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OVERVIEW OF REDUCED ENRICHMENT FUELS— *DEVELOPMENT, TESTING, AND SPECIFICATION**

by

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Overview of Reduced Enrichment Fuels—
Development, Testing, and Specification

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James L. Snelgrove

The U.S. Reduced Enrichment Research and Test Reactor (RERTR) Program[1] was established in 1978 to provide the technical means to operate research and test reactors with low enrichment uranium (LEU) fuels without significant penalty in experiment performance, operation costs, component modifications, or safety characteristics. A large increase in ^{238}U is required to reduce the enrichment, and a 10-15% increase in ^{235}U is required to compensate for the extra absorption in ^{238}U. The additional uranium can be accommodated by redesigning the fuel element to increase the fuel volume fraction in the reactor core and/or by increasing the uranium density in the fuel meat. Since fuel element redesign coupled with the highest density fuel available in 1978 is sufficient for only a few reactors, a fuel development and testing effort was begun to qualify much-higher-density fuels.

The greatest emphasis has been on plate-type fuels, since plate-type reactors are the largest users of highly enriched uranium (HEU). In 1978 U-Al alloys and either UAl_x or U_3O_8 dispersed in Al were commonly used as "meats" in HEU fuel plates, with maximum meat densities of 1.0, 1.7, and 1.3 Mg U/m^3, respectively. UAl_x and U_3O_8 dispersion fuels have been developed and tested for LEU applications up to their practical fabrication limits, 2.4 and 3.2 Mg U/m^3, respectively. To provide even higher uranium densities, needed by many reactors, fuels consisting of uranium silicide compounds dispersed in

Al have also been developed. The major commercial fabricators of plate-type fuels, B&W (U.S.), CERCA (France), and NUKEM (Germany), have played an important role in the development and testing effort. The results discussed below were obtained from tests in the Oak Ridge Research Reactor (ORR), the French CEA's SILOE reactor, and the EEC's High Flux Reactor at Petten, The Netherlands.

In addition to the RERTR Program's work with plate-type dispersion fuels, the CEA developed and tested the "caramel" fuel,[2] consisting of sintered UO_2 wafers in Zircaloy-clad plates; GA Technologies developed highly loaded $UZrH_x$ fuel for TRIGA reactors and tested it in cooperation with the RERTR Program[3]; and the Canadian AECL developed and tested rod-type uranium silicide-Al dispersion fuel.[4]

The dispersion fuels were irradiated to high burnups to establish their limits of usability. Fuels which performed well to essentially full burnup with LEU were tested at intermediate and full enrichments to establish failure thresholds. Fuel swelling and blister threshold temperature were measured as key indicators of irradiation performance. Table I lists high-burnup results for the principal LEU fuels tested. UAl_x and U_3O_8 perform very well as LEU fuels but are limited to modest fission densities because of their relatively low densities. U_3Si_2 was found to be very stable to high fission densities. The miniplates tested contained virtually pure U_3Si_2, whereas the elements exhibiting the highest swelling contained up to 15 vol% U_3Si, which is not nearly as stable in the presence of Al. The tests showed conclusively that U_3Si_2 with 15 vol% U_3Si exhibits stable swelling to virtually full burnup. A whole core demonstration has been conducted in the ORR using 4.8-Mg U/m^3 U_3Si_2 dispersion fuel. Twenty-nine elements have achieved average burnups in excess of 40%.

Low enriched UAl_x, U_3O_8, and U_3Si_2 plate-type fuels are offered commercially by one or more fabricators. Some orders have already been placed, and the process of converting many of the U.S. university reactors to use U_3Si_2 fuel is underway. High-volume-loaded fuels are more difficult to fabricate than those with more modest densities. Development of specifications with adequate, but not overly restrictive, requirements is essential to minimize fabrication cost increases.

High concentrations of fuel particles in the meat make it more difficult to maintain homogeneity, and the greater number of fuel particles at the surface of the powder-metallurgical "compacts" result in more particles penetrating into the cladding or being deposited in nominally fuel-free zones of the plate. Specifications for homogeneity, minimum cladding thickness, and fuel out-of-zone should be no more stringent than necessary to maintain required safety margins.

An important finding from the U_3Si_2 element tests is that the presence of a small amount of uranium solid solution (U_{ss}) in the fuel meat is not detrimental to the irradiation performance of the fuel and is, in fact, preferable to U_3Si. Based on these results, it is recommended that the U_3Si_2 alloy not be heat treated (so that U_3Si will not be formed) and that the presence of some U_{ss} not be prohibited.

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Table I. Summary of Irradiation Results for Highly Loaded LEU Al-Dispersion Plate-Type Fuels

Fuel Type	Test[a] Type	Uranium Density, Mg/m^3	^{235}U Burnup,[b] %	Fiss. Dens. in Meat,[b] 10^{27} f/m^3	Meat Swelling,[c] vol%	Blister Threshold Temp., °C
UAl_x	Mp[d]	2.3-2.5	93	1.1	(-3.9)-(-0.8)	550
	El[e]	2.1-2.3	85-90	0.9	3 - 7	>550
U_3O_8	Mp[f]	3.1-3.6	80-98	1.0-1.2	(-5.4)- 2.2	450-550
	El	3.2	87	1.3	8	450-475
U_3Si_2	Mp	5.0-5.2	79-85	1.9-2.1	1.6 - 3.3	515
	Mp	5.6-5.7	85	2.3	0.1 - 2.9	515
	El	4.6-5.2	97-98	2.3-2.5	9 - 23	550
U_3Si	Mp[g]	5.7-6.1	72-89	1.9-2.6	0.7 - 20.4[h]	525
	Mp	6.9-7.2	78-79	2.5-2.6	13.3 - 44.3[h]	No Test
	El[i]	6.0	74	2.1	14	No Test

[a] Miniplates (Mp) or full-sized elements (El).

[b] Averaged over entire miniplate; at the point of peak burnup of element.

[c] Determined by immersion density for miniplates and by thickness increase in peak burnup region for elements. Thickness increase always overestimates the actual meat swelling. Negative swelling results from sintering of initial meat porosity.

[d] Includes data from Ref. 5.

[e] Includes data from Ref. 6.

[f] Includes data from Refs. 7 and 8.

[g] Includes data from Ref. 8.

[h] Some miniplates experienced very large swelling in regions of substantially higher-than-average uranium density, leading to high average values.

[i] Ref. 9.