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THERMAL NEUTRON FLUENCE MEASUREMENTS IN THE DOSAR FACILITY THERMAL PILE

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THERMAL NEUTRON FLUENCE MEASUREMENTS IN THE DOSAR FACILITY THERMAL PILE

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ABSTRACT

A series of thermal neutron fluence measurements were made in the DOSAR Facility thermal pile, including the measurement of the fluence distribution in the pile, effects of foil spacing upon the fluence measurement, and the determination of the cadmium ratio (bare gold foil activity/cadmium-covered foil activity) at specific areas within the pile.

INTRODUCTION

The well-calibrated neutron facility at the Oak Ridge Graphite Reactor was formerly the primary source of thermal neutrons at ORNL, but the reactor was shut down in November 1963. Therefore, a thermal neutron facility in the form of a graphite pile was constructed at the DOSAR Facility. Enough reactor-grade graphite was available to construct a thermal pile with a cadmium ratio of approximately 200.

The primary objective of these experiments was to calibrate the thermal neutron facility so that in the future, samples could be irradiated in a known thermal neutron fluence. In addition, the effects on the fluence of foil spacing, foil thickness and cadmium covers were studied.

DESCRIPTION OF FACILITY

The graphite thermal pile used in this experiment was located in the Health Physics Research Reactor (HPRR) building at the DOSAR Facility (Fig. 1). The pile, composed of various lengths of AGHT reactor-grade graphite, is essentially a 1.5-m graphite cube. The actual dimensions are 1.52 m high, 1.57 m wide, and 1.65 m long. There are two openings on the west face of the pile in which graphite "stringers" or other sample targets may be placed (Fig. 2). A large opening (20 × 10 × 185 cm) is located at the center of the pile with a smaller opening (10 × 10 × 185 cm) located toward the rear of the facility. Leakage neutrons from the HPRR act as the neutron source in this facility. The reactor is remotely positioned at a distance of 3 m from the front face of the thermal pile.

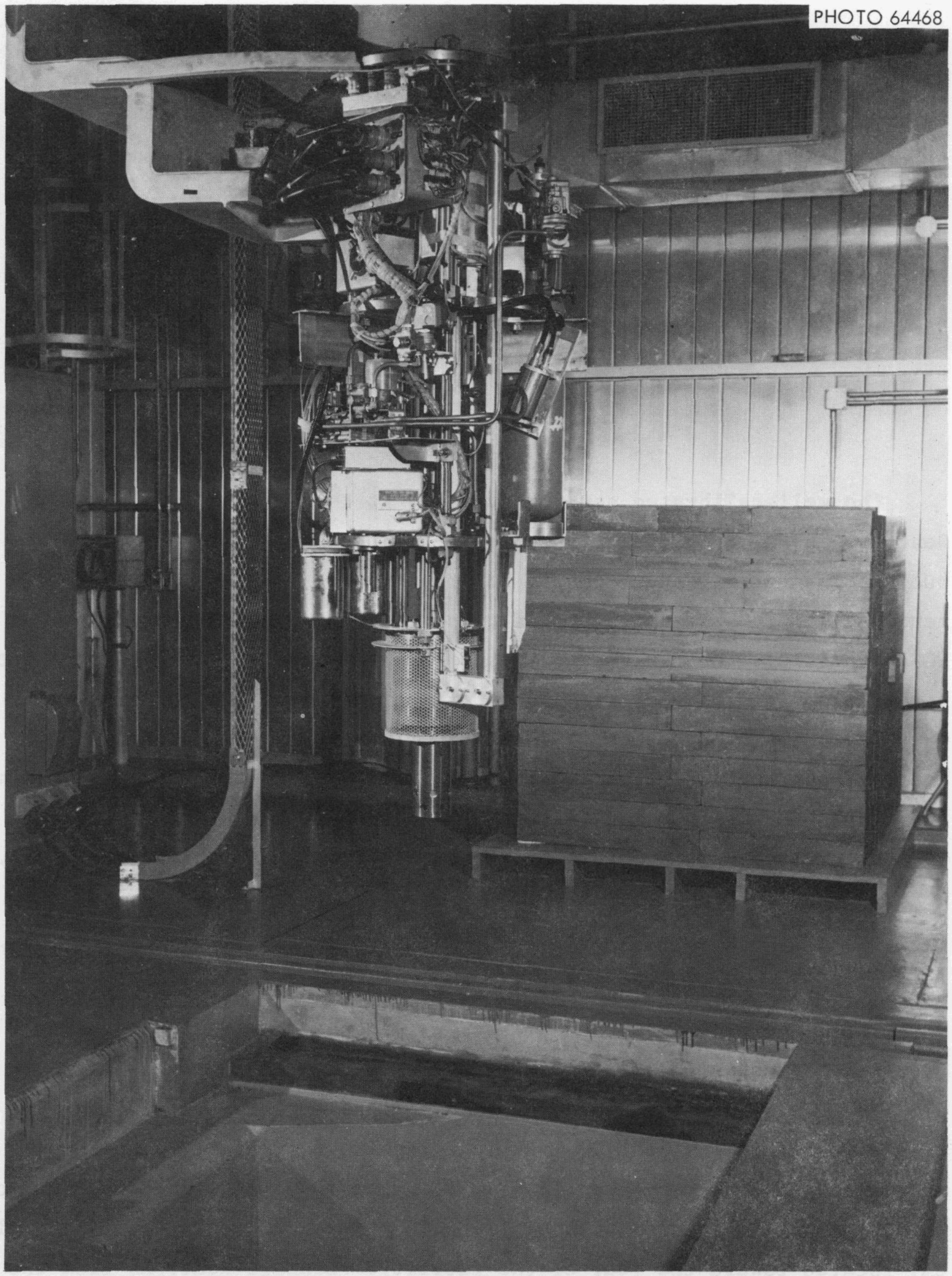

Fig. 1. Photograph of HPRR Showing the Front Face of the Thermal Pile in the Background.

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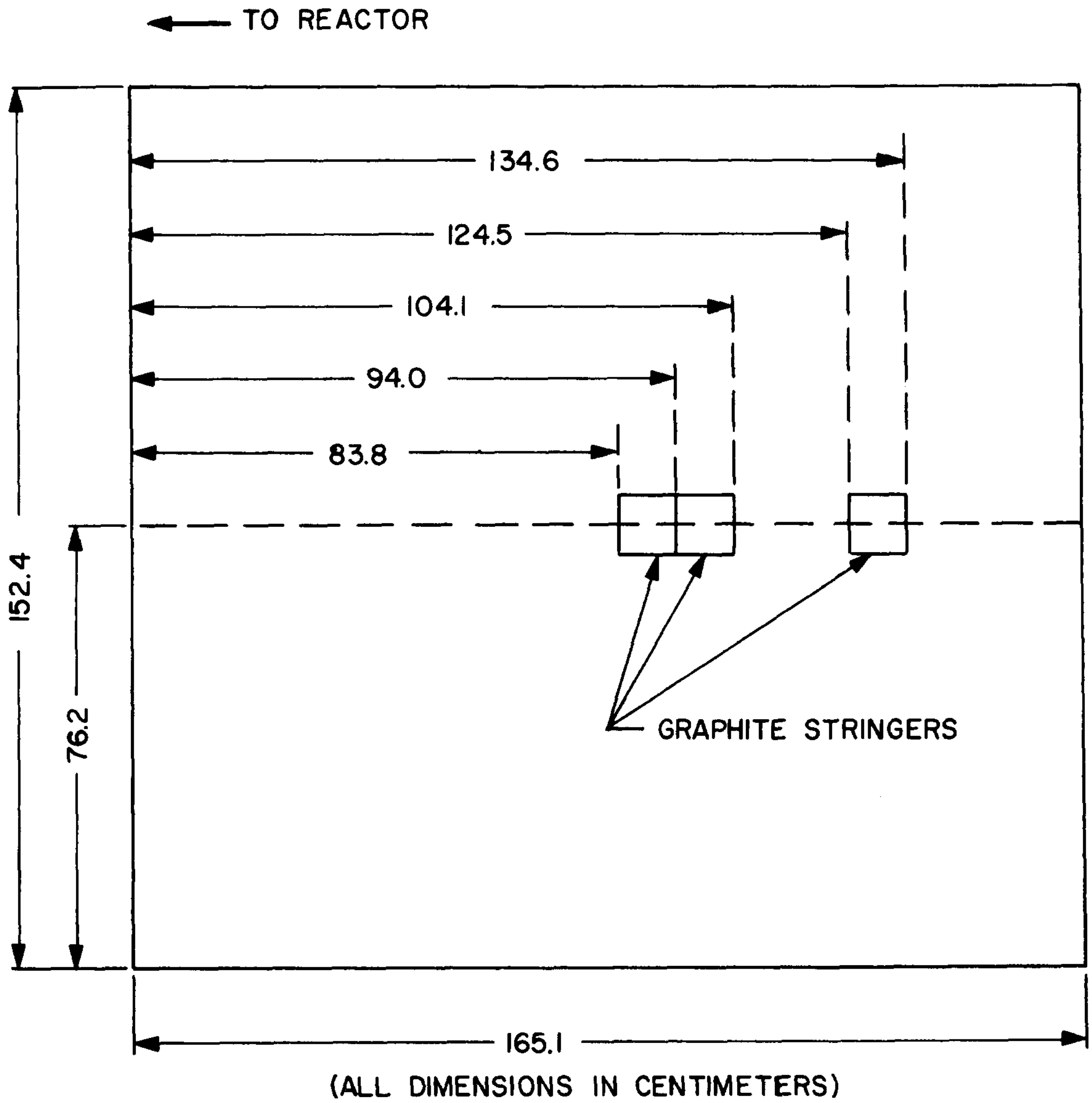

Fig. 2. Side View of Thermal Pile.

The reactor[1] was designed for health physics and biomedical research and is capable of a wide range of dose rates without changes in spectrum or geometry. It is a bare, metal, unmoderated assembly which contains approximately 100 kg of enriched uranium (93.14%) alloyed with 10% by weight of molybdenum. The core is cylindrical, 20 cm in diameter and 23 cm high. The reactor may be operated in the steady-state mode up to power levels of 10 kw or in burst mode with pulses up to 10^{17} fissions per pulse. A supporting framework attaches the reactor to a positioning device which allows the entire assembly to be moved along the centerline of the building or elevated to approximately 10 m in height above the reactor room floor.

COUNTING SYSTEM AND MATERIALS

A typical scintillation counting system[2] was used for measuring the induced activity in the foils. The system used a 2.54- by 3.81-cm sodium iodide crystal and suitable electronics. The system had been calibrated for use in counting the standard 0.127-mm-thick gold foils used in the Hurst Threshold Detector System. Before use the entire system was checked for linearity, gain and response to a standard source.

Three graphite stringers (10 × 10 × 46 cm) were fabricated for use in the experiment. Recessed holes were milled on the two opposite faces of each of these stringers (Fig. 3). These holes were 1.4 cm in diameter and approximately 0.318 cm deep. Seventeen holes were milled on the faces of each stringer except one, which had holes only on one face. On each exposure the stringers were placed in the openings of the pile with the faces containing the holes parallel to the front face of the pile. Thus, from front to back, there were five faces of graphite containing exposure holes.

Gold foils were the only detectors used and were used in thicknesses from 0.0025 to 0.508 mm. All foils were 1 cm in diameter and, except for the 0.127-mm foils, were punched from a common punch. These foils were weighed on a precision balance, and the average thickness was calculated. Cadmium covers, 0.508 mm thick, were used to encase the foils during the thermal fluence determinations.

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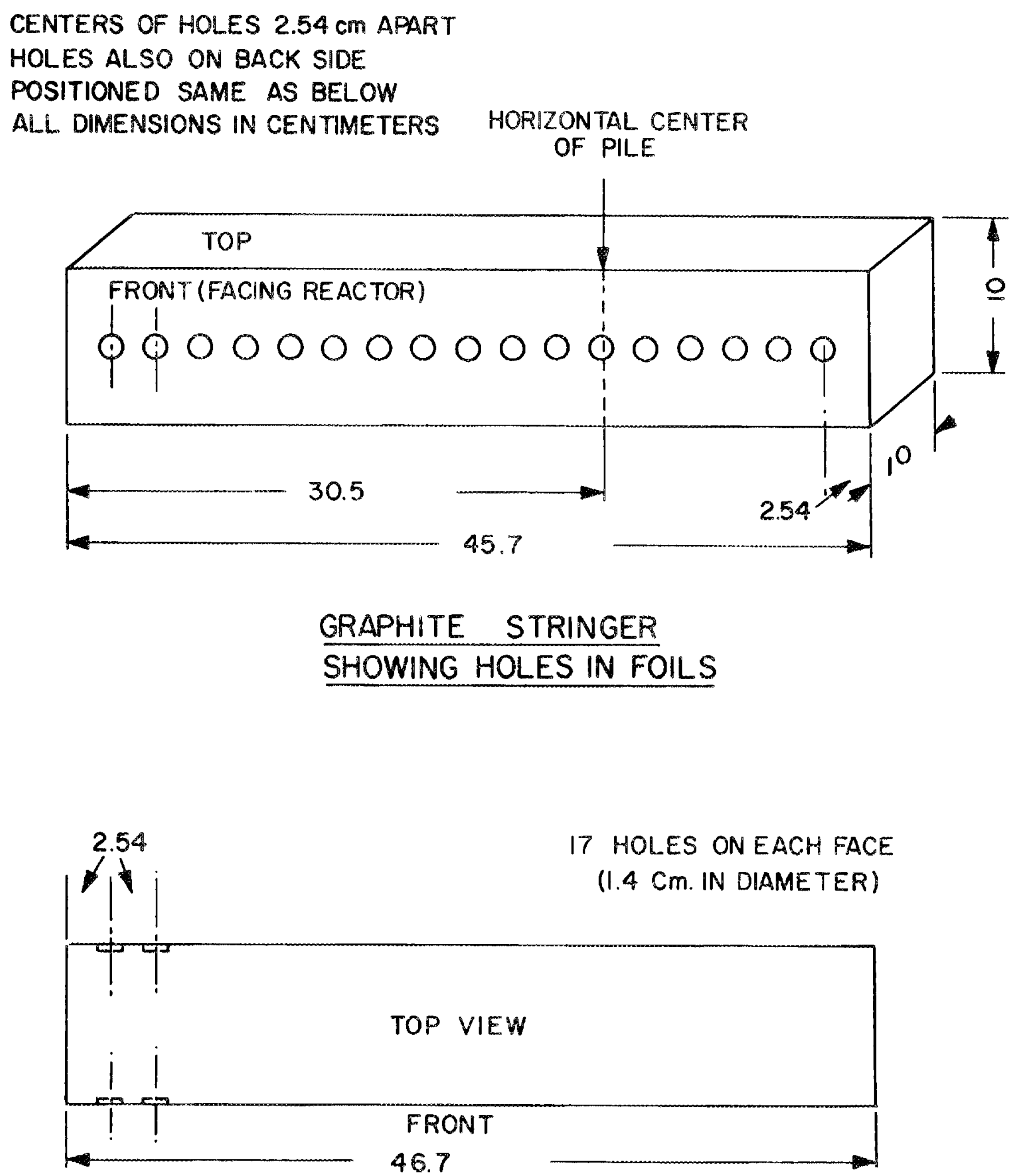

Fig. 3. Sketch of a Typical Graphite Stringer Used in this Experiment.

EXPERIMENTAL PROCEDURE

The HPRR provides a supply of fast neutrons; an average of about 1.3 neutrons escapes the core for each fission. Since the average energy of the neutrons[3] is approximately 1 Mev, a thermalizing medium must be introduced to slow the neutrons to thermal energy. Graphite was chosen as the medium due to its moderating ability, availability, and ease of fabrication.

Gold foils were exposed in the thermal pile by attaching them to graphite stringers which were inserted in the pile. Both bare and cadmium-covered foils were used (in separate exposures) in determining the thermal neutron fluence. A high-level, steady-state operation (∿25 kw-min, typically 5 kw for 5 min) of the reactor was used for all exposures in this series.

After exposure, the foils were removed from the stringers and the induced activities measured with a scintillation counter. Three 1-min counts were taken on each bare foil (<1% standard deviation) while the cadmium-covered foils were counted for one 10-min interval (2 to 6% standard deviation). Foil activities were corrected for decay, which is the time elapsed since reactor shutdown to beginning of the counting period.

When the activity of a bare foil and cadmium-covered foil (both irradiated at the same position and at the same power level) had been measured, it was possible to determine the thermal neutron fluence at the time of reactor shutdown by use of the formula:

$$\phi_{thermal} = 2.56 \times 10^5 \left[\frac{A_b}{(\text{Foil wt})(e^{-\lambda t_b})} - \frac{A_{cd}}{(\text{Foil wt})(e^{-\lambda t_{cd}})} \right] \qquad (1)$$

where

A_b = measured activity of the bare foil,
A_{cd} = measured activity of the cadmium-covered foil,
λ = decay constant for gold-198,
t_b = elapsed time for the bare foil,
t_{cd} = elapsed time for cadmium-covered foil,

and where the value 2.56×10^5 (counter constant for gold) takes into account the efficiency of the counter for the activity of the 0.127-mm gold foils, the absorption cross section, and other properties which were previously determined.

Since the bare and cadmium-covered foils were exposed during separate reactor operations, some means of normalizing the data was necessary. This was accomplished by attaching a large, 22-g sulfur pellet in a reproducible position on the reactor superstructure. The ^{32}P activity induced in the pellet was assayed and corrected for decay. This corrected count rate (called ICRD) is proportional to the total number of fissions taking place in the core during the reactor operation. Therefore, the activity in equation (1), i.e., A_b and A_{cd}, is actually activity/ICRD.

Different foil spacings were used to determine the effect of one foil on the neighboring foils and the fluence distribution across each stringer face. Exposures were made using foils spaced at 5 cm and 7.5 cm on centers.

RESULTS AND CONCLUSIONS

Several interpretations are possible for "thermal" neutrons.[4] A more or less arbitrary energy (usually 0.17 ev or higher) is sometimes chosen and the fluence below that value is called "thermal." Sometimes the limit to thermal energies is considered to be that energy at which the Maxwell-Boltzman part of the neutron energy spectrum is about equal to the 1/E part of the spectrum. More often, no corrections are applied to the usual cadmium difference foil measurements so the "thermal" neutrons reported are really "sub-cadmium neutrons." The first two interpretations mentioned require some knowledge of the spectrum of the neutrons which cannot be obtained by a simple experiment; therefore, in this report the thermal fluence reported shall actually be defined as sub-cadmium fluence. Also of importance in a measurement of thermal fluence is the temperature of the moderating medium. The temperature of the medium was essentially room temperature ($\sim$22°C), and no attempt was made to correct the data to 20°C.

Gold foils (0.127 mm thick), bare and cadmium covered, were used to measure the thermal fluence and cadmium ratio as a function of position in the pile. These data are shown in Fig. 4. The data of Sola[5] were used to correct for the fluence perturbation caused by the foils. No correction

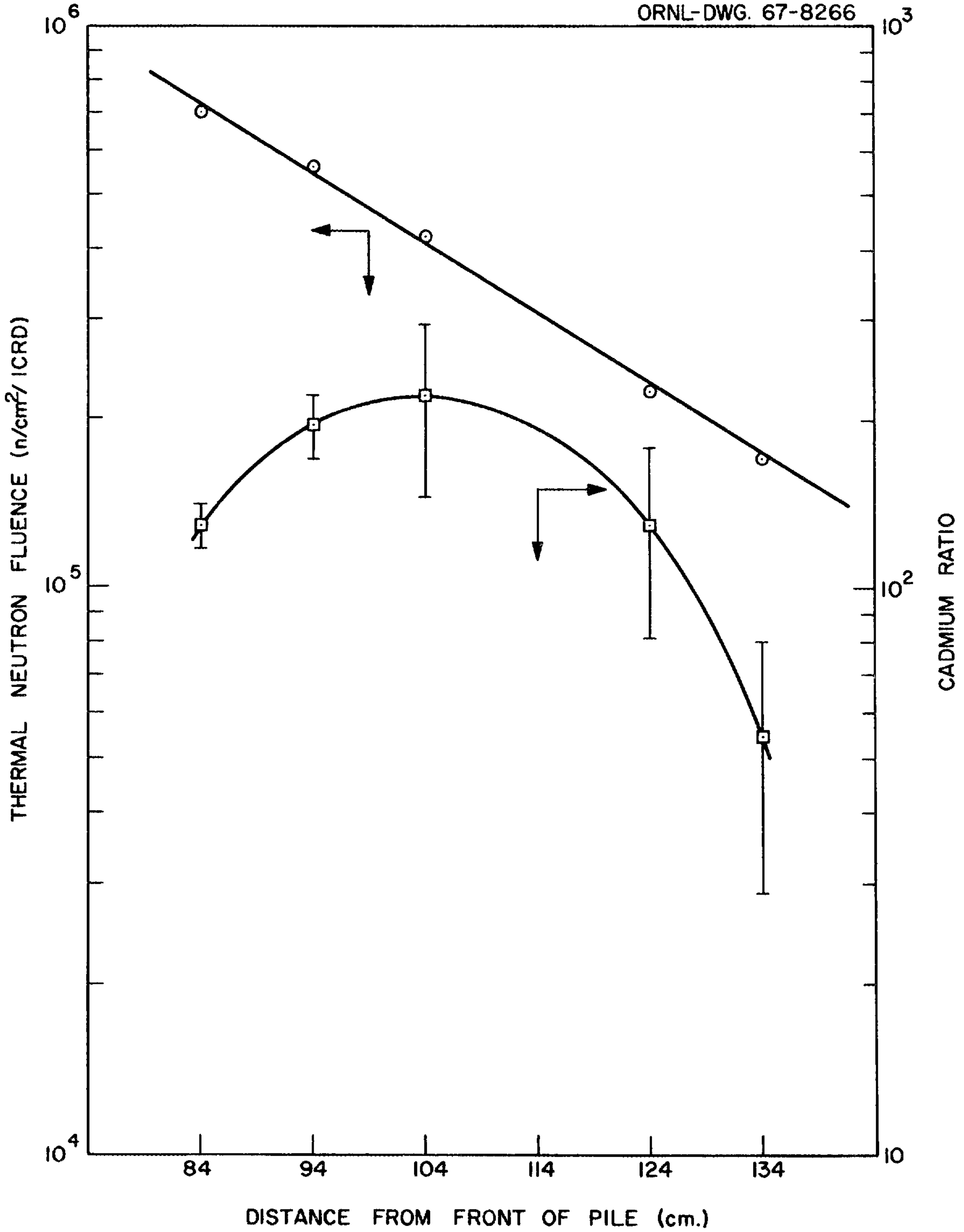

Fig. 4. Thermal Neutron Fluence and Cadmium Ratio vs Position in Thermal Column Runs 1-4.

was made for gamma-ray self absorption in the foil during counting since the detector was calibrated for use with 0.127-mm foils.

A second measurement of the thermal fluence was made using 0.025-mm foils. These data are compared with the 0.127-mm data in Table 1. The data taken with the thinner foils were corrected for fluence perturbation, and a correction was made to account for the difference in gamma-ray self absorption between the 0.025-mm and 0.127-mm samples. This correction was experimentally determined for the counter geometry used in this experiment. The correction curve is shown in Fig. 5 as well as the data of Sola and Crane and Doerner.[6] The figure shows the gamma-ray transmission factor rather than the gamma-ray self-absorption factor. Use of these data should cause a slight overestimate of the thermal fluence.

Data plotted as a function of foil spacing indicated little interaction between foils spaced as close as 5 cm. For example, the thermal fluence measured at the 5-cm spacing gave an average value across the face of the first stringer of 7.02×10^5 neutrons/cm^2/ICRD. The average value at a 7.5-cm spacing was 6.98×10^5 neutrons/cm^2/ICRD. Cadmium covers also showed little effect on the overall measurements so long as all foils in the stringer were cadmium covered.

Before further analysis can be made of the data from foils of various thicknesses, two refinements of technique should be achieved. Very thin foil should be obtained in order to permit a determination of the activity/mg for near zero thickness. Secondly, an improved experiment to determine the gamma-ray self absorption within the foils should be carried out. Most authors simply rely on the transmission method. Usually only the results are reported with no information as to the exact experimental arrangement. The methods generally used are very sensitive to the counter geometry, and thus the results vary widely (as can be seen in Fig. 5).

ACKNOWLEDGEMENTS

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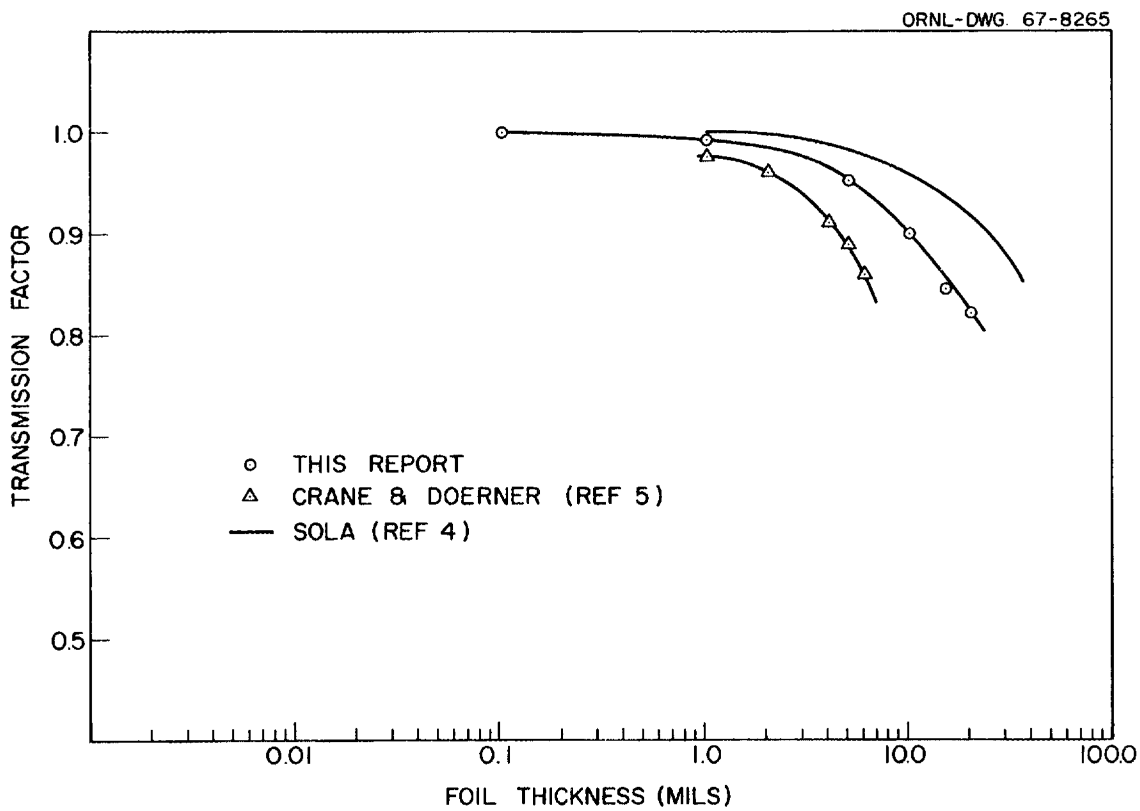

Fig. 5. Gamma-Ray Transmission Through Gold Foil.

Table 1. Comparison of Thermal Fluence Measured with One- and Five-Mil Gold Foils

Position	5-Mil	1-Mil
1	7.00 ± 0.17*	6.99
2	5.60 ± 0.14	5.51
3	4.21 ± 0.11	4.22
4	2.25 ± 0.13	2.44
5	1.71 ± 0.05	1.83

*One standard deviation calculated from the number of observations. Since standard deviation for each analysis of a bare foil was <1%, these were ignored in the calculation.

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