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Subject: Arkansas Nuclear One - Unit - 1
Docket No. 50-313
License No. DPR-51
Licensee Event Report 50-313/2000-003-00

Gentlemen:

In accordance with 10CFR50.73(a)(2)(ii), enclosed is the subject report concerning welds on Reactor Coolant System hot leg level instrument nozzles.

Very truly yours,

Jimmy D. Vandergrift
Director, Nuclear Safety Assurance

JDV/tfs

enclosure

IE22

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NRC FORM 366 (5-92) U.S. NUCLEAR REGULATORY COMMISSION

APPROVED BY OMB NO. 3150-0104
EXPIRES 5/31/95

ESTIMATED BURDEN PER RESPONSE TO COMPLY WITH THIS INFORMATION COLLECTION REQUEST: 50.0 HRS. FORWARD COMMENTS REGARDING BURDEN ESTIMATE TO THE INFORMATION AND RECORDS MANAGEMENT BRANCH (MNBB 7714), U.S. NUCLEAR REGULATORY COMMISSION, WASHINGTON, DC 20555-0001, AND TO THE PAPERWORK REDUCTION PROJECT (3150-0104), OFFICE OF MANAGEMENT AND BUDGET, WASHINGTON, DC 20503.

LICENSEE EVENT REPORT (LER)

FACILITY NAME (1)	DOCKET NUMBER (2)	PAGE (3)
Arkansas Nuclear One - Unit 1	05000313	1 OF 8

TITLE (4) Reactor Coolant System (RCS) Hot Leg Level Instrument Nozzle Welds Cracked Due To Primary Water Stress Corrosion Cracking Resulting From The Use Of Alloy 182 Weld Metal Exposed To RCS Water In A Highly Restrained Weld Joint That Was Not Stress Relieved

EVENT DATE (5)			LER NUMBER (6)			REPORT DATE (7)			OTHER FACILITIES INVOLVED (8)	
MONTH	DAY	YEAR	YEAR	SEQUENTIAL NUMBER	REVISION NUMBER	MONTH	DAY	YEAR	FACILITY NAME	DOCKET NUMBER
02	15	2000	2000	003	00	03	16	2000	FACILITY NAME	DOCKET NUMBER

OPERATING MODE (9)	N	THIS REPORT IS SUBMITTED PURSUANT TO THE REQUIREMENTS OF 10 CFR: (Check one or more) (11)							
POWER LEVEL (10)	000		20.402(b)		20.405(c)		50.73(a)(2)(iv)		73.71(b)
			20.405(a)(1)(i)		50.36(c)(1)		50.73(a)(2)(v)		73.71(c)
			20.405(a)(1)(ii)		50.36(c)(2)		50.73(a)(2)(vii)		OTHER
			20.405(a)(1)(iii)		50.73(a)(2)(i)		50.73(a)(2)(viii)(A)		Specify in
			20.405(a)(1)(iv)	X	50.73(a)(2)(ii)		50.73(a)(2)(viii)(B)		Abstract Below
			20.405(a)(1)(v)		50.73(a)(2)(iii)		50.73(a)(2)(x)		and in Text

LICENSEE CONTACT FOR THIS LER (12)

NAME	TELEPHONE NUMBER (Include Area Code)
Thomas F. Scott, Nuclear Safety and Licensing Specialist	501-858-4623

COMPLETE ONE LINE FOR EACH COMPONENT FAILURE DESCRIBED IN THIS REPORT (13)

CAUSE	SYSTEM	COMPONENT	MANUFACTURER	REPORTABLE TO EPIX		CAUSE	SYSTEM	COMPONENT	MANUFACTURER	REPORTABLE TO EPIX

SUPPLEMENTAL REPORT EXPECTED (14)				EXPECTED SUBMISSION DATE (15)	MONTH	DAY	YEAR
	YES (If yes, complete EXPECTED SUBMISSION DATE)	X	NO				

ABSTRACT (Limit to 1400 spaces, i.e., approximately 15 single-spaced typewritten lines) (16)

On February 15, 2000, with the plant in cold shutdown conditions for a scheduled outage, a weld in a Reactor Coolant System (RCS) hot leg level instrumentation nozzle was found to have been leaking as indicated by boron buildup. Cracked welds were later found on the other six hot leg level instrumentation nozzles of similar design. One weld crack was subsurface. The root cause was determined to have been using Alloy 182 weld metal exposed to RCS water in a highly restrained weld joint that had not been stress relieved, resulting in Primary Water Stress Corrosion Cracking (PWSCC). Six of the nozzles were replaced in accordance with Section XI of the ASME Code using an improved design that included different materials with more resistance to PWSCC. The seventh nozzle was repaired using alternate criteria approved by the NRC because a Section XI repair would have required core offload. This nozzle will receive a Section XI repair during the next refueling outage. The particular nozzle design was used only in these seven locations and is not believed to be installed in any other B&W design operating unit.

A. Plant Status

At the time of this event, Arkansas Nuclear One Unit 1 (ANO-1) was in cold shutdown conditions in an outage to perform scheduled maintenance.

B. Event Description

Welds connecting six hot leg level instrumentation nozzles to the Reactor Coolant System (RCS) [AB] loops were found to have been leaking. The seventh nozzle of this type had not leaked. All seven nozzles had cracked welds, but the crack on the weld that had not leaked was subsurface.

On February 15, 2000, during an inspection of the Reactor Building, Operations personnel discovered boron buildup on insulation below an isolation valve for a hot leg level instrumentation nozzle on RCS loop "A." Upon removal of the insulation, it could be seen that an RCS leak had occurred at the base of the nozzle. The leak appeared to have been small weepage. Insulation was removed from the remaining six potentially susceptible nozzles on both RCS hot legs. Some boron buildup or staining was found on five other nozzles. Further investigation by Non-Destructive Examination (NDE) revealed that the leakage was occurring through flaws in the partial penetration weld that attaches the level tap nozzle to the outside diameter (OD) of the hot leg. Both axial (radial) and circumferential cracking was found. Similar subsurface cracking in the weld for the seventh nozzle was found after removal of the fillet weld as part of the repair process.

Seven similarly designed nozzles were installed in ANO-1 in 1986 as part of the hot leg level instrumentation modification. Three level monitoring connections are in "A" RCS loop and four are in "B" loop. Each of the seven level tap nozzles in the hot leg piping is a 3/4-inch Schedule 160 Alloy 600 (Inconel) (SB-167 annealed) branch connection. The level tap nozzles also consist of an Alloy 600 sleeve (SB-166 annealed) that has been roll expanded in the carbon steel penetration and seal welded with an autogenous (without filler metal) weld to the stainless steel cladding on the inside diameter (ID) of the hot leg pipe. Each nozzle is attached to the outside of the hot leg piping by a J-groove partial penetration weld with a fillet cap. Alloy 182 Shielded Metal Arc Weld (SMAW) weld metal was used for the partial penetration and fillet welds. This particular sleeve, nozzle, and weld design was used only at these seven locations. An eighth nozzle was installed in ANO-1 at the same time but used a different design and stainless steel material. No other B&W-design operating units are believed to contain this field modification or the same configuration and material.

Repair packages were developed in accordance with Section XI of the ASME Code to replace six of the nozzles. One nozzle could not be replaced using this technique since it is on the underside of the hot leg elbow below mid-loop level. Since an ASME Section XI repair would have required core offload and significantly delayed restart, ANO requested and received Nuclear Regulatory Commission approval of an alternate repair technique. This consisted of a weld pad buildup and fillet weld that meets ASME Section III design requirements for allowable stress but leaves the existing flaws in place.

C. Root Cause

Based on the visual and NDE evidence during nozzle removal, as well as laboratory examination of a sample from one of the cracked welds, Primary Water Stress Corrosion Cracking (PWSCC) was the mechanism of cracking of all seven hot leg nozzle welds. This conclusion is based on the following evidence.

- A portion of a weld (mainly the J-groove location and some fillet location) that contained a circumferential segment of a crack was removed from one nozzle. This "boat sample" was examined at the B&W Technologies Lynchburg Technology Center in an attempt to define the cracking mechanism. The laboratory examination concluded that the weld failed primarily by PWSCC. Characteristic features of PWSCC were present on approximately 99 percent of this fracture surface. A small area encompassing less than one percent of the total fracture surface contained fatigue striations indicative of low cycle fatigue, but this was not considered a significant contributor to the cracking. This examination also found secondary cracks, which are frequently found in PWSCC cracking but not in thermal fatigue or mechanical fatigue cracks.

- Cracks were mainly restricted to the Alloy 182 weld metal in the J-groove weld in contact with RCS at the weld root. This weld metal has failed by PWSCC in the presence of RCS water in field replacement nozzles at other nuclear facilities.

- Since the Alloy 182 weld was not stress relieved, it is expected to have had high residual tensile stresses due to the welding that would promote initiation of PWSCC cracks. Alloy 600 nozzles and Alloy 182 weld cracks have been attributed to high weld residual tensile stresses.

- The nozzle design with welds on the ID and on the OD caused high stresses between the Alloy 600 sleeve and Alloy 600 nozzle and the carbon steel hot leg piping. During heat-up and cool-down of the RCS, this design would cause "stress lock-up" or thermally induced stresses, which would be additive to the welding residual stresses. This condition would promote increased susceptibility to PWSCC crack initiation in the Alloy 600 nozzle, Alloy 600 sleeve, and the Alloy 182 weld metal.

- Within the partial penetration weld, cracks (especially radial cracks) appeared to be mainly limited to the J-groove weld. The circumferential cracks appeared to be secondary cracks (branching from the radial cracks), most likely due to the residual stress field within the weld. Secondary branching is a characteristic of stress corrosion cracking.

- The crevice condition between the nozzle and the sleeve for this design tended to exacerbate any environmental effects associated with the weld cracking. This type of crevice condition is known to promote PWSCC.

- After the PWSCC cracks had initiated, they propagated because of the residual stresses within the weld. Propagation of the PWSCC cracks was also probably assisted by the relative thermal expansion stresses between the Alloy 600 sleeve, nozzle, and the carbon steel hot leg piping hole during heat-up and cool-down of the RCS. Thermal expansion stresses also can cause propagation of thermal fatigue cracks, but no significant cracks of this nature were detected.

- The weld discontinuities (e.g., inclusions and lack-of-fusion) that were found in these shielded metal arc welds are known stress risers and crack initiation sites in welds. These discontinuities most likely contributed to initiation of the weld PWSCC. The shielded metal arc welding process (e.g., Alloy 182 weld metal) tends to produce a greater amount of discontinuities than the gas tungsten arc welding process.

- The original rounded PT indications on the fillet weld surface appeared to be connected with circumferential cracking. These indications may have been the result of circumferential cracks reaching the surface. It is also possible that these indications were due to additional branching (i.e., radial cracking) from the circumferential cracks reaching the fillet weld surface.

- There was no evidence of mechanical fatigue due to vibration forces since there was no indication of cracking along the weld toe at any of the nozzle welds. A vibration analysis indicated that the vibration-induced stress is small and well below the endurance limit of the nozzle. Similarly, there was no evidence of thermal fatigue except for one very small area that was found on the laboratory sample. Laboratory investigators stated that this amount of fatigue was not significant. Also, mechanical fatigue and thermal fatigue would have been expected to initiate from the outside surface of the weld, and no indications of this nature were observed. It appears that all cracking emanated from the sleeves at the weld root location, which was wetted by RCS water. Based on these observations, high cycle mechanical fatigue and low cycle thermal fatigue were eliminated as the mechanism of cracking.

Crack arrest may have occurred. This is supported by the following evidence: (1) six of seven nozzles had similar weeping leakage; (2) it is very unlikely for all of these nozzles to leak in the same time in the presence of an active cracking mechanism; and (3) cracking in all of the nozzle welds appeared to have progressed to about the same point, near the OD surface, and then stopped.

The stress state in the J-groove weld was biaxial (as indicated by cracking in both the radial and circumferential directions), and the stress levels were high. The hoop and longitudinal stresses in the hot leg pipe caused the biaxial stress. The crevice formed at the weld root by the end of the sleeve and the nozzle acted as a stress riser increasing the stress in the weld. The biaxial nature, weld residual stresses, and stress riser together acted to propagate both axial and radial cracks to relieve the high stress. Once the stresses were relieved in the highly constrained J-groove weld, the top surface of the fillet and J-groove weld did not have the effect of the stress riser and constraint, and the stress was reduced. In some cases, the near surface stress may have been reduced enough to arrest the advancing cracks before they reached the surface.

The root cause of the ANO-1 hot leg nozzle weld cracking that resulted in penetration of the RCS pressure boundary is a combination of three causal factors. All three causal factors worked together to cause this condition. Removal of any one of the three factors may have prevented it.

- High stresses were associated with this nozzle design that made it very susceptible to PWSCC. These stresses were due to the presence of a weld on both the ID and OD, which caused thermal stresses or "stress lockup" in the nozzles upon heatup and cooldown. In this design the Alloy 600 nozzle and sleeve would have heated up faster than the carbon steel hot leg piping and vice versa during cool-down. This condition led to higher tensile stresses than nozzle designs that have a weld only on the ID or OD. The lock-up stresses associated with this design are in addition to the applied pressure stresses, weld residual stresses, and normal thermal stresses of heat up and cooldown that are experienced by all nozzles. The sleeves probably did not crack on the ID surface because the rolling imparted a compressive stress on the inner surface and the thermal gradient differential between the sleeve and the hot leg wall thickness also imparts an axial compressive stress on the sleeve, neither of which is conducive to PWSCC. Thus, the weld and sleeve-to-weld interface would have a higher susceptibility to PWSCC than the sleeve itself. The lock-up stresses are believed to be oriented axially and thus would impose bending stresses on the weld. This component of the stress may have led to the circumferential segments of the PWSCC cracks. The high tensile stresses of the hot leg nozzle design made these nozzle welds more susceptible to PWSCC.

- It is now well known that Alloy 182 weld metal can fail by PWSCC when it is in contact with RCS if the stresses in the weld joint are high. The susceptibility of Alloy 182 to PWSCC cracking was not well established when the hot leg nozzles were installed in 1986, and the decision to utilize this material was made without the benefit of current industry experience. Alloy 182 was widely used for welding Alloy 600 nozzles in the RCS during original construction of both ANO units, and this weld metal is in contact with RCS in other nozzles. However, all of these original construction welds were either stress relieved and/or they were welded on only the ID, which allows for unrestrained expansion during heat up and cooldown. The original welds do not have the "stress lockup" condition that is associated with the hot leg nozzle design; therefore, they have a lower susceptibility to PWSCC.

- Because the hot leg nozzle welds were not stress relieved, high residual tensile stresses were left in these welds. Under high stress conditions and in the presence of an aggressive environment, these residual stresses would promote initiation and propagation of PWSCC cracks in Alloy 600 and Alloy 182. The only Alloy 600 nozzle welds in ANO-1 that were not stress relieved are nozzles that were installed or repaired after original construction. These were the seven hot leg nozzles and a Pressurizer nozzle that was repaired in 1990. (The Pressurizer nozzle is of a design not susceptible to the hot leg nozzle weld cracking mechanism.) Since the hot leg nozzles had significantly higher residual stresses, they were more susceptible to PWSCC. If the hot leg nozzles had been stress relieved after installation, they may not have failed after 14 years of service. However, there is no industry precedent for performing optional stress relief in this application. Stress relief of nickel-based alloy nozzles installed in the field is not required per the ASME Code, and it was not considered for the installation. Although post weld stress relief of partial penetration welds joining Alloy 600 nozzles to carbon steel piping is not required by the ASME Code, it is now widely recognized that such heat treatments are beneficial in reducing the tendency for PWSCC of the nozzle and weld metal.

In summary, the root cause of the hot leg nozzle weld cracks from PWSCC is the use of SMAW Alloy 182 weld metal that is exposed to RCS water in a highly restrained nozzle design that was not stress relieved after welding.

Two contributing factors to this condition were identified. First, in this nozzle design there was a crevice between the sleeve, nozzle, and J-groove weld root. The crevice acted as a stress riser by increasing the stresses in the weld root and was a contributing factor to the PWSCC cracks in the hot leg nozzle welds. In addition, this crevice tended to worsen the environmental effects of the primary system coolant. Primary water chemistry changes would be delayed within the crevice leading to electrochemical potential differences. The crevice may have concentrated small amounts of impurities that are circulating through the RCS. Any such impurities or changes to the electrochemical potential in the crevice could have contributed to PWSCC of the nozzle welds. The second contributing factor was the weld discontinuities (oxide inclusions and lack-of-fusion) that were present within or near the weld roots. Although the ASME Code requirements for NDE surface inspection were met, subsurface weld discontinuities were found upon grinding removal during the repair. These discontinuities are generally considered not code acceptable when detected by required volumetric examinations. These discontinuities added to the stress on the weld and contributed to the PWSCC.

D. Corrective Actions

Six of the seven level tap nozzles and welds were replaced with an improved design that included use of materials known to be resistant to PWSCC (Alloy 690 materials).

The seventh nozzle weld was repaired using an alternate ASME Code repair. The repair consisted of a weld pad buildup and fillet weld. The repair meets ASME Section III design requirements for allowable stress but leaves the existing flaws in place. Flaw evaluations in accordance with Section XI, IBW-3600 were also performed for the remaining flaws. This repair will remain in service until the next ANO-1 refueling outage. That outage is currently scheduled to start March 16, 2001, during which an ASME Code repair will be performed.

A majority of the accessible small bore RCS nozzles were visually inspected for boric acid buildup and leakage. No additional leakage indications were found.

E. Safety Significance

The unidentified RCS leak rate prior to the scheduled outage was 0.093 gpm. As discussed above, there is evidence that crack arrest may have occurred. If the cracks had continued to propagate, it is postulated that RCS leakage would have gradually increased to a detectable level and remained within the capacity of the makeup system (i.e., leak before break). To assess operability of the level taps if a seismic event had occurred, a finite element analysis was conducted. The model was configured to simulate the penetration with the worst cracking observed. The analysis determined that there was significant margin against structural failure. For these reasons, this condition is judged to have had minimal actual safety significance.

F. Basis for Reportability

Section 3.2.4 of NUREG-1022, "Event Reporting Guidelines - 10CFR50.72 and 50.73," states, "Examples of events that the staff would consider reportable as significant reactor coolant system welding or material defects include items which cannot be found acceptable under ASME Section XI, IWB-3600, 'Analytical Evaluation of Flaws' or ASME Section XI, Table IWB-3410-1, "Acceptance Standards.'" Using this guidance, the leaking welds constituted a serious degradation of a principal safety barrier. Discovery of the first leaking weld was reported to the NRC Operations Center in accordance with 10CFR50.72(b)(1)(i) at 2321 CST on February 15, 2000. A follow-up report was made at 1252 CST on February 18, 2000, when the other five leaking welds were discovered. This report is submitted in accordance with 10CFR50.73(a)(2)(ii).

G. Additional Information

ANO has reported as Licensee Event Reports (LERs) two conditions involving RCS pressure boundary leakage attributed to PWSCC of Alloy 600 nozzles. In LER 50-368/87-003-01 (letter number 2CAN088801) dated August 12, 1988, ANO-2 reported leaking Pressurizer heater sheaths. In LER 50-313/90-021-00 (letter number 1CAN019112) dated January 21, 1991, ANO-1 reported leakage from an Alloy 600 Pressurizer level sensing nozzle. Neither of these conditions was attributed to Alloy 182 weld metal and both involved a joint design different from the hot leg level nozzles. Therefore, these two LERs are not considered to be previous similar events.

Energy Industry Identification System (EIIS) codes are identified in the text as [XX].