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INTRODUCTION

The U.S. Advanced Fuel Cycle Initiative (AFCI) seeks to develop and demonstrate the technologies needed to transmute the long-lived transuranic actinide isotopes contained in spent nuclear fuel into shorter-lived fission products, thereby dramatically decreasing the volume of material requiring disposal and the long-term radio-toxicity and heat load of high-level waste sent to a geologic repository. One important component of the technology development is actinide-bearing transmutation fuel forms containing plutonium, neptunium, americium (and possibly curium) isotopes. Metallic alloy and oxide fuel forms are being developed as the near term options for fast reactor implementation.

There are limited irradiation performance data available on metallic and oxide fuels with high concentrations of Pu, Np and Am, as are envisioned for use as actinide transmutation fuels. Initial scoping level irradiation tests of such metallic fuels are underway in the INL's Advanced Test Reactor (AFC-1B, -1D, -1F & -1H). Non-fertile and low-fertile metallic fuels in the AFC-1B & -1F tests have already been discharged from the reactor at 8 at.% burnup and are nearing the completion of postirradiation examination; performance of all the fuel alloys included in these tests indicated actinide-bearing transmutation metallic fuels are feasible.[1] Similar fuel alloys continue to be irradiated in the AFC-1D & -1H tests and are currently over 20 at.% burnup. Irradiation testing of metallic fuel alloys of U, Pu, Np, Am and Zr, with minor additions of rare earth elements meant to simulate expected fission product carry-over from pyro-metallurgical reprocessing, are planned for the AFC-2A & AFC-2B experiments, which will begin in late 2007. Irradiation testing of oxide fuels of different stoichiometries with high concentrations of Pu, Np and Am are planned for the AFC-2C and AFC-2D experiments, which will begin in early 2008.[2]

The proposed GNEP-1A, and GNEP-1B irradiation experiments in Joyo are a continuation of the metallic and oxide fuel test series in progress in the ATR and the metallic alloy irradiation tests in Phenix.[3] They are designed as fast reactor test analogs of the AFC-2A, -2B, -2C and -2D experiments. The GNEP-1A and -1B experiments will consist of metallic fuel alloys of U, Pu, Np, Am and Zr, some with minor additions of rare earth elements meant to simulate expected fission product carry-over from pyro-metallurgical reprocessing, to be irradiated to burnup levels of 12-15 at.% burnup. The GNEP-1C and -1D experiments will consist of oxide fuels of U, Pu, Np, and Am with two different oxide-to-metal (O/M) ratios, which are candidate values for the fabrication process.

PROPOSED FUEL TEST MATRIX

The fuel compositions and uranium enrichments of the metallic and oxide fuel rodlets in GNEP-1A and GNEP-1B are shown in Table 1; note that the metallic alloy compositions are expressed as a weight percent and the oxide compositions are expressed as a mole fraction for each constituent element.

TABLE 1. Fuel Test Matrix

Rodlet	Composition †	Burnup, at%
Metal		
1	U-20Pu-3Am-2Np-15Zr	13
2	U-20Pu-3Am-2Np-1.5RE*-15Zr	13
3	U-30Pu-5Am-3Np-20Zr	0.27
4	U-30Pu-5Am-3Np-1.5RE*-20Zr	0.27
5	U-20Pu-3Am-2Np-1.5RE*-15Zr w/ODS Cladding	13
Oxide		
1	$(U_{0.75},Pu_{0.2},Am_{0.03}Np_{0.02})O_{1.98}$	19
2	$(U_{0.75},Pu_{0.2},Am_{0.03}Np_{0.02})O_{1.95}$	19
3	$(U_{0.62},Pu_{0.3},Am_{0.05}Np_{0.03})O_{1.98}$	0.27
4	$(U_{0.62},Pu_{0.3},Am_{0.05}Np_{0.03})O_{1.95}$	0.27
5	$(U_{0.75},Pu_{0.2},Am_{0.03}Np_{0.02})O_{1.98}$ w/ODS Cladding	19

†Metal alloy composition expressed in weight percent. Oxide composition expressed in mole fraction.
*RE designates rare earth alloy (6% La, 16% Pr, 25% Ce, 53% Nd).

The fuel compositions in these experiments were selected as a subset of the AFC-2A, -2B, -2C and -2D metallic and oxide fuel tests planned in the ATR. The metallic alloys experiments build upon the irradiation performance data that have been obtained from the AFC-1B, D, F and H metallic fuel tests in the ATR; the oxide experiments build upon data that were obtained in earlier fast reactor tests in EBR-II and FFTF. Compared to the metallic fuel compositions in the previous tests, the

GNEP-1A uranium contents have been increased and the zirconium contents have been decreased, as the GNEP program objectives have evolved to a position where a somewhat higher conversion ratio is deemed as acceptable in future sodium-cooled fast reactors used for actinide transmutation; the lower Zr content results in a denser fuel, though still considerably less dense than the U-20Pu-10Zr fuels irradiated routinely in EBR-II. The transuranic contents in the GNEP-1A fuels is bounded by the previous ATR tests. The new parameter introduced in the GNEP-1A fuel test matrix is a minor addition of rare earth elements (La, Pr, Ce, Nd) in some of the fuels; this is done to simulate rare earth carryover that may result from pyro-metallurgical reprocessing of metallic fuels. In the oxide fuels, the oxygen to metal (O/M) ratio is varied to investigate its interdependence with transuranic content on irradiation performance.

The baseline cladding for the GNEP fuel development effort is the ferritic-martensitic stainless steel UNS S42100 (HT9). The GNEP-1A and GNEP-1B experiments include one test pin each to study the behavior of an advanced oxide dispersion strengthened (ODS) cladding with metallic and oxide transmutation fuel forms.

IRRADIATION TEST ASSEMBLY

The DOE JOYO GNEP-1A and GNEP-1B experiments consist of five test fuel pins each. The proposed irradiation test assembly for these experiments is shown in Figure 1. The currently proposed irradiation test rig is a modified license Type-B Irradiation Rig, which will be licensed for “standard type (open core)” compartments in addition to the currently licensed “capsule” design. The Type-B Irradiation Rig accommodates six irradiation positions. The advantage of the modified license is the standard type (open core) design is greater number of test fuel pins. A “capsule” contains a single test fuel pin and a standard type (open core) can contain from three to five test fuel pins, depending on the diameter. The current U.S. proposal for GNEP-1A and GNEP-1B assumes a five test fuel pin configuration. These would be housed in two open-compartment positions. Figure 1 shows a Type-B Irradiation Rig with three open compartment and three capsule assemblies. The modified license will authorize any combination of standard type (open compartment) and “closed” capsules.

The fuel test pins are designed as full-length Joyo fuel pins with shortened fuel column heights. Stainless steel spacers are included in the design to satisfy Joyo requirements and position the fuel column in the center of the core. The metallic alloy fuel rod consists of the metallic fuel column, insulator pellets, bond sodium, stainless steel spacer, UNS S42100 (HT9) cladding and an inert gas plenum. The oxide fuel rod consists of the oxide fuel column, helium bond and plenum, insulator pellets, stainless steel spacer and sleeves, and stainless steel Type 421 (HT-9) cladding.

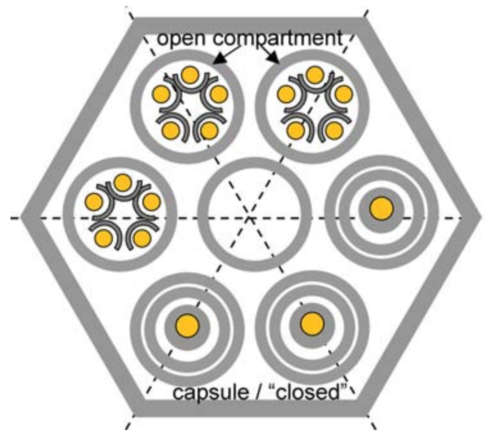
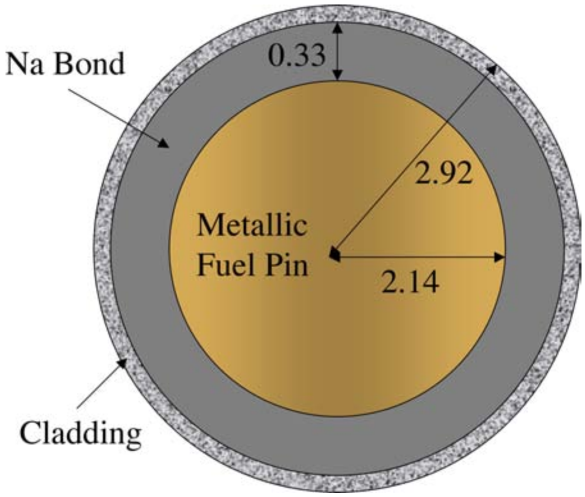


Fig. 1. Schematic of Joyo Type B Irradiation Rig with modified license to include open-compartment and closed capsule. DOE Joyo experiments housed in open compartments.

The fuel rod radial dimensions of the metallic and oxide fuel specimens are shown in Figure 2. The annular gap between the metallic fuel column and fuel rod inner diameter is initially filled by the sodium bond and is designed to accommodate fuel swelling during irradiation. The annular gap between the oxide fuel and fuel rod inner diameter is optimized to accommodate fuel swelling, fabrication tolerances and to minimize fuel centerline temperatures.

Table 2 shows the materials used in constructing the rods along with their design dimensions. The design length of the metallic fuel column is 200 mm (7.88-in.); the design diameter is 4.27 mm (0.168-in). The design length of the oxide column is 200 mm (7.88-in.); the design diameter is 4.83 mm (0.190-in). The bond sodium of the metallic fuel rods is designed to cover and exceed the fuel column height by between 150 mm (5.91-in.). The oxide fuel rods will have a helium fill gas with a design pressure of one atmosphere. Both the metallic and oxide fuel pins will incorporate stainless steel pellet spacers to position the fuel column in the core center and satisfy the design requirement of no voids in the 500 mm core region. Insulator pellets will separate the fuel column from the spacers. The oxide fuel pin will include a spring and sleeves to assure adequate plenum volume to accommodate the fission and helium gas release. The cladding for all rodlets (including welded endplugs) is nominally 1.050 m in length with 5.84 mm (0.230-in.) outer diameter and 4.93 mm (0.194-in.) inner diameter.



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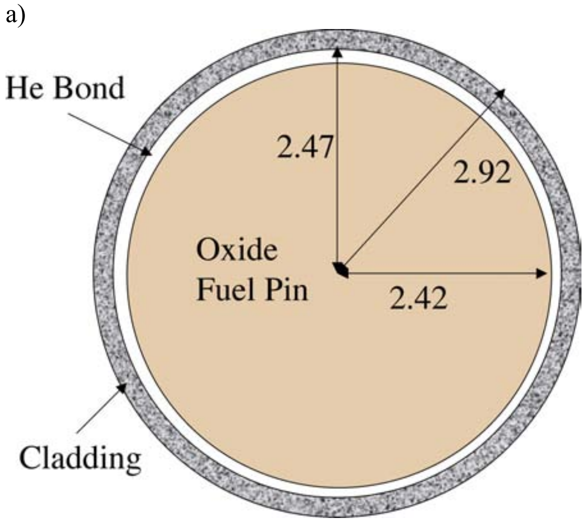

b)
Fig. 2.Radial dimensions of metallic alloy and oxide actinide transmutation fuels for a fast reactor test.

TABLE 2. Fuel Rod Design Data		
Design Parameter	Metal	Oxide
Cladding Material	HT9	HT9*
Cladding O.D.	5.84 mm	5.84 mm
Cladding I.D.	4.93 mm	4.93 mm
Bond Material	Sodium	Helium
Fuel Type	Metallic	Oxide
Fuel Smear Density	75%	82%
Fuel Porosity	0%	15%
Fuel O.D.	4.27 mm	4.83 mm

IRRADIATION TEST CONDITIONS

The fuel experiment design conditions for GNEP-1A and GNEP-1B are shown in Table 3. The design objective is for each pin in these experiments to have a peak linear heat generation rate (LHGR) of 40.0 kW/m. Preliminary calculations predict LHGR between 38-39.4 kW/m based on the fuel test matrix compositions and uranium enrichments in Table 1 and the following assumptions: 1. the peak flux in Joyo at 140 MW for the Row 3 irradiation position, 2. fission cross sections calculated for the Joyo flux spectrum and AFC-2A and -2B experiment geometries, and 3. an assumed heating rate of 196 MeV/fission.

TABLE 3 Irradiation Test Design Objectives

Design Parameter	GNEP-1A Metallic Fuel	GNEP-1B Oxide Fuel
Burnup	12-15 at.%	12-15 at.%
Linear Power	40 kW/m	40 kW/m
Cladding Temperature	<550˚C	<550˚C
Fuel Temperature	<1000˚C	<1800˚C

POST-IRRADIATION EXAMINATIONS

Upon discharge of each experiment from the reactor, cooling at the JOYO for a minimum of 100 days will be required. The experiments will be shipped to the Hot Fuels Examination Facility (HFEF) at Idaho National Laboratory's Materials and Fuels Complex (MFC) for postirradiation examinations.

The primary purpose of the PIE is to characterize the irradiation performance of the metallic transmutation fuels with rare earth content and the oxide fuel forms with different stoichiometry. The PIE data of the metallic fuel compositions will be compared to data of fast neutron irradiations of metallic transmutation fuels without rare earth addition and to data of thermal neutron irradiation of similar compositions. The oxide fuel experiment data will be compared to PIE data obtained from ATR irradiations in a thermal neutron spectrum. The PIE will include visual examination, dimensional inspection, neutron radiography, gamma scanning, gas plenum assay and radiochemistry, optical and electron microscopy, burnup and americium transmutation determinations. The PIE will provide fuel irradiation performance data; specifically, irradiation growth and swelling, helium production, fission gas release, fission product and fuel constituent migration, fuel phase equilibria, and fuel-cladding chemical interaction

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