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STATUS OF CHANNEL BOX WEAR IN DUANE ARNOLD

This memorandum presents a preliminary analysis of results obtained from the neutronic measurements, made at Duane Arnold prior to reactor shutdown for the purpose of plugging the bypass flow holes, and the subsequently measured channel box corner wear. The neutronic data consist of measurements taken with the traversing incore probe (TIP) subsystem and the local power range monitor (LPRM) subsystem. Details of the manner in which the depth of the channel box corner wear is determined will be discussed. The static, transient and accident analyses aspects of channel box corner wear will also be discussed.

Conclusions

From our preliminary analysis of the data, we conclude that:

1) based on mechanical calculations, we can infer what wear value will lead to failure with the steam-line break accident or steady-state operation,

2) based on Duane Arnold data and BNL calculations, we can predict when reactors such as Vermont Yankee, Peach Bottom 2, or Hatch are likley to attain an "unacceptable" state. The correlation of the data has lead to a new TIP noise criterion which should be used to limit plant operation,

3) inspection of channels indicated that new wear may have occurred at the Duane Arnold plant after operaton at 50% power

Neutronic Measurements (D. Fieno)

TIP measurements were recorded for each of the 20 LPRM instrument tubes in the Duane Arnold reactor. Table I is a tabulation of the estimated peak-to-peak noise in the TIP traces as a function of reactor core flow and power. An additional set of data is given in Table I for an approximate saddle-shaped axial power distribution. Figure 1 is an example of an abnormal BWR TIP trace. This TIP trace was obtained for the 16-09 core location and appeared to have the largest peak-to-peak noise content. Table II provides a tabulation of the estimated TIP noise and channel box corner wear data available on June 23, 1975. Wear was measured both below and above the 80 inch elevation and for the corners of the four channel

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boxes facing the LPRM instrument tube. The estimated TIP noise as a function of maximum estimated channel box corner wear is shown in Figures 2a and 2b. The data exhibit a considerable amount of scatter as a result of the complexity of the phenomena relating wear and instrument tube mechanical vibrations and of the uncertainty in the determination of both TIP noise and channel wear. Nonetheless, the data generally support the conclusion that an increase in TIP noise occurs with increased amounts of channel box corner wear (prior to actual failure of a channel box).

The results of calculations performed by our consultants at Brookhaven National Laboratory (BNL) are also shown on Figures 2a and 2b. The calculations correctly predict the trend in TIP noise with channel box corner wear. The BNL calculations were performed with the two-dimensional discrete ordinates S transport program TWOTRAN. The calculations were with eight neutron energy groups (including multiple thermal groups), the S approximation, four fuel bundles, 40% and 60% in-channel void content, and no voids in the bypass water region. The dimensions of the corners of the channel boxes were reduced in the analysis to simulate wear and the resulting increased water moderation around the LPRM instrument tube. Thus, the BNL results are indicative of the TIP detector readings at the center of the bypass water region and touching one channel box corner of the four available. Our BNL consultants are using the TWOTRAN code to study a number of other aspects of the problem, such as variable in-channel void content.

Figure 2c is a plot of the TIP noise as a function of reactor recirculation flow. At 90% flow the TIP noise for two different axial power shapes is included. No essential difference in TIP noise can be noted. From the data in the figure, the slope of TIP noise as a function of flow is 0.08 maximum and 0.04 average. The decrease in TIP noise with flow may be caused by the changing sensitivity of the TIP recording system.

Time recordings were taken at Duane Arnold for all of the fixed LPRM fission detectors. These data have been analyzed to yield the power spectral density (PSD) as a function of frequency. The PSD plot for the B-level LPRM at core location 16-09 is shown in Figure 3. The data show a peak in the 2 to 3 Hz frequency range which is believed due to the vibration of the instrument tube. The data also show a broad peak in the .2 to .8 Hz range which is reactor power dependent.

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Two PSD ratios are defined:

$$R_1 = \frac{\text{PSD } (1.4 \quad 5.0)}{\text{PSD } (.2 \quad .8)}$$

$$R_2 = \frac{\text{PSD } (1.4 \quad 5.0)}{(\text{MEAN})}$$

Both of these ratios are attempts to normalize out the effects of reactor power. The first ratio, R_1, is listed in Table IIIa and the second ratio, R_2, is listed in Table IIIb. The first PSD ratio as a function of channel box corner wear is shown in Figures 4a and 4b while the second PSD ratio as a function of wear is given in Figures 5a and 5b. All of the PSD plots show little trend for the given PSD ratio and channel box wear. High wear may be associated with a low PSD ratio and the converse may also be true, i.e., a high PSD ratio may be associated with a low channel box wear indication. Evidently, the two PSD ratios as defined are not even qualitative indicators of channel box corner wear. A better understanding of the information presented in a PSD analysis is clearly needed. Work in this area is proceeding and, hopefully, will help establish noise analysis as an appropriate means for determining channel wear.

<u>Acceptable Wear of Channel Box</u> (S. B. Kim)

Table IV gives recommended criteria for acceptable worn channels at each operating condition. The values are selected based on a finite element code analysis (elastic-large deflection option) performed by PNL which calculates bending stress at the worn corner for various pressure differentials across the channel wall.

The calculated stresses are compared with allowable stresses to set an acceptable wear. The allowable primary stress values for the steady state and accident are selected as 1.5 times the S_m, stress intensity, and 70% of ultimate stress respectively. For the S_m value, the smaller of 2/3 of yield or 1/3 of ultimate is used. The in-reactor yield and ultimate stresses are selected as 34,000 and 45,000 psi, respectively. This results in 22,500 and 31,500 psi for the steady state and accident allowable stresses respectively. The corresponding allowable wear is 20 mils for both cases. As to

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the pressure differential, the maximum across the channel at its bottom are 12 and 16 psi. If we take the pressure at a point 1/4 of the way to where maximum wear is postulated, the corresponding pressure values become 9 and 12 psi, respectively for the steady-state operation and the steamline break accident. The low cycle fatigue limit is designed for the end of useful service which is up to 4 reactor cycles. We did not consider this amount of service in the above analysis. It is our position that inspection of channel wear at the time of next refueling or at the time of fixing the vibration problem, coupled with our ability to monitor damage with the TIP subsystem, will preclude formation of wear greater than observed at Duane Arnold.

Measurement of Wear (H. VanderMolen)

Channel boxes from the Duane Arnold reactor were measured by means of a borescope. The width of the damaged stripes on the channel box corners was measured directly. The depth of the material removed was conservatively inferred as follows:

> The maximum concavity of the worn surface is determined by the radius of the instrument tube as shown in Figure 6. Simple Pythagorean derivation give the depth of the concavity beneath the chord of intersection:
>
> $$Z_1 = r_1 - \quad r -$$
>
> and the height of the original surface above the chord:
>
> $$Z = r - \quad r -$$
>
> and therefore the total depth of wear is:
>
> $$Z = Z + Z$$

This equation is plotted in Figure 6 where the various symbols are defined.

This maximum concavity corresponds to repeated perpendicular impacts with no transverse motion. Since TV scans of the wear stripes exhibit markings suggesting a "wiping" motion, the flat surface wear shown in Figure 6 is probably a realistic value. This "flat" wear is about 42% of the "concave" wear, so the "concave" values used in this report should bound actual wear very well. The TIP noise data, shown in Figures 2a and 2b, and the PSD ratio, shown in Figures 5a and 5b, are replotted based on the more realistic "flat" wear assumption in Figure 7a, 7b and 8a, 8b, respectively.

Borescope inspection of channels at the Duane Arnold reactor after shutdown showed two regions of wear had occurred on the same side of the channel box. The surface of one region gave the appearance of fresh wear. It is possible that this wear occurred during the period the reactor was operating at reduced power and flow. This is substantiated by the data obtained from the TIP measurements which was at full flow and power taken prior to reduced power operation and were compared to data which were taken at full flow and power after the 50-50 flow/power operation. The increase in peak-to-peak band width at one location was from approximately 6% to 8%.

Safety Implications (S. Israel)

Steady-state operation with channels having excessive wear (but no cracks) would not violate thermal-hydraulic design criteria and operating limits because the assembly flow rates would meet or exceed design values. However, previous analyses have predicted a rapid increase in differential pressure of about 4 psi across the channel boxes during a steam line break accident outside of containment. This increase in differential pressure could result in rupturing some of the more severely worn channels along the affected corners. The consequences of this accident with "failing" channel boxes would probably result in violating the critical heat flux limit in those affected fuel assemblies if their bundle power were high. The amount of fuel damage and peak clad temperatures would be less severe than that predicted for a LOCA with a suction break because the fuel would not be uncovered during the accident.

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