U.S. NUCLEAR REGULATORY COMMISSION

REGION II

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Licensee:	Duke Power Company
Facility:	Oconee Nuclear Station, Units 1, 2 & 3
Location:	P. O. Box 1439 Seneca, SC 29679
Dates:	April 22 - June 6, 1997
Inspectors:	J. Blake, Reactor Inspector J. Coley, Reactor Inspector E. Girard, Reactor Inspector
Accompanying Personnel:	S. Lee, Materials Engineer, NRR
Approved by:	P. Fredrickson, Chief, Special Inspection Branch Division of Reactor Safety

Enclosure

EXECUTIVE SUMMARY

Oconee Nuclear Station, Units 1, 2 & 3
NRC Special Inspection Report 50-269/97-07,
50-270/97-07, 50-287/97-07

This special inspection focused on the licensee's efforts to investigate the causes and to provide corrective actions for an unisolable reactor coolant leak detected April 21, 1997.

Engineering

- The licensee investigation into the causes of the 2A1 high pressure inspection (HPI) pipe crack was thorough and was effective in identifying the physical cause of the leak (thermally induced cracking) and two root causes. (Section E2.1)

- The root causes established by the investigation included inadequate implementation of augmented inspections for cracks in HPI lines and inadequate evaluation and correction of known problems. Related deficiencies were characterized respectively as Apparent Violation (EEI) 50-269, 270, 287/97-07-01: Inadequate Implementation of Augmented Inspections; and Apparent Violation (EEI) 50-269, 270, 287/97-07-02: Inadequately Addressed Thermal Stratification. (Section E2.1)

- The corrective actions taken as a result of the 2A1 pipe crack were adequate for the short term. At the time of the inspection, the licensee's plans for long term corrective action appeared acceptable. Some deficiencies in non-destructive testing techniques were noted. (Section E2.2)

Enclosure

Report Details

General Discussion

This special inspection focused on the licensee's efforts to investigate the causes and provide corrective actions for an unisolable reactor coolant leak detected on April 21, 1997, at Oconee 2. Operational aspects of the leak event and the licensee's formation of a Failure Investigation Process (FIP) team to investigate the event were described in Inspection Report 50-269, 270, 287/97-02.

I. Engineering

E2 Engineering Support of Facilities and Equipment

E2.1 Investigation of the Cause of an Unisolable Reactor Coolant Leak

a. Inspection Scope (92903)

The inspectors evaluated the ongoing progress and findings of the licensee's investigation of the high pressure injection (HPI) leak that occurred April 21, 1997. In performing the evaluation they discussed the investigation with plant personnel; attended Failure Investigation Process (FIP) team meetings; reviewed related correspondence, drawings, reports, inspection records, and laboratory results; viewed photographs and videotapes of the hardware involved; and observed portions of the hardware.

b. Observations and Findings

Leak Event and Physical Evidence of Cause

On April 21, 1997, a reactor coolant leak was detected in Oconee 2. The unit was subsequently shut down and the source of the leak was found to be a crack in the 2½-inch diameter piping/safe end weld of HPI makeup Nozzle 2A1.

Subsequent laboratory examinations of the material containing the crack determined that it had initiated from the inside diameter (ID) through high cycle/low stress thermal fatigue. The crack had initiated at the weld root concavity, was circumferential, progressed a full 360 degrees around the ID of the pipe and penetrated completely through-wall for 77 degrees of the pipe outside diameter. Numerous heat check cracks, apparently caused by rapid surface cooling, were evident on the ID of the adjacent safe end and piping and penetrated an average of about 20% through-wall. In the pipe, these cracks appeared somewhat centered around the flow from a nearby warming line whose function had been to provide a continuous flow to maintain temperature uniformity. A licensee metallurgist informed NRC inspectors that, based on a heavy oxide buildup found on the crack surface, he had concluded that the crack

had been growing for several years. A thermal sleeve installed in the safe end/nozzle assembly was found loose, cracked, and portions were missing near the downstream end.

Description of HPI Nozzle Components and Adjacent Piping

Nozzle 2A1 was fabricated of carbon steel lined with stainless steel. Both the safe end of the nozzle and the thermal sleeve were fabricated of stainless steel. An inconel weld joined the nozzle to the safe end. The thermal sleeve was roll expanded into the ID of the safe end at its upstream end, and the sleeve extended downstream through the nozzle into the loop flow. There were lands on the downstream end of the sleeve to reduce vibration. Weld spots were deposited just upstream of the sleeve and just downstream of the lands to preclude movement of the sleeve in either direction if it became loose.

The upstream piping was of stainless steel and was joined to the safe end by a stainless steel weld (the weld that contained the crack). A few inches upstream of the piping/safe end weld a 1-inch branch connection joined the 2½-inch piping. This pipe served to maintain a continuous flow into and through the line to maintain the temperature constant during periods when there was no makeup flow. A few feet further upstream in the 2½-inch piping was a manual isolation valve preceded by a check valve.

The inspectors found that Oconee 1, 2, and 3, each contained four HPI lines with configurations similar to the line containing Nozzle 2A1. Two of the four were for makeup and two were for emergency injection. The makeup lines differed from the emergency injection lines in that they provided flow throughout operation, whereas the injection lines normally had no flow. Their basic configuration differed only in that there were no warming lines to the emergency injection piping. (Note: "Warming line" is a misnomer. These lines were intended to preclude backflow and heatup by hotter reactor coolant from the loop.)

Related Industry Experience

(1) NRC Information Notice 82-09 and Generic Letter 85-20

HPI cracks similar to those associated with the April 1997 leak were identified in Oconee 2 and 3 HPI lines and in the HPI lines of several other Babcock and Wilcox (B&W) plants in 1982 (reference Information Notice 82-09). They occurred in the safe ends of the HPI nozzles, adjacent HPI piping, and nozzle thermal sleeves. Wherever cracking occurred, the sleeves were found to have become loose and often exhibited wear and other damage; however, loose sleeves were not always accompanied by damage or cracking to the safe end or adjacent piping, loosening of a sleeve was postulated to be a precursor to other damage.

A joint B&W owners group task force investigated and recommended corrective actions for the HPI cracking found in 1982. The recommendations included repairs, stress analysis of modifications, and augmented inspections. In a February 15, 1983, letter to the NRC, the licensee endorsed these recommendations. The letter further stated that the recommended augmented inspections would be implemented for Oconee 2 and 3, but not Oconee 1. The licensee indicated that a different (unspecified) augmented inspection program had been developed for Oconee 1, because it had a unique double thermal sleeve design (considered less susceptible to cracking).

In accordance with the task force recommendations, the augmented inspections of Oconee 2 and 3 were to consist of periodic radiographic testing (RT) and ultrasonic testing (UT) conducted to identify the presence of crack precursors and/or cracks. RT was to be used to detect the loosening of a thermal sleeve (indicated by gap between the inside diameter of the safe end and the outside diameter of the sleeve at the rolled area), which was postulated to be a precursor to cracking. UT was to be used to detect cracks. Frequencies recommended for the augmented inspections varied based on whether repairs or sleeve re-rolling had been previously performed and whether the nozzles were makeup or emergency injection nozzles. For some repairs, the UT recommendation was eliminated or the coverage was reduced. The augmented inspections which the licensee intended for Oconee 1 included a limited amount of UT.

(2) NRC Bulletin 88-08

NRC Bulletin 88-08 informed licensees of thermally induced cracking found in unisolable piping at several plants. The stresses which produced the cracking were attributed to thermal stratification or oscillations that occurred when upstream valves leaked fluid of a significantly different temperature into the piping. The licensee determined that this bulletin applied to portions of the HPI emergency injection piping, but not to the HPI makeup piping, as described in a response to the NRC dated December 29, 1989. Licensee personnel informed the inspectors that it had been reasoned that the continuous flow from the warming lines would preclude thermal stratification or oscillations in the makeup lines.

In the above response to Bulletin 88-08, the licensee indicated that augmented UT exams of welds in the emergency injection lines had identified no reportable indications and that 10 welds per unit would receive augmented UT inspection once per inservice inspection period (3 inspections per 10 year interval) to assure the continued integrity of the piping. Further, the letter stated that the licensee had performed an analysis which confirmed the structural integrity of the HPI injection piping for the 40 year life of the Oconee units. The letter indicated that this analysis assumed a linear top to bottom temperature differential of 150 degrees F in the pipe.

Cause Determination

The inspectors observed that the licensee's FIP team was provided with adequate expertise and other resources. Data for analysis were collected from a variety of sources, including direct observations, measurements and tests; reviews of operational, inspection, test, maintenance, engineering, and modification records; interviews with plant and contractor personnel; and laboratory examinations of the materials involved. The inspectors found that the licensee performed a thorough investigation.

Based on its investigation, the FIP team concluded that the scenario which led to crack formation was high cycle thermal fatigue caused by thermal mixing of warming line, makeup, and reactor coolant flow. The propagation of the through-wall crack was concluded to have occurred over a long period of time. Other contributing factors noted included (1) varying operating conditions which led to the mixing, flow induced vibration, sleeve loosening due to thermal shock; and (2) the association of sleeve loosening with damage to the weld, safe end, and piping.

The FIP team determined two root causes of the leak event, as follows:

Cause 1 - Failure to implement an effective HPI nozzle inspection program based on available industry recommendations.

Cause 1 involved augmented inspections which the licensee had been periodically conducting since 1982 to detect cracks or crack precursors in HPI nozzle components. The FIP team concluded that, if properly implemented, the augmented inspections would have detected the cracks and resulted in repairs to prevent the leak. These inspections had been instituted in response to identification of HPI cracks at various plants in early 1982. The background and basis for the augmented inspections are discussed above under the "Previous Industry Experience" subheading on "NRC Information Notice 82-09 and Generic Letter 85-20."

To evaluate the augmented inspection effort, the inspectors reviewed augmented inspection records, related correspondence, and other documents provided by the FIP team; observed UT of HPI lines during the inspection; and interviewed plant personnel. The inspectors found that the licensee's implementation of augmented inspections exhibited the following deficiencies:

(1) The augmented inspections for Oconee 2 and 3 were to be in accordance with the recommendations of a B&W owners group task force (reference letter to the NRC dated February 15, 1983). The task force recommended periodic RT of the HPI makeup and emergency injection lines to identify the loosening of thermal sleeves, as indicated by gap formed between the thermal sleeve and safe end. The licensee performed the RT for Oconee 1, 2, and 3, but had no definitive acceptance criteria. In the absence of appropriate acceptance

criteria, the licensee failed to promptly address evidence of loosening thermal sleeves in the following instances:

- RT performed by the licensee in 1996 revealed that thermal sleeve/safe end gap was developing in Oconee 2 HPI normal makeup Nozzle 2A1. This gap condition was not formally noted or evaluated at that time. Subsequently, on April 21, 1997, a previously unidentified crack penetrated the 2A1 safe end/piping weld near the thermal sleeve and resulted in an unisolable reactor coolant leak. Numerous additional cracks were discovered in the safe end, adjacent piping, and thermal sleeve. The thermal sleeve was found very loose, exhibited severe localized wear, and downstream portions were broken away.

- RT performed in 1996 showed that Oconee 3 HPI makeup Nozzle 3A1 had a complete thermal sleeve/safe end gap. Similar to the Nozzle 2A1 sleeve/safe end gap, this gap was not formally noted or evaluated at that time. When this gap was identified in a re-review of RT film, following the discovery (in 1997) of 2A1 cracking, the licensee examined the safe end, sleeve, and adjacent piping and identified cracking and other damage.

(2) The licensee failed to perform UT of the safe end/piping welds or the piping adjacent to safe ends during the Oconee 2 and 3 augmented inspections conducted prior to the 1997 leak, even though the B&W task force had reported that cracks had been found in or near these locations and recommended UT of the adjacent piping. The licensee's investigation of the April 1997 Oconee Nozzle 2A1 leak identified cracks in the piping adjacent to the safe end and in the safe end/piping weld. Some of these cracks were postulated to have been growing for years.

(3) The licensee failed to develop RT procedural requirements to assure the quality of RT performed to detect sleeve/safe end gap for Oconee 1, 2, and 3. Penetrameters were generally not used to assure film quality and examination sensitivity. In addition, no limitations were placed on source-to-film distance, presence of water in pipe, source size, temperature, or film speed selection. All these factors are essential elements in effectively monitoring gap growth.

(4) Licensee examiners were deficient in recording indications found by UT, as indicated by the following:

- Records of past UT indicated great variances between the number of (geometric) indications recorded from one inspection to another without explanation. For example, the examinations performed in 1985 for the Unit 3 HPI line 3A1 nozzle to safe end recorded 12 ultrasonic indications; however, examinations performed in 1984 only recorded one indication, examinations performed in 1988 did not record any

indications, and examinations performed in 1989 recorded one indication. The same basic procedure was used for all the preceding examinations and all the indications recorded were subsequently determined to be geometry.

- During a UT examination witnessed by the inspectors in May 1997, on the pipe/safe end weld for line 2A2, an examiner failed to record two significant ultrasonic indications as required by Procedure No. NDE-600, Revision 9. These examples were subsequently confirmed to be geometry.

(Note: During the current inspection, the inspectors observed ongoing UT of Oconee 3 HPI lines and verified that indications were being properly recorded. Additionally, because of the indications not recorded for Oconee 2 line 2A2, the inspectors observed re-UT of five Oconee 2 welds and verified that indications had been properly recorded.)

(5) RTs for sleeve gap and UTs for cracking in Oconee 1 HPI lines were not performed in refueling outage 16 as intended.

Cause 2 - Failure to evaluate known problems effectively and implement appropriate corrective actions.

This cause involved the licensee's failure to act upon the results of temperature measurements obtained in 1990 which indicated the presence of potentially damaging thermal stratification in HPI piping during startup. The measurements were obtained on Oconee 1, as part of a B&W owners group (BWOG) investigation of thermal stratification in core flood, pressurizer spray, and HPI lines. The results were reported in B&W Document 51-1212842-00 (reference August 20, 1993 letter from B&W to the BWOG Thermal Stratification Working Group). The stratification was determined as the difference between the temperatures measured at the top and bottom of system piping at selected locations. The BWOG report indicated that top to bottom temperature differentials were found to be as great as 327 degrees F in the HPI makeup piping to Nozzle 1A1 and as great as 178 degrees F in the HPI emergency injection piping to Nozzle 1B2. This evidence of thermal stratification indicated that assumptions the licensee had used in developing corrective actions for pipe cracking were incorrect, as follows:

(1) The corrective actions which the licensee implemented for thermally induced HPI pipe cracking described in Information Notice 82-09 and Generic Letter 85-20 were developed assuming (apparently incorrectly) that there was no thermal stratification (reference page 23 of report transmitted to the NRC in the licensee's letter of February 15, 1983).

(2) In determining actions to address the cracking described in Bulletin 88-08, the licensee assumed that the conditions which caused the cracking (thermal

stratification or oscillations) would not be present in the HPI makeup lines (reference licensee's October 6, 1988 response to Bulletin 88-08). The temperature differential of 327 degrees F measured in an Oconee 1 makeup line shows that this was incorrect.

(3) The structural analysis of the HPI emergency injection piping referred to in the licensee's December 29, 1989, response to the NRC for Bulletin 88-08 assumed a linear top to bottom temperature differential of 150 degrees F in the pipe. The temperature differential of 178 degrees F measured in an Oconee 1 emergency injection line shows this was incorrect.

The BWOG report attributed the 327 F temperature differential in the makeup piping to a period of back flow from the loop caused by operation with only one reactor coolant pump running. The report recommended changes to plant procedures to preclude this condition. The inspectors asked if this recommendation had been implemented and/or if the potentially adverse impact of the HPI thermal stratification found by the BWOG had been formally addressed through a corrective action process. The licensee indicated that the condition had not been identified on any corrective action document and that no action had been taken on the BWOG recommendation.

c. Conclusions

The inspectors concluded that the licensee had performed a thorough and effective investigation of the causes of the leak. The investigation into the causes of the leak identified the physical cause of the leak (thermally induced cracking) and two important root causes. Based on the evidence reviewed, the inspectors concluded that these causes were valid.

The root causes established by the investigation included inadequate implementation of augmented inspections for cracks in HPI lines and inadequate evaluation and correction of known problems. The former involves deficiencies in inspections that were implemented to provide early detection of cracks in HPI nozzle components and adjacent piping. The latter involves a failure to identify promptly and to initiate corrective action for the thermal stratification (a potential cause of cracking) found in HPI piping. Both were considered apparent violations of 10 CFR 50, Appendix B, Criterion XVI (Corrective Action). They are characterized respectively as Apparent Violation (EEI) 50-269, 270, 287/97-07-01: Inadequate Implementation of Augmented Inspections; and Apparent Violation (EEI) 50-269, 270, 287/97-07-02: Inadequately Addressed Thermal Stratification.

E2.2 Corrective Actions for Unisolable Oconee 2 Reactor Coolant Leak

a. Inspection Scope (92903)

The inspectors evaluated the licensee's development and implementation of corrective actions. The immediate actions which the licensee took after discovery of the leak

included an orderly shutdown and initiation of an investigation of the cause of the leak. Details were described in Inspection Report 50-269, 270, 287/97-02. The licensee's actions were deemed professional and appropriate. As discussed above in E2.1, the physical cause of the leak was found to be thermally induced cracking similar to cracking previously experienced in HPI lines in 1982. During the current inspection, NRC inspectors assessed the extent of condition reviews which the licensee performed to determine whether further cracking was present and the repair actions which the licensee performed to correct the damage found.

The extent of condition reviews which the licensee performed included both re-review of past augmented inspection records and performance of current inspections to determine if cracks (or crack precursors) were present in the HPI makeup or emergency lines of Oconee 1, 2, or 3. The inspectors assessed the licensee's findings by re-reviewing the past and current augmented inspection records and procedures and observing the inspections currently being performed.

The licensee determined that only the lines to Nozzles 2A1 and 3A1 had experienced cracking and required repairs. As discussed in E2.1 above, the line to 2A1 experienced the leak on April 21, 1997, and was found to contain cracks and other damage requiring repair. The 3A1 line was determined to contain similar cracks during the licensee's extent of condition review. For 2A1, the inspectors observed portions of repair welding in progress and the final penetrant and UT exams. Additionally, the inspectors reviewed the licensee's 10CFR50.59 evaluation, modification package, welding records, and final RT records for the 2A1 repair.

At the conclusion of the inspection certain longer term corrective actions remained to be completed. These included programmatic changes to address causes identified by the licensee's investigation, as-well-as inspections of Oconee 1 HPI lines. The inspectors confirmed that the licensee had developed a schedule to address the principal long term actions and that this schedule was satisfactory to the NRC staff.

b. Observations and Findings

Immediate Corrective Actions

The licensee's immediate corrective actions were prompt and appropriate.

Extent of Condition Reviews

The inspectors found that the re-reviews of past records and the current re-inspections performed by the licensee were adequate to identify the extent of cracking present in Oconee 2 and 3 HPI lines. The licensee's re-reviews of RT film and their current UT identified evidence of a loose thermal sleeve and cracks in the safe end of nozzle 3A1. There was no evidence of cracks in other HPI lines aside from that previously found in the line to nozzle 2A1.

While reviewing records and observing the licensee's current UT of HPI lines, the NRC inspectors noted deficiencies in UT performance and in RT procedures that could adversely impact future augmented inspections. These conditions are identified in the list of augmented inspection deficiencies in E2.1 above and are considered part of the related apparent violation. In summary, they are as follows:

- The licensee's UT examiners failed to record geometric indications as specified by their procedures.
  (Note: The inspectors witnessed sufficient UT of the HPI lines to be confident that this did not cause any cracks to go undetected during the current Oconee 2 and 3 UTs.)

- The licensee did not have appropriate procedure requirements to assure the quality of RT performed to detect sleeve/safe end gap.
  (Note: The inspectors considered the radiographs they observed to be of adequate quality but future quality was not assured, due to the lack of documented requirements.)

The only evidence which the licensee had to confirm the adequacy of Oconee 1 lines was from augmented inspections conducted over eight years ago (January 1989). Those records did not reveal any cracks or crack precursors (gap). It was previously postulated that the special sleeve design in the Oconee 1 nozzles would preclude cracking. The licensee has committed to RT and UT the Oconee 1 HPI emergency injection and makeup lines nozzle components during a shutdown to be commenced on or before June 14, 1997 (LER 270/97-01).

Repair Actions

The inspectors found the licensee's repair actions satisfactory for the short term. In observing the completed repairs the inspectors noted that the licensee had installed almost 20 thermocouples on the Oconee 2 piping to permit detection of any thermal conditions that would promote crack development. Data on the thermal conditions in the piping will aid the licensee in developing long term corrective actions.

Other

The licensee's LER 270/97-01 identified planned actions which the inspectors considered appropriate to further address the deficiencies that led to the Oconee 2 leak.

c. Conclusions

The inspectors concluded that the licensee took effective immediate and short-term corrective actions. The licensee's plans for development and implementation of long-term corrective actions appeared acceptable. Deficiencies in UT and RT were noted which were included in Apparent Violation (EEI) 50-269, 270, 287/97-07-01 above.

II. Management Meetings

X1 Exit Meeting Summary

The inspectors presented the inspection results to members of licensee management at the conclusion of the inspection on June 6, 1997. The licensee acknowledged the findings presented. No proprietary information was identified.

Partial List of Persons Contacted

Licensee

E. Burchfield, Regulatory Compliance Manager
D. Coyle, Systems Engineering Manager
T. Curtis, Operations Superintendent
J. Davis, Engineering Manager
W. Foster, Safety Assurance Manager
J. Hampton, Vice President, Oconee Site
D. Hubbard, Maintenance Superintendent
B. Peele, Station Manager
K. Redman, Metallurgist
J. Smith, Regulatory Compliance
R. Todd, Safety Assurance Engineer
C. Tompkins, Supervisor, Mechanical Component Engineering
L. Wilkie, Engineering Manager, Modifications

NRC

D. Billings, Resident Inspector
W. Holland, Acting Maintenance Branch Chief, Region II
M. Scott, Senior Resident Inspector

Inspection Procedures Used

IP92903: Followup - Engineering

Items Opened, Closed, and Discussed

Opened

50-269, 270, 287/97-07-01	EEI	Inadequate Implementation of Augmented Inspections (Section E2.1)
50-269, 270, 287/97-07-02	EEI	Inadequately Addressed Thermal Stratification. (Section E2.1)

List of Acronyms

B&W	Babcock and Wilcox
BWOG	Babcock and Wilcox Owners Group
CFR	Code of Federal Regulations
EEI	Escalated Enforcement Item (Apparent Violation)
FIP	Failure Investigation Process
HPI	High Pressure Injection
ID	Inside Diameter
IP	Inspection Plan
LER	Licensee Event Report
RT	Radiographic Testing
UT	Ultrasonic Testing