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ETR FLUX MEASUREMENTS FOR
CYCLES 51B AND 54

MASTER

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PETROLEUM
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ATOMIC ENERGY DIVISION

NATIONAL REACTOR TESTING STATION
US ATOMIC ENERGY COMMISSION

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U. S. ATOMIC ENERGY COMMISSION

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ETR FLUX MEASUREMENTS FOR
CYCLES 51B and 54

L. D. Weber and C. H. Hogg

A B S T R A C T

The thermal-neutron fluxes in the lattice positions and selected experimental positions of the ETR were measured for Cycle 51B. Gamma heat generation measurements were also measured in various experimental positions for Cycles 51B and 54. Vertical traverses for each position monitored are shown.

Addendum for IDO-16894

The dates of the cycles are:

51B   Dec. 9, 1962 - Jan. 7, 1963

54   Mar. 31, 1963 - May 13, 1963

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ETR FLUX MEASUREMENTS FOR CYCLES 51B and 54

L. D. Weber and C. H. Hogg

I. Introduction

At the beginning of Cycle 51B a complete thermal-neutron flux mapping of the ETR lattice positions and several experimental positions was made. Fast-flux measurements were made in four lattice positions. Also, the gamma heat generation was measured in various experimental positions for Cycles 51B and 54. Summaries of the thermal- and fast-flux data and the gamma heat generation are shown in Figures 1, 2, and 3, respectively. Data from previous ETR flux measurements are tabulated in references 1, 2, 3, 4, 5, 6, and 7. A brief discussion of the basic theory and the experimental procedures will be given.

II. Basic Theory

The average thermal-neutron flux in which a thin sample has been irradiated may be calculated from the activation equation

$$D \text{ (d/s/mg)} = N \sigma nv(1 - e^{-\lambda t})$$

where D is the specific disintegration rate of the sample at termination of irradiation in a thermal flux, nv, for a time, t, σ is the cross section (2200 m/sec), λ is the decay constant, and N is the number of atoms per milligram of monitor wire. When t is small compared to the half-life, as is usually the case with Co^{60} , $(1 - e^{-\lambda t}) = \lambda t$ and $D = N \sigma nv \lambda t$. Solving for nv, we have $nv = D/\sigma N \lambda t$ as the basic equation for calculating thermal flux from irradiated cobalt.

The method of measuring fast-neutron flux is based on the activities induced in threshold detectors when irradiated in a fast-neutron flux. The fast flux is also calculated from the above activation equation with the proper changes.

$$D = \frac{N \bar{\sigma} nv (1 - e^{-\lambda t})}{0.692}$$

D, N, λ , and t are defined as above and the constant 0.692 is the fraction of neutrons in a fission spectrum having energies above 1 MeV, nv is the flux above 1 MeV neutron energy assuming that the neutron energy spectrum in the ETR has a fission neutron spectrum shape down to 1 MeV, and $\bar{\sigma}$ is the cross section of the threshold detector averaged over a fission-neutron spectrum.

The gamma heat generation measurements are based upon the ionization produced in a small cavity in a large mass of absorbing material being transversed by gamma rays. The ionization J, in ion pairs per cm³-sec in a small cavity is given by $J = \Delta E / WP$, where ΔE is the gamma-ray energy absorbed in the medium in ev per cm³-sec; W is the average energy expended per ion pair formed in the gas, and P is the stopping power of the medium relative to that of the gas for the secondary electrons, i.e., an electron will lose the same energy in traveling Δx cm in the medium, or $P \Delta x$ cm in the gas of the cavity. It is only required that the medium (e.g., graphite, bakelite) be thick enough (a few mm) to establish equilibrium between the primary photons and their secondary electrons.⁽⁹⁾ In an ideal thimble chamber, and if all ions formed are collected

$$\begin{aligned} 1 \text{ r/sec} &= 1/(3 \times 10^9) \text{ coulombs/sec} \cdot \text{cc std air} \\ &= 3.33 \times 10^{-10} \end{aligned}$$

and

$$1 \text{ r/hr} = 0.926 \times 10^{-13} \text{ amps/cc of std air}$$

and if

$$1 \text{ r/hr} = 83.8 \text{ ergs/gm}$$

in the air, then

$$1 \text{ watt/gm} = 4.3 \times 10^8 \text{ r/hr}$$

III. Experimental Procedures

The fuel loading for Cycle 51B contained 51 new 400-gm elements. The loading arrangement is shown in Fig. 4.

The thermal-neutron flux was measured using pure cobalt wires (40 mil. dia.). The induced Co⁶⁰ gamma-ray activity in the wires was counted on the MTR wire scanner. The cobalt wires irradiated in the fuel elements were fastened to aluminum wands to position them as near as possible to the center of the element and to prevent them from moving during the irradiation period. The pure cobalt wires were placed in flux monitor holders and then placed in the solid flow restrictors in the experimental positions (Fig. 5).

The fast flux was measured in four fuel positions using pure nickel wire (20 mil. dia.). The induced Co⁵⁸ gamma-ray activity in the wires was counted in a gross count ionization chamber.

The gamma heat generation was measured with a graphite-CO₂ walled ionization chamber (Fig. 6). The chambers were inserted into the

desired experimental positions through empty aluminum tubes from the open top of the reactor. The chambers were raised or lowered in the tubes to make a vertical traverse of the heat generation in each position.

All the measurements were made at low reactor power (1 Mw) and extrapolated to full power (175 Mw).

IV. Experimental Data

The neutron velocity adopted for reporting thermal-neutron fluxes in this report is the most probable velocity (2200 m/sec) of a room temperature Maxwell-Boltzman distribution. Since 40 mil. dia. pure cobalt wire is not "thin" to thermal neutrons, a factor of 1.18 was applied to the data for the self-absorption and flux-depression effects.⁽⁸⁾

The epi-cadmium contribution to the total Co^{60} activity (13%) has been subtracted in calculation of the data for positions within the lattice area. A 5% correction has been made on data for positions in the Al reflector area.

A thermal activation cross section of 36.3 ± 1.5 b and a half-life of $5.27 \pm .06$ y for cobalt was used in calculation of the data.

The fast-neutron fluxes reported are for neutrons greater than 1 MeV in energy assuming a fission neutron spectrum shape. A cross section ($\bar{\sigma}$) of 90 mb averaged over a fission neutron spectrum was used for the threshold reaction $\text{Ni}^{58}(n,p)\text{Co}^{58}$.

The gamma heat generation values are given in watts/gram of graphite. CO_2 gas was used in the cavity of the chamber since it is not affected by neutrons. A value of 32.5 ev per ion pair was used to calculate the energy absorption in CO_2 as applied in the Bragg-Gray Cavity Theorem⁽⁹⁾. Although this chamber may be gamma energy dependent when used in air, it is believed that this causes little error when used in the dense medium of the reactor lattice or reflector. The chamber wall was made thick enough to stop the Al ^{28} betas from the facility liners. Since the chamber is not sealed, corrections for pressure and temperature were made.

A summary of the thermal-neutron flux data is shown in Fig. 1 and the vertical traverses in Appendix I. The four fast-neutron flux traverses are found in Appendix II. The gamma heat generation summaries are shown in Fig. 2 for Cycle 51B and in Fig. 3 for Cycle 54. The vertical traverses for the gamma heat generation measurements are shown in Appendix III for Cycle 51B and in Appendix IV for Cycle 54.

REFERENCES

1. C. H. Hogg, L. D. Weber, and M. W. Echo, Gamma Heat Generation in the ETR, IDO-16519 (1959).
2. L. D. Weber and C. H. Hogg, ETR Thermal Neutron Flux Measurements, IDO-16531 (1959).
3. C. H. Hogg and L. D. Weber, ETR Cycle 18 Thermal and Fast Neutron Flux Measurements IDO-16563 (1961).
4. C. H. Hogg and L. D. Weber, ETR Fast Neutron Flux Measurements, IDO-16535 (1960).
5. L. D. Weber and C. H. Hogg, ETR Thermal Neutron Flux Measurements for Cycle 27, IDO-16719 (1961).
6. L. D. Weber and C. H. Hogg, ETR Gamma Heat Generation Measurements for Cycles 27, 33, and 34, IDO-16653 (1961).
7. L. D. Weber and C. H. Hogg, ETR Fast Neutron Flux Measurements for Cycle 27, IDO-16728 (1962).
8. C. H. Hogg, Thermal Neutron Flux Measurements at the MTR-ETR Site, IDO-16538 (1960).
9. R. D. Evans, The Atomic Nucleus, pp. 721-725, McGraw-Hill Book Company (1955).

	E	F	G	H	I	J	K	L	M	N
5		1.39 1.00 1.39	1.72 1.21 1.36		1.78 1.28 1.39		1.86 1.39 1.34	1.83 1.40 1.31	2.00 1.51 1.32	
6	1.31 .95 1.37			2.09 1.50 1.39		1.85 1.40 1.32				1.95 1.45 1.35
7	1.19 .89 1.34				2.73 2.05 1.33			2.62 1.91 1.37		2.28 1.69 1.35
8	1.43 1.06 1.35			2.86 2.10 1.36		3.35 2.45 1.37	3.19 2.37 1.35		2.66 1.90 1.40	2.41 1.74 1.39
9		1.36 1.03 1.32		2.93 2.20 1.33		3.76 2.75 1.37		2.79 1.98 1.41		
10	1.29 .95 1.36		2.08 1.56 1.33		2.97 2.13 1.39		2.77 2.04 1.36		2.34 1.65 1.42	
11		1.61 1.18 1.37		2.75 2.02 1.36		2.69 1.97 1.36		2.26 1.66 1.36		2.39 1.75 1.37
12	1.37 1.01 1.36			2.96 2.16 1.38	3.21 2.33 1.38		1.99 1.46 1.36		2.16 1.59 1.36	2.18 1.58 1.38
13	1.38 1.01 1.37					2.35 1.74 1.35		1.84 1.38 1.33		1.59 1.21 1.31
14		1.65 1.20 1.37	2.09 1.48 1.41	2.32 1.65 1.40	2.38 1.73 1.37		1.90 1.43 1.33	1.72 1.29 1.33	1.52 1.14 1.33	

Facility

Peak Thermal nv (2200 m/sec) $\times 10^{-14}$
 Average Thermal nv (2200 m/sec) $\times 10^{-14}$
 Peak To Average Ratio

Control Shim

NV > 1 mev

E-12 2.5×10^{14}
 I-7 5.8×10^{14}
 K-10 5.8×10^{14}
 N-11 4.4×10^{14}

PPCo-B-4813

Fig. 1 - A summary of the peak and average thermal fluxes, the peak-to-average ratio, and the fast fluxes measured in Cycle 51B.

Fig. 2 - A summary of the gamma heat generation measurements for Cycle 51B.

Fig. 3 - A summary of the gamma heat generation measurements for Cycle 54.

PPCo-C-4811

FLUX MONITOR HOLDER

SOLID FLOW RESTRICTOR

ALUMINUM EXPERIMENTAL PIECE

Fig. 5 - A diagram showing a typical experimental piece, solid flow restrictor, and flux monitor holder.

Fig. 6 - A graphite-CO₂ ionization chamber used to make gamma heat generation measurements.

APPENDIX I

APPENDIX II

APPENDIX III

APPENDIX IV

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