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FUELS AND MATERIALS DEVELOPMENT PROGRAM

QUARTERLY PROGRESS REPORT

FOR PERIOD ENDING JUNE 30, 1970

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3. ~~/~~ EFFECT OF POWER CYCLING ON LMFBR FUEL-CLADDING BEHAVIOR

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This program investigates the effects of power cycling and transients on fuel behavior and the mechanical interaction of fuel and cladding for a liquid-metal-cooled fast breeder reactor (LMFBR), first for mixed oxide fuel and stainless steel cladding and later for other fuels and claddings. The initial objectives of this study are to compare the mechanical interactions of fuel (flat-ended pellets, dished pellets, and particulate fuel) and cladding during thermal-cycling conditions typical of those to be expected in an LMFBR. The mechanical interactions between (U,Pu)O₂ fuel and stainless steel cladding will affect both the safety and economic characteristics of LMFBR's. Axial separations in the fuel column tend to make the reactor power coefficients more positive. In addition, concentrations of stress in the cladding due to fuel "hourglassing," cracking, and ratchetting combine with power cycling and reduced cladding ductilities to decrease the lifetime of the fuel elements. These mechanical interactions are quite important in defining allowable schemes of fuel management and reactor operating conditions and thus have a significant effect on the reactor economy.

Power Cycling Irradiation Tests

C. M. Cox

The intent of our program is to measure in-reactor the axial extension of the fuel column and cladding and the fuel pin internal gas pressure during operation under carefully controlled conditions, which include programmed power cycles and an occasional overpower cycle. The irradiation capsules will be designed so that the fuel pin operates at LMFBR prototypic power and temperature conditions. The irradiation tests will last 1 to 2 years and will give burnup levels of 5 to 9%.

Power Cycling of Mixed Oxide Fuel with Stainless Steel Cladding to Moderate and High Burnup (R. B. Fitts, R. L. Senn,² J. G. Morgan,¹ J. D. Jenkins²)

As described previously,³ the first two capsules for investigation of power cycling will be designed as prototype Fast-Flux Test Facility (FFTF) Reactor fuel pins and will operate in the poolside facility of the Oak Ridge Research Reactor (ORR).

The design effort on the first capsule (MINT-1) is progressing satisfactorily. The capsule is scheduled to be inserted into the reactor in September or November 1970. The conceptual design is illustrated in Fig. 3.1.

The fuel pin is to be fabricated from 9.6 in. of mechanically blended ($U_{0.75}, Pu_{0.25}$) $O_{1.97}$ solid pellets. The pellets are 0.1943 ± 0.0002 in. in diameter by 0.200 in. long, have a density of $89.4 \pm 0.5\%$ of theoretical, and have dished ends. The cladding is 20% cold-worked type 316 stainless steel, 0.230 in. in outside diameter and 0.015 in. in wall thickness. The resulting smear density of the fuel will be 84.4% of theoretical. The fuel pin will be immersed in NaK, which is to be used as a heat-transfer medium in the capsule.

There are 12 thermocouples in this capsule: 6 monitor the temperature gradient along the push rod and length-measuring system, and 6 are arranged in opposed pairs along the fuel pin. They are to be brazed to the inside of the primary containment in the NaK that surrounds the fuel pin to minimize the possibility of mechanical interaction between the thermocouples and fuel pin. Development work on this brazing operation is under way.

A pressure transducer was selected for measuring the internal pressure of the fuel pin during the test. It monitors the deflection of a diaphragm with a variable-permeance transducer. A conceptual design is shown in Fig. 3.2. An analysis of the expected buildup of pressure from fission gas within the fuel pin indicates that by the end of a 10% burnup test about 56 cm^3 of fission gases (45% of that generated) will have been released from the fuel column, and the internal gas pressure during operation will be about 20 atm.

Fig. 3.1. Capsule for Studies of Mechanical Interaction of Fuel and Cladding.

Fig. 3.2. Proposed Pressure Transducer.

The system for measuring changes in length, which will detect and monitor mechanical interactions of fuel and cladding, is based upon two variable-permeance devices similar to linearly variable differential transformers. These record the position of two magnetic cores in a push rod that rests on top of the fuel stack. One of the variable-permeance devices is attached to an extension of the fuel cladding and measures the relative change in length between fuel and cladding (differential transducer). The other is attached to the outer containment and measures the absolute change in the length of the fuel column (fuel-length transducer). Thus, we can monitor the growth of both fuel and cladding. A system for calibrating and zeroing the measurement system during testing is being designed to fit in the top of the cladding extension. The main approach now being considered employs an electromagnet to raise the push rod and thus the magnetic cores to two known positions to provide two points on the calibration curve of each variable-permeance device and permit the detection and correction of any calibration changes that might occur during the approximately 1 1/2-year duration of the test.

The expected movement of transducer bodies and cores during irradiation was analyzed to determine the desired location of these items in the capsule. In this analysis, the hardware components not associated with the fuel were assumed to operate at approximately 170°C based upon

temperatures measured in the extensometer capsules⁴ for the Medium Power Reactor Experiment.

The design analysis is not sensitive to this assumption since 75% or more of the location changes are associated with the thermal expansion of the fuel⁵ and the cladding⁶ around it. The transducer readings calculated for the instrument that monitors the change in fuel length and for the one that monitors the length differential of the fuel and cladding are shown in Figs. 3.3 and 3.4. These calculated readings are based on the assumption that the capsules are assembled in such a way that the transducers and their cores are centered with respect to each other. As is apparent from these plots, the readings to be obtained are quite sensitive to, and thus will measure, the temperature (T_p) at which plastic deformation of the fuel due to internal and external stresses on the fuel eliminate the effects of thermal expansion. The curves were constructed using the simplified assumption that as soon as T_p is reached, there will be no more thermal expansion of the fuel. Thus, the transducer readings are a function of the temperature of the center of the fuel until that temperature reaches T_p . Creep deformation of the fuel and mechanical interaction of the fuel and cladding will affect these curves in the operating equipment. Creep of the fuel will not cause large changes, and mechanical interaction will produce greater changes on the transducer for fuel length than on the transducer for the length differential between fuel and cladding.

Based on the results of this analysis, we shall assemble the capsule so that the core of the transducer for the length differential between fuel and cladding is located 0.120 in. below the centered position and so that the core of the transducer for fuel length is 0.200 in. below center. These positions will provide maximum utilization of the ± 0.200 -in. range of optimum transducer operation.

We prepared a tentative operating sequence for the MINT-1 capsule based upon the plan to operate for one-half of the test [about 165 days to about 2.7% fissions per initial actinide metal atom (FIMA)] at 10 kw/ft and the remainder (165 days to 7% FIMA) at 16 kw/ft with occasional cycles of 20% overpower. This sequence will simulate the

Fig. 3.3. Reading from Fuel-Length Transducer as a Function of Rate of Heat Generation and Temperature of Plasticity (T_p) for the Fuel. Transducer and core were initially centered.

Fig. 3.4. Reading from Fuel-Cladding Differential Transducer as a Function of Rate of Heat Generation and Temperature of Plasticity (T_p) for the Fuel. Transducer and core were initially centered.

operation of a fuel pin in a peripheral position of the FFTF Reactor for one-half of its life followed by a movement into a central core location.

The irradiation tests of mechanical interaction will be used as one of the reference cases for the working group on LMFBR fuel element modeling.⁷ We shall assume steady-state operation of the MINT-2 capsule at the overpower heat rate of 19 kw/ft for the first calculations. The principal differences between operation of this fuel pin in the ORR and in an LMFBR are the low cladding flux, shown below:

Burnup (% FIMA)	Neutron Flux [neutrons cm ⁻² sec ⁻¹ (> 0.1 Mev)]
	$\times 10^{13}$
0	1.50
2	1.54
4	1.57
6	1.61
8	1.66
10	1.71

The flux depression in the fuel is indicated in Fig. 3.5. The very large power depression follows from the high ²³⁹Pu concentration in the 0.198-in.-diam 92% dense (U_{0.75},Pu_{0.25})O_{1.98} fuel pellets.

Fig. 3.5. Effect of Burnup on Radial Power Profile of Fuel for MINT Capsule.

Notes

1. Reactor Chemistry Division.
2. Reactor Division.
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4. S. C. Weaver, R. B. Fitts, et al., Results from Irradiation Testing of UO₂ Fuel Pins Designed for the Medium Power Reactor Experiment, ORNL-TM-2859 (August 1970).
5. A. Roth et al., Trans. Am. Nucl. Soc. 10(2), 457-458 (November 1967).
6. W. H. Bridges, The Physical and Tensile Properties of Type 316 Stainless Steel, ORNL-TM-3037, in press.
7. P. Patriarca, A. L. Lotts, and C. M. Cox, "LMFBR Fuel Element Design and Model Development," pp. 65-80, this report.