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Subject: Arkansas Nuclear One - Unit 2
Docket No. 50-368
License No. NPF-6
Information to Support Upcoming Steam Generator Meeting

Gentlemen:

On July 15, 1993, during Entergy Operation's meeting with the NRC to discuss eddy current methodologies utilized at Arkansas Nuclear One, Unit 2 (ANO-2), the Staff asked for certain information to be transmitted for their review. Entergy committed to provide this information to the Staff prior to ANO's August 30, 1993, steam generator (SG) meeting with the NRC. The items requested by the Staff are discussed below.

1. Response to Question on the Use of a 79% Average Throughwall as the ANO-2 Regulatory Guide 1.121 Maximum Crack Limit

NRC Regulatory Guide (RG) 1.121 describes a method for determining allowable limits for degradation of steam generator tubing. Tubes with degradation which could exceed this limit are required to be removed from service by the installation of plugs at each end of the tube or modified to be acceptable for further service by the installation of suitable sleeves which meet RG 1.121 requirements.

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In the spring of 1992, an active circumferentially-oriented intergranular stress corrosion cracking (IGSCC) damage mechanism was identified in the expansion transition region above the tubesheet in the ANO-2 steam generators. Since that time extensive eddy current examinations utilizing motorized rotating pancake coils (MRPC) have been performed in this area. All potential circumferential indications identified by MRPC regardless of depth have been removed from service or repaired when identified.

Since the damage mechanism was first discovered, a conservative analysis has been performed to demonstrate that cracks will not, with a high degree of certainty, initiate and propagate to a point that would exceed the RG 1.121 limit before the end of the proposed operating cycle. This has been accomplished by statistical evaluations of flaw distributions based upon operating experience at ANO-2 and other similar plants.

For circumferential cracks in vertical tubing the worst case tube load is in the axial direction, and is proportional to the average crack depth (total metal loss distributed uniformly over 360°) due to three times the operating pressure difference (per RG 1.121) applied within the "U" bend area (see Figure 1). Hoop stress within the defect area is not limiting and is lower than axial stress because the defect area is effectively bounded by a short axial length (0.25") planar defect (conservatively assuming no strengthening from ligaments between microcracks). This is further supported by data from NUREG/CR-0277 which indicate high burst pressures for short axial length simulated defects.

The limiting axial stress is inversely proportional to the non-defected cross section of the tube (within the defect area). Figure 2 illustrates the tube failure mode due to a burst test of a pulled ANO-2 tube (the tube is parted without bulging).

Since the non-defected cross section is mathematically determined by the average tube wall defect penetration, then the average (and not maximum) defect penetration is the controlling parameter for structural integrity for the defect area of the tube. This is confirmed by burst tests of pulled tubes from ANO-2 and others. Millstone Point 2 (MP-2) extensive burst tests agree with calculations based on average wall penetration (for the same type circumferential cracking and tubes as at ANO-2).

The ANO-2 burst test agrees with calculations based on average tube wall penetration as follows. Calculated burst pressure for a 72% throughwall (TW) average defect utilizing the same methodology as that to establish the 79% RG 1.121 limit for Tube 64-48, pulled during 2R9, is 5600 psi. The actual burst pressure was 5818 psi. The unaccounted for strength (5818/5600 - 1 = 3.9%) is believed to be due to ligaments between microcracks. We believe that actual ligament strengthening is greater than that demonstrated by Tube 64-48, since this tube was damaged during removal. Also, an 0.25 inch axial extent was assumed for calculation of the allowable circumferential crack. This would be the same as a groove 0.25" wide all the way around the circumference. Since the ANO-2 cracks are tight cracks, this is conservatively simulating the flaws and provides additional margin for safety. The RG 1.121 calculation is included as Attachment 1.

CE burst tests were performed with ANO-2 pulled tubes not physically supported as well as they are in the SG. Asymmetric defects will result in higher burst test pressures (due to reduced tube primary bending stresses at the defect) if the tube is physically supported the same as in the generator, i.e., with a simulated first support grid in conjunction with a simulated tubesheet.

One of the most significant conclusions drawn from the MP-2 burst test program is that an eggcrate (EC) support substantially improves the burst performance of asymmetric cracks (i.e., those cracks which generate significant bending stresses when pressurized). The burst pressures of supported samples were twice that of unsupported samples. Since an EC support neutralizes the bending moment generated by a pressurized asymmetric notch/crack, failure pressure under such conditions can be predicted by calculating axial stress only.

2. Request for the Analysis that Determined a Best Estimate of 77 New Circumferential Cracks at the End of Cycle Ten

The analysis assuming 77 cracks at the end of the current cycle of operation is based on determining the number of cracks per Effective Full Power Day (EFPD) from October 1992 (2R9) until May 1993 (2P93). After a run time of 188 EFPD 48 circumferential cracks were found, yielding a rate of 0.254 cracks per EFPD. With 305 EFPD remaining until 2R10, the expected number would be 0.254(305) = 77. Additionally, Dominion Engineering was contracted to estimate the rates of degradation of the ANO-2 SG tubes for use in short term outage planning and longer term strategic planning. The analyses include projections of rates of progression of all degradation mechanisms that have been observed in the SG's to date, and anticipated rates of degradation from other mechanisms that are expected to occur based on industry experience with similar steam generators.

For most of the degradation mechanisms, it was assumed that the time dependence of the best estimate number of tubes requiring repair as the result of that degradation mechanism is described by a Weibull probability distribution. The basic Weibull distribution for failure times is:

$$F = 1 - \exp[-(t/\Theta)^b]$$

where F is the fraction of the tube population that has failed at time t, and Θ (characteristic time) and b (Weibull slope) are adjustable parameters of the Weibull distribution. These parameters are determined by fitting observed data for the plant being analyzed or from analyzed industry experience for a given degradation mechanism.

This problem can be addressed by establishing statistical distributions to describe the individual Weibull parameters for each degradation mechanism, and then convoluting these parameter distributions to determine a probability distribution for the occurrence of the mechanism based on the Weibull parameters. This convolution can be easily performed by use of a Monte Carlo type random sampling analysis which utilizes many trial samplings from each Weibull parameter distribution to approximate the degradation mechanism probability distribution. The desired confidence levels on the bounding case can then be selected from this new probability distribution for the mechanism.

Realistic bounding cases for the aggregate of all mechanisms can be established by convoluting the probability distributions for each degradation mechanism, as described above, again using a Monte Carlo analysis. A new probability distribution for the aggregate is obtained from the Monte Carlo analysis, and the desired confidence levels for the bounding case can be selected from this distribution.

Based on this approach, the estimated values are 22, 37, and 110, for optimistic, best, and pessimistic estimates, respectively, of the number of circumferential cracks at the end of the operating cycle for a T_{hot} of 599°F. Since the aforementioned number of 77 is higher than the Weibull estimates, it is used for our analysis.

Curves representing the optimistic, best, and pessimistic estimates for the "A" and "B" SG's are included in Attachment 2. Additionally, a draft curve revised to include the May 1993 outage is included as the last curve in that attachment.

3. Response to Question on the Number of Tubes Reanalyzed in 2P93 Due to Noise

During 2P93, May 1993, 28 tubes were flagged by analysts as requiring retest due to bad data, most likely due to noise. The use of an optical link between acquisition and analysis allowed the analysts to stay within a few tubes of the acquisition, and therefore prevents the collection of larger amounts of bad data before being recognized and corrected.

4. Response to Question on the Predicted Probability of the Worst Case Flaw Found in 2P93.

The worst case flaw in 2P93, was calculated to be 51.4% TW by MRPC data. Looking at the previous data, the probability of not having a flaw of that size would be 83% based on the projected estimate of 37 cracks at the outage.

5. Response to Question on the Use of MRPC to Determine the Average %TW and the Request to Use a 50% TW Threshold for the Portion of the Crack not Seen by MRPC.

Figure 3 shows the change to the distribution curves resulting from assuming a 50% TW threshold for the portion of assumed cracks not seen by MRPC. Using the 50% threshold drastically shifts the curve right, but also changes its shape such that it forms a normal distribution curve. We do not believe that SCC behaves in this manner, but rather that there are many more small cracks than large ones, giving a distribution that is not uniform and normal. Utilizing the 50% threshold does, however, cause one cracked tube to be calculated as ≥ 79% TW that wasn't in our original calculation, and thus causes the probability of not having a crack in excess of RG 1.121 limits to decrease from 97.4% to 96.8%.

6. Response to Question on the Scope of SG Inspections at the Next Refueling Outage

The current ECT scope for the next refueling outage (2R10) is as follows:

- 100% full length bobbin, both SG's
- 100% HL top of tubesheet MRPC, both SG's
- 20% CL top of tubesheet MRPC, both SG's
- 20% partial drilled TSP's tube dents, MRPC, both SG's

We believe the above information provides complete responses to the questions raised during our July 15, 1993, meeting with the NRC. We look forward to our August 30, 1993, meeting with the NRC staff to discuss our analytical results and future plans regarding the ANO-2 steam generators. Should you have any questions regarding this submittal, please contact me.

Very truly yours,

for James J. Fisicaro
Director, Licensing

JJF/JJD
Attachments

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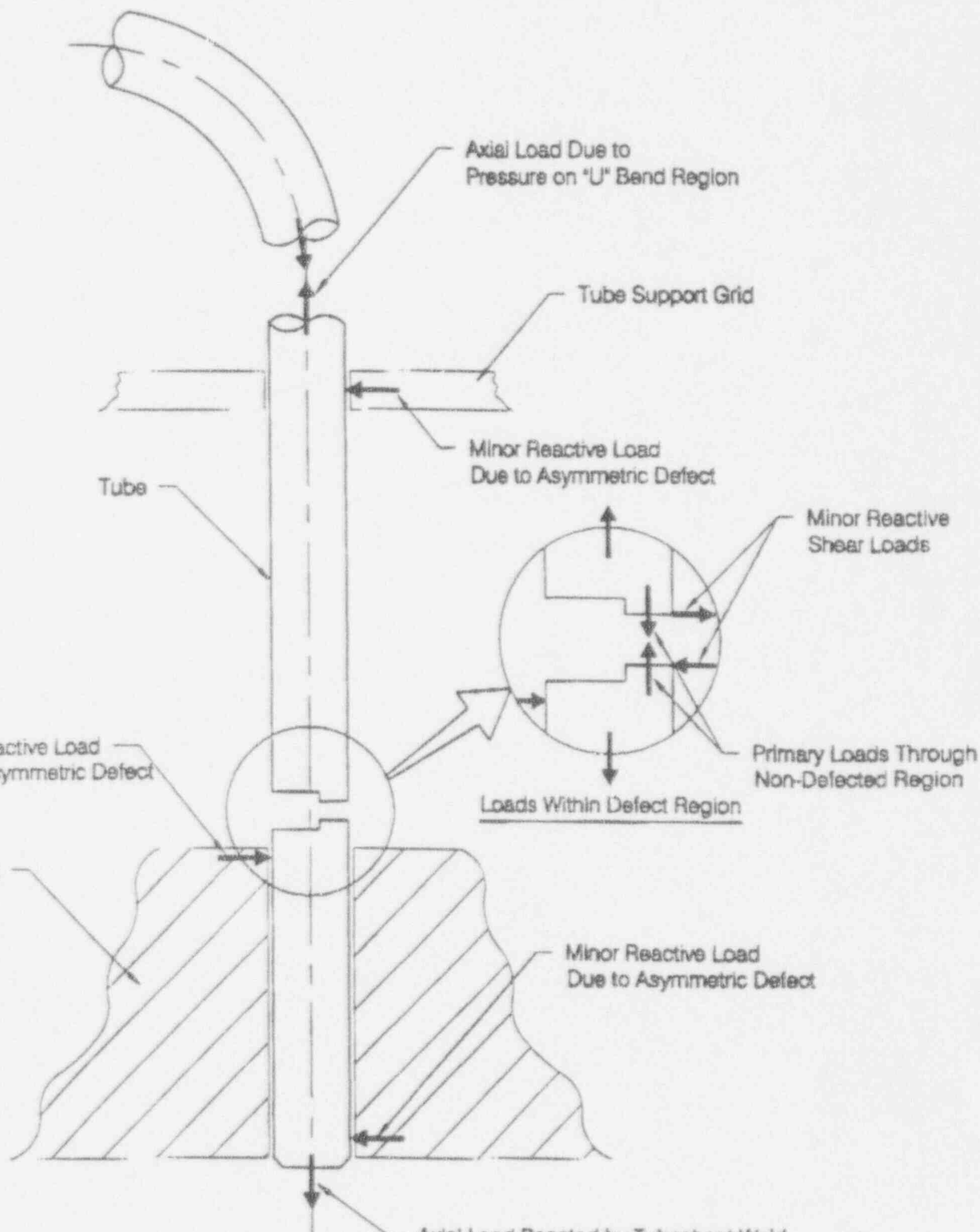
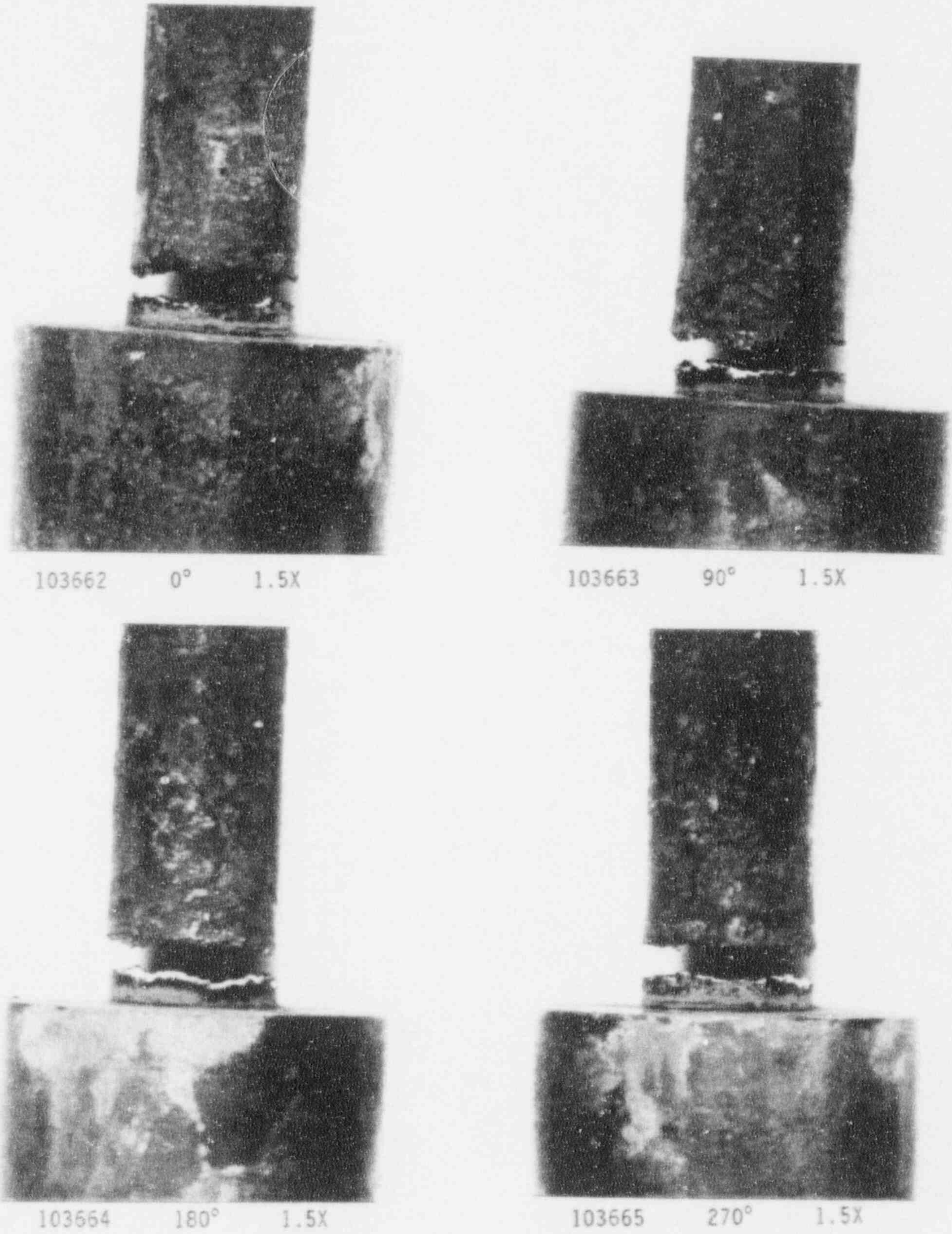
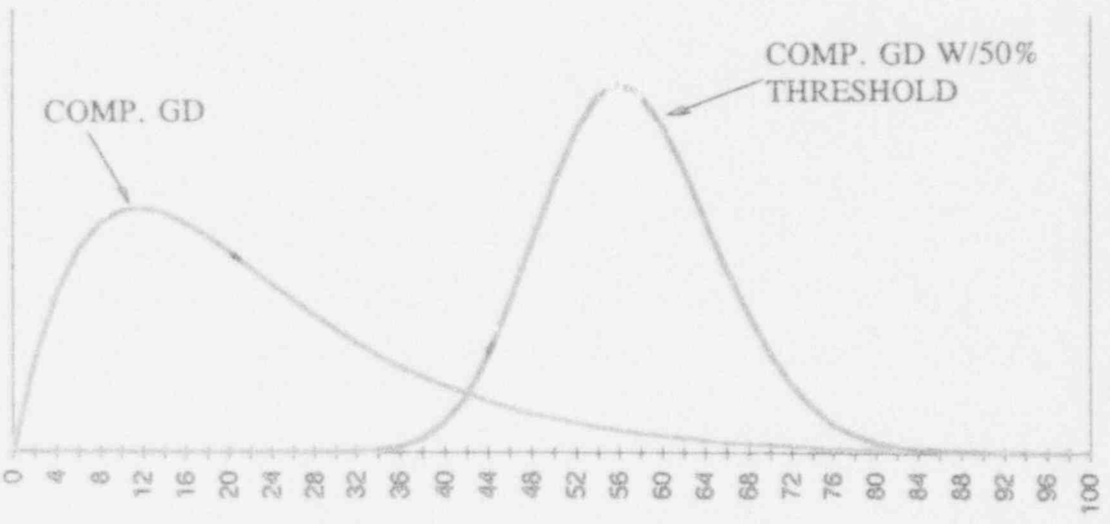


Figure 1. Free Body Schematic Load Diagram for
Asymmetric Defect at Top of Tubesheet



Post Burst Test Photographs of Steam Generator A Tube R64L48.

FIGURE 2



EFFECT OF THRESHOLD LIMITS ON DISTRIBUTION CURVES

FIGURE 3

ATTACHMENT 1

ANO-2 Reg. Guide 1.121 Analysis