From: Gregory Cranston
To: Wayne Schmidt
Date: Thu, Jul 27, 2000 2:07 PM
Subject: IP2 Inspection Report Rev. A

See attached first draft.

Also, I will be out of town from Aug 6 to Aug 29 on business and vacation. If you think you will need my assistance regarding the report or any other documentation let me know so I can try to reserve a laptop to take with me when I go to Zetec so I can respond to email and provide other input.

A/204

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INDIAN POINT 2 STEAM GENERATOR SPECIAL INSPECTION REPORT
Greg Cranston, Rev. A, 7/26/2000

Report Details

BACKGROUND

Summary of Plant Event

Following the steam generator (SG) tube failure on February 15, 2000, Con Edison took the Indian Point 2 nuclear plant to a cold shutdown condition. Con Edison conducted an evaluation and found that the tube that failed was row 2 column 5 (R2C5) in SG 24. This tube had cracked at the apex of the u-bend, due to primary water stress corrosion (PWSCC) cracking. Con Edison conducted SG Eddy Current (EC) inspections in all the SGs and conducted visual inspections of the steam side of the SGs. During these EC inspections Con Edison noted that greater than 1% of the tubes were found with defects placing them in a condition that required NRC approval for restart. At the conclusion of the inspection the unit remained in cold shutdown pending NRC restart approval.

Indian Point 2 Steam Generator History

The team compiled a history of the Indian Point 2 SGs as part of the information gathering phase. The history starting from initial operation is provided in Attachment 2.

Brief discussion of what led up to the event from 1995 - Wayne

EPRI Guidance - How it fits with TS and Regulations

Wayne

Eddy Current Technique

Wayne

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Applicable SG Degradation Mechanisms

PWSCC/Denting/Hour-glassing - **Greg**

The steam generators (SGs) at Indian Point 2 have experienced a broad range of SG tube problems requiring plugging of the tubes. The causes are common to the industry and include: tube sheet (TS) primary water stress corrosion cracking (PWSCC), TS outside diameter stress corrosion cracking (ODSCC), ODSCC in the sludge pile area, ODSCC and PWSCC in the tube support plate (TSP) regions, u-bend PWSCC, u-bend ODSCC, and tube restrictions due to denting at the TSP. The failure mechanism for the February 15, 2000, tube failure in SG24 was due to u-bend PWSCC.

A significant, contributing cause to the stress factor of PWSCC in the u-bend region of the tube is upper TSP flow slot hour-glassing which results from denting of tubes at the TSP as described below.

Denting of the tubes is the direct result of corrosion of the carbon steel tube support plates. When the SG is shutdown and cool there is a circumferential gap between the tube that passes through the TSP and the hole in the TSP through which the tube passes. The gap is there by design to allow for thermal expansion of the tube when the high temperature reactor coolant is pumped through the SG tubes. However, while the SG is shutdown corrosion products can form, based on water chemistry, and harden in that gap. When the SG is heated up for operation the tubes try to expand but are prevented from fully expanding at the TSP due to the hardened corrosion products in the gap. The forces generated cause two things to happen. First, since the tube cannot expand where it passes through the TSP, but does expand above and below the TSP, the tube becomes dented, circumferentially, where it passes through the TSP. The next time the SG is cooled down the tube contracts, the dent remains, and a gap is recreated. Again corrosion products can form in the gap (influenced by feedwater water chemistry) and refill the gap. During the next SG heat-up additional denting can occur as described above. This denting process can continue indefinitely until eventually the tube inside diameter is so restricted that an eddy current probe will not pass through and/or significant cracking of the tube is detected in the dented region, at which time the tube is plugged. See discussion below for the SGs plugging history due to tube restrictions.

Second, the same forces that cause the tube to dent also act against the tube support plate, particularly on the flow slots that run along the TSP diameter inside the hot and cold legs of the Row 1 (shortest radius bend) tubes. These flow slots allow the secondary side feedwater being heated by the reactor coolant inside the tubes to pass through the tube sheets. As the SG heats up, the forces that dent the tube also exert force on the TSP and, where the structural resistance is low enough, can cause deformation and/or cracking of the TSP. One area where the structural resistance is low is at the flow slots. There are six evenly spaced flow slots running along the diameter of each TSP. The flow slot openings are about 15 inches long (along the TSP diameter and spanning about twelve tubes) and about 3 inches wide. Though the forces on the TSP (due to the same corrosion buildup that causes tube) can exist at all locations where a tube passes through the TSP (there are six TSPs between the TS and the top of the tubes before the u-bend) the forces at the flow slots are of greater concern since the forces can cause hour-glassing of the flow slots which contributes to the stress in the tubes.

The flow slots have the least structural resistance to lateral forces in the middle of their long dimension where the ligaments (TSP steel between the rectangular flow slot and circular tube penetration) have less support. The same forces that cause tube denting where the tube passes through the TSP also push against the support plate steel between tube being dented and the flow slot opening. This happens on both sides of the flow slot forcing the sides of flow slot inward at the middle of the flow slot causing the previously rectangular shaped flow opening to develop the shape of an hour-glass. Cracking of the TSP can and has occurred both near flow slots and at other locations in conjunction with tube denting forces in the TSP. This deformation of the flow slots reduces the flow area. But more significantly, when this hour-glassing occurs at the top TSP it causes the hot and cold legs of the short radius u-bend tubes to be forced closer together at the top TSP reducing the bend radius of the u-bend. This places additional

stress on the associated u-bend which, in turn, contributes to and has resulted in PWSCC, the cause of the tube failure in SG24 on February 15, 2000.

As stated in Con Edison's "Indian Point 2 Steam Generator data Book," dated December 1, 1997, "Con Edison performed visual spot checks at the top support plate in the wedge area of SGs 22 and 23." However, Con Edison did not sufficiently assess eddy current probe restrictions in the upper support plate, commonly caused by tube denting, during the 1997 steam generator inspections, with respect to the potential for flow slot hour-glassing adversely impacting tubes beyond row 1. Though required by their Technical Specifications, Con Edison did not have an accurate method of measuring nor any documented criteria for determining when significant hour-glassing of the upper tube support plates had taken place. As such, Con Edison could not effectively assess the impact flow slot hour-glassing would have over the next operation cycle on short radius u-bend tubes.

In conjunction with their root cause evaluation, Con Edison included the following statements: "Based on the stress model, it is believed that very minor hour-glassing, which is not visible during visual inspections, was most likely reached during the initial active-denting years of the IP2 steam generators." "Con Edison performed visual inspections of all upper support plant flow slots, and these flow slots all appeared to be similar (i.e., hour-glassing was not visually detected, implying that the extent of hour-glassing is minimally low)." "Since hour-glassing is not visually apparent or minimal after 25 years of service at Indian Point 2, and since leg displacement beyond that necessary to induce PWSCC is conservatively assumed, there would be no benefit to establishing an hour-glassing "base-line" for postulating additional hour-glassing effects during the next cycle."

The inspection team noted that these statements do not appear consistent with photographs of the flow slots that show extensive hour-glassing in the lower TSPs. The inspection team found extent of condition evaluation conducted by Con Edison was inadequate regarding the potential for increased apex stresses and PWSCC that would result from flow slot hour-glassing, which may have contributed to the cause of the flaws in the R2C67 tube in SG 24 (detected in 1997) and to the flaws in several other tubes, including the tube that failed (R2C5 tube in SG24), that could have been detected in 1997 as indicated by a reanalysis of the 1997 data tapes in 2000.

In 1975 Con Edison elected to plug all Row 1 tubes in all four SGs due to problems that had occurred at another utility. At that same time an additional 9 tubes were plugged due to restrictions. From 1976 through 1982 Con Edison plugged an additional eighty (80) tubes due to restrictions. Over the next five years, from 1984 through 1989, there was a significant increase (more than double) in the number of tubes plugged due to restrictions (192). Only two additional tubes were plugged from 1990 through 1996 due to restrictions. From 1984 through 1995 four hundred and twenty one (421) tubes were plugged due to pitting (>40% through wall indication). Tubes plugged for 'other' reasons (bad data, for example) from 1976 through 1996 totaled sixty-three (63).

In 1997 the first u-bend PWSCC indication was detected and the tube plugged (R2C67 in SG 24). After identifying the apex u-bend PWSCC flaw in SG 24 tube R2C67, Con Edison took no actions to determine the root cause and did not take appropriate actions to determine the extent of condition and to ensure that this new tube failure mechanism was understood. Also, in 1997, twenty (20) tubes were plugged for restrictions, bringing the total tubes plugged due to restrictions for all four SGs to three hundred and three (303). Forty seven (47) tubes were plugged due to tube sheet (TS) crevice indications for the first time and an additional twenty six (26) were plugged due to tube support plate (TSP) indications, also for the first time. Tube plugging for 'other' reasons in 1997 was forty six (46), which was three or more times higher than any previous year (except in 1975 when all Row 1 tubes were plugged).

The licensee attributed this significant increase in the number of tubes plugged in 1997 due to the greater number of tubes examined and the use of a more sensitive Cecco-5 probe.

However, coupled with the 1997 increase in the number of indications of tube flaws, was Con Edison's failure to identify several factors that caused significant limitations and uncertainties in data collection and analyses (low signal to noise ratios in the eddy current probe data such that the noise which would mask unacceptable flaws in the SG tube), reducing the probability of detection of a tube flaw thereby allowing or increasing the likelihood that steam generator tubes with detectable flaws would be left in service. So, even though Con Edison attributed a higher number of flaws detected to the fact that a greater number of tubes were inspected, they failed to recognize an even greater number of flaws could, and did, exist that were masked by high eddy current probe signal noise. Con Edison attributed the noise, or low signal to noise ratio, to deposits on the tube outside surface. And, even though the noise levels were high enough to mask flaws of a magnitude that would require plugging of the tube, Con Edison accepted those high noise levels.

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Dent trending info provided in response to question 13 on Root Cause Report.
Ovality trending info provided in response to question 11 on Root Cause Report. Also see Attachment 1in the u-bend CMOA.

NRC RAI Letter dated March 24, 2000 - Comments on IP2 responses in Con Edison letter dated June 19, 2000.

<u>Question 3</u>
Con Edison states that, "Restriction to the movement of an eddy current inspections probe can be from a variety of causes..... Examples are: Rotating coil probes may be used with motor that has a larger diameter than the test coil, and the motor may be obstructed rather that the probe head, though the effect is the same".

Additionally, Con Edison states that the, "Rotating probe can sometime pass a restricted location as the probe is pushed into the tube indicating that the restriction has a larger diameter than the

nominal probe size. However when the probe is spun and pulled through the tube to gather data the probe may become restricted or stop rotating".

What causes the probe to become restricted whin it is spinning (particularly if the motor has a larger diameter than the probe)? If the motor diameter is not larger than the probe then why does it become restricted or stop rotating? Usually spinning helps an object pass through a restriction, doesn't it?

The new conduit used to introduce the eddy current probe into the steam Generator was identified as a contributor to restriction calls since it provided a higher resistence to motion of the probe. **Why wasn't the conduit changed to eliminate the new problem?**

Question 5
Provide the structural analysis of TSPs assessing TSP structural integrity and deformation (including hour glassing) over the next inspection interval and impact of predicted displacements on u-bend integrity and propensity to cracking.

The model assumes stress remains constant throughout the time for crack initiation. **Is this a reasonable basis? If the plant goes thru any shutdowns with associated cool downs and heat-ups the stress could increase due to denting increases.**

The RAI response does not address the structural integrity aspects of the TSPs. **Check Attachment 1 to the u-bend CMOA provided to the NRC June 2, 2000.**

Root Cause Evaluation - Issue No. 5

The Con Edison response included the following statements:

"Based on the stress model, it is believed that very minor hour-glassing, which is not visible during visual inspections, was most likely reached during the initial active-denting years of the IP2 steam generators."

"Con Edison performed visual inspections of all upper support plant flow slots, and these flow slots all appeared to be similar (i.e., hour-glassing was not visually detected, implying that the extent of hour-glassing is minimally low)."

"Since hour-glassing is not visually apparent or minimal after 25 years of service at Indian Point 2, and since leg displacement beyond that necessary to induce PWSCC is conservatively assumed, there would be no benefit to establishing an hour-glassing "base-line" for postulating additional hour-glassing effects during the next cycle."

These statements do not appear consistent with photographs of the flow slots that show extensive hour-glassing.

Altran Corporation Technical Report No 96245-TR-01, Rev. 0, dated May 1997

The Technical Report recommended that Row 3, Tubes 2 to 14, in SG 23 be plugged to provide protection to all active tubes from the inadvertent release of any TSP section from the flow slots.

1BIS REVIEW OF 1997 u-bend INSPECTION (Special Inspection- Cornerstone REACTOR SAFETY - Barriers)

1BIS1 Flaw Detection/Identification

a. Inspection Scope - Ian

Technique Qualification
Noise Signals
1997 Failure to Detect u-bend indications

b. Issues and Findings

1997 data contained significant noise possible due to deposits on the u-bends tubes. This issue was not identified by Con Edison. Techniques to minimize the effects of the noise on data quality were not used and a careful review of noise data was not taken.

1BIS2 Data Analysis Guideline Review -Ian

a. Inspection Scope

b. Issues and Findings

1BIS3 Analysis Training Review - Ian

a. Inspection Scope

b. Issues and Findings

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1BIS4 Steam Generator Secondary Side Conditions - **Greg**

During the 1997 outage all of the active tubes were examined, using eddy current inspections, over their full length and new tube degradation mechanisms were found on the surface of the tubes. Stress corrosion cracking of the tube was found in the tube sheet (TS) crevice, at the tube support plate (TSP) intersections, in the sludge pile, and in a small radius u-bend. Tubes were plugged based upon indications evaluated at 40% or larger of the wall thickness, linear indications (axial or circumferential), Cecco-5 eddy current probe indications at TSP intersections, and tube roll transition cracks that were not re-rolled or did not meet re-roll criteria after re-rolling at the tube to TS interface. Tubes that did not pass the smallest eddy current probe (610 mil diameter) due to restrictions were plugged. A total of 173 tubes were plugged in all four steam generators (SGs) which represents the highest number of tubes plugged during any one outage.

Sludge and other deposits on the tubes have played a key role in eddy current testing results. As stated in Con Edison's "Indian Point 2 Steam Generator data Book," dated December 1, 1997, "Since the early years of operation at Indian Point 2, a relatively large amount of sludge has been accumulation in the steam generators. Sludge development started during the early years of plant operation, when industry guidelines on pH and dissolved oxygen were different than the current limits." "In 1978, a sludge lancing program was initiated. Since then sludge lancing has been performed during each outage. The amount of sludge removed during each outage was typically 200 lb./SG. Much of the sludge accumulated in the steam generators was usually hard (Rockwell T 60-80). Unlike the deposits in other plants, the deposits around the steam generator tubes at Indian Point 2 contain large amounts of hematite (Fe_2O_3), interspersed with metallic copper." "In general, development of tube deposits and hard sludge was not found to promote severe tube corrosion."

Con Edison went on to say that, "In addition to the extensive conventional sludge lancing performed during each outage, Indian Point 2 developed and implemented the CECIL robotic system for inspection and removal of hard sludge." "No removal of hard deposits from the upper bundle is expected because of the absence of corrosion evidence on the tubes. The risks of damage to the tubing and support plates outweigh the benefits of hard sludge removal or chemical cleaning. This deposit does not appear to cause significant reduction in heat transfer. In general, development of tube deposits and hard sludge was not found to promote severe tube corrosion. The accumulation of deposits has not resulted so far in degradation to the thermal performance of the steam generators. Thus, neither corrosion issues nor heat transfer issues justify chemical cleaning at Indian Point 2. The use of enhanced techniques of chemical cleaning, such as pressure pulsing or high temperatures, is likely to pose severe hazards to vulnerable components, such as the tube support plates which are already damaged." However, Con Edison failed to address the fact that deposits on the outside diameter of the SG tubes is one of the primary contributors to the noise observed during eddy current testing. So even though the deposits may not promote severe tube corrosion, these same deposits can create the high noise levels that mask the detection of tube flaws that, if detected, would require that the degraded tube be plugged.

In 1997 the first u-bend PWSCC indication was detected and the tube plugged (Row2,Column67 in SG 24). Also, twenty (20) tubes were plugged for restrictions (up from one (1) tube in 1995), bringing the total tubes plugged due to restrictions for all four SGs to three hundred and three (303). Forty seven (47) tubes were plugged due to tube sheet (TS) crevice indications for the first time and an additional twenty six (26) were plugged due to tube support plate (TSP) indications in the sludge pile (up from 12 in 1995), also for the first time. Tube plugging for 'other' reasons in 1997 was forty six (46), which was three or more times higher than any previous year (except in 1975 when all Row 1 tubes were plugged). The licensee attributed this significant increase in the number of tubes plugged in 1997 due to the greater number of tubes examined and the use of a more sensitive Cecco-5 probe.

However, coupled with the 1997 increase in the number of indications of tube flaws, was Con Edison's failure to identify several factors that caused significant limitations and

uncertainties in data collection and analyses (low signal to noise ratios in the eddy current probe data such that the noise which would mask unacceptable flaws in the SG tube), reducing the probability of detection of a tube flaw thereby allowing or increasing the likelihood that steam generator tubes with detectable flaws would be left in service. So, even though Con Edison attributed a higher number of flaws detected to the fact that a greater number of tubes were inspected, they failed to recognize an even greater number of flaws could, and did, exist that were masked by high eddy current probe signal noise. Con Edison attributed the noise, or low signal to noise ratio, to deposits on the tube outside surface. And, even though the noise levels were high enough to mask flaws of a magnitude that would require plugging of the tube, Con Edison accepted those high noise levels. Consequently, Con Edison returned Indian Point, Unit 2, to service in 1997 with existing flaws, including the SG 24, R2C5, the tube that failed on February 15, 2000, that could have been detected, based on a independent NRC review of the eight u-bend PWSCC indications detected during the 2000 inspection.

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Altran Corporation Technical Report No 96245-TR-01, Rev. 0, dated May 1997

The Technical Report recommended that Row 3, Tubes 2 to 14, in SG 23 be plugged to provide protection to all active tubes from the inadvertent release of any TSP section from the flow slots.

1IES5 Event Risk Significance Core Damage Frequence and Large Early Release - SRA/Wayne

4OA. OTHER ACTIVITIES (OA)
Special Inspection (S)

4OAS1 Review of 1997 u-bend PWSSS Indications - Wayne

c. Inspection Scope

d. Issues and Findings

4OAS2 Review of Root Cause Analysis - Wayne

a. Inspection Scope

b. Issues and Findings

4OAS3 Independent QDA/ QA Audits- Surveillances - Wayne

a. Inspection Scope

b. Issues and Findings

4OA3 Overall Conclusion on 1997 u-bend Inspection Program - Wayne

a. Inspection Scope

b. Issues and Findings

4OAS4 Management Meetings

.1 Exit Meeting Summary

On Team presented their overall findings to members of Con Edison management led by Mr. A. Alan Blind. Con Edison management acknowledged the findings presented and agreed with the Team's conclusions. The $$$$$$$$$$ some Westinghouse proprietary information. The proprietary information was reviewed and returned to Con Edison and was not included in the report.

During the exit, the $$$$$$$$$$ violations were discussed related to this inspection and two additional non-cited violations related to a Regional inspector's review of the permanent modification area. Should Con Edison management elect to contest these NCVs, a written response should be provided within 30 days of the date of this inspection report, with the basis for their denial, to the Nuclear Regulatory Commission, ATTN: Document Control Desk, Washington, DC 20555-0001; with copies to the Regional Administrator, Region I; the Director, Office of Enforcement, United States Nuclear Regulatory Commission, Washington, DC 20555-0001; and the NRC Resident Inspector at the Indian Point 2 facility.