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PHASE III FUEL SAMPLE IRRADIATION

IRRADIATION REQUEST - ORNL - 21

I. Introduction

A series of in-pile fuel samples irradiation experiments were initiated in July of 1954 to obtain radiation damage information on fuel material similar to that specified for the Army Power Package Reactor. Phases I and II of the program have been described in previous reports^(1,2,3,4,5,6). This report will describe Phase III of the program. A Phase IV of the program will be initiated during the next fiscal year and will be described in a later report.

Phase III of the program was undertaken to determine the effect of the method of preparation of the uranium dioxide and various degrees of cold rolling upon the resultant radiation damage of the fuel plate.

1. ORNL CF 55-4-153, Neill, F. H. Irradiation of Stainless Steel Fuel Samples in MTR-Irradiation Request ORNL-21.
2. ORNL CF 55-4-163, Beaver, R. J. and M. J. Feldman, MTR Test #3 of APPR Fuel Element.
3. ORNL CF 55-5-106, Beaver, R. J., Corrosion Testing of Capsulated Sections from APPR Composite Stainless Steel-UO₂-B₄C Bearing Fuel Plates.

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II. Design and Fabrication

This phase of the experiment requires irradiating miniature fuel plates in the reflector of the MTR to approximately 40% burn-up of the U-235 atoms. The fuel plates consist of product level enrichment UO_2 particles uniformly dispersed and embedded in a matrix of stainless steel which is clad on all sides with wrought type 304L stainless steel. A small quantity of poison, in the form of B_4C , is added to the fuel bearing section (see Table I). Uranium dioxide is prepared by four methods and plates containing each type are processed to three degrees of cold reduction.

The following subsections describe the essential parameters of the method of preparation of each type of uranium dioxide:

1. Type A: Reduction of burned chips.
 - a. Chips burned to U_3O_8 .
 - b. Sifted to remove #235 mesh fraction.
 - c. Reduced to UO_2 at 1100°C for two hours.
 - d. Sintered at 1800°C for one hour.
2. Type B: Hydrogen peroxide precipitated.
 - a. Peroxide precipitation of nitrate solution.
 - b. Reduced to UO_2 at 900°C for four hours.
 - c. Sintered at 1800°C for one hour.

-
4. ORNL CF 55-6-47, Beaver, R. J., Testing of APPR Type UO_2 -Stainless Steel Elements in the MTR.
 5. ORNL CF 55-6-31, Beaver, R. J., Specifications of Stainless Steel MTR Irradiation Test Elements.
 6. ORNL CF 55-6-39, Cunningham, J. E., Revision on MTR Irradiation Request ORNL-17.

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3. Type C: Steam oxidation of metal.

- a. Steam oxidation of chips at 350° C.
- b. Heated to 900° C in hydrogen atmosphere.
- c. Sintered at 1800° C for one hour.

4. Type D: Reduction of uranium trioxide.

- a. Peroxide precipitation of nitrate solution.
- b. Converted to $\text{UO}_3 \cdot \text{H}_2\text{O}$ in autoclave at 250° C for nine hours.
- c. Converted to UO_2 at 950° C for 30 minutes.
- d. Sintered at 1700° C for two hours.

Representative photomicrographs of each type of oxide used in this experiment are shown in Figures 1 through 4.

Each core was cold pressed at 30.2 tsi after blending, sintered in a dry hydrogen atmosphere for one hour at 1150° C, and coined to final size at 30.2 tsi. The cores were cylindrical in shape, having a 5/16 inch diameter and a nominal height of 0.276 inches.

The plates were hot rolled at 1150° C from a billet thickness of 0.366 inches to a nominal plate thickness of 0.040 inches. One fuel containing each type oxide was given 10% cold reduction; a second set of plates was given 30% cold reduction; and the third set retained in the as-hot rolled condition.

The fuel plate composition is indicated in the following table.

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Figure 1
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Type A Oxide: Reduction of Burned
Chips

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Figure 2
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Type B Oxide: Hydrogen Peroxide
Precipitated

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Figure 3
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Type C Oxide: Steam Oxidation of
Metal

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Figure 4
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Type D Oxide: Reduction of Uranium
Trioxide

TABLE I

FUEL PLATE COMPOSITION

1. Core Composition:

17.92 w/o UO_2 , 44-88 μ -particle size range.

0.19 w/o B_4C , minus 325 mesh particle size.

81.89 w/o high silicon type 304 prealloyed stainless steel, minus 100 mesh particle size.

2. Uranium Loading per Plate:

0.34 grams of U-235

0.42 grams of UO_2

The finished overall core and plate dimensions are given in the following table.

TABLE II

FINISHED OVERALL CORE AND PLATE DIMENSIONS

Plate Identification Code	Core Width (in.)	Core Length (in.)	Overall Plate Width (in.)	Overall Plate Length (in.)	Overall Plate Thickness (in.)
A 0	0.313	2.563	0.875	4.0	0.040
A10	0.313	2.844	0.875	4.0	0.036
A30	0.313	3.594	0.875	4.5	0.028
B 0	0.313	2.656	0.875	4.0	0.039
B10	0.313	2.906	0.875	4.0	0.035
B30	0.313	3.813	0.875	4.5	0.027
C 0	0.313	2.531	0.875	4.0	0.040
C10	0.313	2.906	0.875	4.0	0.035
C30	0.313	3.813	0.875	4.5	0.027
D 0	0.313	2.594	0.875	4.0	0.039
D10	0.313	2.813	0.875	4.0	0.036
D30	0.313	3.594	0.875	4.5	0.028

The minimum cladding thickness in any plate is 0.004 inches.

The identification code consists of two parts: A letter to designate the type of contained oxide (refer to section on oxide preparation), and a number to designate the percentage of cold reduction.

III. Time of Irradiation

For the results to be most meaningful, it is necessary that all samples be irradiated to the same total nvt and in addition all samples should be exposed to the radiation field for approximately the same length of time. It is suggested that if it is not possible to irradiate all the samples at an equal flux then they should be rotated periodically during the irradiation in order to fulfill the latter requirement.

The estimated nvt required for 40% burn-up is determined as follows:

$$dN/dt = -N \phi \alpha \sigma \quad (1)$$

where N = number of U-235 atoms per unit volume (cm^{-3})

σ = absorption cross section of U-235 (cm^2)

ϕ = unperturbed flux (neut/ cm^2 -sec)

α = reciprocal of the disadvantage factor (0.80)

t = time (seconds)

Solving Equation (1)

$$N(t) = N(0)e^{-\alpha\phi t\sigma} \quad (2)$$

or

$$\text{Burn-up} = \frac{N(t)}{N_0} = e^{-\alpha\phi t\sigma} \quad (2a)$$

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Assuming an average reflector temperature of 125° F, the absorption cross section for U-235 is

$$\sigma_a = (602.7 \times 10^{-24}) \left(\frac{293^\circ \text{K}}{327^\circ \text{K}} \right) = 569 \times 10^{-24} \text{ cm}^2 \quad (3)$$

Then solving equation for total integrated flux the required nvt is:

$$\text{nvt} = 1.12 \times 10^{21}$$

Assuming 60% operation and a flux of 1×10^{14} neut/cm²-sec in the reflector the estimated irradiation time is:

$$\frac{1.12 \times 10^{21}}{(1.0 \times 10^{14})(3600)(24)(0.60)} = 216 \text{ days} \quad (4)$$

IV. Estimated Heat Generation

The power generation in the fuel sample is given by

$$P = 0.45 \times 10^{-10} M_f \phi \quad (5)$$

where P = total power per sample (watts)

M_f = mass of U-235 (grams)

ϕ = thermal flux (neut/cm²-sec)

Substituting in Equation (5) and assuming a flux of 1×10^{14}

$$\begin{aligned} P &= (0.45 \times 10^{-10})(0.34)(1 \times 10^{14}) \\ &= 1.53 \times 10^3 \text{ watts} \end{aligned}$$

The thermal flux is given by:

$$\frac{q}{A} = \frac{492P}{A} \quad (6)$$

where A = total surface area over core (in.²)

$\frac{q}{A}$ = thermal flux (Btu/hr-ft²)

Substituting in Equation (6)

$$\frac{q}{A} = \frac{492 \times 1.53 \times 10^3}{1.092 \times 2}$$

$$= 3.44 \times 10^5 \text{ Btu/hr-ft}^2$$

The gamma heating can be estimated from Ref. 7. For this sample weight it will be 15 watts for a typical (A-33) reflector location. As this is insignificant compared to fission heat it is omitted.

F. H. Neill
F. H. Neill

R. C. Waugh
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FHNeill:vj
April 12, 1954

7. IDO-16093, Hogg, C. H., Gamma Heating Measurements in the MTR.

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