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INFLUENCE OF BURNUP ON HEAT-RATING-TO-MELTING FOR UO_2-PuO_2 FUEL

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INFLUENCE OF BURNUP ON HEAT-RATING-TO-MELTING FOR UO_2-PuO_2 FUEL

R. D. Leggett, R. B. Baker, D. S. Dutt, and S. A. Chastain

This paper summarizes the results of an irradiation test (HEDL-P-20) conducted to evaluate the influence of burnup on the linear heat rating to incipient fuel melting, Q'_m, for 75% UO_2-25% PuO_2 fuel. The very short term irradiation was conducted in Row 1 of the EBR-II to simulate 115% of FTR full power using an irradiation history similar to that used for the HEDL-P-19 test.(1) Prototypic FTR fuel pins (0.230 in. O.D., type 316, 20% CW stainless steel) were included that were pre-irradiated to 0% BU, 0.3% BU, 0.7% BU, and 1% BU at a simulated 100% FTR power. One 0.250 in. O.D. pin (PNL-2-5) clad with type 304 stainless steel was also included that was preirradiated to ∿ 7% BU. Fuel-cladding diametral gap sizes were varied from 3.5 to 7.5 mils (the FTR range) by centerless grinding the pellets to different diameters, helium and 80 He + 20 Xe fill gases were used, and as-built fuel microstructure was also a test variable. The preirradiation of the 0.230 in. O.D. pins was done in Row 3 of the EBR-II for one reactor cycle and one-half reactor cycle, respectively.

Table I provides a summary of the results of the test. All seven of the 0.230 in. O.D., "fresh", pins had extensive fuel melting, but fuel melting was indicated in only one of the preirradiated pins. This pin was fabricated with a 3.5 mil gap and preirradiated to ∿ 0.3% BU. Similar pins preirradiated to 0.7% BU and 1% BU showed no melting. The high burnup PNL-2-5 pin (0.250 in. O.D.) also had fuel melting, but this is believed to be due to the 20% higher heat generation rate in this larger pin, rather than to a reduction in thermal performance at very high burnup.

TABLE I

RESULTS OF THE HEDL-P-20
HEAT-RATING-TO-MELTING TEST

Pre-Irradiation Burnup, At.%	Total Pins	Pure He Pin Fill Gas 3.5*	5.5*	7.5*	Mixed*	Other*	20% Xe-80% He Pin Fill Gas 7.5*	Comments
0	7	--	1	2**	1	2***	1	All pins had fuel melting
0.3	5	1	1	1	1	--	1	Only the 3.5 mil gap pin had fuel melting
0.7	3	1	1	1	--	--	--	No fuel melting
1	3	1	1	1	--	--	--	No fuel melting
7	1	--	--	--	--	1	--	PNL-2-5 (0.250 in. O.D., 6 mil gap) had fuel melting

*As-built, fuel-cladding, diametral, gap size--mils

**One pin contained fuel with spherical porosity

***P-19 spare pins, 7.2 and 8 mil gap

The marked improvement in Q'_m with burnup is illustrated by Figure 1. The arrows above the neutron radiographs show the axial extents of fuel melting, and the curves depict the axial power profiles for the P-20 and P-19 tests. The flatter profile for P-20 was caused by changing the reflector in EBR-II from uranium to stainless steel and by employing a special core loading for this test.[2]

The HEDL-P-20 test has shown that, by the time 0.3% BU is reached, the heat rating to melting, Q'_m, is at least 19 kW ft in a prototypic FTR fuel pin, which is an improvement of about 20% relative to zero burnup fuel.[1] This improvement comes about by the very rapid closure of the fuel-cladding gap[3] which eliminates the dependence of Q'_m on as-built gap size. For "fresh" fuel,[1] increasing the size of the diametral gap beyond 5 mils results in a sharp reduction in Q'_m. Since viable fabrication processes require gap sizes larger than 5 mils, it has been necessary to allow for this reduction in Q'_m in the thermal design of fast reactor fuel pins. Now, after a short incubation period (< 0.3% BU), not only can thermal ratings be increased by 20% but the restrictive (and expensive) limits on the maximum fabricated gap size can be relaxed.

References

1. R. D. Leggett, E. O. Ballard, R. B. Baker, G. R. Horn, and D. S. Dutt, "Linear Heat Rating for Incipient Fuel Melting in UO_2-PuO_2 Fuel," ANS Trans., V15, No. 2, November, 1972, p. 752, Washington, D. C.

2. L. B. Miller, R. E. Jarka, J. L. Gillette, and F. S. Kirn, "Increasing the Central Power in EBR-II," ANS Trans., V17, November, 1973, p. 180, San Francisco, California.

3. D. S. Dutt, R. B. Baker, and S. A. Chastain, "Modeling of the Fuel Cladding Postirradiation Gap in Mixed-Oxide Fuel Pins," ANS Trans., V17, November, 1973, p. 175, San Francisco, California.

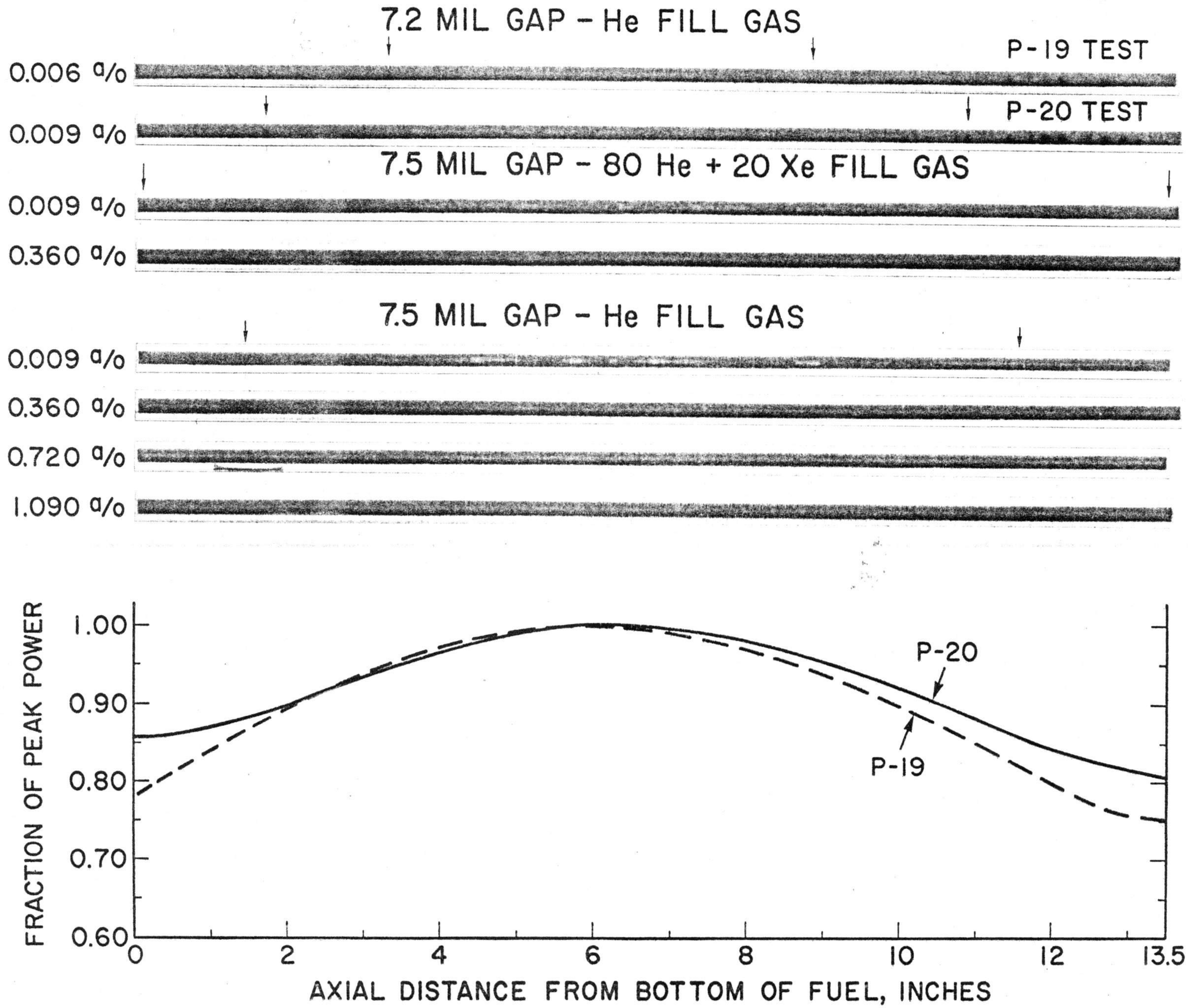
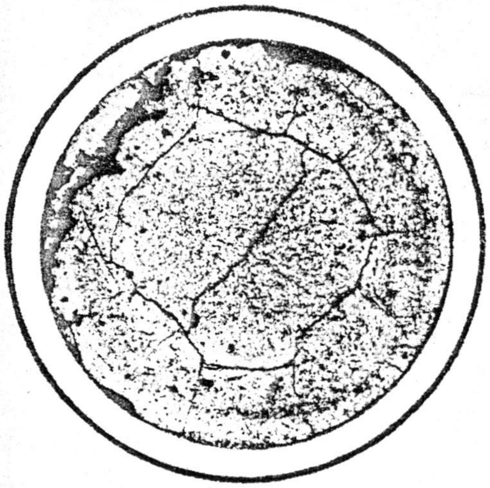


FIGURE 1
Increased Power Capability with Burnup
for Mixed-Oxide Fuel



a. Rod F9D-10. Coprecipitated UO_2-PuO_2 fuel irradiated to a burnup of 8.0 at.% at a peak linear power of 8.9 kW/ft.

b. Rod F9D-15. Physically mixed UO_2-PuO_2 fuel irradiated to a burnup of 7.9 at.% at a peak linear power of 8.7 kW/ft.

Fig. 1. Microstructural comparison of coprecipitated and physically mixed UO_2-PuO_2 fuel at 8 at.% burnup.

TABLE I

Fabrication Parameters and Irradiation Conditions for Fuel Rods F9D-10 and F9D-15

FABRICATION PARAMETERS	Rod F9D-10	Rod F9D-15
Fuel rod diameter (in.)	0.25	0.25
Cladding thickness (in.)	0.015	0.015
Cladding alloy	Type 316 SS	Type 316 SS
Fuel composition	UO_2-25PuO_2	UO_2-25PuO_2
Fuel fabricaton process	Coprecipitated	Physically Mixed
Fuel form	Solid pellets	Solid pellets
Fuel O/M	1.98	1.98
Fuel pellet density (%TD)	91.9	91.5
Smeared density (%TD)	88.0	86.3
Fuel/cladding diametral gap (in. x 10^{-3})	4.0-7.7	5.1-7.9
OPERATING CONDITIONS[a]		
Peak linear power (kW/ft)	8.9	8.7
Peak burnup (at.%)	8.0	7.9
Peak fast fluence, E>0.1 MeV(10^{23} n/cm^2)	0.48	0.47
Peak cladding temperature (°F)	905	888

[a]Based on fission rates given in "Guide for Irradiation Experiments in EBR-II" modified by a factor of 0.91 as currently recommended by the EBR-II Project.

These initial data and observations indicate that coprecipitated and physically mixed $(U,Pu)O_2$ fuel exhibit similar behavior at nominal operating conditions planned for near-term U.S. reactors.

4. Influence of Burnup on Heat-Rating-to-Melting for UO_2-PuO_2 Fuel, *R. D. Leggett, R. B. Baker, D. S. Dutt, S. A. Chastain (Westinghouse-Hanford)*

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Preirradiation Burnup (at.%)	Total Pins	Pure He Pin Fill Gas					20% Xe-80% He Pin Fill Gas	Comments
		3.5[a]	5.5[a]	7.5[a]	Mixed[a]	Other[a]	7.5[a]	
0	7	-	1	2[b]	1	2[c]	1	All pins had fuel melting
0.3	5	1	1	1	1	-	1	Only the 3.5-mil-gap pin had fuel melting
0.7	3	1	1	1	-	-	-	No fuel melting
1	3	1	1	1	-	-	-	No fuel melting
7	1	-	-	-	-	1	-	PNL-2-5 (0.250-in. o.d., 6-mil gap) had fuel melting

[a]As-built, fuel/cladding diametral gap size (mil).

[b]One pin contained fuel with spherical porosity.

[c]P-19 spare pins, 7.2- and 8-mil gap.

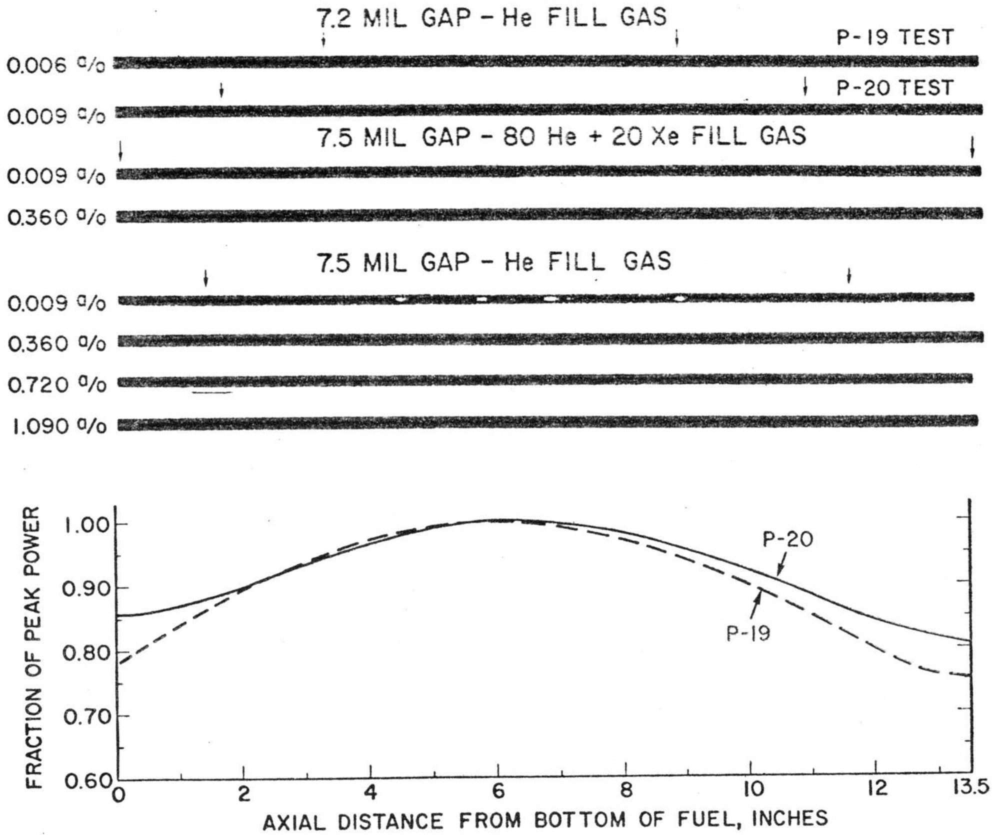

Fig. 1. Increased power capability with burnup for mixed-oxide fuel.

of Q'_m on as-built gap size. For "fresh" fuel,[1] increasing the size of the diametral gap beyond 5 mil results in a sharp reduction in Q'_m. Since viable fabrication processes require gap sizes larger than 5 mil, it has been necessary to allow for this reduction in Q'_m in the thermal design of fast reactor fuel pins. Now, after a short incubation period (<0.3% BU), not only can thermal ratings be increased by 20% but the restrictive (and expensive) limits on the maximum fabricated gap size can be relaxed.

1. R. D. LEGGETT, E. O. BALLARD, R. B. BAKER, G. R. HORN, and D. S. DUTT, "Linear Heat Rating for Incipient Fuel Melting in UO_2-PuO_2 Fuel," *Trans. Am. Nucl. Soc.*, 15, 752 (1972).

2. L. B. MILLER, R. E. JARKA, J. L. GILLETTE, and F. S. KIRN, "Increasing the Central Power in EBR-II," *Trans. Am. Nucl. Soc.*, 17, 180 (1973).

3. D. S. DUTT, R. B. BAKER, and S. A. CHASTAIN, "Modeling of the Fuel Cladding Postirradiation Gap in Mixed-Oxide Fuel Pins," *Trans. Am. Nucl. Soc.*, 17, 175 (1973).