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IRRADIATION REQUEST ORNL-MTR-28

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FROM: F. H. Neill and C. F. Leitten, Jr.

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For The Atomic Energy Commission

H. R. Canale
Chief, Declassification Branch

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PHASE I ABSORBER ROD SAMPLE IRRADIATION
IRRADIATION REQUEST ORNL-MTR-28

I. Introduction

In order to evaluate the radiation damage to be expected in the APPR-1 absorber rods, a series of irradiation tests have been initiated. This report will cover Phase I of the testing program.

For the initial test, Five (5) samples have been prepared, each have a densification and boron loading identical to that specified for the APPR. Future samples will be fabricated with approximately 60% and 120% of designed boron loading. It is the specific purpose of this experiment to determine the radiation damage as a function of the burn-up and the boron loading of the specimen. Table I indicates the test conditions for the Phase I samples.

TABLE I⁽¹⁾

TESTING SCHEDULE

<u>Sample No.</u>	<u>Plate Identification</u>	<u>Burn-up of B-10 Atoms Atom Percent</u>
1	1	20
2	5	40
3	6	60
4	7	80
5	8	90

II. Design and Fabrication of Samples

As indicated in Table I, this phase of the experiment requires irradiating miniature absorber plates in the beryllium reflector of the MTR to varying

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1. ORNL CF 56-4-160, Beaver, R. J., Minutes of Meeting held at Oak Ridge National Laboratory, April 19, 1956, on APPR-1 Control Rod Program.

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degrees of B-10 atom burn-up. These plates consist of enriched B-10 powder uniformly dispersed in an iron matrix and roll clad on all sides with type 304L stainless steel.

The overall starting frame thickness was one inch. Initially, the billet contained four evenly spaced stacks of three cores. The cores were cold pressed at 30 tsi after blending, sintered in a dry hydrogen atmosphere for one-half hour at 2050° F, and coined to final dimensions at 30 tsi. The cores were cylindrical in shape having a 1/2-in. diameter and a nominal height of 0.333 in.

The miniature plates were hot rolled at 1100° C from a billet thickness of 1.632 in. to a nominal plate thickness of 0.156 in. Reductions of 10% per pass and a single rolling direction were used. This rolling procedure is identical to the established APPR-1 absorber plate fabrication.

The absorber plate composition is indicated below in Table II.

TABLE II

ABSORBER PLATE COMPOSITION

1. Core Composition:

3.03 w/o boron; 100%-100 mesh, 90%-200 mesh range

96.83 w/o electrolytic iron; minus 100 mesh particle size

2. Boron-10 loading per plate:

0.618 gms of boron

0.574 gms of B-10

The finished overall core and plate dimensions are given in Table

III.

TABLE III

FINISHED OVERALL CORE AND PLATE DIMENSIONS

<u>Plate Identifi- cation</u>	<u>Maximum Core Width (in.)</u>	<u>Nominal Core Length (in.)</u>	<u>Overall Plate Width (in.)</u>	<u>Overall Plate Length (in.)</u>	<u>Overall Plate Thickness (in.)</u>	<u>Minimum Edge SS (in.)</u>	<u>Minimum End SS (in.)</u>
1	0.516	4.313	1.000	6.594	0.157	0.219	0.391
5	0.516	4.438	1.000	6.563	0.156	0.219	0.344
6	0.516	4.438	1.000	6.563	0.156	0.234	0.359
7	0.516	4.469	1.000	6.609	0.155	0.219	0.453
8	0.516	4.469	1.000	6.609	0.155	0.234	0.469

The nominal core-clad thicknesses are 0.090 and 0.033 inches, respectively.

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III. Length of Irradiation

The estimated exposure required in the MTR to achieve the burn-up shown in Table I is indicated on Fig. 1. The method of calculation is indicated in Appendix A. The number of cycles and months of in-pile time shown on the abscissa of Fig. 1 are only approximate as the MWD per cycle varies between cycles.

IV. Heat Generation in Samples

The principal source of heat generation in the absorber section samples results from the following reaction:

From Equation (A-7) in Appendix A and from Fig. 2 the thermal neutron current into the sample (J_+) can be determined as a function of flux.

Since the sample is black to thermal neutrons, the neutron current will initially represent the number of reactions shown in Equation (1).

The heat flux from the sample can be written as:

$$\frac{Q}{A} = CJ_+ E_R \quad (2)$$

where E_R = energy release given in Equation (1).

For a typical example assume a flux of 1×10^{14} . Then the heat flux is given by:

$$\begin{aligned} \frac{Q}{A} &= (0.4 \times 10^{14} \frac{\text{Neut}}{\text{cm}^2 \text{ sec}})(2.792 \text{ Mev}) \frac{1.65 \times 10^{-13} \text{ watt-sec}}{\text{Mev}} \frac{92.9 \text{ cm}^2}{\text{ft}^2} \frac{3.413 \text{ Btu}}{\text{watt-hr}} \\ &= 584 \frac{\text{Btu}}{\text{hr-ft}^2} \end{aligned}$$

TABLE IV

HEAT FLUX FROM ABSORBER SAMPLE

<u>Unperturbed Thermal Neutron Flux Neut/cm² sec</u>	<u>Heat Flux Btu/ft²-hr</u>
1×10^{14}	584
2×10^{14}	1164
3×10^{14}	1752
4×10^{14}	2336

IV. Sample Holder

The absorber samples are mounted individually in open aluminum tubes which are 1-1/8" O.D. - 0.058 wall with an overall tube length of 7". Each tube is numbered corresponding to the number of the sample it contains. The sample numbers are indicated in Table I.

APPENDIX A

Estimate of Burn-Up

In order to estimate the burn-up in the absorber samples the following model is used.

The absorber sample is assumed to be a sphere of radius "a" which is black to thermal neutrons. It is located in an infinite medium of reflector material in which there is an established fast neutron flux.

The neutron diffusion in the reflector volume is given by:

$$-D \nabla^2 \phi_{th} + \sum_a \phi_{th} = S \quad (A-1)$$

where S is the source term.

Solving Equation (A-1) for the flux

$$\phi(r) = \frac{A}{r} e^{-Kr} + \frac{S}{\sum_a} \quad (A-2)$$

and

$$\frac{d\phi}{dr} = - \frac{Ae^{-Kr}}{r^2} (Kr + 1) \quad (A-2a)$$

The first boundary condition to be satisfied is that the outward current (J_+) at the interface (a) is zero

$$J_+(a) = \frac{\phi(a)}{4} - \frac{D}{2} \left(\frac{d\phi}{dr} \right)_a = 0 \quad (A-3)$$

Combining Equations (A-2), (A-2a), and (A-3)

$$A \left[\frac{e^{-Ka}}{4a} + \frac{De^{-Ka}}{2a^2} (Ka + 1) \right] = - \frac{S}{4 \sum_a} \quad (A-4)$$

Solving for A

$$A = - \frac{\frac{S}{\Sigma_a}}{\frac{e^{-Ka}}{a} \left[1 + \frac{2D}{a} (Ka + 1) \right]} \quad (A-5)$$

The inward current $J_-(a)$ can now be calculated:

$$J_-(a) = -D \left(\frac{d\phi}{dr} \right)_a$$

$$= -DA \left[\frac{e^{-Ka}}{a^2} (Ka + 1) \right] \quad (A-6)$$

$$= -D \left[\frac{\frac{S}{\Sigma_a}}{\left[\frac{1}{a} + \frac{2D}{a^2} (Ka + 1) \right]} \right] \left[\frac{Ka + 1}{a^2} \right]$$

$$= - \frac{S}{\Sigma_a} \left[\frac{D(Ka + 1)}{a + 2D(Ka + 1)} \right] \quad (A-7)$$

The reflector material of the model is the same as that in the MTR which is assumed to be 98% Be and 2% water. With this assumption it is possible to calculate the nuclear constants.

$$D = 0.696 \text{ cm}$$

$$L^2 = 455 \text{ cm}^2$$

$$K = 0.047 \text{ cm}^{-1}$$

$$\Sigma_a = 0.00153 \text{ cm}^{-1}$$

The source term (S) in Equation (A-7) can be determined by writing the diffusion equation in the reflector of the MTR:

$$-D \nabla^2 \phi_{th}^R + \Sigma_a \phi_{th}^R = S$$

For distances in the order of the beryllium irradiation holes, the flux fall-off is nearly linear, hence

$$D \nabla^2 \phi_{th}^R \approx 0$$

or

$$S = \sum_a \phi_{th}^R \quad (A-8)$$

where ϕ is assumed to be the unperturbed flux in the reflector.

Solving for the current into the sphere per unit area from Equation (A-7):

$$\begin{aligned} J_+ &= \frac{S}{\sum_a} \left[\frac{D(Ka + 1)}{a + 2D(Ka + 1)} \right] \\ &= \frac{S}{0.00153} \left[\frac{0.696 [(0.047)(1.198) + 1]}{1.198 + (2)(0.696) [(0.047)(1.198) + 1]} \right] \\ &= \frac{S}{0.00153} (0.395) \\ &= 0.395(\phi)_\phi \end{aligned}$$

The inward current is shown in Fig. II as a function of unperturbed flux.

To calculate the burn-up of the boron in the samples as a function of time in the MTR, the following sample specifications are used for the core of 3.4% B-10 and 90% densification:

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Thickness of sample matrix	$\ell = 0.2413 \text{ cm}$
Loading of enriched boron	3.4 w/o
Loading of B-10	3.03 w/o
Void volume in matrix	10%
Density of boron	$d_B = 2.3 \text{ g/cc}$
Density of B-10	$d_{B-10} = 2.05 \text{ g/cc}$
Density of iron	$d_{Fe} = 6.9 \text{ g/cc}$
Density of matrix	$d_M = 6.06 \text{ g/cc}$

Number of B-10 atoms per cc

$$\begin{aligned} N(0) &= \frac{A_O d}{A} \\ &= \frac{(0.603 \times 10^{24})(0.0303)(6.06)}{10} \quad (A-9) \\ &= 1.12 \times 10^{22} \text{ atoms/cc} \end{aligned}$$

The total number of B-10 atoms per unit area of longitudinal cross section is given by:

$$\begin{aligned} N_T(0) &= \ell N(0) \quad (A-10) \\ &= (0.2413)(1.12 \times 10^{22}) \\ &= 0.270 \times 10^{22} \text{ atoms/cm}^2 \end{aligned}$$

Burn-up is defined as:

$$\text{B.U.} = \frac{N(0) - N(t)}{N(0)} \quad (A-11)$$

The number of B-10 atoms destroyed per unit area of longitudinal cross section as a function of time is given by:

$$\ell [N(0) - N(t)] = 2 [(J_+ - J_-)t] \quad (A-12)$$

and,

$$J_- = J_+ R \quad (A-13)$$

where,

$$R(t) = \frac{1}{1 + \alpha} \left[\alpha e^{-\alpha} + (2 - \alpha^2) \int_0^1 e^{-d/x} x dx \right] \quad (A-14)$$

$$\alpha = \sum_a \ell$$

The derivation and graphical solution of Equation (A-14) is given in Reference (2).

Combining Equations (A-12) and (A-13)

$$\ell [N(0) - N(t)] = 2 [J_+ (1 - R) t] \quad (A-15)$$

or burn-up from Equation (A-11) is given by:

$$B.U.(t) = 2 \left[\frac{J_+ (1 - R) t}{N(0) \ell} \right] \quad (A-16)$$

FHNeill:vj
June 27, 1956

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2. ORNL CF 56-5-6, Gross, E. E. and F. H. Neill, Test of APPR Type Control Rod in the MTR.

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FIGURE I
Boron-10 Burn-Up
MTR IRRADIATION TEST

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ORNL-LE-DWG.-14882

FIGURE II
NEUTRON CURRENT INTO ABSORBER SAMPLE

EUGENE DIETZGEN CO.
MADE IN U. S. A.

NO. 340/ 20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH

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