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ANALYSIS OF FUEL-CLADDING CHEMICAL INTERACTION AT HIGH BURNUP

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MASTER

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The HEDL fuel-cladding chemical interaction (FCCI) wastage correlation[1] has been revised to incorporate additional data from the HEDL P-23 high temperature test series at peak fuel pin burnups of $\sim$ 90.0 MWd/kgM. The previous HEDL correlation was developed from a data base of fuel pins with peak burnups of $\sim$ 50.0 MWd/kgM. Therefore, in order to predict the amount of cladding thickness loss to be expected at current anticipated fuel pin lifetimes in the range of 90-100 MWd/kgM a major extrapolation of the actual irradiation experience was necessary. To provide the needed data for the extension of the correlation to high burnups the irradiation of the HEDL P-23A subassembly in EBR-II was extended to a peak fuel pin burnup of $\sim$ 90.0 MWd/kgM. Details of fuel pin fabrication, irradiation, examination, and analysis to peak burnups of $\sim$ 50.0 MWd/kgM have been reported previously.[1,2,3]

An advanced matrix type reaction was observed in the high burnup fuel pin (Figure 1). The character and extent of the interaction made it impossible to estimate the location of the original cladding inner surface to determine cladding thickness loss due to FCCI by measuring the depth of penetration. Therefore, it was necessary to measure total cladding thickness for the high burnup pin. In order to place the entire data set on the same basis, cladding thickness was also measured for the lower burnup pins. Cladding thickness was measured on 225X photographs of the polished cladding at 16 equally spaced locations on the circumference of each sample. From these measurements an average cladding thickness was calculated.

Significant circumferential variations ($\sim \pm$ 25 microns) in total cladding thickness were measured due primarily to eccentricity of the tubing. Therefore a meaningful measurement of maximum cladding thickness loss is not available from the thickness measurements due to the uncertainties in as-fabricated cladding thickness at a specific location. Measurements were corrected for sodium cladding surface corrosion,[4] cladding swelling, inelastic strain, and ferrite layer formation which influence total cladding thickness.

The extent of cladding thickness loss for a constant temperature indicated an increase in the rate of reaction at the high burnup. This accelerated attack suggested a two part equation for the data correlation; one describing the low burnup data and a second describing the accelerated high burnup attack. Data were fitted to an equation using standard non-linear regression techniques. The resultant equation describing the data is:

$$D = \begin{cases} 2.07 \times 10^5 \sqrt{B}\, e^{-\frac{9776}{T}} & \text{for } B < 4.68 \\ 2.07 \times 10^5 \sqrt{B}\, e^{-\frac{9776}{T}} + 4.47 \times 10^4 (B-4.68)\, e^{-\frac{8416}{T}} & \text{for } B > 4.68 \end{cases}$$

where D = depth of attack in microns,

B = fuel pin axial averaged burnup in atom percent, and

T = time averaged cladding inner surface temperature, °K.

The surface described by the correlation is shown in Figure 2.

The extension of the data base of P-23A fuel pins to high burnups represents a source of FCCI data that are consistent in temperature, cladding, fuel composition, and exposure at current anticipated reference fuel goal burnup levels. The advanced matrix type reaction at high burnup is proceeding at a faster rate than an extrapolation of the lower burnup data would indicate. As additional data become available from the P-23 test series, the form of the burnup dependence in the range above 5 at.% burnup will be refined. In addition, as appropriate data become available, primarily from the P-23C subassembly[5], an initial fuel O/M dependence will be incorporated into the data correlation. Subsequent revisions to the data correlation will include expansion of the data base to include additional P-23 series results which should provide the confidence intervals for the parameters in the equations.

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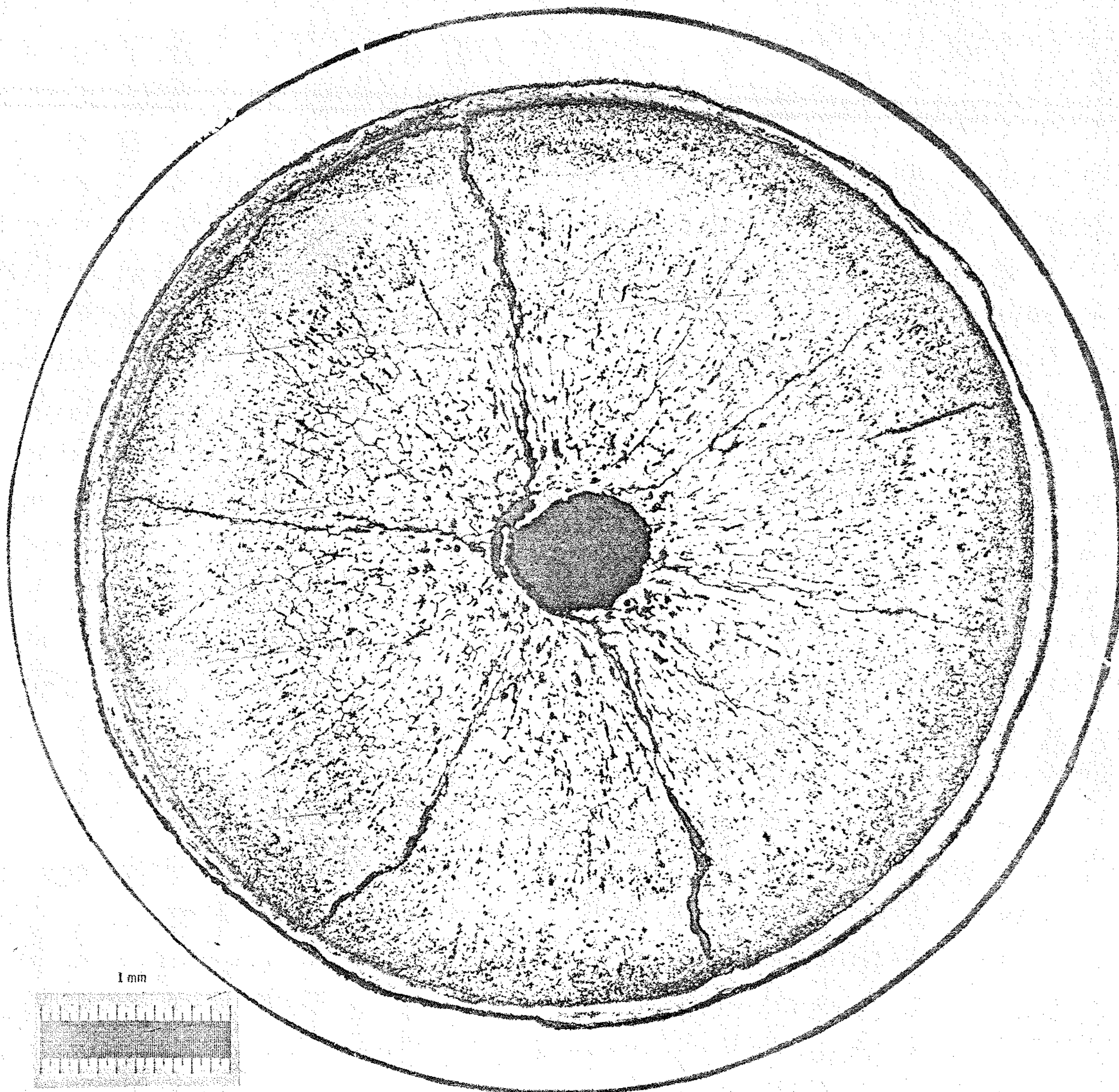

END OF LIFE FUEL CENTER TEMPERATURE = 3460°F (1900°C)

Figure 1. Nature and Extent of Fuel-Cladding Chemical Interaction in the High Burnup P-23A-20 Fuel Pin (90.0 MWd/kgM) at a Cladding Inner Surface of 700°C.

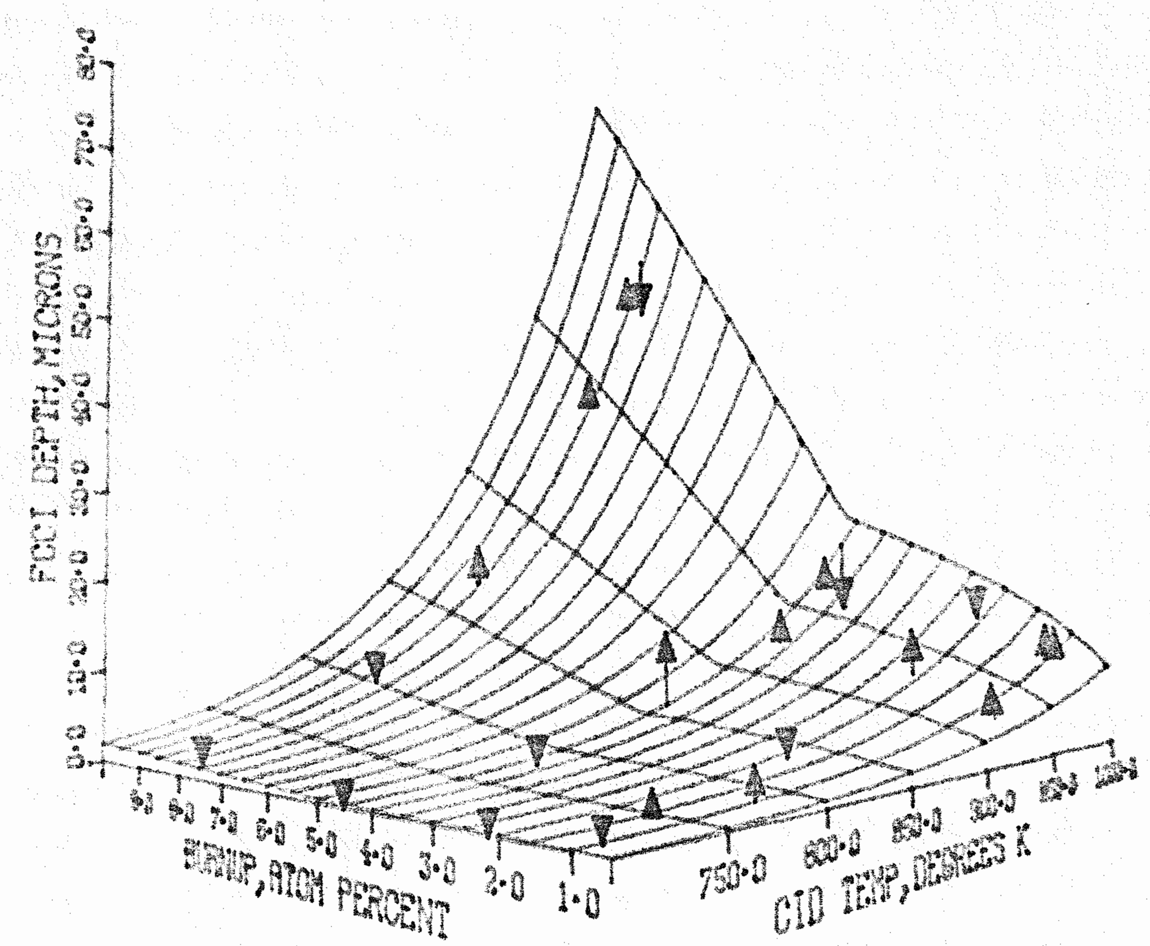

Figure 5. Surface Predicted by the Revised HEDL FCCI Data Correlation. Arrows Point from the Predicted Value to the Observed Value.