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SUBJECT: Rev to Problem Investigation Rept PIR-1-091-0104:pressure boundary defect indications noted in plugs installed in steam generators.Weld plug will be installed over explosive plug.

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DUKE POWER

December 17, 1991

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

Subject: Oconee Nuclear Station
Docket Nos. 50-269, -270, -287
Special Report Concerning Steam
Generator Tube Plugs

Gentlemen:

This report is provided for information regarding Steam Generator tube plugs.

If you have any questions, please contact Rick Matheson at (803) 885-3119.

Very truly yours,

J W Hampton

J. W. Hampton
Vice President

/ftr

Attachment

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DUKE POWER COMPANY
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PROBLEM INVESTIGATION REPORT

Attachment to Section I

Revision 1: This document contains changes made to correct inaccurate plug quantities and totals provided in the original of this attachment to PIR 1-091-0104. These changes do not affect the intent, consequences, or the corrective actions of the PIR.

I. Description of Problem:

Eddy current testing of the explosively installed tube plugs in the Unit 1 A and B Steam Generators identified a significant number of plugs with pressure boundary defect indications. The number is even larger if plugs with non-pressure boundary defects are included. These explosive plugs were installed by Babcock and Wilcox (B&W). The original installation dates of these plugs range from 1973 to 1982. The majority of them were installed between 1977 and 1981.

The exact cause of these defects is uncertain. Some may be the result of the initial installation explosion process. Others are likely caused by the phenomenon known as Primary Water Stress Corrosion Cracking (PWSCC). The occurrance of this phenomenon in steam generator plugs fabricated of Inconel 600 material is an industry wide problem. It has been documented internally by PIR 4-088-0226 and PIR 4-089-0156. Within the industry it has been addressed by documents such as NRC Bulletin No. 89-01 and NRC Information Notice No. 89-65.

The documents listed above did not specifically address explosive plugs of Inconel 600 material. However, in efforts to pro-actively address this plug concern, inspections of all plugs - rolled, ribbed, welded, and explosive were begun at Oconee. Initially, the inspections of explosive plugs were limited to a few fiberoptic visual inspections and a "poking" of the explosive plug to verify that the toe, or pressure boundary end, was still intact.

However, beginning with the Oconee Unit 3 EOC-12 refueling outage, a new rotating pancake coil eddy current probe was utilized to perform NDE on the explosive plugs in the 3A and 3B Steam Generators. A total of 70 explosive plugs were examined. Of these 14 had stabilizers attached. From the examinations, 13 of the 14 stabilizer plugs had defect indications, and only 1 of the 56 non-stabilized plugs had a defect. All 14 of the stabilized locations, and the 1 non-stabilized location, had a welded plug installed behind the explosive plug as a repair.

In the Unit 1 Steam Generators there are a total of 451 explosive plugs. Only one of these plugs, in the B hot leg (h/l), has a stabilizer attached. These plugs were examined using the eddy current technique. Based on the Unit 3 results it was expected that only a small percentage of the explosive plugs, primarily in the hot legs, plus the one stabilizer, would have defects. However, as it turned out, a significant number of the plugs had indications.

	Total Number of Explosive Plugs	Number with Indications	Number Repaired
A h/l	19	18 @	19
A c/l	28	5 #	0
B h/l	185	110	104*
B c/l	219	28	25 +

@ - Of the 18 plugs with indications only 16 required repair (pluggable).

- These indications were permeability variation (perm) calls

* - This 104 consisted of approximately 68 pluggable indications, some 32 incomplete runs that we chose not to rerun, and 4 obstructions.

+ - This 25 consisted of 11 pluggables, 8 obstructions, 4 with no data, 1 bad data (RBD) not resolved, and 1 with a ECT probe stuck in the tube.

Thus, a total of 148 explosive plugs were repaired this outage. This leaves 303 unrepaired explosive plugs in the Unit 1 Steam Generators to be addressed (inspected and/or repaired) in the future. The numbers of explosive plugs remaining in all Oconee Steam Generators are given below:

	Unit 1	Unit 2	Unit 3
A h/l	0	2	2
A c/l	28	2	21
B h/l	81	9	6
B c/l	194	29	26

The eddy current inspection of explosive plugs will be an on-going activity in the steam generators each refueling outage.

Repairs (typically by installing a welded plug over the explosive plug) will be made to any explosive plug with a pressure boundary defect. Pro-active repair of non-defective explosive plugs may be performed to minimize the time and cost of repeated inspections.

Original issue: 9-19-91
Revision 1 issue: 12-4-91 JHB

STEAM GENERATOR TUBE EXPLOSIVE PLUGS POTENTIALLY DEFECTIVE IN REACTOR COOLANT SYSTEM PRESSURE BOUNDARY

SUMMARY

Non-destructive evaluation of the explosively installed plugs in the Unit 1 steam generators has identified a significant number of plugs with pressure boundary defect indications. This problem was discovered during the Unit 1 refueling outage, which began August 1, 1991. Units 2 and 3 were operating at 100 percent Full Power. Problem Investigation Report # 1-091-0104 was generated on September 19, 1991 and this report is being issued for industry awareness. All three Oconee units had explosive plugs installed in steam generator tubes between 1973 and 1982 by Babcock and Wilcox. Explosive plugs are no longer used as a method of plugging steam generator tubes at Oconee. It is highly suspected that the defects are due to primary water stress corrosion cracking in materials fabricated from Inconel 600 material. However, destructive testing has not been performed to confirm this. Repairs have been made on Unit 1 and Unit 3 to all steam generator tubes in which explosive plugs were found to have Reactor Coolant System pressure boundary defects. Unit 2 explosive plugs have not been examined. Remaining tubes with explosive plugs will continue to be inspected and/or repaired during each Unit's refueling outage.

BACKGROUND

The once through steam generator produces superheated steam and provides a barrier between the primary and secondary sides of the system to prevent fission products and activated corrosion products from entering the secondary steam system. In order to ensure barrier integrity, steam generator tubing is inspected through an approved inservice inspection program during each refueling outage. Inservice inspection of generator tubes includes a non-destructive evaluation by eddy current testing. When this testing indicates tube wall degradation greater than the Technical Specification limit, the tube is either repaired, by sleeving, or removed from service, by plugging. Several types of plugs have been used to remove defective steam generator tubes from service at Oconee. They are welded plugs, mechanical plugs (rolled and ribbed plugs), and explosive plugs.

Explosive plugs were installed by Babcock and Wilcox between 1973 and 1982. These cylindrical shaped plugs are made of Inconel 600 material and are approximately 3 1/2 inches long. The toe end, which is the pressure boundary side, is closed and the heel end is opened. The explosive plug is placed inside the tube to be plugged, approximately 9 to 12 inches into the tube sheet area. A charge is detonated remotely through wires that are attached to the charge through the opened end (heel end) to the detonation device. When the charge is detonated the plug expands and kinetically welds the outside wall of the plug to the inside wall of the steam generator tube. When a steam generator tube is removed from service in this manner, a portion of the welded area becomes part of the Reactor Coolant System pressure boundary.

In certain areas of the steam generator, stabilizing rods are required to be placed in the tubes that are removed from service. The purpose of the stabilizer is to minimize the possibility that defective tubes could be

torn loose due to flow induced vibration from the secondary (shell) side and cause damage to other tubes. The stabilizer is attached to the plug.

The Bobbin Coil is the most common method of eddy current testing because of its rapid inspection speed and high mechanical reliability. Two other methods of eddy current testing, which use surface riding rotating pancake coils, are Eddy 360 and MRPC (Motorized Rotating Pancake Coil). These two methods have much slower inspection rates, but are more sensitive to defect indications, especially circumferential cracks.

Throughout the industry, primary water stress corrosion cracking (PWSCC) has been suspected or proven in all of the Alloy 600 cracking incidents in which the crack initiated on the primary side in the steam generators. Three factors contributing to PWSCC are stress, material, and environment.

PROBLEM DESCRIPTION

In 1985, Duke Power Company began experiencing problems with primary water stress corrosion cracking (PWSCC) in steam generator tubing fabricated of Inconel 600 material.

Before Unit 1 was shutdown for refueling in January, 1989, a 0.02 gallon per minute steam generator tube leak was identified. After shutdown, during a drip test, leakage was identified from two tubes that were plugged with explosive plugs in addition to leaks in two other tubes. The two explosive plugs were repaired by drilling out a portion of the plug and installing rolled plugs.

In 1989, NRC Bulletin 89-01 and Information Notice 89-65 were issued describing failures of steam generator plugs due to PWSCC. Information Notice 89-65 recommended that all Inconel 600 heats used for plugs should be considered potentially susceptible to PWSCC.

Due to industry operating experience and experience within Duke Power Company concerning PWSCC, efforts to verify the integrity of plugs and the integrity of the Reactor Coolant pressure boundary were begun. Although explosive plugs had not been addressed in the earlier findings, the approach was to inspect all plugs - rolled, ribbed, welded, and explosive. Initially, the inspections of explosive plugs were limited to a few fiberoptic visual inspections and a "poking" of the plug to verify that the toe, or pressure boundary end, was still intact. Because the technology was not available to adequately test the explosive plugs, Babcock and Wilcox (B&W) and Duke Power Company began research to develop an eddy current test for this purpose. A new type of probe was developed by Zetec shortly before February, 1991. The tip of this probe was designed to match the geometry of the toe end of the explosive plug.

During the Unit 3 End of Cycle-12 refueling outage beginning February 13, 1991, this new eddy current probe was used to perform non-destructive testing on the explosive plugs in the 3A and 3B Steam Generators. All 70 explosive plugs that were installed in Unit 3 steam generator tubes were examined using the Eddy 360 method of testing. Of these 70 plugs, 14 had stabilizers attached. From the examinations, 13 of the 14 plugs with stabilizers attached had defect indications and only 1 of the 56 non-stabilized plugs had a defect indication. All 14 of the stabilized

locations, and the 1 non-stabilized location, were repaired by installing a tapered welded plug of Inconel 690 behind the explosive plug.

Unit 1 Steam Generators contained a total of 451 explosive plugs. During the Unit 1 End of Cycle-13 refueling outage, which began August 1, 1991, most of these explosive plugs were examined. The same type probe that had been used to detect the indications on Unit 3 was used with the Motorized Rotating Pancake Coil eddy current test. 161 explosive plugs out of the 438 plugs that could be tested were found to have indications. 148 plugs were repaired with welded plugs. Approximately 13 locations contained obstructions and could not be tested. Since these plugs could not be examined, preventative repairs were made by the installation of welded plugs. Some of the explosive plugs contained defect indications that were in the heel end of the plug and therefore did not require plugging. Only one of the explosive plugs installed on Unit 1 had a stabilizer attached and it had a defect indication. This plug was included in the number that was repaired.

Explosive plugs installed in Unit 2 Steam Generator tubes have not been tested with the new probe.

The number of explosive plugs remaining on each unit which have not been repaired are as follows: Unit 1 - 303, Unit 2 - 42, and Unit 3 - 55.

CONCLUSIONS

Before the development of the improved probe, there had been no method available to adequately inspect the explosive plugs. Initially, the inspections of explosive plugs were limited to a few fiberoptic visual inspections and a "poking" of the explosive plug to verify that the toe, or pressure boundary end, was still intact. During the Unit 3 End of Cycle-12 refueling outage, a research and development program to test the plugs was formulated by Duke Power and Babcock and Wilcox (B&W). A newly developed probe was used, and the results of the eddy current testing identified defects in 20 percent of the installed explosive plugs.

Based on the relatively low number of indications found in the explosive plugs during Unit 3 refueling outage, the number of indications found on Unit 1 was unexpectedly high. 37 percent of the installed explosive plugs were found to have defect indications. The newly developed probe was used for both Unit 3 and Unit 1. The eddy current method used on Unit 3 was Eddy 360 and on Unit 1 was Motorized Rotating Pancake Coil. The difference in the eddy current method used should have had no impact on the test results. Because of the limited experience with the new eddy current probe and because of limitations inherent in the explosive plug examination process (e.g., interference caused by debris in the plugs), the level of confidence that these indications are valid is lower than that achieved by conventional eddy current testing of steam generator tubes. The explosive plugs with defect indications in the area of the pressure boundary area are considered to be potentially defective and have been repaired by installing a welded plug behind the explosive plug. In most cases the explosive plugs have been left in place, with a welded plug installed behind the explosive plug essentially removing the explosive plug from service.

Industry wide the cause of similar type defects in Inconel 600 materials are attributed to Primary Water Stress Corrosion Cracking (PWSCC). Defect

indications could be due to the initial stress induced on the metal when the explosion process is performed. Qualification testing performed by B&W before the explosive plugs were installed in 1973 included installation of explosive plugs into mock-up blocks. These blocks were cut and sectioned and then tested to verify full bonding of the plug to the tube material. One indication was noted from an archive mock-up block section during the eddy current test program. This may have been due to a problem with the installation process. After the installation of the explosive plugs into the steam generator tubes, the only testing that was performed was a visual inspection to verify proper location. PWSCC has been identified within the industry to cause defects in materials fabricated from Inconel 600. However, destructive testing on the explosive plugs would be required in order to provide conclusive evidence of the cause of the defects. Due to the cost associated with steam generator repairs, these plugs cannot easily be removed for this type of testing.

Similar problems have been documented at Oconee by Problem Investigation Report (PIR) 4-088-0226 and PIR 4-089-0156. PIR 4-088-0226, which was originated on October 13, 1988, addressed problems existing in heat W-592 of Inconel 600 material used for steam generator tube plugs and the susceptibility of this material to stress corrosion cracking. Rolled, ribbed and welded plugs were fabricated from heat W-592 material. A representative sample of plugs were inspected and defects were found. Corrective action for this PIR was that all plugs fabricated from heat W-592 would be removed and replaced.

PIR 4-089-0156, which was originated on October 19, 1989, addressed rolled plugs fabricated from four heats of Inconel 600 material that were confirmed by B&W to be susceptible to PWSCC and six additional heats that were potentially susceptible to PWSCC. The recommendation was made that ribbed, welded and explosive plugs fabricated from these heats of material also be addressed. Rolled plugs were believed to be the most susceptible to PWSCC. Corrective action for this PIR was that an inspection program be established to inspect and repair Inconel 600 rolled plugs.

The corrective actions for these previous PIRs led to the development of the inspection technique that identified the problem. Based on the quantity of explosive plugs installed at Oconee and the complexity of repair, an inspection technique was developed to manage the explosive plug examination. This technique was utilized for the first time during the Unit 3 refueling outage in February, 1991.

Oconee has never experienced a forced outage due to leakage from an explosive plug. The steam generator leak rate that was identified before the Unit 1 refueling outage in January, 1989, may have been due to the leak of two explosive plugs. At the time of the visual test during the outage, two other tubes were also identified to be leaking. A determination could not be made as to the amount of leakage that was attributed to the defective explosive plugs, if any.

These defect indications in the explosive plugs are classified as incipient failures and constitute an equipment failure on each of the steam generators in which these defects have been detected. Equipment failures on Unit 1 A-Once Through Steam Generator (OTSG), Unit 1 B-OTSG, Unit 3 A-OTSG and Unit 3 B-OTSG are NPRDS reportable.

Radiation exposure related to steam generator work was increased due to repairing the defective explosive plugs. Portions of the steam generators were decontaminated and local shielding was used to reduce dose rates. Dose reduction was considered in determining the method of plug repair and workers did not receive radiation doses in excess of Duke Power Company administrative limits. No unplanned or unmonitored offsite releases of radioactivity were made as a result of these defective explosive plugs.

The safety concern in this incident was a possible steam generator tube rupture due to the failure of an explosive plug. The steam generator tube rupture accident assumes the severance of a steam generator tube which initiates a blowdown of primary coolant through the break and into the steam generator. The primary system response is similar to a small LOCA. The consequences of the worst case LOCA are demonstrated to be within the limits specified in 10CFR50.46. The main safety concern is the release of fission products from the secondary system which are in high concentration due to the primary to secondary coolant leakage. For all accidents resulting in a release of fission products to the environment, the dose consequences are shown to be within the limits specified in 10CFR100.

During the time that explosive plugs have been installed in the steam generators in the three Oconee units, steam generator tube leaks have been promptly diagnosed and corrective actions taken. The health and safety of the public were not compromised and no personnel injuries occurred as a result of this event.

CORRECTIVE ACTIONS

In future refueling outages on all three units, inservice inspections will continue to be performed to identify indications in explosive plugs. As these are identified, corrective measures will be taken to repair those plugs with pressure boundary defects. Due to the high cost associated with steam generator tube eddy current testing and the relatively low numbers of explosive plugs installed in steam generator tubes on Unit 2 and Unit 3, corrective measures for repair may be taken without inspecting first.

Prepared By: Barbara R. Holcombe Date: 12-12-91

Approved By: SGBenesole Date: 12-12-91

References

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Technical Specifications 4.17
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NRC Bulletin number 89-01
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EPRI NP-7094 "Literature Survey of Cracking of Alloy 600 Penetrations in PWRs"