Duke Energy

W. R. McCollum, Jr.
Vice President

Duke Energy
Oconee Nuclear Station
7800 Rochester Highway
Seneca, SC 29672
(864) 885-3107 OFFICE
(864) 885-3564 FAX

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U.S. Nuclear Regulatory Commission
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Subject: Oconee Nuclear Station, Unit 2
Docket Nos. 50-270
Licensee Event Report 270/2001-002, Revision 0
Problem Investigation Process No.: O-01-01455

Gentlemen:

Pursuant to 10 CFR 50.73 Sections (a)(1) and (d), attached is Licensee Event Report 287/2001-002, Revision 0, concerning the discovery of reactor pressure vessel head leakage due to stress corrosion cracks found in several control rod drive nozzle penetrations.

This report is being submitted in accordance with 10 CFR 50.73 (a)(2)(i)(B) and (a)(2)(ii)(A). For this event, the overall safety significance of this event was minimal and there was no actual impact on the health and safety of the public.

Very truly yours,

W. R. McCollum, Jr.

Attachment

IE22

cc: Mr. Luis A. Reyes
Administrator, Region II
U.S. Nuclear Regulatory Commission
61 Forsyth Street, S. W., Suite 23T85
Atlanta, GA 30303

Mr. D. E. LaBarge
U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Washington, D.C. 20555

Mr. M. C. Shannon
NRC Senior Resident Inspector
Oconee Nuclear Station

INPO (via E-mail)

NRC FORM 366 (6-1998) U.S. NUCLEAR REGULATORY COMMISSION

LICENSEE EVENT REPORT (LER)

(See reverse for required number of digits/characters for each block)

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TITLE (4)
Reactor Pressure Vessel Head Leakage Due to Stress Corrosion Cracks Found in Several Control Rod Drive Nozzle Penetrations

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
04	28	01	2001	- 002 -	00	06	25	01		05000
									FACILITY NAME	DOCKET NUMBER 05000

OPERATING MODE (9): 5

POWER LEVEL (10): 0%

THIS REPORT IS SUBMITTED PURSUANT TO THE REQUIREMENTS OF 10 CFR §: (Check one or more) (11)

	20.2201(b)		20.2203(a)(2)(v)	X	50.73(a)(2)(i)(B)	50.73(a)(2)(viii)
	20.2203(a)(1)		20.2203(a)(3)(I)	X	50.73(a)(2)(ii)	50.73(a)(2)(x)
	20.2203(a)(2)(i)		20.2203(a)(3)(ii)		50.73(a)(2)(iii)	73.71
	20.2203(a)(2)(ii)		20.2203(a)(4)		50.73(a)(2)(iv)	OTHER
	20.2203(a)(2)(iii)		50.36(c)(1)		50.73(a)(2)(v)	Specify in Abstract below or in NRC Form 366A
	20.2203(a)(2)(iv)		50.36(c)(2)		50.73(a)(2)(vii)	

LICENSEE CONTACT FOR THIS LER (12)

NAME	TELEPHONE NUMBER (Include Area Code)
L.E. Nicholson, Regulatory Compliance Manager	(864) 885-3292

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
B6a	RCS	NZL	B&W	Y					

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)**

At approximately 1500 hours on April 28, 2001, a visual inspection of the top surface of the Oconee Nuclear Station Unit 2 (ONS-2) Reactor Pressure Vessel (RPV) head found evidence of small accumulations of boric acid deposited at the base of Control Rod Drive Mechanisms (CRDMs) Nos. 4, 6, 18, and 30. This RPV head inspection was performed as part of a normal surveillance during a planned refueling outage.

Subsequent surface dye-penetrant test (PT) inspections of the weld area and nozzle outside diameter (OD) identified several axial cracks on four CRDM nozzles that initiated near the toe of the fillet weld and had propagated radially into the nozzle material as well as axially along the OD surface. These cracks are believed to be the leakage pathway for the boric acid deposits on the Unit 2 RPV head. Eddy current (EC) examination revealed two shallow axial flaws on CRDM nozzle 16 and craze cracking on all four CRDM nozzle ID surfaces. Supplemental ultrasonic test (UT) examinations were used to size the EC indications and determine the through-wall extent of other indications that EC could not resolve. The UT results confirmed the existence of some cracks (none through wall) predominately axial with one short OD initiated circumferential crack on CRDM Nozzle 18.

The most probable root cause of the Alloy 600 CRDM Nozzle leaks is primary water stress corrosion cracking based on comparison of the PT, EC and UT results from the four ONS-2 CRDM nozzles and the documented NDE and metallurgical results of the previous ONS-1 and ONS-3 CRDM analyses, material samples and repairs. Prior to exiting the refueling outage, these nozzles were repaired. Additional short and long-term corrective actions to address potential future recurrences of this event are being managed via the Oconee Corrective Action Program.

EVALUATION:

BACKGROUND

There are 69 Control Rod Drive Mechanism (CRDM) [EIIS:AA] nozzles [EIIS:NZL] that penetrate the reactor pressure vessel (RPV) [EIIS:RCT] head. The CRDM nozzles are approximately 5-feet long and are welded to the RPV head at various radial locations from the centerline of the RPV head. The nozzles are constructed from 4-inch outside diameter (OD) alloy 600 material. The lower end of the nozzle extends about 6-inches below the inside of the RPV head.

The alloy 600 used in the fabrication of CRDM nozzles was procured in accordance with the requirements of Specification SB-167, Section II to the 1965 Edition including Addenda through Summer 1967 of the ASME B&PV Code. The product form is tubing and the material manufacturer for the ONS Unit 2 CRDM nozzles was the Babcock and Wilcox (B&W) Tubular Products Division.

Each nozzle was machined to final dimensions to assure a match between the RPV head bore and the OD of each nozzle. The nozzles were shrink fit by cooling to at least minus 140 degrees F., inserted into the closure head penetration and then allowed to warm to room temperature (70 degrees F. minimum). The CRDM nozzles were tack welded and then permanently welded to the closure head using 182-weld metal. The shielded manual metal arc welding process was used for both the tack weld and the J-groove weld. During weld buildup, the weld was ground, and dye penetrant test (PT) inspected at each 9/32 inch of the weld. The final weld surface was ground and PT inspected.

The weld prep for installation of each nozzle in the RPV head was accomplished by machining and buttering the J-groove with 182-weld metal. The RPV head was subsequently stress relieved.

EVENT DESCRIPTION

At approximately 1500 hours on April 28, 2001, a visual inspection of the top surface of the Oconee Nuclear Station Unit 2 (ONS-2) Reactor Pressure Vessel (RPV) head found evidence of small accumulations of boric acid deposited at the base of several Control Rod Drive Mechanisms (CRDMs). This RPV head inspection was performed as part of a normal surveillance during a planned refueling outage.

Boric acid deposits were identified around four of the sixty-nine total CRDM nozzles (Nos. 4, 6, 18, and 30). The amount of boric acid around each of the CRDM nozzles was estimated to be no more than a few cubic inches. After confirming that the Reactor Coolant System (RCS) [EIIS:AB] pressure boundary had been compromised, at 2114 hours on April 28, 2001, an 8-hour notification was made in accordance with 10CFR50.72(b)(3)(ii)(B) reporting requirements.

Eddy Current (EC) inspections of the four CRDM Nozzles were performed on May 3, 2001 in an effort to identify any significant indications that could support a through-wall leak. Results of these EC examinations revealed no significant inside diameter (ID) surface cracking although craze crack

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indications were identified. Dye penetrant tests (PT), also conducted on May 3, 2001, showed a series of both recordable and non-recordable indications on the outside diameter (OD) of the nozzles. These OD indications were either on the face of the J-groove weld, the face of the fillet weld, or at the toe of the fillet weld-to-nozzle junction. Ultrasonic test (UT) inspections of the four CRDM housing's ID and J-groove welds performed on May 3 and 4, 2001 generally revealed a variety of OD surface cracks.

Although the leakage of primary coolant through the CRDM nozzles was so minimal that it was detectable only by the observed accumulation of boric acid crystals on the RPV head, Technical Specification Limiting Condition for Operation 3.4.13(a) limits RCS operational leakage to "No pressure boundary leakage" while in MODES 1 through 4. Additionally, the RCS leakage from the CRDM nozzle penetrations resulted in a degradation of one of the plant's principal safety barriers. Accordingly, this event is being reported in accordance with 10CFR50.73(a)(2)(i)(B), and 10CFR50.73(a)(2)(ii)(A) reporting criteria.

No operator intervention was required as a result of this event. Prior to the discovery of this event, Unit 2 was in Mode 5 at 0 percent power and Units 1 and 3 were operating in Mode 1 at approximately 100 percent power.

CAUSAL FACTORS

The apparent root cause of the four alloy 600 CRDM nozzle leaks is Primary Water Stress Corrosion Cracking (PWSCC).

General Discussion

Alloy 600 is used extensively in nozzle applications in the reactor vessel and Pressurizer [EIIS:PZR]. It is also used for hot and cold leg piping as well as steam generator tubing in Combustion Engineering and Babcock and Wilcox fabricated plants. It is recognized these small-bore nozzles have suffered numerous cracking incidents, and the industry has evaluated and documented the results of many failure analyses. The conclusion resulting from this work is that the failure mechanism is a form of stress corrosion cracking referred to as PWSCC.

PWSCC was generally thought to initiate at the nozzle inside surface adjacent to the partial penetration J-groove welds. ONS has also recently experienced PWSCC on the nozzle OD and adjacent J-groove weld region. This area has been shown to have high residual stresses resulting from the weld process and, in some cases, from surface distress due to machining, grinding or reaming operations. In thin wall product forms, this area could also have an altered microstructure from welding (weld heat affected zone). It is well established that PWSCC can occur in materials provided that three conditions are present:

1) susceptible material,
2) high tensile stress, and
3) an aggressive environment.

Virtually any small-bore alloy 600 nozzle (including CRDM Nozzles) attached with a partial penetration weld possesses these characteristics. In PWR applications, numerous small-bore alloy 600 nozzles and Pressurizer heater sleeves have experienced leaks attributed to PWSCC. Generally, these components are exposed to 600 degree F or higher temperatures and primary water, as are the ONS-2 CRDM nozzles.

This Event

Boric acid deposits helped identify the leaks from CRDM Nozzles on the ONS 2 Reactor Vessel Head during a refueling shutdown. These deposits were found during normal post-shutdown visual inspections. The same experienced engineer, who discovered the condition, has visually inspected the Oconee reactor vessel heads for several years. The ability to identify leaks by visual inspections was enhanced by increasing the size of inspection openings in the shroud and by removing preexisting boric acid deposits from the top of the head. Some of the preexisting boric acid deposits were the result of previous leakage from spiral-wound gaskets at the CRDM nozzle flanges. These latest visual inspections of the reactor vessel head surface confirmed that the deposits were fresh boric acid and that the location and appearance of the deposits suggested that they had come from the area around the four identified CRDM Nozzles.

Subsequent surface PT inspections of the weld area and nozzle Outside Diameter (OD) identified several axial cracks on four CRDM nozzles that initiated near the toe of the fillet weld and had propagated radially into the nozzle material as well as axially along the OD surface. These cracks are believed to be the leakage pathway for the boric acid deposits on the Unit 2 RPV head.

Eddy current examination revealed two shallow axial flaws on CRDM nozzle 16 and craze cracking on all four CRDM nozzle ID surfaces. Supplemental UT examinations were used to size the EC indications and determine the through-wall extent of other indications that EC could not resolve. The UT results confirmed the existence of some (none through wall) cracks predominately axial with one short OD initiated circumferential crack on CRDM Nozzle 18.

The PT, EC and UT results were combined to determine the extent of the existing cracking and support the nozzle repair plans for the leaking CRDM nozzles.

Conclusion

The most probable root cause of the Alloy 600 CRDM Nozzle leaks is PWSCC. This conclusion is based on comparison of the PT, EC and UT results from the four ONS-2 CRDM nozzles and the documented NDE and metallurgical results of the previous ONS-1 and ONS-3 CRDM analyses, material samples and repairs.

The leakage path characterized by the UT and PT examinations falls within the outer boundary of the CRDM nozzle wall region where Finite Element Analysis (FEA), including the effects of welding residual stresses and operating conditions, predict high hoop stresses. The crack geometry is consistent with the FEA that shows the hoop stress (that could drive a crack in the axial orientation) is higher than the axial stress (that could drive a crack circumferentially) at high stress locations. Crack growth into the nozzle wall is also consistent with analysis predictions that high hoop stresses extend through the weld material and into the nozzle wall. The mostly axial oriented cracks (36 of 37 identified flaws are axial indications) are consistent with FEA results, and with a root cause determination of PWSCC.

The most significant indication was the single circumferential flaw found above the J-groove weld contour in CRDM Nozzle 18. This circumferential flaw was OD initiated and extended approximately 11% (0.070 inches) through wall and was about 1.26 inches in length.

The ONS-2 failure modes are consistent with the previous ONS-1 CRDM Nozzle 21 cracking (which was more weld-oriented), the previous ONS-2 inspections that looked at the ID CRDM nozzle surfaces for axial crack initiation and the extensive ONS-3 OD surface initiated cracking.

CORRECTIVE ACTIONS

Immediate:

A Failure Investigation Process (FIP) Team was assembled to assess the event including its cause(s), necessary corrective actions, and past/future unit operational impacts.

Subsequent:

1. A combination of EC, UT, and PT inspections were performed on each of the four leaking CRDMs.
2. Prior to exiting the ONS-2 refueling outage, the four leaking nozzles were repaired, including the addition of a new pressure boundary weld (see description below for additional repair details).

   The repair process for the four CRDM nozzles was to initially remove all indications in the nozzles identified during the non-destructive examinations. The initial repair action was to roll the nozzle above the J-groove weld, then to machine (with a 3/100-inch radial overbore) the lower region of the CRDM nozzle, including portions of the J-groove weld. The final surface was PT examined prior to preheating for the weld repair process. A new pressure boundary weld (with a temper bead weld) was formed between the CRDM nozzle and the RPV head low alloy steel at a location above the previous J-groove weld and below the rolled nozzle area. Protective compressive surface stress remediation was then performed and the final repair was PT and UT examined.

3. Walkdown inspections of other PWSSC susceptible alloy 600 nozzle connections on the ONS-2 Pressurizer were performed on April 26, and May 8, 2001. The piping in the area of the safety relief valve piping, the lower instrument nozzles, and the lower heater connections were visually inspected. Results showed that there was no evidence of boron deposits on or around these connections and as such, it was determined that PWSCC has not adversely effected the ONS-2 Pressurizer nozzles to the point where pressure boundary leakage had occurred.

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Planned:

Although repairs have been completed for the four leaking CRDM nozzles, the potential for future leakage events of alloy 600 CRDM nozzle components (including the 182 weld material) on the existing RPV head, due to PWSCC, remains a concern for all three Oconee Units. An aggressive management plan that focuses on continued RPV head nozzle inspections and repairs was determined to be the best approach to address PWSCC in the short-term.

In the long-term, the RPV heads will be replaced at all three Oconee Units to prevent recurrence of this event.

These short and long-term actions as well as other planned corrective actions are being addressed via the Oconee Corrective Action Program. There are no pending NRC Commitment items contained in this LER.

SAFETY ANALYSIS

The degraded condition of the four leaking CRDM nozzles did not represent a challenge to the nuclear safety of the plant. The cracks were primarily in the nozzle base metal and had axial or circumferential locations and orientations that would resist nozzle ejection. These cracks propagated until they resulted in leaks that were detected during a planned RPV head surveillance.

Primary coolant leakage from the cracks was minimal due to the relatively tight cracks. The total leakage from the four CRDM nozzles did not exceed Technical Specification limits for unidentified RCS inventory loss nor were there obvious increases in Reactor Building Normal Sump levels or increases in Reactor Building air sampling radiation activity. No reactor building or area radiation alarms sounded. The small amounts of boric acid crystal deposits that were observed around the CRDM Nozzles had caused no observable corrosion to the RPV head. The absence of corrosion is not surprising since the EPRI *Boric Acid Corrosion Guidebook* states that the corrosion rate of carbon steel in the presence of dry boric acid crystals is very low.

ONS currently has a structured approach to managing these CRDM PWSCC concerns. Non-destructive examinations were conducted on the ID of all ONS-2 CRDMs in 1994 and all those locations with indications have been subsequently re-inspected. These ID inspections have shown no measurable ID surface flaw growth on ONS-2. Following discovery of cracking initiating in the welds on ONS-1 and ONS-3, significant information has been obtained from non-destructive and destructive examinations which is being used to improve the existing PWSCC susceptibility models. Inspections of the top surface of the RPV head are performed at each scheduled refueling outage and have proven to be effective in the detection [and subsequent repair] of leaking nozzles.

For the circumferential crack found in CRDM No. 18, a thorough evaluation of all the axial and circumferential flaws, as documented within the Framatome-ANP Safety Evaluation, Revision 1, confirms that there is no chance of gross nozzle failure, thus precluding the possibility of a rod ejection event. Based on additional analysis, the ONS-2 leaks could have been leaking for the past 1 to 7 years. As such, any leakage through CRDM nozzle cracks is initially so small that it may take years for the accumulation of boric acid to fill the nozzle to head annulus and thereby become visible at the surface of the head. This data also supports the previous conclusion that the CRDM nozzles would leak first and would be discovered by station personnel during normal RPV head surveillance inspections. Finally, fracture mechanics analysis has shown that the 1.26" flaw is bounded by an earlier ONS-3 circumferential flaw analysis that found acceptable a 180° through wall flaw with a factor of safety greater than three.

In conclusion, PWSCC of the ONS-2 CRDM nozzles did not pose a nuclear safety risk. The basis for CRDM cracking not being a safety risk include:

- Leak rates from cracks within the annulus region of the nozzle are low,
- Cracks are primarily oriented in an axial direction thus making the potential for complete nozzle failure and control rod ejection a low probability event ,
- Cracks that are circumferentially oriented are either below the J-groove weld or do not have the extent required to be a safety concern from a structural standpoint,
- Leakage from cracked nozzles will result in visible boric acid deposits around a nozzle that would be discovered during routine walkdowns during normal shutdown activities,
- At Oconee, the reactor heads have been cleaned and larger inspection windows have been cut into the service structure that should enhance the ability to find any nozzles that may develop a leak in the future.

ADDITIONAL INFORMATION

This event did not include a Safety System Functional Failure nor involve a personnel error. There were no releases of radioactive materials, radiation exposures in excess of limits or personnel injuries associated with this event.

This event is considered reportable under the Equipment Performance and Information Exchange (EPIX) program.

SIMILAR EVENTS

Within the last year, ONS-1 LER 269/2001-006-01 reported RCS pressure boundary leakage due to PWSCC failure of several thermocouple and one CRDM (No. 21) RPV head penetrations. In addition, ONS-3 LER 287/2001-001-00 reported similar type leakages around nine of the sixty-nine total CRDM nozzles. There were no other LERs over the last three years that reported past PWSCC of alloy 600 components or leaks involving RPV head penetrations.

PWSCC is not new either to the domestic or worldwide nuclear industry. However, findings from ONS CRDM examinations has revealed OD initiated flaws in addition to the ID initiated flaws reported by most of the industry. As evidenced from similar PWSCC discoveries at ONS-1 and ONS-3, all of the Oconee Units will remain susceptible to future PWSC cracking of alloy 600 components. Until a planned corrective action to replace all of the RPV heads is implemented, this type of event may be expected to recur.

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