ENCLOSURE

OAK RIDGE NATIONAL LABORATORY
OPERATED BY MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE U.S. DEPARTMENT OF ENERGY

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Mr. Ken Karwoski

Office of Nuclear Reactor Regulation
Materials and Chemical Engineering Branch
U.S. Nuclear Regulatory Commission
MS OWFN 7D4
Washington, DC 20555

Dear Ken:

On Tuesday, May 4, I traveled to the Palo Verde Nuclear Power Plant, near Phoenix Arizona, to review their eddy-current inspection of their steam generators. This plant has three identical units, each producing about 1250 MW of power, and each having two Combustion Engineering System 80 steam generators. Unit 2 experienced a tube rupture in Steam Generator 2 on March 14, that resulted in leakage of about 250 gallons/min. from the primary to the secondary loop. The plant was safely brought to shutdown and the steam generators opened and examined. The ruptured tube was determined to be due to a long axial defect in the free span of the tube, between the 8th and 9th egg-crate support plates of tube R117 C144 in steam generator 2.

Inspections with the bobbin probe

All accessible tubes in the generators were inspected full length with the bobbin probe. This probe is quite fast and generally very reliable for axial defects. However, several factors combine to make this inspection inadequate. They are listed as follows:

1. This crack appears to be similar to IGSCC that occurs on the outer diameter of tubes at the support plates. The signals from this type of crack are reduced by bridging of the eddy-current flow across the crack face by ligaments. A study by Westinghouse showed these defects had 1/5 the signal amplitude produced by an EDM notch with the same length and depth. Free span defects at McGuire also have been low amplitude and very difficult to detect.

2. While the ODSCC that occurs at the support plates is relatively abrupt due to the concentration of the crack initiating chemicals under the support, cracking in the free span can produce long cracks that are tapered. While both absolute as well as differential data are recorded for the bobbin probe, most of the analysis is performed on the differential data. Normally, other tube variations obscure the absolute readings, particularly for defects with signals this small.

3. There is a noise signal produced by pilgering, or variations in the tube inner diameter produced during the fabrication process. The defect signal is mostly vertical, while the pilgering noise is adjusted to be mostly horizontal. However, there will be small vertical components that can mask small defect signals. While this noise does not completely eliminate the bobbin probe as a screening device, it does reduce its effectiveness. It will also severely reduce the ability to measure the depth of the defects. The pilgering noise signal at Palo Verde ranges between 1 and 3.4 volts, and is larger than that at any other plant that I have reviewed.

At the present, the bobbin probe is being used as a screening measurement to detect the regions of the generators where the corrosion is occurring. When these areas are detected, they are then inspected with the RPC probe.

Rotating pancake coil inspection

The RPC is slow, with an axial inspection speed of about 0.2 in. per second. It does appear to have higher sensitivity to the free span axial defects than the bobbin probe in this case. While the RPC signal from IGSCC types of cracks is also reduced due to current bridging across the crack face, the RPC inspection is not further degraded by the cracks being tapered and by the pilgering. Due to the slow scanning speeds and the long length of tubing to be scanned (generally between the 8th and 9th egg crate support plates), only about 4 tubes per hour can be scanned. Other methods of increasing the inspection speed are being investigated.

Inspection results

The ruptured tube (R117 C144 of steam generator 2) revealed a crack in the free span about 9 in. long. Another tube (R105, C156 of steam generator 2), had a crack almost

as large that was over 2 1/2 in. long and over 80% deep. This tube probably would have ruptured soon, or if there was a transient. A rotating pancake scan of this tube is shown in Figure 1.

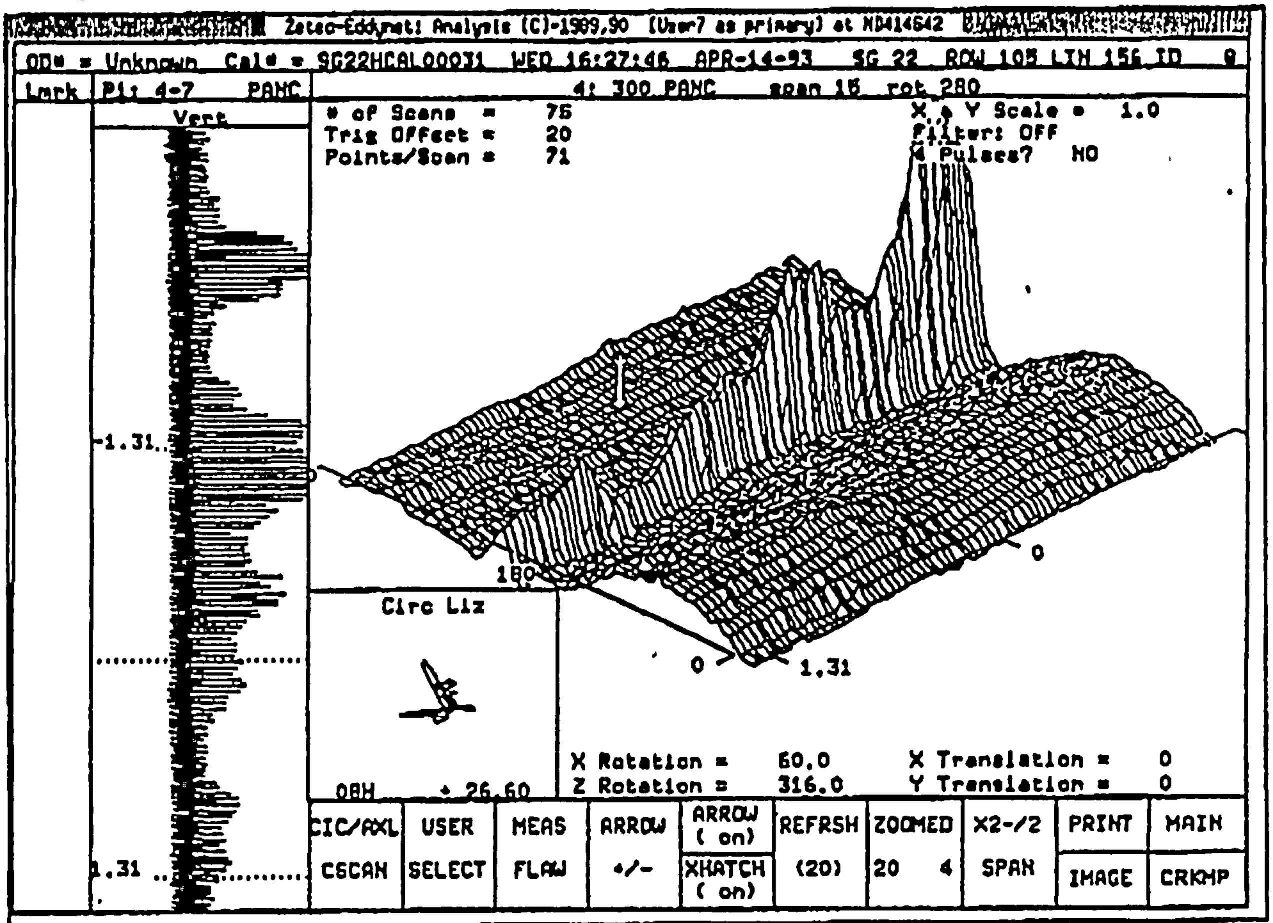

Figure 1 Rotating pancake scan of tube R105 C156 of steam generator 2, made in April of 1993.

This tube had been inspected at the prior outage in November of 1991 using the bobbin probe. A bobbin coil plot of the tube at this location is shown in Figure 2. There is no indication at this location on any of the 8 lissajous plots. There is some small drift on the 100 KHz absolute channel, but this is normal for this type of tube scan. When the location of the defect is well known, a more sensitive examination of a particular region can be made, and the pilgering noise is less of a factor. This tube does not show even any "noise signals" that may be the start of a defect on the bobbin coil scan.

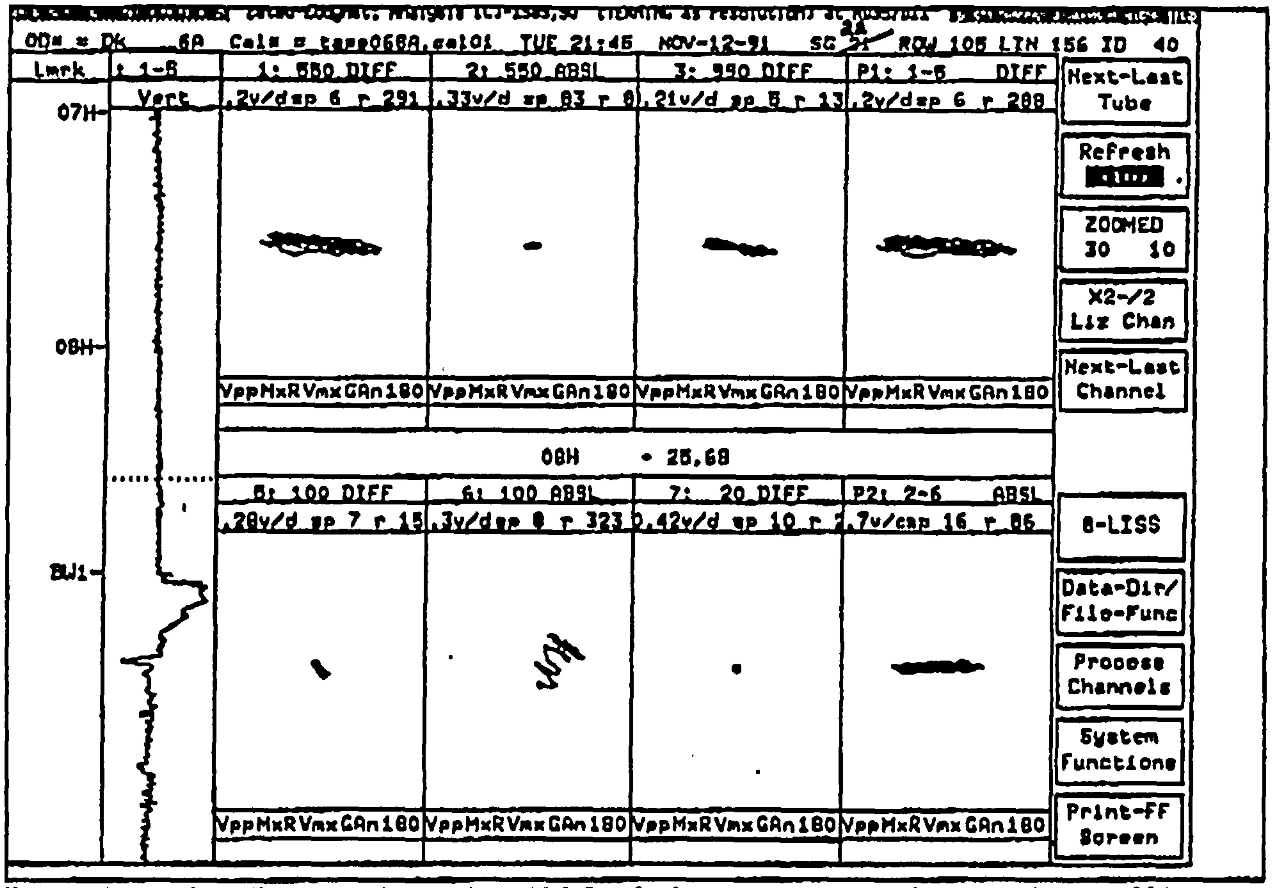

Figure 2 Bobbin coil scan made of tube R105 C156 of steam generator 2 in November of 1991.

The scan in Figure 2 can be compared to the scan in Figure 3. Figure 3 is the bobbin coil scan of the same tube made in April of 1993. The defect is clearly visible in the 550 KHz differential channel, with a signal level of 4.47 volts. The expanded horizontal channel, (the right hand chart under the lissajous) shows the defect and the "sine wave" effect of pilgering, which is somewhat greater than a volt. The expanded vertical channel (the left hand chart under the lissajous) shows several vertical signals. This relatively long defect gave several "hits" on the differential channel, indicating that the defect was irregular, with stopping and starting points. The defect depth, which is measured from the angle of the lissajous figure, was reported as 80% at this point, and 84% at another. Since the pilgering noise has a direct effect on the phase angle (by varying the horizontal position of the signal) there can be considerable error in the depth measurement, particularly when the horizontal variation is greater than the vertical defect signal. However, from the amplitude of this signal, the length of the indication, the RPC scan

of the defect, and considering the measured depth on several of the bobbin "hits", the defect is probably in excess of 80% in places.

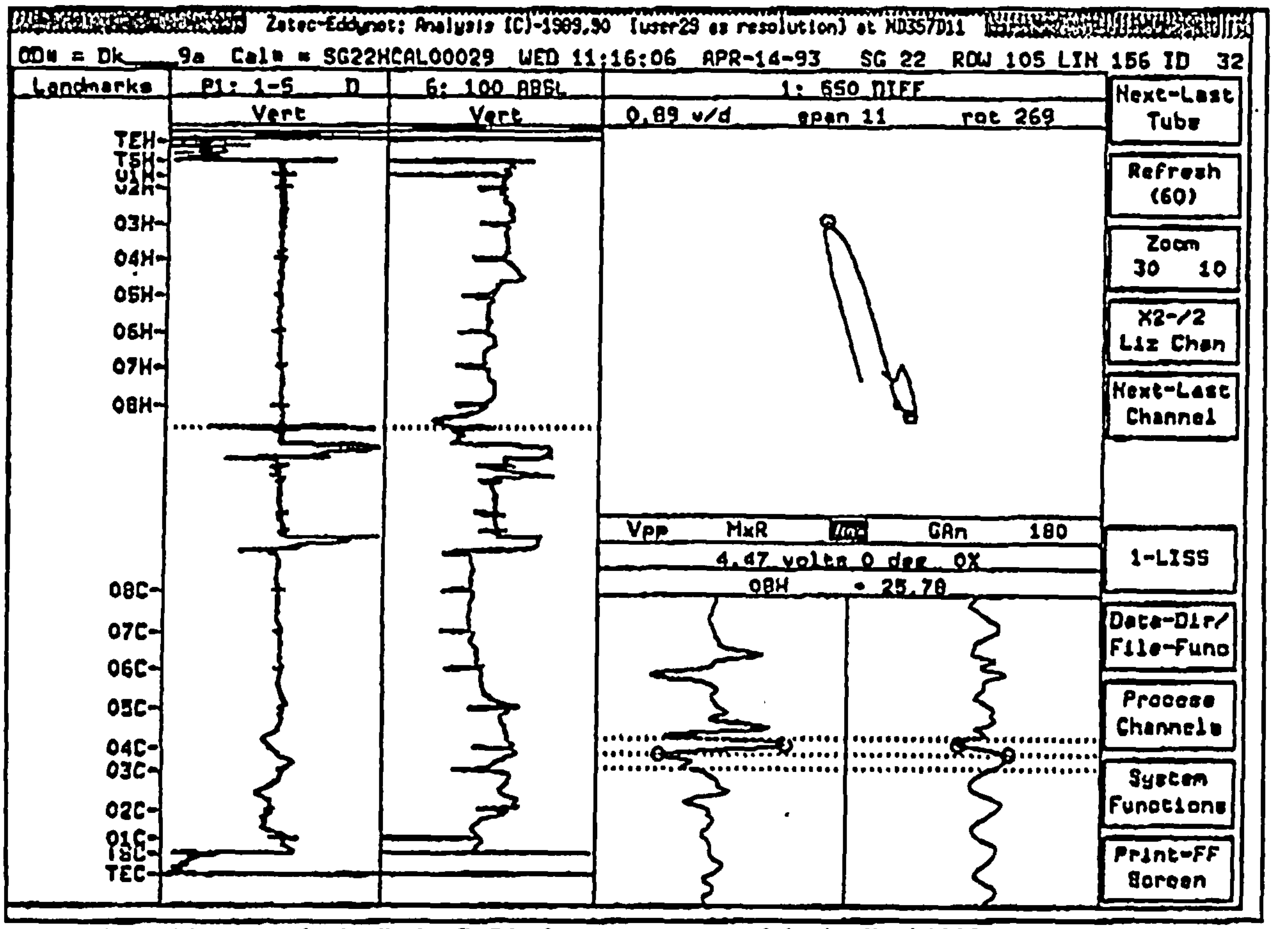

Figure 3 Bobbin scan of tube R105 C156 of steam generator 2 in April of 1993

In Figure 4 we show the bobbin trace of the ruptured tube made in November of 1991. The sensitivity of this plot is much larger than the former plot, and the pilgering noise is showing up much greater on the horizontal channel. There is essentially no vertical signal in the region of the defect.

Neither of these tubes had any trace of a bobbin coil signal in the prior outage, indicating that the cracks were quite fast growing. While the pilgering noise can reduce the detection level of the bobbin probe, if the analyst knows the exact spot to examine, the reduction in sensitivity is not as large. However, there was no bobbin indication at all on these scans. Since this tube did rupture, we can conclude that with the current bobbin

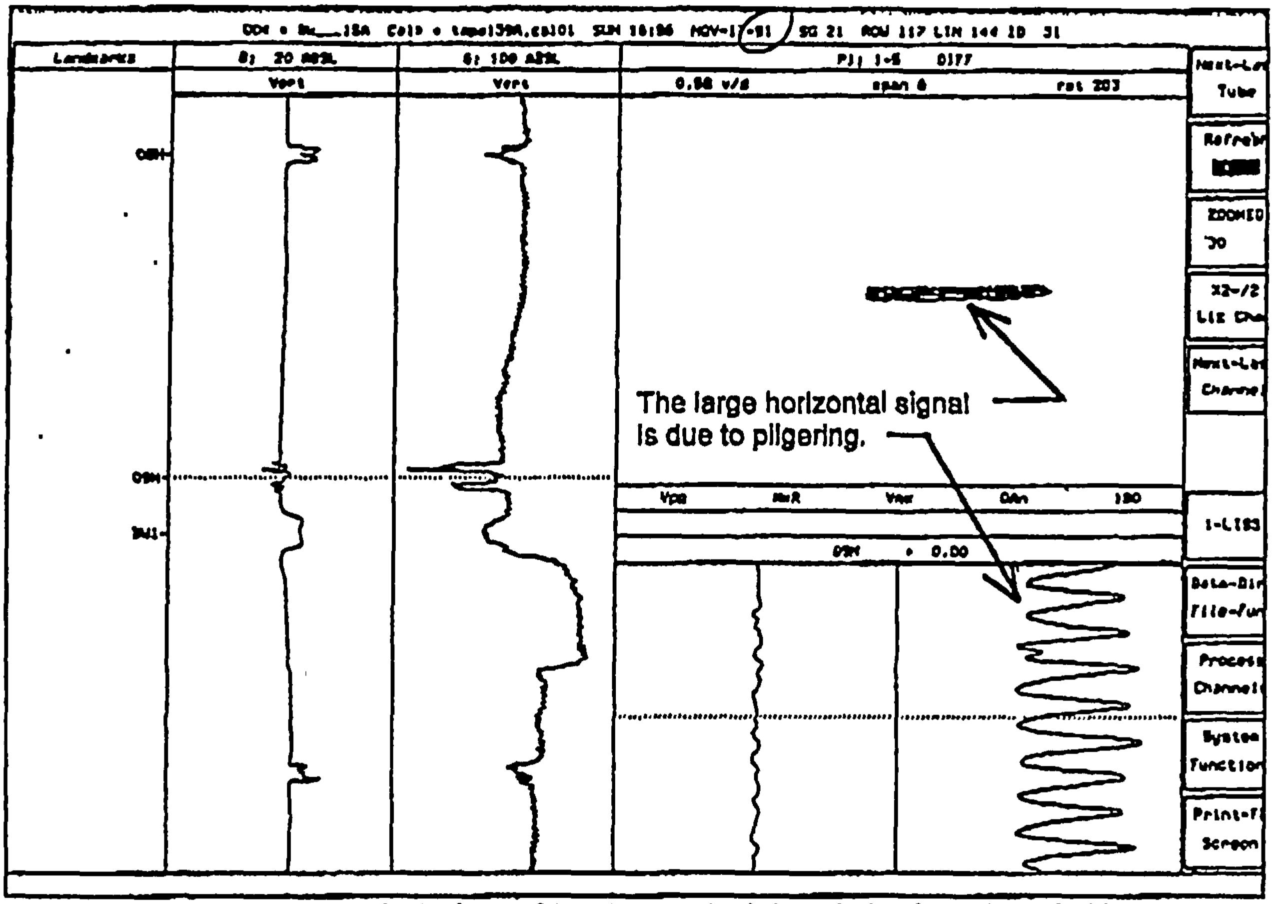

Figure 4 Bobbin probe scan of tube R117 C144 (ruptured tube) made in November of 1991

inspection methods, defects can grow from not detectable to rupture during one cycle. It should be noted that one free span defect of this type was found and plugged in the generators in the 1991 outage, but no special (i.e., RPC) inspection program was initiated.

Inspection summary to date

The bobbin was used as a screening device to locate the regions in the generator in which these defects occur. At the time of our visit, the bobbin had located 7 possible defects, and the RPC had found 16 in the same region. This region was a band toward the periphery of the generator, with most of the indications between the 8th and 9th hot leg egg-crate support plates, although one defect had been found in the horizontal section of one of the tubes. This is clearly the region with the most severe defects, although there may be smaller defects in other regions.

The bobbin probe, as it is presently applied, has been demonstrated as being inadequate to reliably detect these defects, and the RPC has demonstrated more sensitivity. However, the RPC also may not be sensitive enough to detect these flaws reliably. The present pancake probes are able to scan at a rate of 0.2 in. per second.

At our request, a summary table was prepared by the utility for all axial defects (both those at support structures and those in the free span). Of the total of 45 RPC confirmed defects, 12 of these were ruled to have no bobbin indication (NBI). The average vertical signal of these 12 bobbin misses was 0.33 volts, with the maximum being 0.64 volts for a crack at a support and the maximum free span indication being 0.48 volts.

Estimated detection levels

Based on the measurements made thus far and some very rough approximations the expected detection level for this type of defect is as follows:

RPC defect detection level at a crack depth of about 50%
Bobbin defect detection level at a crack depth of about 70%

The RPC is expected to detect signals on the order of 0.1 volts. The voltage signal from a 50% EDM slot is about 0.5 volts. A study from Westinghouse showed that ODSCC cracks, due to ligament bridging produced only about 20% of the signal of an EDM notch.

The bobbin voltage for a long 70% EDM notch is about 4 volts, and the signal will be reduced to about 20% due to ligament bridging, and another estimated 50% reduction due to the taper of the crack, giving a signal of 0.4 volts. Smaller signals can be detected by the bobbin if the analyst knows exactly where to look, and further signal processing may improve the bobbin detectability.

Possible inspection improvements

Efforts are being made to speed the inspection and increase the detectability of this type of defect. A three coil rotating pancake probe that would scan at a rate of 0.6 in. per second is being tested. Also, a second probe positioner fixture is being added to the generator that will allow two probes to be run in parallel. An experimental rotating field

probe that can inspect 25 tubes per hour, full length, is being fabricated and was to be tested on Wednesday, May 12. This probe can be constructed to go around the bend, and reportably, has a greater sensitivity than the RPC. However, since this probe is not sprung against the tube wall, it may be sensitive to the pilgering signal that the bobbin probe sees. This probe reportably makes 50 readings around the circumference of the tubing, and the "bottleneck" for inspection speed may be the rate at which the data can be recorded. The MIZ-30, with its higher data acquisition rate may be needed in order to achieve the higher inspection speeds with this probe.

The 16 coil array probe being designed by ORNL and being manufactured by Zetec would allow an inspection speed of about 6 in. per second, with the MIZ-30. This probe uses a larger diameter coil than the RPC, and also may be more sensitive to the pilgering. This probe will not be tested until the Fall of 1993, and is being constructed for 7/8 in. diameter tubing first.

Advanced signal processing methods, such as a neural-network back-propagation method may be able to reduce the pilgering noise for both the bobbin and rotating field probe. This signal processing method could increase the ability of the bobbin probe to detect this type of defect, and allow more sensitive and faster screening of the data.

Possible sources of degradation

Some of the defects face each other, indicating the possible presence of a common corrosion region between the tubes. Video scans of the tubes surrounding a removed tube showed possible deposit bridging between two tubes. Better scans with an "improved" camera were planned. There appears to be a "deposit" bridge between some of the tubes between the 8th and 9th supports. Rough scans indicated that this material appeared to have the same conductivity as lead. However, better scans for both lead and copper should be obtained before any conclusions are drawn. Lead, at one time, was listed as being a possible generator contaminant.

Most of the scans showed what was termed as a "deposit" signal, associated with the defect. Most of the defects in free-standing tubes appear to grow out of a "seam" or a region of different eddy-current properties both here and at McGuire. This "seam" is a

region with different electrical or magnetic properties. It appears that, for most of the defects, both a deposit and a seam are necessary for a defect to occur.

Conclusions and recommendations

Tube pulls, which should give much needed insight into this problem, are being performed. Any final conclusions about the nature of this problem should wait until the results of the metallography is known. However, it is apparent that free span cracking is the most difficult and dangerous problem facing the industry today. The eddy-current test as it is presently performed, is not adequate to detect this type of degradation before it goes through wall.

This problem is not specific to Palo Verde nor to Combustion generators. While it has been officially reported at two McGuire plants and Palo Verde unit 2, I believe that it is more common in the industry. Due to the low detectability threshold, if a plant has not been "sensitized" to this problem with a tube rupture, the chances of detecting this phenomenon is very low. Palo Verde plugged a tube with one of these defects in the last outage, but was not able to detect other defects before the tube ruptured. This type of defect is more dangerous and harder to detect than the ODSCC at the tube supports. Palo Verde had a number of tubes with this type of defect that might have ruptured if a transient had occurred.

In general, the training and analyst procedures were adequate. The data analyst guidelines were supplemented with a training booklet, which was a collection of viewgraphs. We suggested that captions and explanations be added to the figures.

Sincerely yours,

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