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METALLIC FUEL DEVELOPMENT

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METALLIC FUEL DEVELOPMENT*

by

L. C. Walters

Metallic fuels are capable of achieving high burnup as a result of design modifications instituted in the late 1960's. The design modifications are described by reference to Fig. 1. The gap between the fuel slug and the cladding is fixed such that by the time the fuel swells to the cladding the fission gas bubbles interconnect and release the fission gas to an appropriately sized plenum volume. Interconnected porosity thus provides room for the fuel to deform from further swelling rather than stress the cladding. In addition, the interconnected porosity allows the fuel pin to be tolerant to transient events because as stresses are generated during a transient event the fuel flows rather than applying significant stress to the cladding. Figure 1 also indicates the typical range of design parameters.

Until 1969 a number of metallic fuel alloys were under development in the United States. At that time the metallic fuel development program in the United States was discontinued in favor of ceramic fuels. However, development had proceeded to the point where it was clear that the zirconium addition to uranium-plutonium fuel would yield a ternary fuel with an adequately high solidus temperature and good compatibility with austenitic stainless steel cladding. Furthermore, several U-Pu-Zr fuel pins had achieved about 6 at.% bu by the late 1960's, without failure, and thus the prospect for high burnup was promising.

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Throughout the 1970's, EBR-II continued to operate with U-Fs* driver with the irradiation of more than 100,000 pins to burnups of 18.5 at.%. Included in the EBR-II operation was the whole core transient program conducted in the early 1980's. This experience base with U-Fs fuel provided the evidence that metallic fuel was capable of reliably achieving high burnup and was robust under transient conditions. Figure 2 shows the burnup limit history for EBR-II fuel, where the MK-IA fuel is high smear density fuel capable of only low burnup performance, while the MK-II and MK-IIA fuel represents the lower smear density (75%) fuel. Figure 3 shows the number of fuel elements irradiated as a function of burnup.

In 1984, renewed attention was directed toward metallic fuels in the United States. An aggressive fuel development program was implemented to determine the potential of ternary metallic fuel. A facility was constructed to fabricate the fuel and by early 1985 several ternary fuel experiments were under irradiation in EBR-II and later tests were initiated in FFTF. In parallel with the irradiation testing a broad based program was initiated to provide the technology base to understand performance through property evaluation and modeling. Figure 4 shows the tests under irradiation, along with the materials included in the tests, and the burnups achieved. To date, no in-reactor, end-of-life failures have occurred.

Figure 5 shows a typical micrograph of a U-19 wt.% Pu-10 wt.% Zr fuel pin clad in D-9 irradiated to 10 at.% burnup. The cladding is in excellent condition with little evidence of cladding attack. General characteristics, typical of this micrograph, are that the porosity is nonuniformly distributed and that zirconium tends to migrate from the

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* Fissium is an equilibrium concentration of fission-product elements left by the pyrometallurgical reprocessing cycle demonstrated at EBR-II. It consists of 2.4 wt.% molybdenum, 1.9 wt.% ruthenium, 0.3 wt.% rhodium, 0.2 wt.% palladium, 0.1 wt.% zirconium, and 0.01 wt.% niobium.

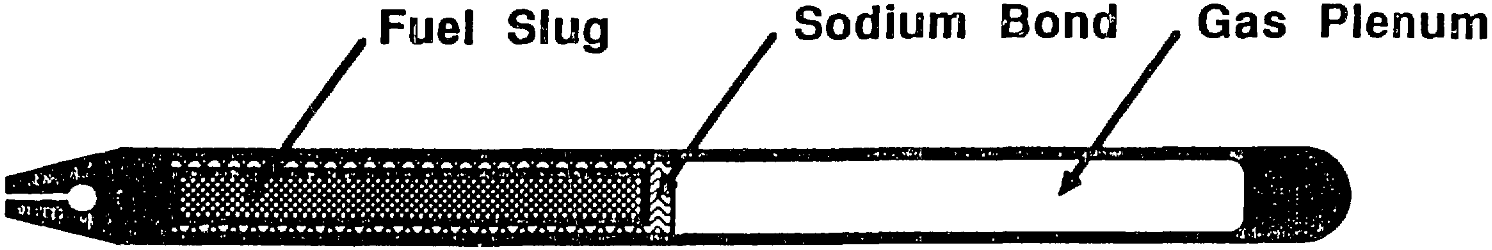
center of the pin toward the periphery. The extent of zirconium migration allows the solidus temperature in the pin center to remain high enough for adequate design margin.

Figure 6 shows the fission gas release as a function of burnup for several alloy compositions. It can be concluded that fission gas release is generally insensitive to alloy composition, where this fission gas release phenomenon is an essential characteristic for high burnup.

In summary, the results from the late 1960's, the experience gained through operation of EBR-II with metallic fuel, and most importantly the recent high burnup information obtained on the ternary U-Pu-Zr alloy show that metallic fuel is a strong candidate for future application to liquid metal fast reactors.

Figure 1.

Metallic Fuel Element



Plenum-to-Fuel RATIO: 1.0 to 1.5

Cladding DIAMETER: 5.8 to 7.4 mm

Wall THICKNESS: 0.4 to 0.5 mm

Fuel SMEAR DENSITY: 75%

LINEAR HEAT RATING: 50 to 60 Kw/m

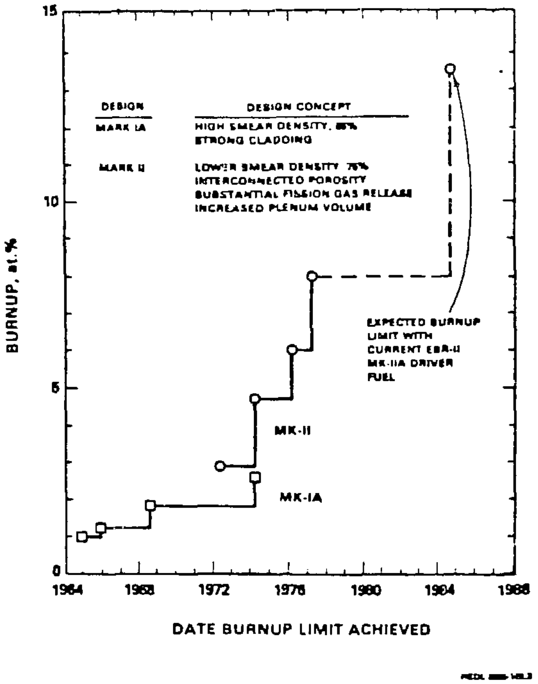


FIGURE 2. Burnup Limit History for EBR-II Driver Fuel.

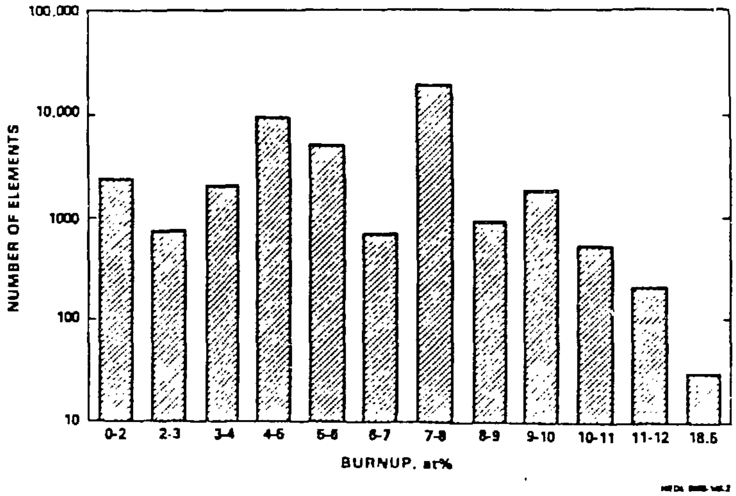


FIGURE 3. Histogram of MK-II Driver Fuel Utilization in EBR-II.

Figure 4.

BURNUP STATUS OF IFR FUEL TESTS (7-8-87)

TEST ID	FUEL U-*x*PU-10ZR *x*=wt.%	CLAD TYPE	CURRENT BURNUP PEAK at. %
X419	0,8,19	D9	10.0
X420	0,8,19	D9	10.4
X421	0,8,19	D9 /316 SS	11.0
X435	0	D9	1.0
IFR-1	0,19	D9	4.6
X425	0,8,19	HT9	6.2
X429	0,8,19	HT9/316 SS	3.4
X430	0,19	HT9	.6
X423	0,3,8,19,22,26	316 SS	4.3
X428	8,19	316 SS	2.2
XY-24	19	316 SS	4.2
XY-27	8	316 SS	3.2

Figure 5.

U-19Pu-10Zr FUEL, L/L_0=.49, 10 at.% BU

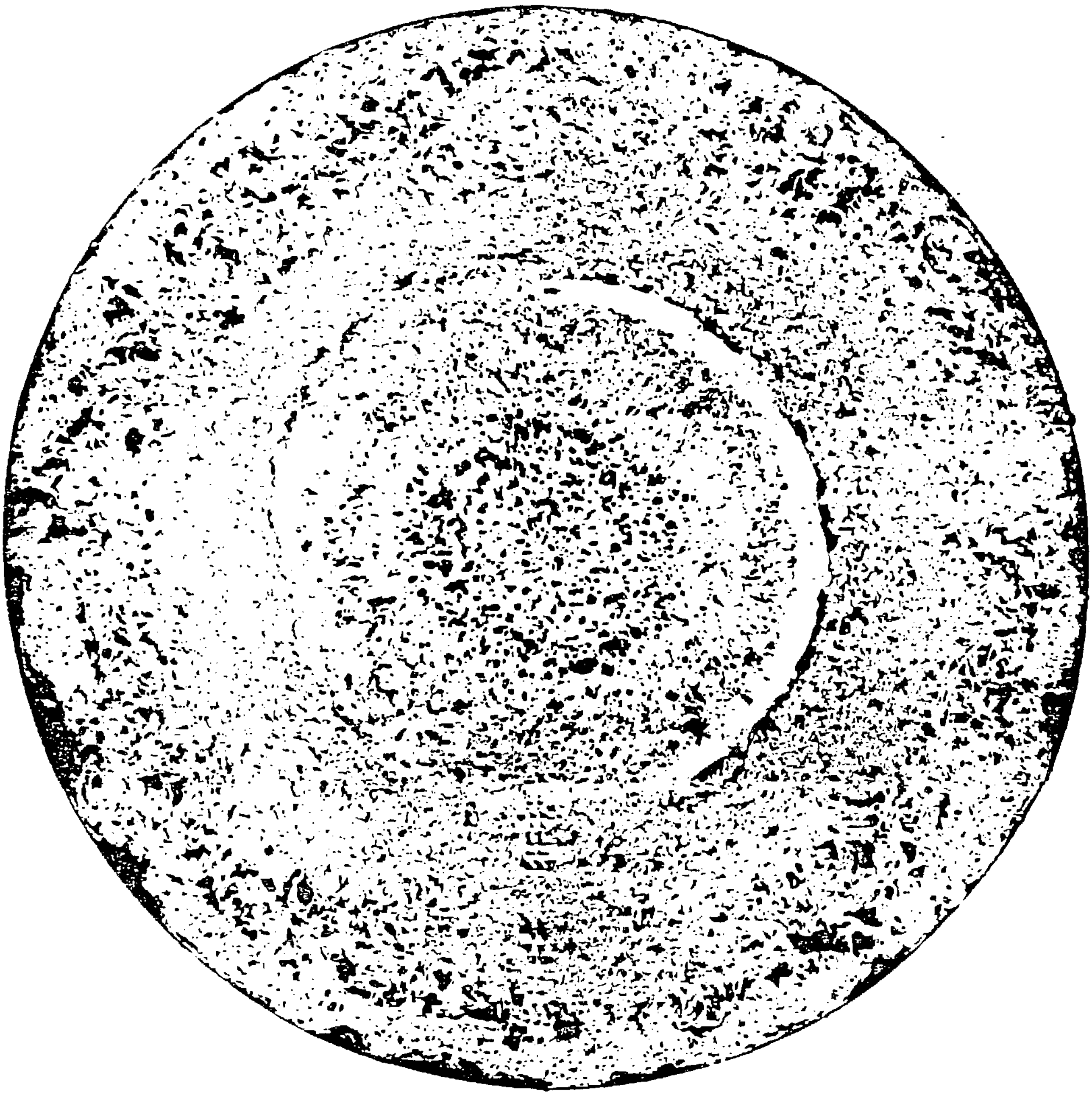


Figure 6.

FISSION GAS RELEASE IN .230 IN. DIAMETER ELEMENTS