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LINEAR HEAT RATING FOR INCIPIENT FUEL MELTING IN UO_2-PuO_2 FUEL

R. D. Leggett, E. O. Ballard
R. B. Baker, G. R. Horn and D. S. Dutt

Results are presented for an experiment (HEDL-P-19) conducted in EBR-II to determine the effect of the initial, cold, diametral fuel-cladding gap size (3.2 to 10.0 mils) on the linear heat rating to incipient fuel melting, Q'_m, in mixed oxide (75% UO_2 - 25% PuO_2) fuel pins under very rapid LMFBR startup conditions. Eight 0.250 in. OD X 0.016 in. wall and eight 0.230 in. OD X 0.015 in. wall, He bonded pins clad with type 316 stainless steel (20% CW) were irradiated in an encapsulated pin subassembly in Row 2 of the EBR-II. Each fuel pellet was measured to ± 0.2 mil, weighed and its position in the 13 1/2 in. long fuel column recorded. Most of the pellets were centerless ground to a predetermined size. Four pins - two of each size - contained pellets that were sintered to size. The fuel density and O/M of the 0.230 in. OD pins were 90.75% TD and 1.96, respectively. The 0.250 in. OD pins contained fuel with a density of 92.40% and an O/M of 1.97.

This test was conducted to verify that no fuel melting will occur in the FTR at 115% of the 400 MW rating. EBR-II was raised to 54.5 MW in seven hours, held for one hour, raised rapidly to 62.5 MW (to simulate 15% overpower), held for 10 minutes and then scrammed to "quench-in" the fuel structure. Peak linear power generation was 16.9 to 17.6 KW/ft for the 0.230 in. OD pins and 20.0 to 21.4 KW/ft for the 0.250 in. OD pins.

Fuel melting occurred in all of the 0.250 in. OD pins with melt radii in peak power positions varying from 30 to 50 percent of the fuel radius. The 0.230 in. OD pins with initial gap sizes 7.2 mils and larger exhibited fuel melting at peak power positions to about 30% of the radius; pins with gap sizes 5.7 mils and smaller showed no fuel melting. The axial extents of melting toward the bottom and top of the pins were determined and Q'_m's at these positions were evaluated. Figure 1 shows the relationship between Q'_m and gap size after normalizing to a cladding ID temperature of 1060°F, 0.230 in. diameter pins and to a fuel density of 90.75% TD. Q'_m remains essentially constant (19.5 KW/ft) for initial gap sizes below 5 mils suggesting that there is positive fuel-cladding contact (at Q_m') for starting gaps of less than 5 mils. No effect of pellet surface condition (sintered or ground) was observed.

The data were fitted by regression techniques with three types of relationships, cubic, arc-tan and hyperbolic. Any of the three relationships agree well with observations. We believe that for gap sizes larger than 5 mils, the hyperbolic fit best describes the data and physical situation.

These results should permit the direct use of linear heat rating to incipient fuel melting for the thermal design of LMFBR fuel.

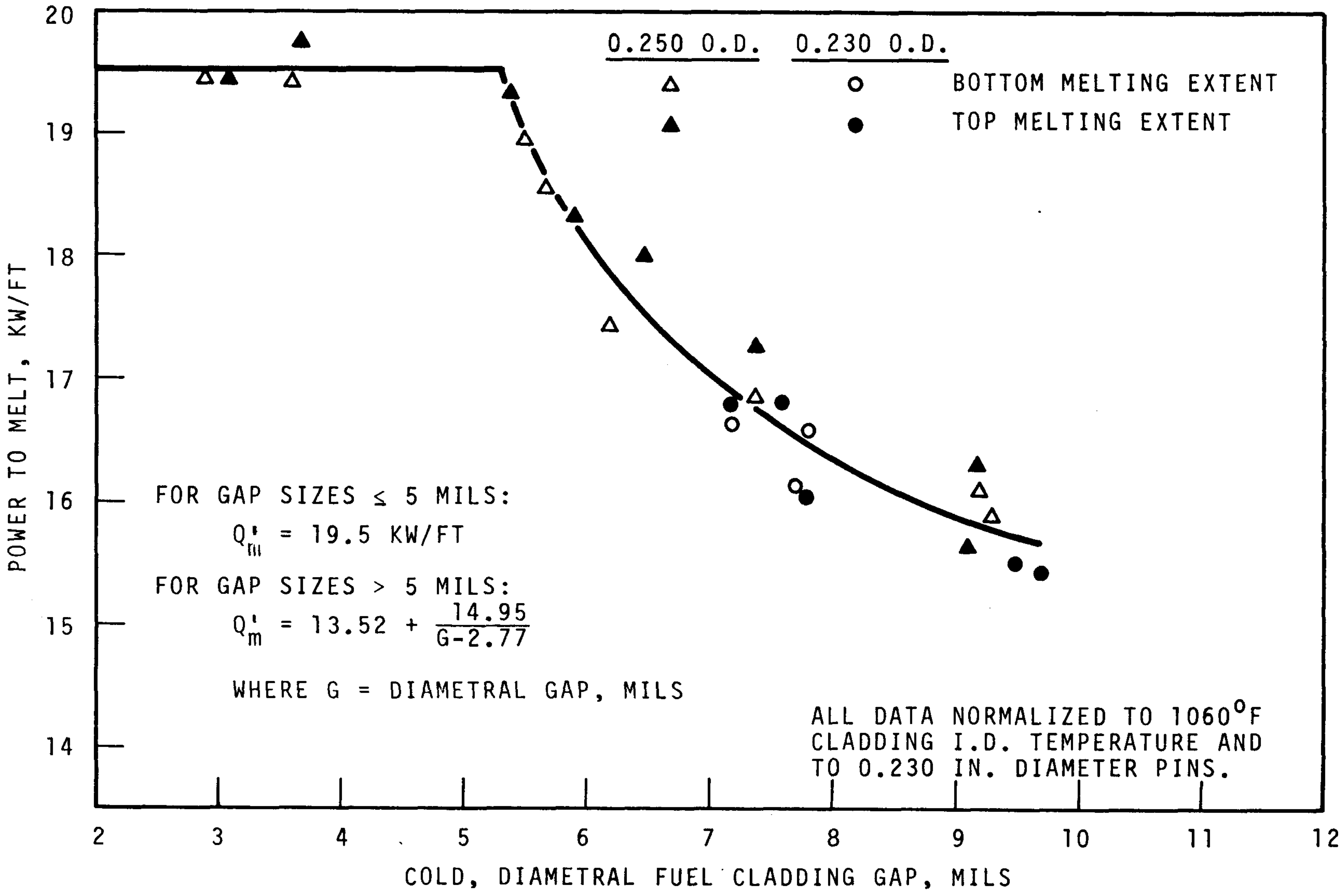

FIGURE INFLUENCE OF INITIAL FUEL-CLADDING GAP SIZE ON THE LINEAR HEAT RATING FOR INCIPIENT FUEL MELTING IN MIXED OXIDE FUEL PINS

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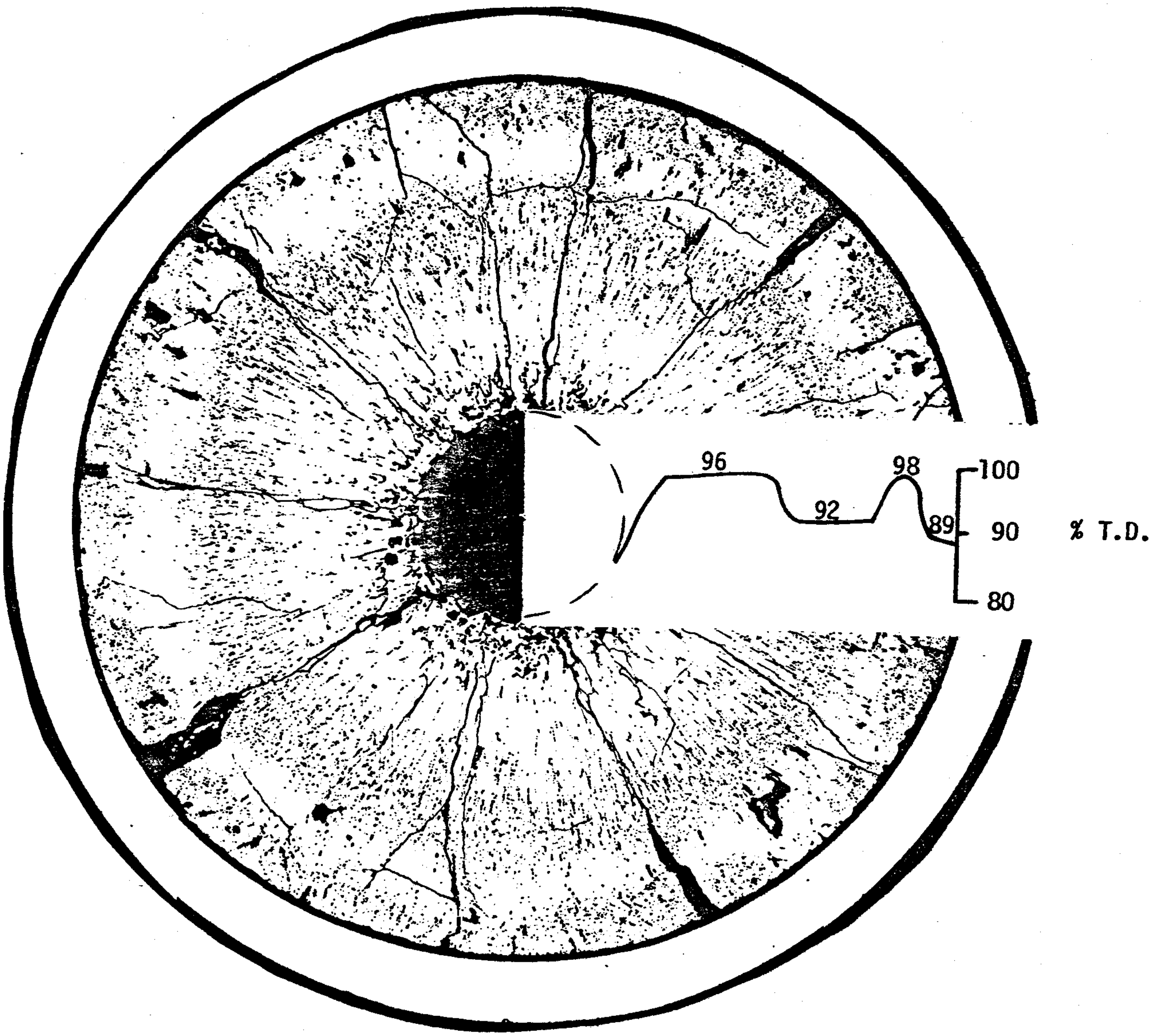

Fig. 1b. Microstructure and porosity distribution profile at the peak flux region of fuel rod F9C-31.

is an increased amount of porosity near the central void, probably because the pores and gas bubbles migrate more slowly in this region where the temperature gradient is much lower.

The results from these and other fuel rods suggest that the three-region model in its usual form[1] does not adequately describe the fuel microstructure and porosity distribution in typical mixed-oxide fuel rods. The existence of lower density outer and inner regions, and of higher density (~97% TD) and lower density (~91% TD) regions of equiaxed grain growth, are clearly established. A multiregion model would appear to provide a more accurate microstructural description. The number and type of regions should be chosen for the particular conditions being analyzed.

Further characterization of fuel microstructures, as a function of power and burnup, and an analysis of the thermal and mechanical implications of this model to overall fuel rod behavior are in progress.

5. Linear Heat Rating for Incipient Fuel Melting in UO_2-PuO_2 Fuel, *R. D. Leggett, E. O. Ballard, R. B. Baker, G. R. Horn, D. S. Dutt (West-Hanford)*

Results are presented for an experiment (HEDL-P-19) conducted in EBR-II to determine the effect of the initial, cold, diametral fuel-cladding gap size (3.2 to 10.0 mil) on the linear heat rating to incipient fuel melting, Q'_m, in mixed-oxide (75% UO_2 - 25% PuO_2) fuel pins under very rapid LMFBR startup conditions. Eight 0.250-in.-o.d. × 0.016-in.-wall and eight 0.230-in.-o.d. × 0.015-in.-wall He-bonded pins clad with Type 316 stainless steel (20% CW) were irradiated in an encapsulated pin subassembly

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1. V. Z. JANKUS and R. W. WEEKS, "LIFE-II—A Computer Analysis of Fast-Reactor Fuel-Element Behavior as a Function of Reactor Operating History," *Nucl. Eng. Design*, 18, 83 (1972).

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in Row 2 of the EBR-II. Each fuel pellet was measured to ±0.2 mil, weighed, and its position in the 13½-in.-long fuel column recorded. Most of the pellets were centerless ground to a predetermined size. Four pins—two of each size—contained pellets that were sintered to size. The fuel density and O/M of the 0.230-in.-o.d. pins were 90.75% TD and 1.96, respectively. The 0.250-in.-o.d. pins contained fuel with a density of 92.40% and an O/M of 1.97.

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Fuel melting occurred in all of the 0.250-in.-o.d. pins with melt radii in peak power positions varying from 30 to 50% of the fuel radius. The 0.230-in.-o.d. pins with initial gap sizes 7.2 mil and larger exhibited fuel melting at peak power positions to about 30% of the radius; pins with gap sizes 5.7 mil and smaller showed no fuel melting. The axial extents of melting toward the bottom and top of the pins were determined and Q'_m's at these positions were evaluated. Figure 1 shows the relationship between Q'_m and gap size after normalizing to a cladding i.d. temperature of 1060°F, 0.230-in.-diam pins and to a fuel density of 90.75% TD. Q'_m remains essentially constant (19.5 kW/ft) for initial gap sizes below 5 mil suggesting there is positive fuel-cladding contact (at Q'_m) for starting gaps of <5 mil. No effect of pellet surface condition (sintered or ground) was observed.

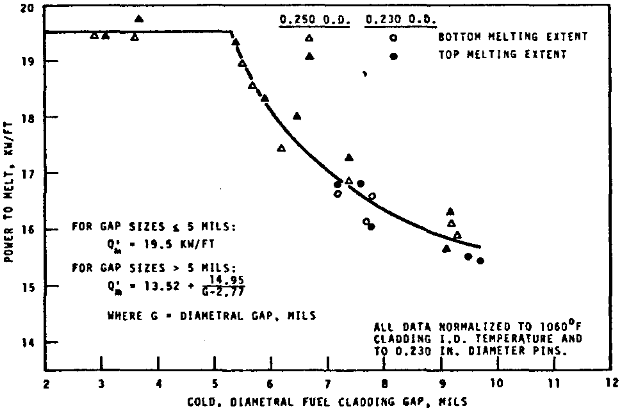

Fig. 1. Influence of initial fuel-cladding gap size on the linear heat rating for incipient fuel melting in mixed-oxide fuel pins.

The data were fitted by regression techniques with three types of relationships, cubic, arc-tan, and hyperbolic. Any of the three relationships agree well with observations. We believe that for gap sizes larger than 5 mil, the hyperbolic fit best describes the data and physical situation.

These results should permit the direct use of linear heat rating to incipient fuel melting for the thermal design of LMFBR fuel.

6. Analysis of Uranium and Plutonium Migration in Irradiated Mixed-Oxide Fuels,*

R. O. Meyer (ANL)

Considerable evidence has been reported[1-3] that vapor transport is responsible for the radial redistribution of uranium and plutonium that occurs in mixed-oxide fuels. During the vapor-transport process, various molecular species move through pores or cracks in the radial temperature gradient, and vapor pressures of these species vary with composition of the solid phase. Since, in general, the ratio of Pu/U in the vapor is different from the solid, radial composition changes are expected to occur.[4]

The rate of migration of the actinide molecules is limited by diffusion through the fission- or cover-gas atmosphere in pores and cracks, and a general phenomenological equation for the flux can be written as

$$J_i = -D_i \nabla c_i - \frac{c_i D_i Q_i^*}{kT^2} \nabla T \quad , \tag{1}$$

where i identifies the diffusing species, D is the diffusion coefficient, c is the concentration, and Q^* is the heat of transport.

If the terms on the right side of Eq. (1) are specialized to describe vapor-phase diffusion and to include the effect of allowable vapor path, a continuity equation can be obtained with the result

$$\frac{\partial c_i'}{\partial t} = -\nabla \cdot J_i \quad , \tag{2}$$

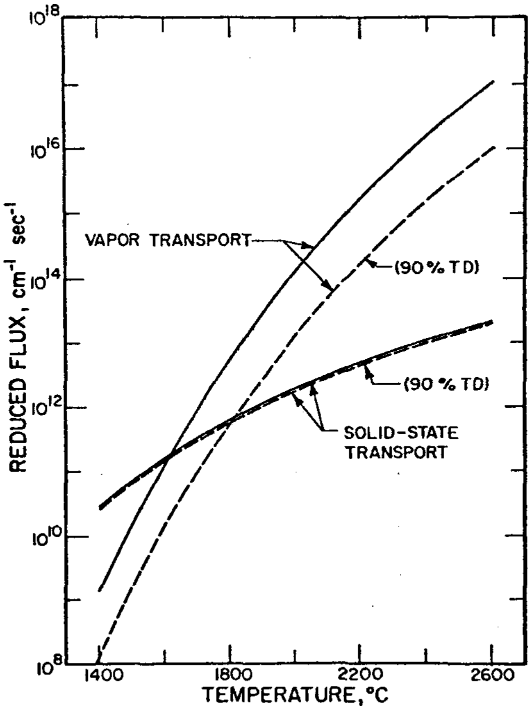

Fig. 1. Relative vapor-phase and solid-state transport fluxes assessed by comparing the *Concentration x Diffusion Coefficient* for the vapor-phase and solid-state mechanisms. Dashed lines show the effect of the available diffusion paths for 90% dense fuel.

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*Sponsor: D. R. O'Boyle