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FUEL ELEMENT MANUFACTURED AND IRRADIATED AT BATAN, INDONESIA**

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POSTIRRADIATION EXAMINATION OF A LOW ENRICHED U_3Si_2 -Al FUEL ELEMENT MANUFACTURED AND IRRADIATED AT BATAN, INDONESIA

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ABSTRACT

The first low-enriched U_3Si_2 -Al dispersion plate-type fuel element produced at the Nuclear Fuel Element Center, BATAN, Indonesia, was irradiated to a peak ^{235}U burnup of 62%. Postirradiation examinations performed to date shows the irradiation behavior of this element to be similar to that of U_3Si_2 -Al plate-type fuel produced and tested at other institutions. The main effect of irradiation on the fuel plates is a thickness increase of 30-40 μm (2.5-3.0%). This thickness increase is almost entirely due to the formation of a corrosion layer (Boehmite). The contribution of fuel swelling to the thickness increase is rather small (less than 10 μm) commensurate with the burnup of the fuel and the relatively moderate as-fabricated fuel volume fraction of 27% in the fuel meat.

INTRODUCTION

Presently, the RSG GAS reactor fuel consists of low enriched (LEU) U_3O_8 dispersed in aluminum in the form of hot-roll-bonded plates with aluminum alloy cladding: This fuel has a maximum loading of 3.2 g cm^{-3} and is fabricated at BATAN.

Several years ago BATAN began a program to acquire the technology to fabricate U_3Si_2 dispersion fuel^[1], which would make it possible to increase the uranium loading in the fuel meat to 5 g cm^{-3} .

The fuel element (RI-SIE) was removed from the reactor core when the fuel had reached a ^{235}U depletion of approximately 50%. After an appropriate cooling period the element was γ -scanned at the reactor hot cell, and subsequently shipped to the BATAN RMI hot cell facility for detailed postirradiation examination.

This paper presents results of the non-destructive postirradiation examination of the first U_3Si_2 test element that consisted of 21 fuel plates with an uranium loading of 3.2 g cm^{-3} (equivalent to the current U_3O_8 fuel).

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Destructive examinations are in progress. Initial results of scanning electron microscopy on a cross-section of the plate shows that the fission gas bubble morphology and fuel-aluminum interaction are consistent with previous observations on U_3Si_2 -Al dispersion fuel irradiated at comparable burnup.

EXPERIMENTAL DATA

The as-built data of element RI-SIE-2 as recorded at the BATAN fuel element production installation (FEPI) are given in Table I. Data pertaining to the irradiation in the 30 MWth RSG GAS reactor is given in Table II.

TABLE I AS-BUILT PARAMETERS FOR PLATE IDA 0036 FROM ELEMENT RI-SIE-2	
Fuel Composition	U_3Si_2
Uranium Mass	59.99 g
Fuel Mass Loading	3.2 g U/cm^3
Fuel volume Fraction	27%
As-fabricated Porosity	2%
Meat Matrix	Al
Cladding	Al Mg2
Plate Thickness	1.32 mm
Meat Thickness	0.64 mm
Plate Length	625
Plate Width	70.70 mm
Meat Width	61.4 mm
Meat Length	570 mm

POST IRRADIATION EXAMINATION

Visual Inspection and Plate Removal

The element was visually inspected and photographed with a through-the-hot-cell-wall periscope at a magnification of 12X.

The overall appearance of the aluminum side plates and the two outer fuel plates was as expected. The cladding surfaces had the typical luster of irradiated aluminum having formed a thin layer of hydrated aluminum oxide (Boehmite). No blisters, pits or other evidence of cladding damage was found. A fuel plate from the center position in the element, identified as plate IDA 0036, was removed by milling a slit in the side plate through which the plate could be extracted. Visual inspection showed this plate to be in excellent condition.

TABLE II
IRRADIATION FOR ELEMENT RI-SIE-2

Time at Power	259 days
Total Weight	1259.63 grams
²³⁵ U	249.54 grams
Enrichment	19.81%
Burnup, ²³⁵ U Depletion	48.8%
Average Flux	$2.0 \times 10^{14} \text{ cm}^{-2}\text{S}^{-1}$
pH Coolant	6.5-7
Heat Flux	32.3 W cm^{-2}
Power Average	60 KW
Coolant Temperature	(in) 42°C (out) 54°C
Nominal	

γ-Scanning

A Ge-Li detector installed outside the hot cell was used to measure the axial γ activity of plate IDA-0036. The γ radiation is admitted to the detector through the cell wall by means of a 1.1 m long stainless steel collimator.

Complete γ energy spectra were obtained at 5 cm intervals along the length of the plate. The intensity of several characteristic peaks was determined by counting the total pulse height under a Gaussian distribution through the γ energy peaks, and by making the appropriate corrections for dead-time, background and compton scattering contributions. The result for some long half-life nuclide of interest are summarized in Table III.

These nuclides are formed by different reactions ¹³⁴Cs results from neutron capture in ¹³³Cs which it self is formed by ²³⁵U fission. However, ¹³⁷Cs is a product of ²³⁵U fission only, and with its long half-life best reflects the ²³⁵U depletion profile in the fuel plate. The different peaking factors for the axial profiles of these nuclides reflect the difference in neutron fluence dependence of their accumulated yields.

As mentioned before, γ-scanning was also performed on the entire element at the reactor facility. A Ge/Li detector was used there as well but with a more rapid scanning method by which simply the pulse height at the γ energy peak of interest is counted in addition to the gross count of the entire γ energy spectrum. Figure 1 shows a comparison of the two methods. The profiles of ²³⁷Cs are very similar owing to the fact that this higher energy peak is not much affected by compton contributions. The self shielding effect of the more massive element compared to a single plate results in a flatter distribution for the lower energy peak counts and the gross counts. The similarity in the ¹³⁷Cs results obtained from either singular plate or whole element indicates that the rapid scanning method of the element also yields a good representation of the burnup or ²³⁵U depletion profile.

TABLE III
GAMMA SCAN PROFILE PARAMETERS FOR ^{134}Cs AND ^{137}Cs
COUNTING TIME 3600 S DETECTOR GeLi

Nuclide	Energy keV	t 1/2	I Net Count	Peaking Factor I _{max} /I _{ave} .
^{134}Cs	604.7	2.07 years	90677	1.58
^{137}Cs	661.6	30.0 years	260627	1.26

Plate Thickness Measurements

Plate thickness was measured at 5 cm intervals along 3 axial tracks on the fuel plate with a thickness gauge having an accuracy of 0.005 mm. A "dummy" fuel plate was measured at the fuel manufacturing installation and in the hot cell facility to determine any systematic differences between the as-fabricated and post-irradiation measurement. Statistical evaluation of the comparative measurements indicated a difference of +30 μm between the two instruments. Accordingly, all hot cell measurements were decreased by 30 μm to reflect the true difference between pre- and postirradiation thickness data. The average values of the three axial tracks on plate IDA 0036 is plotted in Fig 2.

In lieu of detailed destructive examination results we have chosen to use previously accumulated data of $\text{U}_3\text{Si}_2\text{-Al}$ irradiations to analyze the thickness changes measured in the present test.

The maximum burnup in the plate was calculated by multiplying the total element burnup by the ^{137}Cs peaking factor:

$$\text{Bu}^{\text{max}} = 1.27 \times 49\% = 62\%$$

This burnup corresponds to an accumulative fission density in the U_3Si_2 fuel of $3.3 \times 10^{27} \text{ m}^{-3}$. From fuel swelling data obtained from previous experiments^[2] shown in Fig. 3 we

obtained an equivalent swelling $\frac{\Delta V^F}{V_0^F} = 12\%$. The fuel swelling is related to the meat swelling as follows.

$$\frac{\Delta V^F}{V_0^F} = \left[\frac{\Delta V^m}{V_0^m} + \frac{V_O^P - V^P}{V_0^m} \right] \frac{V_O^m}{V_0^F}$$

where V_O^P is the as-fabricated porosity in the meat (2% for this plate), V^P in the residual porosity not consumed by fuel swelling. This yields a value for $\frac{\Delta V^m}{V_0^m}$ of 1.0%. Since meat swelling is completely transferred to meat thickness increase, Δth^m , we obtained

$$\Delta th^m = 0.01 \times 0.64 \text{ mm} = 6 \text{ } \mu\text{m}$$

with the customary assumption that the cladding density remains unchanged, we obtained a plate thickness increase due to fuel swelling of 6 μm . This calculation can be performed for the entire axial profile which is indicated in Fig. 3. It appears that the swelling contribution to the plate thickness increase is rather small.

The difference between the total thickness increase and the fraction due to fuel swelling can be attributed to Boehmite formation, amounting to $\sim 30 \text{ } \mu\text{m}$. It has been verified that one half of the Boehmite layer thickness represents aluminum cladding consumed by the oxidation process. Thus the total Boehmite thickness is $2 \times 30 \text{ } \mu\text{m} \approx 60 \text{ } \mu\text{m}$, that is, $\sim 30 \text{ } \mu\text{m}$ on each side of the plate.

By comparison, Boehmite thickness observed on the same cladding alloy (Al Mg2) irradiated in the Oak Ridge Research reactor was $\sim 25 \text{ } \mu\text{m}$. A calculation of the Boehmite thickness using a correlation developed at Oak Ridge National Laboratory^[3] yields a value of $\sim 20 \text{ } \mu\text{m}$. Considering the accuracy of the measurements, the difference in operating conditions, and the difference of the coolant chemistry of the different reactors, the value of $\sim 30 \text{ } \mu\text{m}$ derived for the present test appears to be very reasonable.

CONCLUSION

The BATAN produced and tested LEU- U_3Si_2 -Al dispersion fuel element performed well to a peak ^{235}U depletion of 62%. Non-destructive postirradiation examination revealed no cladding damage or plate distortions and the fuel plate thickness increase was found to be consistent with that measurement in previous irradiation tests on similar fuel. the plate thickness increase is almost entirely due to Boehmite formation.

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REFERENCES

1. A Suario and S. Soentono, "Progress in the Development of Uranium Silicide (U_3Si_2 -Al) Fuel at BATAN," Proc. RERTR meeting, November 3-7, 1994, Jakarta, Indonesia (to be published).
2. G. L. Hofman, J. Rest, R. C. Bircher, and J. L. Snelgrove, "Correlation of Irradiation-Induced Microstructural Changes and Fission Gas Swelling in Uranium Compounds," Proc. of the 1990 International Meeting on Reduced Enrichment for Research and Test Reactors, ANL/RERTR/TM-18, Newport, Rhode Island, September 23-27, 1990.
3. J. C. Griess, et al., "Effect of Heat Flux on the Corrosion of Aluminum by Water, Part IV, ORNL-3514 (February 1964).

Figure 1

Figure 2

Figure 3