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HIGH-TEMPERATURE IRRADIATION
TEST OF UO_2 CERMET FUELS

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HIGH-TEMPERATURE IRRADIATION TEST OF UO₂ CERMET FUELS

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Niobium-clad niobium cermets and Type 430 stainless steel-clad molybdenum and chromium cermets, all containing 80 volume per cent 20 per cent enriched UO₂, prepared by vapor-deposition techniques or from the powders and densified and clad by gas-pressure bonding, were subjected to high-temperature high-heat-flux irradiation in the MTR. Two instrumented double-walled capsules, each containing duplicate NaK-immersed cylindrical specimens of the three compositions were involved. Specimen diameters were varied according to the particular cermet thermal conductivity in an attempt to secure central temperatures of about 0.6 of the matrix melting point. Probably because of weld failures in both capsules, irradiation temperatures were higher than intended, causing loss of the chromium cermets in one capsule and all of the cermets in the other capsule. The remaining specimens were given a post-irradiation dimensional and metallographic examination. The niobium-clad niobium-UO₂ cermet exhibited excellent stability at estimated center-line temperatures above 2500 F. A density decrease of only 1.4 per cent was measured at a burnup of about 4 a/o. Although the capsule overheating caused the molybdenum-UO₂ cermet to partially melt, areas only a few mils from the melted zone showed no evidence of damage from the adverse conditions of the irradiation.

INTRODUCTION

Data obtained from a study of cermet fuels⁽¹⁾ demonstrated that 80 volume per cent UO₂-refractory metal cermets could be successfully fabricated into dense bodies. The physical and mechanical properties of these cermets showed considerable improvement over those of solid UO₂. The materials appeared potentially useful as high-temperature reactor fuels. An evaluation of their resistance to irradiation damage was therefore initiated.

Irradiation specimens containing 80 volume per cent UO₂ with metal phases of chromium, molybdenum, and niobium were fabricated by green pressing the powders and further densifying and cladding the cores in a high-pressure autoclave at elevated temperatures. The molybdenum and chromium cermets were clad with Type 430 stainless steel. Niobium was employed as the cladding on the niobium-matrix specimens. In all instances a void space was incorporated into the specimens at each end of the core for the accumulation of fission gases.

Duplicate specimens of each type were contained in each of two capsules to be irradiated in the MTR to 2.5 and 4 per cent burnup of the total uranium atoms present at a center-line temperature of 0.6 of the melting point of the particular matrix metal.

(1) References at end.

SPECIMEN PREPARATION

Materials

Fuel

The fuel chosen for this program was spherical UO_2 having a particle size of minus 100 plus 200 mesh. It had been found from previous experience that an optimum dispersion can be obtained with this particle size and shape.

Calculations made on various fuel enrichments from natural to fully enriched indicated that a 20 per cent enrichment of the fuel would perform most successfully in an irradiation capsule. The difficulty encountered in the choice of a fuel enrichment was the need to maintain a high center-line temperature (in the order of 0.6 of the melting point of the particular refractory metal of the cermet) yet keep the heat flux within the capsule to a tolerable level. The high thermal conductivities of the cermets require that the irradiation be conducted in a high thermal-neutron flux to attain the required center-line temperature. Under these conditions the 20 per cent enrichment appeared most favorable. The actual analyzed value of the enrichment in the UO_2 incorporated in the specimens was 19.85 per cent and the total uranium content was 88.20 w/o.

Metal Phase

Specimens were fabricated with matrices of the three refractory metals, chromium, molybdenum, and niobium, previously studied.⁽¹⁾ The molybdenum and chromium used were in the form of high-purity powders of minus 325 mesh. The niobium metal was coated directly onto each particle of UO_2 by vapor deposition. These metals were chosen on the basis of available nuclear and thermodynamic data and their compatibility with UO_2 .

Cladding

It was necessary to pick a cladding material for the three types of cermets which were to be tested. Among the requirements for the cladding material were: a coefficient of expansion similar to that of the core material, some strength at 1700 F (calculated cladding fuel-core interface temperature), a satisfactory nuclear cross section, and compatibility with the core materials.

After screening various metals, Hastelloy X, Type 430 stainless steel, and niobium were chosen to clad dummy cores. The Hastelloy X failed during pressure bonding. The other claddings were checked by cycling 25 times between 200 and 1850 F, heat treating for a continuous 168-hr period at 1800 F, and examining metallographically. It was concluded from these tests that niobium was the optimum cladding for the UO_2 -niobium cermet. The ferritic stainless steel performed satisfactorily with the UO_2 -chromium cermet; however, a reaction took place between the UO_2 -molybdenum cermet and the stainless steel cladding, causing the interface to crack during heat treating. This fault was corrected in the next specimen by inserting a 0.005-in.-thick molybdenum barrier

foil between the cladding and core before pressure bonding. A narrow reaction zone was found between the barrier foil and stainless steel; however, there was good bonding throughout and no evidence of cracking found after heat treating or cycling, as shown in Figure 1.

It was decided at this point to clad the niobium-containing specimens with niobium and the UO_2 -chromium and UO_2 -molybdenum specimens with Type 430 stainless steel. A molybdenum barrier foil was employed between the Type 430 stainless steel cladding and the UO_2 -molybdenum cores.

Specimen Design

A cylindrical specimen shape was chosen as being the most workable configuration for a cermet to be clad by pressure bonding. Since the program was limited to the irradiation of two capsules, the most information could be obtained by placing two each of the three types of cermets in each capsule. Two burnup levels could then be obtained for each type and each type could be compared to the others at the same two burnup levels. Because the three cermets have different thermal conductivities, it was necessary to vary the specimen diameters and to locate the specimen pairs at positions in the capsule corresponding to the desired unperturbed flux. Calculations showed that to obtain the desired center-line temperatures of 2350 ± 100 F, 2800 ± 100 F, and 2800 ± 100 F for chromium, molybdenum, and niobium cermets, respectively, the core diameters must be 0.300 in., 0.400 in., and 0.246 in., respectively.

Calculations showed that a 0.035-in.-thick cladding of Type 430 stainless steel or niobium in conjunction with an internal void space would be sufficient to retain the fission gas formed during irradiation. This void space was incorporated into the specimens by inserting 3/16-in.-long stainless steel or niobium filler plugs at each end of the cores before pressure bonding. These were drilled out after pressure bonding, and a 1/16-in.-long end plug was electron-beam welded into the end of the tube, leaving a 1/8-in.-long void space at each end of the core, as shown in Figure 2.

Specimen Fabrication

The UO_2 -molybdenum specimens contained two pellets each prepared by blending 81.2 w/o minus 100 plus 200-mesh spherical UO_2 having an enrichment of 19.85 per cent of the uranium atoms with 18.8 w/o minus 325-mesh molybdenum powder for 2 hr in a V-type mixer. A dispersing agent of ethylene glycol was then added (1/2 w/o), and blending was continued for 2 hr. The pellets were green pressed at 30 tsi in a double-action cylindrical die measuring 0.431 in. in diameter.

The UO_2 -chromium specimens also contained two pellets each and were prepared from the same batch of UO_2 . The chromium was a high-purity minus 325-mesh powder. The UO_2 was coated with camphor by making a slurry with camphor and alcohol, air drying at room temperature, and screening. The coated UO_2 made up 85.9 w/o of the cermet blend and was mixed with the chromium powder for 2 hr in a V-type mixer. A 1/2 w/o camphor-alcohol solution (1/2 oz to 600 cm^3) was added, and the powder was mixed for 2 hr followed by screening. Pellets of this blend were pressed in a double-action die measuring 0.337 in. in diameter.

250X

RM18306

FIGURE 1. CERMET OF 80 VOLUME PER CENT UO_2 - MOLYBDENUM PRESSURE BONDED WITH A MOLYBDENUM BARRIER FOIL BETWEEN THE CORE AND TYPE 430 STAINLESS STEEL CLADDING

2X

RM19105

FIGURE 2. LONGITUDINAL SECTION OF TYPICAL CERMET IRRADIATION SPECIMEN

The specimen is 80 volume per cent UO_2 - niobium pressure bonded with niobium. The void space at each end of core is for the collection of fission gas. The cladding thickness is 0.045 in.; it appears thicker since the specimen was not sectioned on the diameter.

The UO_2 in the UO_2 -niobium specimens was from the same batch of UO_2 powder. Each spherical particle was coated with high-purity niobium to the extent of 20 volume per cent by a vapor-deposition process. This powder was pressed directly into pellets at a pressure of 30 tsi in a double-action die measuring 0.269 in. in diameter. Three fuel pellets were placed in each specimen.

The fuel pellets were inserted into their respective tubes. Spacer plugs 1/4 in. long were placed in each end inside the 1/8-in.-long end plug. The tubings, spacers, and end plugs employed were fabricated of Type 430 stainless steel with a 0.005-in. molybdenum barrier for the UO_2 -molybdenum specimens, Type 430 stainless steel for the UO_2 -chromium specimens, and niobium for the UO_2 -niobium specimens. The UO_2 -molybdenum and UO_2 -chromium specimens were degassed at 600 C under a vacuum of 1×10^{-4} mm of mercury to evacuate the dispersing agent. All specimens were then sealed by welding the end plugs with an electron-beam welder under vacuum. The specimens were bonded under an isostatic helium gas pressure of 10,000 psi for 3 hr at 2300 F.

The temperature, time, and pressure conditions employed are necessary to obtain densification of the cermet cores. Since severe grain growth takes place in the Type 430 stainless steel cladding under these conditions, it was necessary to machine the densified cores from the chromium and molybdenum cermet specimens and reclad. These cermets were, therefore, pressure bonded again with the same type of cladding but under autoclave conditions of 2-1/2 hr at 2050 F and 10,000 psi. The cladding was bonded to the core under these conditions but very little grain growth took place.

A 1/8-in.-long void space was incorporated into each end of the specimens by drilling out the end and spacer plugs and electron-beam welding 1/16-in. end plugs in each end. The specimens were then photographed and radiographed. A spare specimen of each type was sectioned for metallographic examination.

Figures 3a, 3b, and 3c show typical areas of the molybdenum, chromium, and niobium metal-phase cermets, respectively. It can be seen from these photomicrographs that the greater portion of the porosity is within the UO_2 particles themselves. The densities of the three 80 volume per cent UO_2 cermet fuel cores were: UO_2 -molybdenum, 92.5 per cent of theoretical; UO_2 -chromium, 97 per cent of theoretical; and UO_2 -niobium, 91 per cent of theoretical. There was a continuous metal phase through each cermet; however, the superior metal-phase continuity in the cermet fabricated from niobium-coated particles is evident in Figure 3.

Table 1 gives details of the irradiation specimens.

250X

RM19112

- a. UO_2 -Molybdenum Cermet Prepared From Blended Powders

250X

RM19111

- b. UO_2 -Chromium Cermet Prepared From Blended Powders

250X

RM19113

- c. UO_2 -Niobium Cermet Prepared From UO_2 Powder Niobium Coated by Vapor-Deposition Techniques

FIGURE 3. 80 VOLUME PER CENT UO_2 CERMETS AFTER ISOSTATIC PRESSING FOR 3 HR AT 2300 F AND 10,000 PSI

TABLE 1. COMPOSITIONS, DIMENSIONS, AND WEIGHTS OF 80 VOLUME PER CENT UO_2 CERMET IRRADIATION SPECIMENS

Capsule	Specimen	Matrix Material	Cladding	Nominal Core Dimensions, in.		Core Weight, g	Total U Weight, g	U-235 Weight, g
				Diameter	Length			
BMI-39-1	2	Molybdenum	Type 430 stainless ^(a)	0.400	0.75	14.7780	10.58	2.10
	3	Molybdenum	Type 430 stainless ^(a)	0.400	0.75	14.7403	10.56	2.10
	4	Chromium	Type 430 stainless	0.300	0.75	8.6030	6.52	1.29
	6	Chromium	Type 430 stainless	0.300	0.75	8.4458	6.39	1.27
	7	Niobium	Niobium	0.246	0.60	4.5855	3.28	0.65
	8	Niobium	Niobium	0.246	0.60	4.5190	3.23	0.64
BMI-39-2	9	Niobium	Niobium	0.246	0.60	4.4053	3.15	0.625
	11	Molybdenum	Type 430 stainless ^(a)	0.400	0.75	14.7964	10.59	2.10
	12	Molybdenum	Type 430 stainless ^(a)	0.400	0.75	14.7055	10.53	2.09
	14	Chromium	Type 430 stainless	0.300	0.75	8.5096	6.45	1.28
	15	Chromium	Type 430 stainless	0.300	0.75	8.6611	6.56	1.30
	18	Niobium	Niobium	0.246	0.60	4.4451	3.18	0.63

(a) Cladding contains a 0.005-in. -thick molybdenum barrier foil between the core and stainless steel.

SPECIMEN ENCAPSULATION AND IRRADIATION

A capsule was designed to accommodate duplicate specimens of all three materials by adjusting the specimen diameter and positioning the specimens within the capsule in accordance with the normal vertical flux profile in the MTR. The capsule design took into consideration the different heat-dissipation rates from each specimen and the requirement to obtain a fuel center-line temperature of 0.6 times the melting point of each specimen while maintaining the same fuel-surface temperatures for the three different materials. The specimen dimensions and target temperatures and heat-generation rates are shown in Table 2. A picture of a semiassembled capsule designed for this program is shown in Figure 4.

TABLE 2. DIMENSIONS AND TARGET TEMPERATURES AND HEAT-GENERATION RATES FOR 80 VOLUME PER CENT UO_2 CERMET IRRADIATION SPECIMENS

Matrix	Over-All Specimen Dimensions, in.		Cladding-Fuel Core Interface Temperature, F	Fuel Center-Line Temperature, F	Heat-Generation Rate, Btu/(hr)(in.)		
	Diameter	Length			Fission	Gamma	Total
Niobium	0.32	0.975	1700	2700	5,750	440	6,190
Chromium	0.37	1.125	1700	2450	8,650	450	9,100
Molybdenum	0.47	1.125	1700	2725	15,600	670	16,270

Duplicate capsules, BMI-39-1 and BMI-39-2, were irradiated in the MTR for 50 and 82 days, respectively. Thermocouples were located at each specimen surface to monitor temperature performance during irradiation. As the irradiations progressed, thermocouple failure was experienced. The temperature data listed in Table 3 were, therefore, obtained early in the irradiation.

N80989

FIGURE 4. SUBASSEMBLY OF BMI-39 SERIES IRRADIATION CAPSULE

TABLE 3. TEMPERATURE DATA FOR 80 VOLUME PER CENT UO_2
CERMET SPECIMENS DURING IRRADIATION IN CAPSULES
BMI-39-1 AND BMI-39-2

Matrix	Average Cladding-Fuel Core Temperature, F	Average Center-Line Temperature ^(a) , F
<u>Capsule BMI-39-1</u>		
Niobium	1820	2890
Chromium	2030	2980
Molybdenum	2180	3580
<u>Capsule BMI-39-2</u>		
Niobium	1680	2560
Chromium	1840	2650
Molybdenum	1850	2980

(a) Temperature calculated from nuclear heat-generation rates, design heat-transfer studies, and thermal conductivity values for the cermets.

POSTIRRADIATION EXAMINATION OF SPECIMENS

The postirradiation examination included measurement of specimen density and dimensions, visual inspection of specimen surfaces, analysis of dosimeter wires, determination of specimen burnup, and metallographic examinations of the fuel, matrix, and cladding from selected specimens. The results of each phase of the postirradiation examination are discussed separately below.

Capsule Opening and Visual Examinations

The specimens, which were located in a nickel inner capsule containing NaK as the specimen heat-transfer medium, were separated from the outer capsule by fins and a small helium-filled annulus. During attempts to remove the outer capsule shell, considerable amounts of fission gas and NaK were encountered in the annulus between the two capsule shells. The presence of NaK and fission gas in the area between inner and outer capsules indicated a failure of the inner capsule in both experiments.

The inner capsules, apparently failing as a result of faulty welds in the nickel-stainless steel junction, lost NaK which resulted in the uncovering and subsequent melting of the top specimen in both capsules. In Capsule BMI-39-1 where the temperatures were highest, all specimens reacted and melted as a direct result of this initial failure. In Capsule BMI-39-2 only the top specimen was lost by melting. Hot-cell examination was then restricted for the most part to the niobium and molybdenum specimens contained in Capsule BMI-39-2.

The specimen immediately below the melted top specimen in BMI-39-2 was of similar composition and appeared in good condition with no observed swelling or distortion. The condition of these top two specimens of 80 volume per cent UO_2 -niobium, clad with niobium, is shown in Figure 5.

4X

HC8992

a. Specimen 9

This was the top specimen. It melted subsequent to the loss of NaK coverage.

4X

HC8989

b. Specimen 18

This specimen was irradiated immediately below Specimen 9. The cladding appeared intact after irradiation. Density change was -1.4 per cent.

FIGURE 5. THE TWO TOP SPECIMENS FROM CAPSULE BMI-39-2

The specimens contain a core of 80 volume per cent UO_2 -niobium and a cladding of niobium. Specimen burnup was about 4 per cent of the uranium atoms.

The two bottom specimens in the capsule were of 80 volume per cent UO_2 -molybdenum, clad with Type 430 stainless steel. It was noticed during the postirradiation examination of these specimens that the cladding contained a longitudinal impression along one side in a position corresponding to a dosimeter-wire attachment. A crack appeared at the base of the impression in the cladding, and in one specimen some fuel was observed protruding from the crack. Swelling was observed in both specimens, as shown in Figure 6. The cladding on the two chromium-matrix specimens apparently melted, and the specimens reacted extensively with the NaK. No further examinations were made of these two specimens.

Physical Measurements

Specimens that appeared intact after removal from the irradiation capsule were measured with friction-thimble micrometers to determine swelling. Diameter measurements were obtained at four locations along each specimen; the specimens were rotated 90 deg and remeasured. Length measurements were made on the end caps at 120-deg intervals. A density measurement for the niobium- UO_2 specimen was obtained by carbon tetrachloride displacement. These results are reported in Table 4.

Neutron Dosimetry

Neutron dosimeters fabricated of 0.014-in.-diameter nickel-0.5 w/o cobalt wire were irradiated in positions adjacent to the surfaces of the irradiation specimens. The dosimeter wires were removed, identified, and radiochemically analyzed to determine the quantity of cobalt-60 formed during the irradiation. Three dosimeter wires were recovered, identified, and analyzed from Capsule BMI-39-2.

The specimen burnup, based on dosimetry values, ranged from about 2.5 to 3.4 total uranium a/o. Radiochemical and isotopic analyses of one niobium-matrix specimen from this capsule showed, respectively, 4.28 and 3.94 a/o of the initial total uranium consumed due to uranium-235 depletion.

Metallographic Examination

One specimen from Capsule BMI-39-1 and four specimens from BMI-39-2 were sectioned for a microstructural study of the changes produced by irradiation. The specimens were mounted in Bakelite, ground on water-lubricated silicon carbide papers, and polished in Syntron vibrators employing 1- μ diamond paste on cashmere cloth and Lind B on Microcloth. The specimens were also examined in the etched condition to observe the cladding, matrix, barrier layers, and fuel.

The appearance of the sound portion of Specimen 7 from BMI-39-1 is shown in Figure 7. The upper half of this specimen, which was not metallographically examined, was not covered by NaK during part of the in-pile exposure. This caused an extremely large temperature gradient from top to bottom of the specimen and gross swelling and rupture in the uncovered portion of the specimen.

4X

HC8995

a. Specimen 11

4X

HC8993

b. Specimen 12

FIGURE 6. APPEARANCE OF THE TWO UO_2 -MOLYBDENUM CERMET SPECIMENS
AFTER IRRADIATION IN CAPSULE BMI-39-2

TABLE 4. SUMMARY OF DATA FOR 80 VOLUME PER CENT UO_2 CERMET SPECIMENS IRRADIATED IN CAPSULE BMI-39-2^(a)

Specimen	Matrix	Cladding	Specimen Dimensions, in.				Dimensional Change, per cent		Remarks
			Preirradiation		Postirradiation		Length	Diameter	
			Length	Diameter	Length ^(b)	Diameter ^(c)			
11	Molybdenum	Type 430 stainless steel	1.140	0.469	1.135	0.497	-0.3	+5.8	Specimen contained longitudinal crack in cladding and swelling near center
12	Molybdenum	Type 430 stainless steel	1.110	0.469	1.125	0.491	+1.3	+4.8	Specimen contained longitudinal crack in cladding and swelling near center
18	Niobium	Niobium	1.003	0.315	1.005	0.317	+0.2	+0.7	Specimen in good condition; no swelling observed; decrease in density after irradiation was 1.4 per cent

(a) The remaining three specimens of this capsule were not measured because of their poor condition, i.e., large ruptures.

(b) Length measurements were made on end caps approximately 120 deg apart.

(c) Average of eight diameter measurements: four were taken along specimen length, the specimen was rotated 90 deg, and four additional measurements were taken.

As can be observed in the low-magnification view, Figure 7a, cracks and a small central void were present in the middle of the specimen. This structure is believed to be the result of the thermal gradient produced by the partial loss of NaK covering the specimen. Examination at high magnification revealed sound cladding-core integrity of this specimen (Figure 7b) and large areas essentially unchanged from the preirradiation condition (Figure 7b and 7c). The region near the center, however, showed evidence of the extreme heat in the core resulting from the uncovered top half of the specimen (Figure 7d).

Specimens 11 and 12 from BMI-39-2, which were composed of 80 volume per cent UO_2 -molybdenum clad with Type 430 stainless steel, were metallographically examined. Both specimens were damaged as a result of the capsule failure and subsequent overheating; however, a large portion of the core remained intact. In general, the microstructures of both specimens were similar.

Specimen 12 is depicted metallographically in Figure 8. In Figure 8a a wide peripheral crack can be observed near the core-cladding interface. The longitudinal dosimeter-wire impression and a crack in the cladding are also visible. The center of the specimen contained a large void, while the stainless steel cladding possessed an extremely coarse grain structure.

The nature of the peripheral crack or void between fuel-matrix and molybdenum barrier layer is shown in Figure 8b. Although cracks were not noted during out-of-pile thermal-cycling tests on control specimens, the tests were made employing normal operating temperatures. The cracks are therefore thought to be the result of the extreme conditions of this particular irradiation test. The region between the peripheral crack and central void (Figure 8c) was a continuous matrix phase which did not appear to have been affected by the irradiation. Near the central void there was segregation of the fuel and metal phase, as shown by the columnar, radiating UO_2 grains (Figure 8d).

The compatibility of UO_2 with the molybdenum matrix is reflected by the lack of reaction between these components as shown in Figure 8c. Additional photomicrographs (Figure 9) also indicated little reaction between the UO_2 and molybdenum.

An examination of Specimen 18 (80 volume per cent UO_2 -niobium clad with niobium) was also performed. There were no cladding cracks, blistering, or swelling noted on this specimen as shown in Figure 5, although a duplicate specimen immediately above it was not covered by NaK and completely disintegrated as shown also in Figure 5 (Specimen 7). The apparent change in density for Specimen 18 was -1.4 per cent.

The examination of Specimen 18 revealed the excellent condition of the UO_2 particles and niobium metal phase (Figure 10). The niobium appeared continuous throughout the specimen and retained the UO_2 particles completely. No evidence of damage to either the niobium in the core or the cladding due to contact with the UO_2 particles (Figure 11) was observed. The specimen core did contain a longitudinal crack running approximately half its length (Figure 11), but this crack could have occurred during specimen fabrication rather than during irradiation.

4X

HC9264

a. Over-All View of Metallographic Mount

125X

Polished

HC9313

b. Cladding-Matrix Interface

250X

Etched

HC9320

c. Outer Region in Matrix

FIGURE 7. MICROSTRUCTURE OF SPECIMEN 7 (80 VOLUME PER CENT UO_2 -NIOBIUM CERMET NIOBIUM CLAD) AFTER IRRADIATION IN CAPSULE BMI-39-1

The upper half of this specimen was irradiated without NaK coverage, resulting in partial melting and segregation near the core center line.

250X

Polished

HC9319

d. Overheated Region at Center

4X

HC9267

a. Over-All View of Metallographic Mount

Note large grain size of stainless steel cladding.

50X

Polished

HC9335

b. Void at Core-Cladding Interface

100X

Polished

HC9350

c. Region Showing Continuous Matrix

250X

Polished

HC9339

d. Columnar UO_2 Adjacent to Central Void

FIGURE 8. MICROSTRUCTURE OF SPECIMEN 12 (80 VOLUME PER CENT UO_2 -MOLYBDENUM CERMET CLAD WITH TYPE 430 STAINLESS STEEL) AFTER IRRADIATION IN CAPSULE BMI-39-1

The molybdenum matrix is continuous except near the central void, where segregation is visible.

a. As-Polished Structure of Continuous Molybdenum Region

b. Molybdenum After Etching

FIGURE 9. MICROSTRUCTURE OF SPECIMEN 12 (80 VOLUME PER CENT UO_2 -MOLYBDENUM CERMET CLAD WITH TYPE 430 STAINLESS STEEL)

Note excellent metal- UO_2 contact and absence of evidence of molybdenum- UO_2 reaction.

100X

Polished

HC9280

250X

Polished

HC9292

250X

Etched

HC9294

FIGURE 10. MICROSTRUCTURE OF SPECIMEN 18 (80 VOLUME PER CENT UO_2 -NIOBIUM CERMET CLAD WITH NIOBIUM) AFTER IRRADIATION IN CAPSULE BMI-39-2

The continuous niobium phase surrounds every UO_2 particle. No evidence of damage to the niobium network was observed.

4X

HC9262

a. Over-All View of Metallographic Specimen

100X

HC9275

b. Cross-Sectional View Showing Core-Cladding Interface

100X

HC9289

c. Cross-Sectional View Showing Transverse Crack in Core

FIGURE 11. METALLOGRAPHIC SECTION OF SPECIMEN 18 (80 VOLUME PER CENT UO_2 -NIOBIUM CERMET CLAD WITH NIOBIUM) AFTER IRRADIATION IN CAPSULE BMI-39-2

DISCUSSION AND CONCLUSIONS

A metallographic examination was performed on specimens of each fuel type. On the basis of these examinations, the 80 volume per cent UO_2 -niobium cermet cores clad with niobium appeared to withstand the experimental irradiation conditions the best. There was no segregation of metal phase or fuel in the sound niobium-matrix specimen from Capsule BMI-39-2, and only a small amount of segregation was noted in the partially melted niobium-matrix specimen from Capsule BMI-39-1. The cladding appeared bonded in specimens examined from the capsules, and no niobium- UO_2 reaction was observed.

On the basis of the two UO_2 -molybdenum specimens metallographically examined, this cermet also shows promise as a high-temperature fuel. Aside from the region which exhibited a void and central melting, the metal phase was continuous and did not show reaction with the UO_2 particles. The cermet structure only a distance of two UO_2 particles away from the molten zone was completely intact, exhibiting excellent UO_2 -molybdenum contact and compatibility. The peripheral cracking observed in both Specimens 11 and 12 undoubtedly caused increased specimen central temperatures over the design conditions because of the thermal-barrier effect of the void; however, the cermet structure which remained intact showed excellent resistance to irradiation damage. The selection of a higher temperature compatible cladding such as molybdenum would certainly increase the apparent high-temperature radiation stability of this material.

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