James S. Baumstark
Vice President
Nuclear Engineering

Consolidated Edison Company of New York, Inc.
Indian Point 2 Station
Broadway & Bleakley Avenue
Buchanan, New York 10511

Internet: baumstarkj@coned.com
Telephone: (914) 734-5354
Cellular: (914) 391-9005
Pager: (917) 457-9698
Fax: (914) 734-5718

June 15, 2000

Re: Indian Point Unit No. 2
Docket No. 50-247

Document Control Desk
US Nuclear Regulatory Commission
Mail Station P1-137
Washington, DC 20555-0001

Subject: Response to the Staff's Questions Regarding the Root Cause Evaluation for Steam Generator Tube Rupture Event of February 15, 2000 (TAC No. MA8219)

Reference:
1) Con Edison Letter to USNRC dated April 14, 2000
2) USNRC Letter to Con Edison dated April 28, 2000

Pursuant to 10 CFR 50.54(f), Consolidated Edison Company of New York, Inc. (Con Edison) hereby provides responses to the staff's initial review of Con Edison's Root Cause Evaluation of the February 15, 2000 steam generator tube rupture event. This assessment was transmitted to the staff via Reference 1. A public meeting was held on May 3, 2000 to discuss the staff's questions regarding the root cause evaluation. These questions were forwarded to Con Edison prior to the meeting via Reference 2. Subsequent to the May 3, 2000 public meeting, it was requested that Con Edison provide written responses to the questions regarding the root cause evaluation. This letter provides Con Edison's responses to issues 2, 6, 14 and 16, which were identified in Reference 2. Additional responses will be forthcoming as they become finalized.

No new regulatory commitments are being made by Con Edison in this correspondence.

Should you or your staff have any concerns regarding this matter, please contact Mr. John McCann, Manager, Nuclear Safety & Licensing.

Sincerely,

Attachment

A001

C Mr. Hubert J. Miller
Regional Administrator-Region I
US Nuclear Regulatory Commission
475 Allendale Road
King of Prussia, PA 19406

Mr. Patrick D. Milano, Project Manager
Project Directorate I-1
Division of Regulatory Projects I/II
US Nuclear Regulatory Commission
Mail Stop 14B-2
Washington, DC 20555

Senior Resident Inspector
US Nuclear Regulatory Commission
PO Box 38
Buchanan, NY 10511

Attachment

Response to Root Cause Evaluation Issues Nos. 2, 6, 14 and 16

Consolidated Edison Company of New York, Inc.
Indian Point Unit No. 2
Docket No. 50-247
June 2000

Root Cause Evaluation – Issue No. 2

Section 2 states that inability to detect the precursor indication in R2C5 due to noise was the principle cause of the leakage event and that the growth rate of the indication between 1997 and 2000 was moderate and not a principle cause. Given the low voltage response of the 1997 signal and the high signal to noise, what level of accuracy can be assumed for the depth of the 1997 indication? On what basis? How does the inferred growth rate of this indication compare to expected growth rates based on comparable industry experience and laboratory crack growth data (e.g., NUREG/CR-5752)?

Response:

Section 2 states that inability to detect the precursor indication in R2C5 due to noise was the principle cause of the leakage event and that the growth rate of the indication between 1997 and 2000 was moderate and not a principle cause. Given the low voltage response of the 1997 signal and the high signal to noise, what level of accuracy can be assumed for the depth of the 1997 indication? On what basis?

The standard deviation for sizing of +Point average depths is typically between 7% and 10%, which is consistent with the two depth estimates. The maximum +Point voltage for R2C5 indication is about 2.5 volts including combined noise plus indication, which permits some separation of the signal from the background noise as described below. The data was evaluated at 400 kHz since the high frequency +Point probe was not available in 1997. The flaw signal can be distinguished from the noise by comparing the signal response within the indication to the deposit ('ridge') response at the edges of the flaw. This separation is applied to identify the phase response for the flaw as it extends from the noise response. For sizing considerations on this indication, the deposit effects result in a separation of the phase angles between the entrance and exit legs of the phase response that must be considered in the sizing evaluation. The signal to noise level and sizing evaluations are described below.

The signal to noise (S/N) ratio varies along the length of the observed indication since both the crack and noise signals vary in amplitude and phase along the crack. For example, the amplitude of the crack signal drops off near the end of the crack leading to a low S/N ratio for any noise level at that point. The estimate for S/N therefore implies the maximum value of S/N for the crack indication. To support sizing of the indications, it is necessary to identify and separate the flaw part of the phase response from the noise response. Figure 1 shows the R2C5 noise signal of about 1 volt at a distance away from the observed crack. Figure 2 shows the maximum flaw plus noise signal to be about 2.5 volt which gives a signal to noise ratio of about 1.5. The portion of the total signal undistorted by the noise, representing the crack signal, is about 1.4 volt as shown in Figure 3 giving an alternate S/N about 1.4 at this location. The phase response of this crack signal must be used to size the indication and not the total peak to peak phase response. Figure 4 shows the overall crack plus noise signal at another location to be about 1.5 volt, where the estimate for the undistorted portion of the total signal is about 1 volt. At this location the noise level is about 0.5 volt and leads to a S/N of about 2.

The similarity of the phases for the noise signal and the crack plus noise signals is notable relative to increasing the difficulty of recognizing the presence of the crack at this location. Similar cases can occur where a crack indication can be confused with noise from a permeability variation or a geometry effect. The high frequency +Point data collected during the Indian Point-2 inspection suggests that the source of the noise observed in the U-bends is sludge plus copper deposits on the tube OD. The U-bends also include variation in wall thickness around the circumference due to bending effects and the focus of the high frequency probe on ID effects reduces the influence of wall thickness variations.

NDE sizing uncertainty evaluations comparing NDE and destructive examination have shown that the best agreement with destructive examination results is obtained when depths obtained from split phase response signals are averaged. Westinghouse guidelines for +Point sizing recommend that duplicate depths be reported at a common position when split phase responses are found, and data processing of the NDE results averages the depths at common positions. This procedure was applied for R2C5 to obtain the best estimate profile shown in the attached Figure 6 from the U-bend CMOA. Near the 6.40 axial distance in Figure 6, a flaw signal could be seen but not sized (expected to be shallow) and a depth of 30% was assigned as a threshold depth for this partial length of the flaw. One leg of the phase response frequently is in the OD plane for R2C5 (Figure 3, for example). This effect has also been seen in laboratory PWSCC specimens with deep indications, and averaging of phase responses was adequate for these indications in comparisons of NDE sizing with destructive exam results. However, it is desirable for growth estimates to define a lower depth estimate for the flaw. This was obtained by evaluating the part of the split phase response with the shallowest depths (always in ID plane) as a separate sizing estimate. The result for the lower depth estimate is shown as the alternate estimate in Figure 6. The two depth estimates are expected to bound the average depth of the indication. A maximum depth of about 92% is obtained from both evaluations. Allowing for uncertainties, all data would indicate that the maximum depth is between 85% and 100%.

The structurally significant part of a crack profile is the deepest section that results in the lowest burst pressure for the indication. This is called the burst effective length or profile in Figure 6. The two depth estimates result in burst effective average depths between about 73% and 80% or about a 7% difference between the two estimates. The standard deviation for sizing of +Point average depths is typically between 7% and 10%, which is consistent with the two depth estimates. Benchmark analyses to predict the February 2000 leakage event indicate that the best estimate profile of Figure 6 is more likely than the alternate estimate. Based on all evaluations, the alternate estimate of Figure 6 is a lower bound estimate, and the most likely estimate is close to the best estimate or potentially slightly deeper.

How does the inferred growth rate of this indication compare to expected growth rates based on comparable industry experience and laboratory crack growth data (e.g., NUREG/CR-5752)?

The growth rate for R2C5 is obtained as the difference in the average depth required for ligament tearing at normal operating conditions at the leakage in February, 2000 and the 1997 burst effective depth profile. The throughwall crack opening after leakage was about 2.2 to 2.4 inches in length. For the R2C5 flaw length, the ligament tearing average depth for tearing at normal operating pressure differential is calculated to be between 87% and 90% by the ANL and Framatome ligament tearing model with the Framatome model requiring about 2% greater depths than the ANL model. These results are calculated for the expected row 2 flow stress of 79 ksi at operating conditions. Due to the cold work applied in bending, the range of flow stresses in U-bends is reduced relative to the straight leg tubing, and the influence of potential differences in flow stress for R2C5 on the average tearing depth is expected to be small. The higher 90% average depth is applied for the growth evaluation. Subtracting the two burst effective average depths from 90% results in average depth growth rates of 6.6% and 11.1% per EFPY (Cycle 14 = 1.48 EFPY). The larger growth rate of 11.1%/EFPY has been conservatively assigned to R2C5 in developing the Indian Point-2 growth distribution even though the deeper 1997 crack depth is a better estimate of the depth. This value represents the largest growth rate from the nine indications that could be sized in both 2000 and 1997. The maximum depth growth rate cannot be reliably obtained since the crack could have been throughwall prior to the end of the cycle.

The Indian Point-2 growth rates are compared in the U-bend CMOA with data obtained from other plants for PWSCC at dented TSP intersections corrected to the Indian Point-2 590 °F operating temperature. At 95% cumulative probability, the Indian Point-2 growth rates are about 30% higher than that obtained for dented TSP intersections. Both the dented TSP intersections and the U-bends with leg displacements due to denting have crack initiation and growth based on ovalizing and plastically deforming the tube so that stress levels above yield are expected for both conditions. Crack growth rates would be expected to be of the same magnitude. The approximately 30% increase in growth rates for the Indian Point-2 U-bends is reasonable recognizing the difference in cold work level and a possible small active strain rate at Indian Point-2.

Reliable crack growth data for tube integrity analyses must be obtained from operating SG data, not laboratory crack growth data. Laboratory growth rates are higher than found in operating SGs due to the accelerated conditions used in laboratory experiments. Field experience shows average crack growth rates closely grouped around 3 to 6% TW/EFPY or about 5% = 2.5 mils/EFPY. R2C5 had a growth rate of about 5 to 6 mils/EFPY. Since laboratory cracking tests involve accelerated testing, the laboratory tests increase test temperatures, loading severity or chemical aggressiveness, and the test results must be extrapolated to service conditions. The history of quantitative extrapolation of laboratory measured growth rates to service conditions has not been successful. For example, laboratory growth rates could not predict the success of alternate repair criteria for leaving indications in service over long periods of operation even with conservative repair criteria. Only the very lowest edge of laboratory crack growth rates match observed field performance including R2C5. Measurements of crack growth in length as a function of the linear elastic stress intensity factor (K) are not applicable to SG tubing as a dominant influence for growth behavior. Pulled tube morphologies and the pictures of R2C5 after ligament tearing (at least 5 torn ligaments visible in the picture) show that crack growth in length is a function of multiple crack initiation sites coalescing to form longer macrocracks. Even throughwall cracks often increase in length by joining with cracks nucleated ahead of the main crack tip (where K is 0).

Figure 1
Indian Point-2
R2C5 Noise Level of About 0.9 Volts Away from Flow

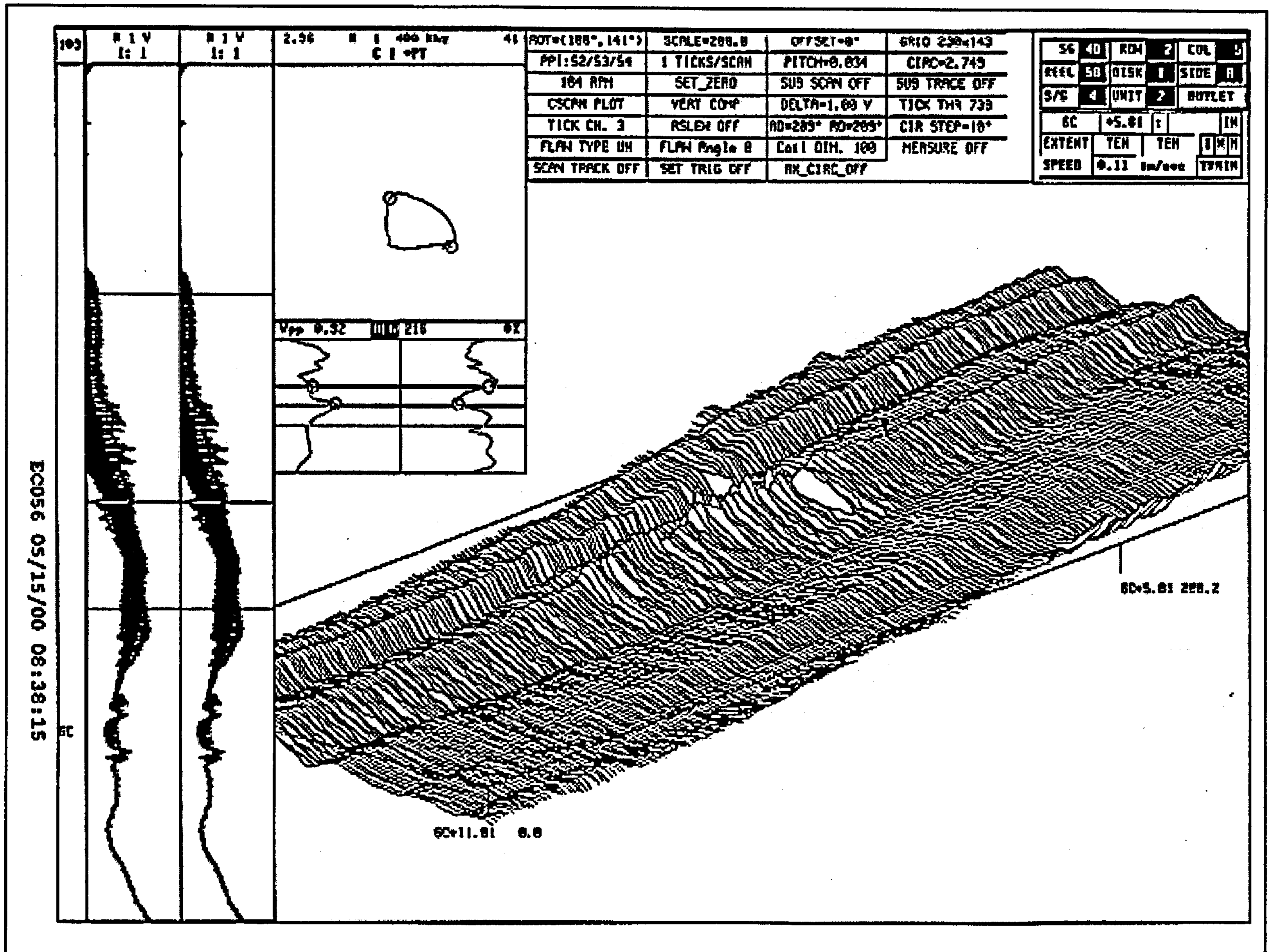


Figure 2
Indian Point-2
R2C5 Combined Noise Plus Flaw Peak Voltage of 2.46 Volt

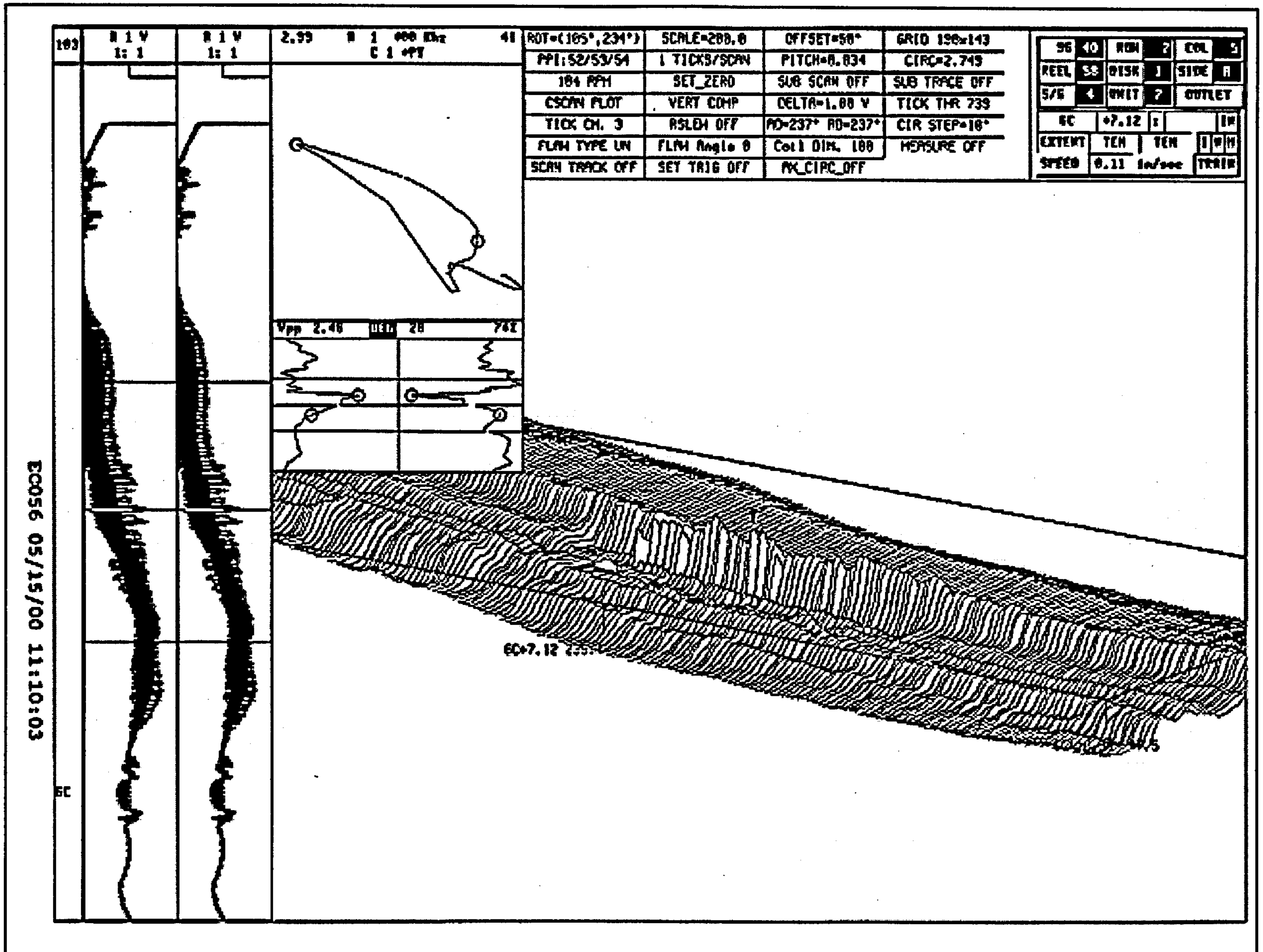


Figure 3
Indian Point-2
R2C5 Peak Flaw Voltage of 1.38 Volt

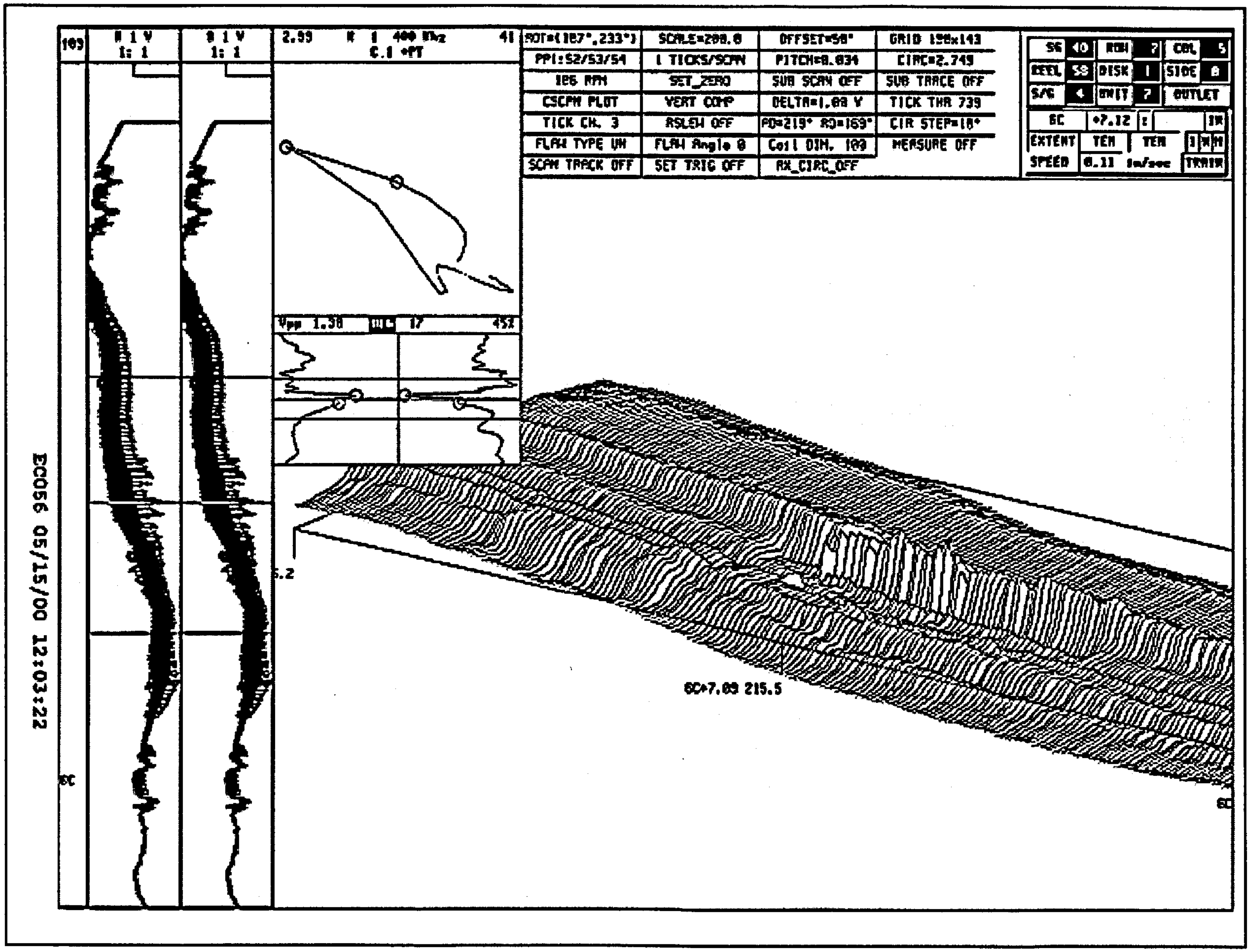


Figure 4
Indian Point-2
R2C5 Combined Noise Plus Flaw Voltage of 1.48 Volt at a Second Location

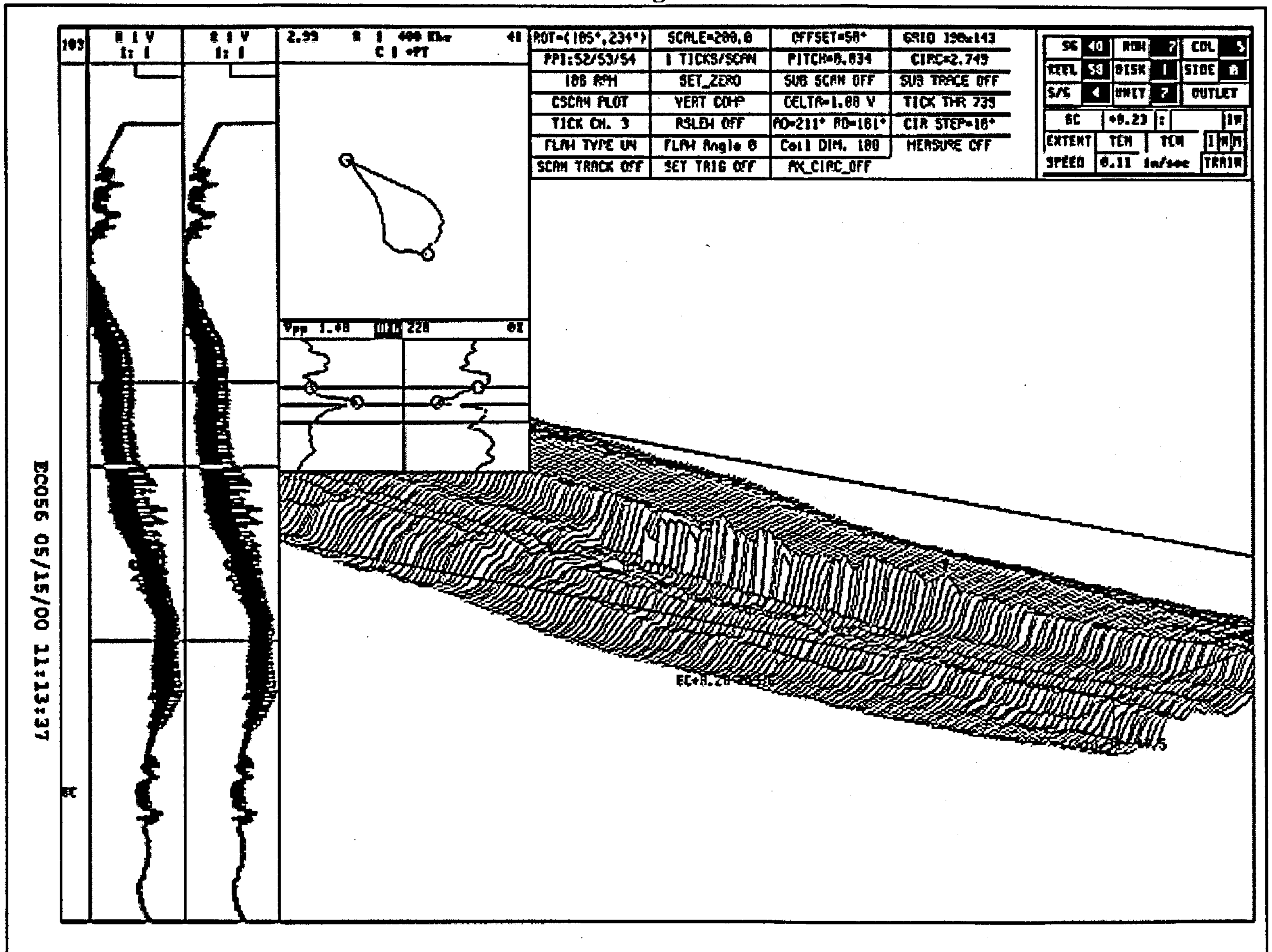
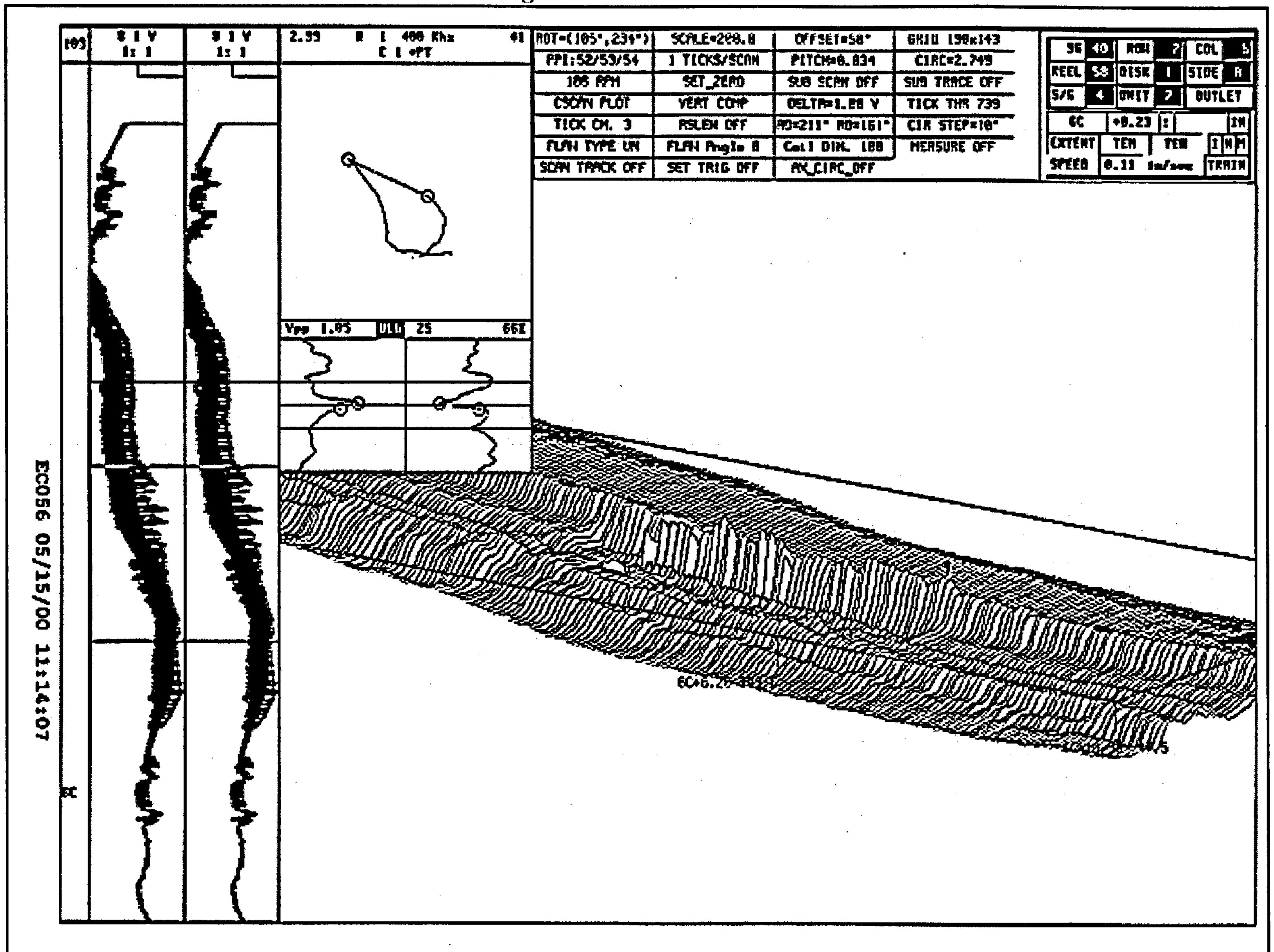
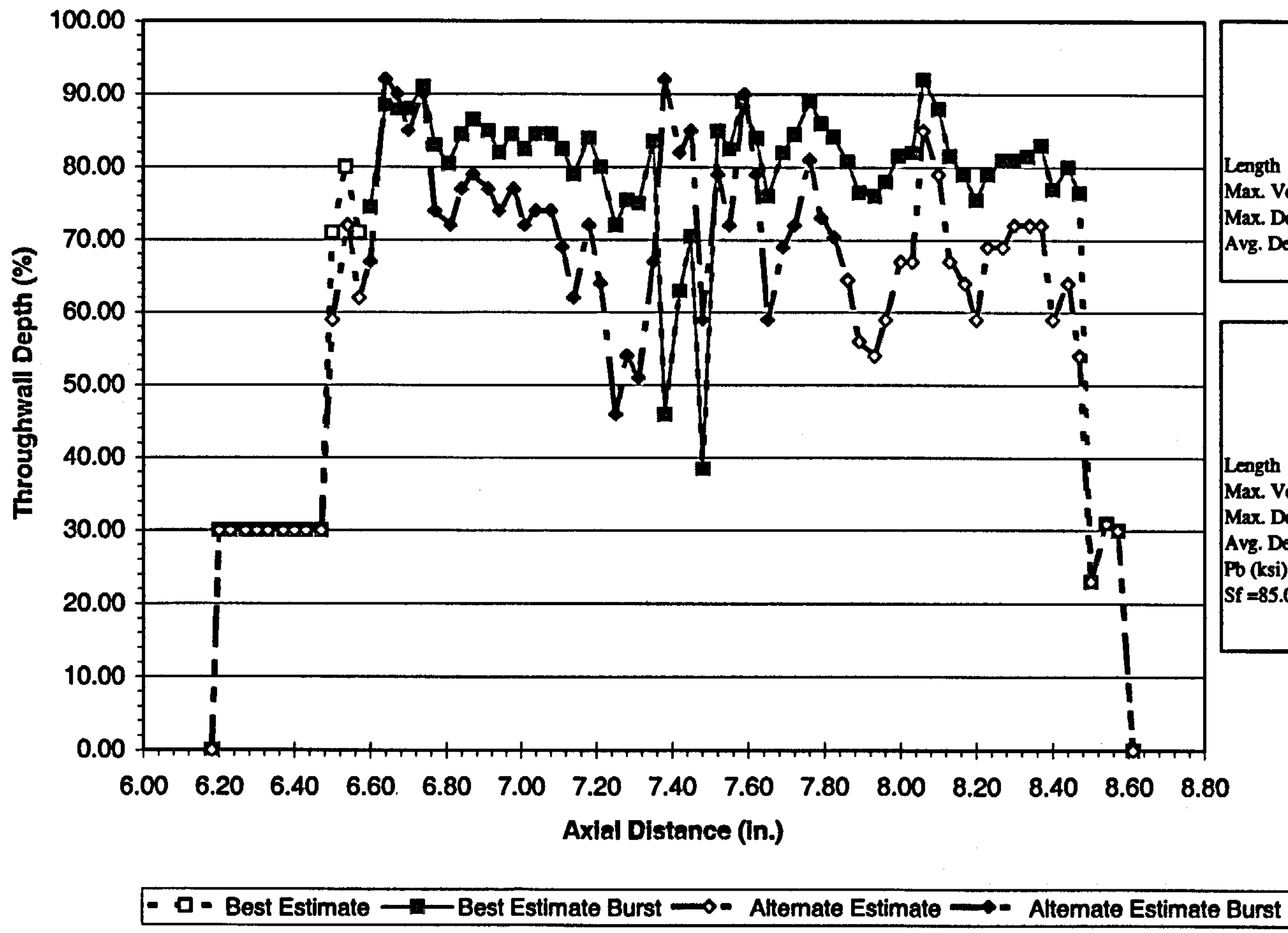


Figure 5
Indian Point-2
R2C5 Flaw Voltage of 1.05 Volt at a Second Location



PWSCC Version 2.0

Figure 6
SG4, U-bend, Tube R2C5, Crack 1 - 1997
NDE Depth vs. Axial Length



NDE Profiles

	Alternate Estimate 1997	Best Estimate 1997
Length	2.43	2.43
Max. Volts	2.24	2.31
Max. Depth (%)	92.0	92.0
Avg. Depth (%)	63.0	70.6

Burst Effective Profiles

	Alternate Estimate 1997	Best Estimate 1997
Length	1.22	1.87
Max. Volts	2.24	2.31
Max. Depth (%)	92.0	92.0
Avg. Depth (%)	73.6	80.2
Pb (ksi)	4.663	3.528
Sf =85.00 (ksi)		

Root Cause Evaluation – Issue No.6

Section 5 states that an apex indication was found in SG 24, R2C67, in 1997 with a length of 0.4 inches. You elected not to perform an insitu pressure test of this location on grounds that the Westinghouse screening criteria were met. These screening criteria are intended to account for eddy current measurement error. What was the basis for the assumed measurement error? Was this assumption applicable to the very low signal to noise ratio existing in the subject tube? Describe the supporting qualification data for samples simulating the IP2 specific noise conditions. Apart from plugging the tube, you apparently took no further action at that time to assess the potential for significant flaws developing in the U-bend during the next operating cycle. Given the evidence of hourglassing of the uppermost support plates, the apex location of the R2C67 indication, and the quality of the eddy current inspection data for the inner row u-bends, and the experience from the Surry 2 tube rupture, why wasn't imminent failure of the inner row tubes anticipated?

Response:

Section 5 states that an apex indication was found in SG 24, R2C67, in 1997 with a length of 0.4 inches. You elected not to perform an insitu pressure test of this location on grounds that the Westinghouse screening criteria were met. These screening criteria are intended to account for eddy current measurement error. What was the basis for the assumed measurement error?

The application of eddy current measurement error for insitu screening criteria depends upon the crack length. If the crack length is shorter than the throughwall crack length (critical length) that would satisfy the $3\Delta P_{NO}$ burst margin requirement, an acceptable crack could be throughwall and there is no need to assign a depth uncertainty to the measurement. In addition, if the crack was near throughwall, a RPC or +Point measurement will overestimate the crack length due to crack lead-in and lead-out effects. Thus, a measured crack length less than the critical length will satisfy the condition monitoring requirements and allowances for NDE uncertainties are not required for the short crack burst screening criteria. For a row 2 U-bend, the critical crack length is 0.6 inch or much longer than the R2C67 measured length of 0.4 inch. Thus, this indication did not require pressure testing.

For leakage screening, the criteria applied in 1997 were a maximum +Point voltage of 2.0 volt (currently higher than 2V based on extensive testing) and a maximum depth of 75%. The depth guideline included an allowance of 15% for NDE sizing uncertainties and 5% for ligament tearing. The 15% maximum depth sizing uncertainty bounded sizing studies for deep cracks. The R2C67 depth was estimated at about 50% or well below the screening criterion and leak testing was not required.

Was this assumption applicable to the very low signal to noise ratio existing in the subject tube? Describe the supporting qualification data for samples simulating the IP2 specific noise conditions.

In 1997, signal to noise criteria were not applied and were not required by the EPRI ISI guidelines. No evaluation was made relative to this effect on sizing although the indicated depth was shallow enough that considerations of noise would not have led to leak testing.

Apart from plugging the tube, you apparently took no further action at that time to assess the potential for significant flaws developing in the U-bend during the next operating cycle.

Con Edison assessed the significance of flaws detected during the 1997 outage in a manner similar to previous outages. Specifically, Con Edison employed the services of Dominion Engineering to assess the significance of PWSCC that occurred in R2C67. The evaluation performed by Dominion Engineering utilizes Wiebull statistical analysis to project future incidents of PWSCC in Row 2. Prior to the 1997 inspection, Dominion Engineering predicted that the first low row PWSCC event at Indian Point 2 would not take place for several more cycles . When the first Row 2 tube with PWSCC was identified in the 1997 inspection (end of cycle 13), Dominion Engineering updated their previous projection. Finding of one PWSCC on a Row 2 U-bend at Indian Point 2 during the 1997 eddy current inspection was not entirely unexpected given the nature of statistical projections. The updated projection predicted a single tube with PWSCC for the end of cycle 14 in 2000. Therefore, there was no expectation that the defect found in 1997 would indicate a significant probability of an imminent failure. Con Edison felt confident that subsequent occurrences of U-bend PWSCC would be detected during the normal course of steam generator inspections.

Given the evidence of hourglassing of the uppermost support plates, the apex location of the R2C67 indication, and the quality of the eddy current inspection data for the inner row u-bends, and the experience from the Surry 2 tube rupture, why wasn't imminent failure of the inner row tubes anticipated?

The evidence of hourglassing of the TSPs and the apex location of the R2C67 indication do not imply imminent failure. The dominant denting had occurred many years prior to the 1997 inspection and no indications had been found and no U-bend leakage had been identified since the denting progression had been slowed to low or zero levels. There was no reason to believe in 1997, or even now in 2000, that hourglassing implies an imminent failure. The indication found in 1997 was based on the first +Point inspection of the U-bend following prior inspections with the bobbin coil. The first +Point inspections typically lead to an inspection transient (step increase in numbers of indications). The finding of a single U-bend indication in the +Point inspection after prior bobbin coil inspections was no surprise after about 16 EPFY of operation, and this relatively small indication in combination with hourglassing were not any indication of imminent failure. The Surry-2 tube rupture occurred in a row 1 tube after about 2 EFPY of operation when denting progression was very active with hourglassing progressing to flow slot closure, which exceeds that at the top TSP at Indian Point-2. It is difficult to reconcile how this experience implies imminent failure when one small apex crack is found after 16 EFPY of operation. Considerations of potential failures based on the quality of the eddy current data are based on hindsight since criteria on data quality were not in place in 1997 across the industry, and guidance was only developed following the current evaluation of R2C5. There were no criteria and no database to form a postulate that the noise effects could mask a flaw such as that present in R2C5 in 1997. It is very doubtful that any review in 1997 of the finding of a single apex flaw in row 2 at Indian Point-2 would have rationally led to consideration of a potential imminent flaw.

Root Cause Evaluation – Issue No. 14

The root cause report should discuss the relative susceptibility of Alloy 600 mill-anneal tubing at IP2 to PWSCC relative to that for other plants. What was the range of mill anneal temperatures?

Response:

The nominal mill anneal temperature for Indian Point 2 tubing was 1850 °F as presented at the May 3 NRC public meeting. Detailed records on the temperature range are not currently available. Based on an EPRI review of the microstructure of Indian Point 2 tubing compared to other tubing with defined heat treatments, the mill anneal temperature range was estimated at 1830 to 1855 °F. Con Edison has commissioned a review of the processing and heat treatment of the tubing used in the fabrication of the IP2 steam generators and, in particular, those tubes which were used to fabricate those in Rows 2-4. IP2 steam generator tubing was manufactured by Huntington Alloys with a relatively high temperature final mill anneal (1850°F). Certified Material Test Reports (CMTR) are available for the tubing used in the four steam generators. While the CMTR data does not allow us to identify properties on a tube by tube basis, they do allow us to identify material properties on a heat by heat basis. The tubing material utilized in the Indian Point 2 steam generators is less susceptible to stress corrosion cracking than tubing annealed at a lower temperature, typical of later generator tubing manufactured by Westinghouse (final mill annealing in the 1700-1750°F range). Based on general assessments of the influence of mill annealing temperature on SCC such as Figure 3 of NUREG/CR-5272, the mill annealing temperature is above the poor range of SCC resistance and in a range of uncertain performance. The relative low susceptibility of Indian Point 2 to SCC compared to other plants can be qualitatively assessed due to the lower operating temperatures at Indian Point as well as material considerations. The occurrence of PWSCC at the partial depth roll expansion transitions and at the dented TSP intersections has been toward the lower range of plant experience.

Root Cause Evaluation – Issue No. 16

Section 7 doesn't address specified ovality limits on the small radius U-bends which may have been introduced during fabrication. What kind of post process inspections were performed to verify acceptable ovality, for example, ball gauge measurements? The data cited for Turkey Point isn't helpful here since the Turkey Point generators had experienced significant hourglassing in 1976.

Response:

The Alloy 600 tubes installed in the Indian Point 2 steam generators were fabricated to a Westinghouse specification which identified the material as ASTM B163-61T and special code ruling case 1336 (annealed) Ni-Cr-Fe alloy, except the maximum cobalt content was limited to 0.1%. The Westinghouse steam generator specification required the following:

- ovality to be less than or equal to 10% of the nominal tube diameter (defined as maximum diameter minus minimum diameter divided by the nominal diameter);
- tolerance on leg spacing for the first three rows at the point of U-bend tangency to be ±1/32 in.;
- maximum wall thinning to be 10% of nominal wall thickness;

The manufacturers of the tubing, Huntington Alloy Products Division, provided CMTRs for the U-bends indicating that the specified requirements including ovality and minimum wall requirements were met. The CMTRs accounted for the number of tubes required for rows 2, 3, and 4.

The engineer in charge of process control at Huntington Alloys at the time the U-bends were manufactured was contacted regarding the manufacturing process. A summary of the information provided is given below. Personnel at Huntington Alloys have reproduced the bending process applied previously.

The Huntington Alloys bending process applied a ball mandrel and concave die to support the circular cross section of the tube. The internal mandrel was made of copper alloy (AMCO Grade 20) with about 12% Al and 4% Fe. For row 3 U-bends up to row 5, the internal mandrel was eliminated, but the concave die continued to be used. Larger rows were bent around a cone. The bending operator set up the process utilizing a number of trial pieces. These trial pieces were used to confirm that ovality of the bends was within tolerance, and that no unacceptable geometry or surface variations resulted from the setup. An acceptable bending setup was checked and approved by a quality inspector, and a full-length tube was bent for setup verification measurements on a gauge table. The measurements on the gauge table included ovality measurements (OD micrometer measurements) at the tangent points (clamp point and trailing tangent) and at the apex of the tube and leg spacing verification. Wall thinning measurements were made outside the flow of the process on tubes that were destructively examined. After approval of the setup, at least the first tube after each setup change was verified by a quality inspector. The recollection of the Huntington Alloys process engineer is that the collective results of an ovality study performed showed that the row 1 and row 2 ovality consistently fell into a 4%-7% range.