GA-A15972

TRIGA HIGH WT-% LEU FUEL DEVELOPMENT PROGRAM

FINAL REPORT

by
G. B. WEST

MASTER

Prepared under
Contract EY-76-C-03-0167
Project Agreement 64
for the San Francisco Operations Office
Department of Energy

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GENERAL ATOMIC COMPANY

DISCLAIMER

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ABSTRACT

The principal purpose of this work was to investigate the characteristics of TRIGA fuel where the contained U-235 was in a relatively high weight percent (wt-%) of LEU (low enriched uranium - enrichment of less than 20%) rather than a relatively low weight percent of HEU (high enriched uranium). Fuel with up to 45 wt-% U was fabricated and found to be acceptable after metallurgical examinations, fission product retention tests and physical property examinations. Design and safety analysis studies also indicated acceptable prompt negative temperature coefficient and core lifetime characteristics for these fuels.

1. INTRODUCTION

This is the final report for General Atomic Project 3272 entitled "TRIGA High Wt-% LEU Fuel Development Program," funded by the U.S. Department of Energy under Contract Agreement EY-76-C-03-0167, Project Agreement 64.

LEU fuel is fuel with Low Enriched Uranium (enrichment less than 20%). The work was done as part of the program to meet the United States' objective of reducing the trade in unirradiated Highly Enriched Uranium (HEU) fuels for research and test reactors so as to significantly decrease the nuclear proliferation risks associated with the potential diversion of these fuels during fabrication, transportation, and storage. The principal purpose of the work reported herein was to investigate the characteristics of TRIGA fuel where the contained U-235 was in a relatively high weight percent (wt-%) of LEU rather than a relatively low weight percent of HEU.

The DOE-funded work under this program was divided into 8 tasks:

1. Program Management
2. Design and Safety analysis
3. Fuel fabrication Tests (with Depleted Uranium)
4. Metallurgical Examination
5. Fission Product Release
6. Physical Properties
7. Hydrogen Pressure
8. In-Pile Test Planning

A summary of the work performed and results obtained for each of the tasks is presented in the following 8 sections of this report.

2. PROGRAM MANAGEMENT

This task provided for preparation of the work scope, costs, and schedules for each task in the program. Principal activities included monitoring, coordinating, and evaluating the analytical and experimental programs and preparing the required reports.

3. DESIGN AND SAFETY ANALYSIS

Under this task, analyses were carried out to determine design and safety characteristics of the highly loaded uranium-zirconium hydride fuel. The analysis effort was directed at two principal objectives:

1. Showing that LEU fuel with a high weight percent of uranium has a satisfactory prompt negative temperature coefficient.

2. Determination of core operating lifetime.

Calculations were accomplished through use of standard General Atomic nuclear analysis methods.

Table 1 shows the calculated prompt negative temperature coefficient and core lifetime for TRIGA-LEU fuels being marketed in 1978.

TABLE 1
CALCULATED BEGINNING OF LIFE PROMPT NEGATIVE TEMPERATURE COEFFICIENT (α) AND CORE LIFETIME

TRIGA Fuel Type	Diameter (in.)	Length (in.)	Wt-%		Uranium Enrichment (%)	x 10^{-5} = α Average (23-700°C)	Core Lifetime[a] (MW Days)
			U	Er			
Original	1.5	15	8.5	0.00	20	10	~100
LEU	1.5	15	20	0.50	20	11	1200
LEU	1.5	15	30	0.92	20	8	3000
FLIP	1.5	15	8.5	1.58	70	10	3500
10 MW	0.5	22	10	1.70	93	6	4800
10 MW-LEU	0.5	22	45	0.66	20	5	4000
14 MW	0.5	22	10	2.80	93	8	8000
14 MW-LEU	0.5	22	45	1.40	20	6	7000

[a] Before initial reload

4. FUEL FABRICATION TESTS (WITH DEPLETED URANIUM)

About 80 pieces of TRIGA-LEU fuel were fabricated and hydrided using standard production techniques. Samples were 30 and 45 wt-% U (depleted), with some samples containing up to 1.5 wt-% erbium. Most samples were nominal 0.5 in. diameter, but some were of the 1.5 in. nominal size. No significant differences from currently manufactured fuel were noted in the fabricability within this composition range.

5. METALLURGICAL EXAMINATION

Selected samples of the hydrided high wt-% LEU fuel were examined with the electron microprobe and subjected to metallographic and x-ray diffraction tests. The structure of the hydrided high wt-% fuel follows the normal pattern for standard TRIGA fuels. The grain structure, phase distribution, and homogeneity are all acceptable.

6. FISSION PRODUCT RELEASE

Fission gas release measurements were made on prototypic specimens from room temperature to 1100°C in the TRIGA King Furnace Facility. The furnace facility is designed for in-core irradiation of fuels up to temperatures of 2000°C. The fractional releases, under steady-state operating conditions, of the gaseous nuclides of krypton and xenon were measured as a function of temperature by operating the TRIGA reactor at a low power level and maintaining the desired fuel temperature through electrical resistance heating. Clean helium was used to sweep the fission gases released during irradiation from the furnace into a standard gas collection trap for gamma counting.

The results of these tests on TRIGA-LEU fuel agree well with data from similar, earlier tests on the original TRIGA fuel composition. The correlation used to calculate the release of fission products from TRIGA fuel, that is

$$\psi = 1.5 \times 10^{-5} + 3.6 \times 10^{3} e^{-1.34 \times 10^{4}/T}$$

where T = fuel temperature (°K)

remains applicable for the high uranium loaded (TRIGA-LEU) fuels as well as the 8.5 wt-% U-ZrH fuel for which it was originally derived.

The first term of this function is a constant for low-temperaature release; the second term is the high-temperature portion, where above 400°C the controlling mechanism is a diffusion-like process and is dependent on the fuel temperature.

The correlation applies to a fuel element which has been irradiated for a time sufficiently long that all fission product activity is at equilibrium and the release fraction is at its theoretical maximum.

7. PHYSICAL PROPERTIES

Measurements were made of the thermal diffusivity of uranium-zirconium hydride in which the uranium content was 8.5, 30, and 45 percent by weight. The data from these measurements, in conjunction with the best available data for density and specific heat, was used to determine the thermal conductivity of these materials.

The thermal conductivity so determined was found to be both independent of temperature and uranium content and is

$$k = 0.18 \pm 0.009 \text{ W/cm-°C}$$
$$= 0.043 \pm 0.002 \text{ cal/sec-cm-°C}$$

The temperature independence does not agree with measurements made by others. As an example, a value of $0.042 + 1.79 \times 10^{-5}T$ cal/sec-cm-°C has been used for several years for the thermal conductivity for design calculations on TRIGA fuel.

Two specimens of 45 wt-% uranium-zirconium hydride were thermally cycled over 100 times from room temperature to 800°C. The linear expansion as a function of temperature was measured with a dilatometer. Although a phase transformation takes place at about 650°C which results in an isothermal density change, a least square fit to the data from the first and last thermal cycle of both specimens showed a maximum deviation of measured values to the fit of less than 10%. From these measurements, the expansion coefficient for 45 wt-% $UZrH_{1.6}$ is

$$\varepsilon = 7.38 \times 10^{-6} + 15.1 \times 10^{-9} \; T \; (°C)^{-1} \; .$$

When compared with the previously used design value, the two values for the expansion coefficient differ by about 40% at 100°C (the new value is larger) and are equal at 700°C. From the two coefficients, the difference in the radial expansions of a fuel rod operating at a peak temperature of about 600°C would be about 0.01 mm for a 1/2-in.-diameter fuel element.

A very significant test result obtained as part of the thermal expansion measurement is that the material was found to be dimensionally stable in length when thermal cycled 100 times through the uranium phase change temperature of about 650°C. The results show that even for high uranium content, the ZrH matrix successfully stabilizes the material. Uranium metal would have elongated significantly in such a test. Some small changes in diameter at the ends of the test sample were noted but tentatively attributed to hydrogen loss at high temperature in the non-closed test environment.

The measurements of the thermal diffusivity and expansion of uranium-zirconium hydride containing high weight fractions of uranium show that these properties are relatively insensitive to uranium content. The thermal conductivity deduced from the thermal diffusivity measurements was independent of the temperature whereas other measurements indicate a strong temperature dependence. Although the difference between the thermal conductivity from the older data and the present (including low wt-% U) is about 20% at 600°C, this only translates to a difference in peak temperature in an operating reactor from 620°C to 670°C. Similarly, the difference in the thermal expansion between an 8.5 wt-% U-$ZrH_{1.6}$ and a 45 wt-% $UZrH_{1.6}$ fuel element operating at maximum temperature would be only about 0.01 mm for a 1/2-in.-diameter element.

The currently reported measurements are used to show that the wt-% of uranium in $UZrH_{1.6}$ has a small effect, if any, on the thermal conductivity or thermal expansion of the $UZrH_{1.6}$ for uranium contents up to 45 wt-%. The thermal conductivity measurements included fuel with an 8.5 wt-% uranium loading, equivalent to TRIGA fuels used for over 20 years and from which many fuel temperature measurements have been made. The currently reported measurements show essentially no difference in conductivity between the fuel with 8.5 wt-% uranium and the more recently developed highly loaded TRIGA-LEU fuel with 45 wt-% uranium. The conductivity derived from the measurements reported herein is within the range of previously reported data but slightly lower than has been used to this time for the design of TRIGA reactors.

Thermal linear expansion measurements were done in this program for only $UZrH_{1.6}$ with 45 wt-% uranium, and indicate a small increase in expansion characteristics compared with fuel with about 7 to 10 wt-% uranium.

8. HYDROGEN PRESSURE

An evaluation has been completed on hydrogen dissociation pressures in UZrH. The most significant results are:

1. Uranium-zirconium hydride fuel containing hydrogen at H/Zr ratios of 1.5 or greater is composed only of zirconium hydride and very nearly pure uranium.

2. The equilibrium hydrogen dissociation pressure of the fuel depends only on the H/Zr ratio and the temperature and is independent of the uranium content.

A verification of the second conclusion is obtained from the production hydriding process. Results from the manufacture of the 80 test samples indicate no discernable difference in the pressure-temperature relationship during the hydriding process for high weight percent fuel versus standard TRIGA fuel.

9. IN-PILE TEST PLANNING

The DOE-funded portion of this task consisted of preparing an application for a license amendment for the TRIGA Mark F reactor at General Atomic to allow testing of the TRIGA-LEU fuel containing up to 45 wt-% U, and planning the in-pile test programs. Actual in-pile testing has been funded by GA.

The license amendment was issued and testing of LEU fuel has been in progress in the TRIGA Mark F reactor since April 1978. The initial LEU program involved the addition to the core of two nominal 1/2-in.-diam LEU fuel elements (one with internal thermocouples) each with 45 wt-% U, 20% enriched. Later, a nominal 1-1/2-in.-diameter LEU fuel element (with 20 wt-% U, 20% enriched) was added. At this writing, these fuel elements are still undergoing tests, having successfully passed all previous phases of the test program. The Nuclear Regulatory Commission license for the Mark F reactor (R-67) permits up to a full core loading of LEU fuel elements with uranium loadings up to 45 wt-%.

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