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EFFECTS OF LOCAL CESIUM CONCENTRATIONS ON MIXED-OXIDE FUEL BEHAVIOR

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Local peaks in cesium concentrations were found to influence the thermal-mechanical behavior of mixed-oxide fuel pins at high burnup. Cesium is known to move both radially and axially in mixed-oxide fuel pins during irradiation[1,2]. It has been identified as one of the fission products involved in fuel-cladding chemical interaction[3] and appears to be associated with local cladding strain, fragmentation of insulator pellets, and restrictions in the central void.[2] A high burnup fuel pin (PNL-8-10[4]) which showed many of these phenomena during nondestructive examination was selected for destructive examination.

This pin was irradiated in EBR-II at a peak linear power of ∿ 400 W/cm (12 kW/ft) with peak cladding temperatures of ∿ 540°C (1000°F) to a peak burnup of ∿ 8.7 at%. The mixed-oxide pellet fuel (75 wt% UO_2, 25% PuO_2) had an initial oxygen-to-metal ratio of 1.956 and a planar smeared density of 90% of theoretical. The pin was clad with .041 cm (0.016 in) thick, .635 cm (0.250 inch) diameter, solution-annealed type 316 stainless steel. These parameters, except for the solution-annealed cladding are typical of Breeder Reactor fuel but are not prototypic of FFTF. The destructive examinations were structured to provide a direct comparison of behavior in areas of "high" and "low" cesium concentrations within the fuel column and in the upper insulator.

In the region of the upper UO_2 insulator the high cesium concentration and attendant cesium-urania reaction zone are found to be restricted to a narrow region on the circumference of the first insulator pellet (Figure 1). This reaction zone resulted in extensive fragmentation of the insulator pellet ∿ .24 cm (.1 inch) above the fuel-insulator interface. Densification of the insulator pellet fragment adjacent to the fuel column appears to have occurred and may be due to increased temperatures resulting from the increased thermal resistance of the crack. The cesium-urania reaction region appears to consist of two zones, a high density area where the urania insulator pellet has undergone grain boundary attack and dissolution and a lower density zone with a more porous cesium-urania reaction product.

Cesium concentrations in the fuel column have sometimes been found to be associated with areas of local cladding strain and constrictions in the central void.[2] Two sections were removed from the fuel column of PNL-8-10 to examine these phenomena. A longitudinal section (Figure 2) taken at a location of high cesium activity showed, in addition to the expected mechanical constriction of the fuel as had been seen in other pins, an apparent indication of incipient fuel melting in the central void. The axial extent of this region corresponds with that of the cesium concentration peak, and may be the result of a degradation of the fuel-to-cladding heat transfer rate due to the cesium-fuel reaction product. The presence of a two phase, apparently low melting, fuel-fission product material which has formed "bridges" in the central void precludes attributing this solely to the locally high cesium concentration. A transverse section through a region of similar high cesium concentration indicates, that the cesium-fuel reaction product is nonuniformly distributed in the fuel-cladding gap. This circumferential variation appears to have resulted in, or from asymmetric fuel restructuring with the fuel thermal center (central void) being shifted toward the region of higher cesium concentration. This would support the hypothesis that the cesium-fuel reaction products can cause a degradation of the fuel-to-cladding heat transfer rate or that a skewed radial temperature distribution can cause a circumferential variation in cesium migration.

The current observations have described the effects of locally high cesium concentrations on fuel and insulator materials. In addition, evidence was found of decreased fuel-to-cladding heat transfer rates at cesium concentration peaks. Although the presence of a low melting fuel-fission product material in the central void makes positive analysis impossible, it appears that these reactions may be severe enough to result in local fuel melting at moderate pin powers ($\sim$ 400 w/cm) under steady-state conditions. Although these phenomena associated with cesium migration are observed in some high power, high burnup, mixed-oxide fuel irradiated in EBR-II, no cladding breaches have been associated with these cesium concentrations.[5,6] Sufficient understanding of these phenomena is being sought in order to properly assess their expected influence on the behavior of the longer FFTF driver fuel pins.

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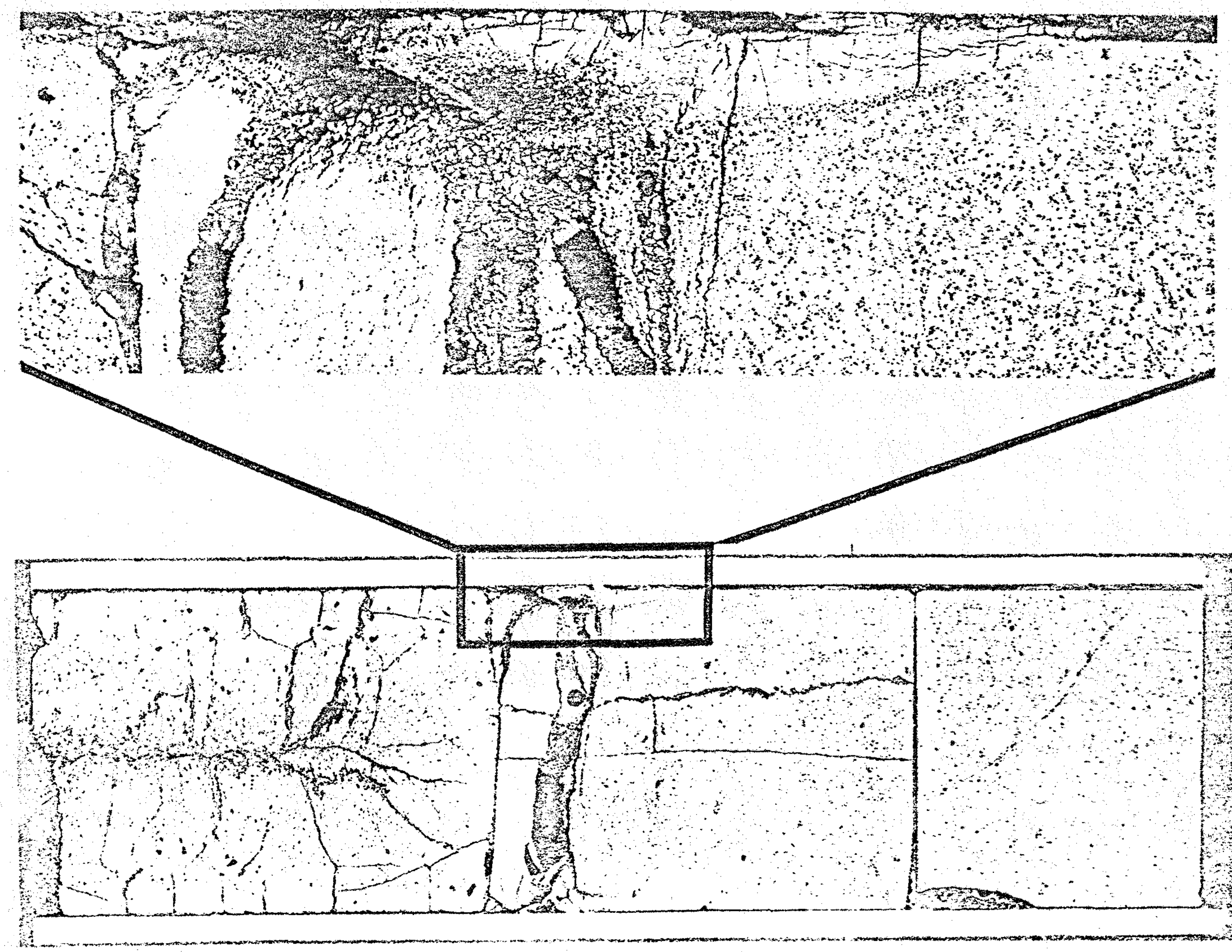
MIXED OXIDE FUEL IRRADIATED IN EBR-II

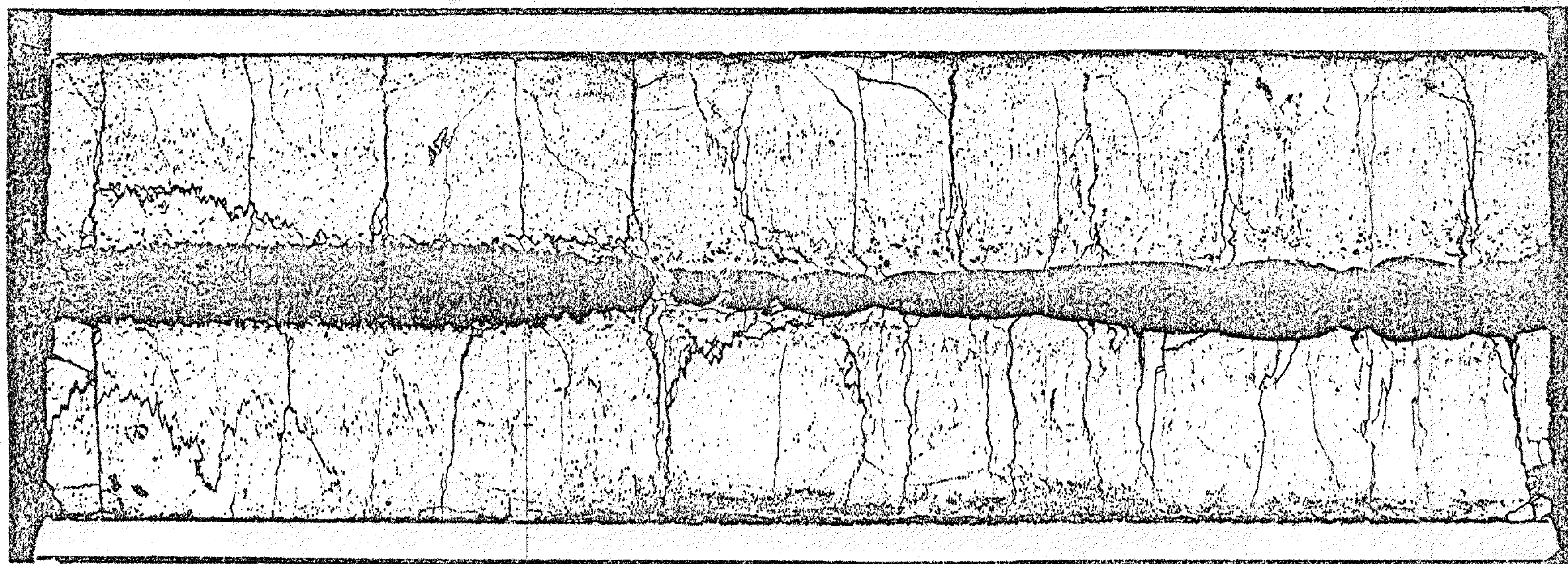


FUEL | INSULATOR

PNL-8-10
Sample CC
As Polished
1μ Diamond and Hyprez

Figure 1. Cesium Reaction in Upper Insulator Pellets. Note Densification of Insulator Pellet Fragment Adjacent to Fuel and Details of Cesium-Insulator Reaction Zones.

MIXED OXIDE FUEL IRRADIATED IN EBR-II



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PNL-8-10
Sample T
As Polished
1μ Diamond and Hyprez

Figure 2. Cesium Reaction in Fuel Column. A Mechanical Constriction in the Central Void Due to the Cesium-Fuel Reaction in the Fuel-Cladding Gap. Central void shows Fuel-Fission Product Bridge and the Scalloped Appearances Typical of Incipient-Fuel-Melting.