Program *WCAP-15555), Surry and North Anna Power Stations, August 2000
28. WCAP-18503, Rev. 2, Resolution of North Anna Power Station Time Limited Aging Analysis for Subsequent License Renewal, September 2021
29. CA12331144, CA to Eng-SLR to evaluate the schedule and order of pump refurbishments based on operational history (pump cavitation/wear).
30. CA12378356, CA to Inns-Eng to disposition structural deformation on the pump casing, including any possible FM concerns - STARTUP (PRIOR TO CORE ONLOAD).
31. Procedure 1-PT-27, Revision 34, RCS Flow and Loop Delta T Measurement.
32. NAPS Technical Specifications, Revision 71, TS 3.4.1 & Bases, LCO 3.4.1.