SECRET
SECURITY INFORMATION

ORNL-1398
Reactors-Research and Power

5a

RECALIBRATION OF THE X-10 STANDARD GRAPHITE PILE

[redacted]

OAK RIDGE NATIONAL LABORATORY · U.S. ATOMIC ENERGY COMMISSION

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
CARBIDE AND CARBON CHEMICALS COMPANY
A DIVISION OF UNION CARBIDE AND CARBON CORPORATION

UCC

POST OFFICE BOX P
OAK RIDGE, TENNESSEE

SECRET
SECURITY INFORMATION

ORNL 1398

[redacted]

This document consists of 9 pages. No. 5 of 158 copies, Series A.

PHYSICS DIVISION

Contract No. W-7405-eng-26

RECALIBRATION OF THE X-10 STANDARD GRAPHITE PILE

DECLASSIFIED Per Letter Instructions Of AEC 8-5-53

W. C. Brown for SUPERVISOR CENTRAL FILES ORNL 9/10/53

E. D. Klema, R. H. Ritchie and G. McCammon

Date Issued: OCT 17 1952

OAK RIDGE NATIONAL LABORATORY
operated by
CARBIDE AND CARBON CHEMICALS COMPANY
A Division of Union Carbide and Carbon Corporation
Post Office Box P
Oak Ridge, Tennessee

[redacted] to an unauthorized person is prohibited.

[redacted]

RECALIBRATION OF THE X-10

STANDARD GRAPHITE PILE

Abstract

The thermal neutron flux in slot number 11 of the X-10 standard graphite pile has been measured by counting the γ-rays from activated gold foils with a sodium iodide scintillation counter of known efficiency.

Because of an indicated discrepancy in the calibration of the X-10 standard graphite pile as compared with the standard piles of other laboratories,[1] the X-10 pile has been recalibrated by a different method from that of the previous calibration.[2]

In the present experiment slot number 11, 115 cm. from the neutron source, in which the cadmium ratio as measured with indium foils is > 300, was recalibrated by counting the γ-rays from a gold foil exposed for several days in that slot with a sodium iodide scintillation counter of known efficiency.

Gold foils are particularly suitable for such absolute measurements since the Au^{198} decays almost exclusively by the γ-ray at 411 kev.[3] Thus if one counts a gold foil with a counter of known efficiency for this energy γ-ray, he can determine the absolute disintegration rate of the active atoms in the foil. The aluminum foil holder used in this work was

---

1. Alan D. Conger and Norman H. Giles, Jr., ORNL-409, p. 12. (From Table 1, the thermal flux in the treatment box was measured as 1) 1.09×10^9 neutrons/cm^2/sec from the Oak Ridge Standard Pile calibration, or 2) 1.29×10^9 from the Argonne thermal column calibration.)

2. T. Arnette and H. Jones, CP-2804.

3. A. R. Brosi, B. H. Ketelle, H. Zeldes and E. Fairstein, Phys. Rev. 84, 586 (1951).

sufficiently thick to stop the beta particles from the gold.

The efficiency of the NaI scintillation counter, employing a crystal 1-1/2 inches in diameter and 1 inch long with a 5819 photomultiplier, was determined by β-γ coincidence counting as follows. A small sample of gold was irradiated in the X-10 graphite reactor and counted in the β-γ coincidence counter of the ORNL Chemistry Division to establish its absolute disintegration rate. This sample was then measured in the high-pressure ionization chamber of the Chemistry Division in order to calibrate the chamber. The use of the intermediate step of the high-pressure ion chamber was necessary since the round 1-mil gold foils used in the calibration of the standard pile, being 1-1/4 inches in diameter, were too large for absolute β-γ counting.

The NaI counter was then calibrated by measuring an active 1-1/4 inch gold foil in the high-pressure ion chamber and counting it on the NaI counter. In the final measurements, a calibration of the NaI counter was made on the same day on which the foil exposed in slot number 11 was counted. The calibration of the high-pressure ion chamber remains very constant with time, and it can be used to calibrate other counters at any time. The half-life of the measured activity was checked on both the high-pressure ion chamber and the NaI counter to make sure the correct activity was being observed.

The absolute disintegration rate of the gold foil exposed in slot number 11 was obtained by counting on the NaI counter as described above. The calculated saturated activity needs to be corrected only for the perturbing effect of the foil on the thermal neutron flux. Bothe[4] has developed a correction for self-protection and perturbation effects using diffusion theory. More recent work by T. H. R. Skyrme[5] utilizes transport theory. He considers an infinite isotropically scattering medium throughout which thermal neutrons are produced uniformly. The introduction of a circular foil of radius a and thickness τ (units of mean free path in the foil) into the medium is considered to introduce an equivalent negative disc source of zero thickness, radius a, and strength equal to the number of captures taking place in the foil. The effect of this negative source upon the flux at the foil is then found and the average reduction in the number of captures in the foil is given to second order in τ. In the present work this correction was made on the basis of Skyrme's theory and amounted to 4.2%.

The number of captures occurring in the foil is calculated, in both the Skyrme and the Bothe theories, by assuming a monoenergetic flux of isotropically distributed neutrons incident on the foil. The appropriate energy is that corresponding to the average velocity of an assumed Maxwellian distribution. One may see from the work of Zahn,[6] who takes into account the energy distribution for several different angular distributions, that this procedure gives accurate results here.

The thermal flux was calculated from the corrected saturated

---

4. Bothe, Zeit. f. Physik 120, 437 (1943). (Translated in CP-2964.)
5. MS 91.
6. C. T. Zahn, Phys. Rev. 52, 63 (1937).

activity of the gold foil according to the following formula:

$$\phi_{th} = \frac{A \, A_s}{E \, N_o \, m \, \sigma_a}$$

where

A is the atomic weight of gold

A_s is the saturated activity of the gold foil

E is the efficiency of the NaI counter

N_o is Avogadro's number

m is the mass of the gold foil

σ_a is the absorption cross section for gold.

The previous determinations of flux in the standard pile have relied upon an empirical fitting of indium resonance activation data by a sum of three gaussians (arising in the "age" theory for the slowing down of fast neutrons in the pile), calculation of the number of neutrons arriving at thermal energy (taken to be 0.025 e.v.) from the empirical expression, and the use of diffusion theory to determine the resulting spatial distribution of thermal neutrons. The flux found in this manner is very insensitive to the exact "thermal energy" value chosen.

Though diffusion theory assumes slow neutrons to be monoenergetic, actually the distribution of neutron velocities will resemble more or less closely the characteristic Maxwellian form. In obtaining the final figure for the flux in slot number 11 by the absolute method, a Maxwellian distribution of velocities with a most probable value corresponding to room temperature (2200 m/sec or 0.025 e.v. energy) has been assumed. Thus in calculating the neutron flux giving rise to the observed activation in the gold foil (assumed to have a cross section $\alpha \frac{1}{v}$) the following effective activation cross section has been used:

$$\sigma_{effective} = \frac{\int_0^\infty M(v)\ \sigma(v)\ dv}{\int_0^\infty M(v)\ dv} = \frac{\sigma_{0.025\ e.v.}}{1.128},$$

where $M(v)\ dv = e^{-(v/v_o)^2}\ v^3 dv$ and v_o is the most probable velocity. The measured cross section of gold at a velocity of 2200 m/sec of 95[7] barns has therefore been reduced to 84 barns for the calculation under the above assumption.

The thermal neutron flux in slot number 11 calculated as described above is 703 neutrons/cm^2/sec. This value is to be compared with the value of 654 neutrons/cm^2/sec as given in the previous calibration described in CP-2804.

If flux is to be determined in a given field in which one can assume a Maxwellian distribution corresponding to room temperature, one has only to multiply the activation of a thin foil exposed in the field by the ratio of the known flux in the standard pile to the activation of the foil when placed at that point in the pile. If a thin absorbing material is placed in the calibrated field, the activation resulting from the known flux must be calculated using a cross section given by $\frac{\sigma_{at\ most\ probable\ energy}}{1.128}$ if the absorber has a $\frac{1}{v}$ cross

---

7. H. Pomerance, Phys. Rev. 83, 641 (1951).

section, or by averaging the known cross section over the assumed Maxwellian distribution if the $\frac{1}{v}$ law does not hold.

If one wishes to determine the flux with a thick foil in a medium which has a diffusion length different from that of the standard pile, the perturbation by the foil of the fluxes in the pile and in the medium in question will be different. A correction for this effect should be made using the Bothe or the Skyrme theory.

It is a pleasure to acknowledge our indebtedness to Dr. A. R. Brosi of the ORNL Chemistry Division for his aid in the β-γ coincidence and the high-pressure ion chamber measurements. We wish to thank Mr. David G. Ott of the Oak Ridge School of Reactor Technology, who made the preliminary measurements, and Mrs. Elizabeth Johnson, who assisted in carrying out the final measurements.