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Performance of Metal Fuel Elements in an Operational Overpower Transient*

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Excellent performance of metallic fuel elements for liquid-metal-cooled reactors (LMRs) under steady-state operating conditions has been demonstrated in numerous irradiation tests^{1,2} in the Experimental Breeder Reactor-II (EBR-II) and the Fast Flux Test Facility. At the same time, several transient tests³ have been conducted in the Transient Test Reactor Facility under simulated severe accident conditions. The purpose of this study was to investigate the behavior of metal fuel elements in the operational transient regime bounded by the steady-state and accident conditions.

As part of this study, a slow-ramp operational transient test was conducted in EBR-II. The test, designated OPT-1, contained 19 test elements: fifteen with U-19Pu-xZr ($x = 6, 10, 14$) fuel and HT9 cladding, two with U-10Zr fuel and 316 stainless steel cladding, and two with U-10Zr fuel and HT9 cladding. Before the test, the elements were irradiated to peak burnups of ≈ 5 -13 at.% at peak linear powers of ≈ 35 -50 kW/ft. All elements were sodium bonded and all but three had the reference fuel smear density of 75% of theoretical density (TD); the three exceptions had a more aggressive density of 85% TD. Inclusion of the high-density experimental elements was intended to accentuate the transient effects and to show additional safety margins.

The transient power ramp was $0.1\% \Delta P/P_0/s$, achieved with EBR-II's automatic control rod drive system. When the programmed peak power was reached, the ramp was terminated immediately with a scram. The duration of the transient was 315 s and the attained individual element overpowers (with respect to the prior steady-state linear power) ranging from 28 to 42%. In comparison, the trip-system settings for LMRs are typically ≈ 10 -15% overpower.

No cladding breaches were detected by the reactor instruments during the test. Integrity of the test element cladding was further verified in a leak check of the test assembly while it was being discharged from the reactor. The ability of metal fuel elements to survive a protected operational transient with a margin at least equal to the trip setting was thus demonstrated. It is significant to note that even the aggressive, high-density fuel elements maintained their cladding integrity.

In addition to cladding breaching margins, other potential performance issues with metal fuels under operational transient conditions are transient fuel swelling and accelerated fuel/cladding chemical interaction. The former may cause fuel column elongation and cladding deformation,

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while the latter may result in a thinning of the cladding and, under unfavorable conditions, liquefaction (eutectic formation) of the fuel surface. Accordingly, the posttest evaluation concentrated on the determination of fuel column stability, cladding strain, and morphology of fuel/cladding interface.

The condition of the fuel columns for all 19 test elements was evaluated with neutron radiography and gamma scanning. Comparison of the pre- and posttransient data showed no discernible changes in either fuel column length, fissile density distribution, or condition of the transverse fuel cracks (occasional transverse fuel cracks are normal in irradiated metal fuel columns). In the axial gamma scans, the ^{137}Cs distribution above the fuel region was the only part that showed notable changes. Because fission-product cesium collocates with the sodium bond, this observation indicates that bond sodium moves readily within the element because of (a) expansion or contraction of the fuel and (b) releases of fission gas bubbles into the plenum.

Comparison of the pre- and posttransient cladding diameter profiles indicated there were no transient cladding strains in any elements with the reference 75% theoretical density, regardless of fuel or cladding variables. Only in the aggressive 85% TD fuel elements were there measurable incremental cladding strains. The strain occurred only over the upper half of the fuel column and the magnitude was small, $\approx 0.1\%$ max. The cause of the strain in these elements was apparently fuel/cladding mechanical interaction, whose presence was evident in these high-density elements even after the steady-state irradiation.

A high-burnup (11 at.%) U-19Pu-10Zr/HT9 element with the reference 75% fuel smear density was destructively examined. The results, when compared with sibling examination data, showed no discernible effects of the transient on fission-gas release, fuel microstructure, or condition of the fuel/cladding interface. There were no indications of fuel surface liquefaction or incremental cladding wastage.

The OPT-1 test successfully showed that irradiated metal fuel elements can withstand a protected operational overpower transient. Fuel elements with the reference smear density incurred no discernible degradation of the element condition. Only the experimental high-smear-density elements showed minor effects -- in the form of a small incremental cladding strain. Judged on these positive results, metal fuel elements should continue to perform satisfactorily in an LMR after a protected operational transient.

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