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REACTOR PHYSICS
QUARTERLY PROGRESS REPORT
APRIL–JUNE, 1957

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

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ABSTRACT

NUCLEAR MEASUREMENTS

The transport mean free path of thermal neutrons in diphenyl has been measured by the boron poisoning method to be 0.80 ± 0.05 cm. This permits calculation of the horizontal buckling for the uranium rod lattices in the 2-1/4-foot-diameter tank, the result being 47.5 ± 0.1 m^{-2}. This leads to values of 1.3 ± 0.9 and 17.8 ± 0.5 m^{-2} respectively for the bucklings of the natural (0.72 per cent) and enriched (0.91 per cent) uranium lattices for which the diphenyl moderator-to-fuel volume ratio is 4.

Scintillation equipment is being set up to replace the Geiger counters at present in use for activation analysis. The scintillation equipment is also being adapted for use in resonance escape and fast-effect measurements.

I. NUCLEAR MEASUREMENTS

A. ORGANIC MODERATED LATTICES (W. W. Brown, M. Glaubman)

An exponential experiment with cylindrical uranium fuel rods in diphenyl moderator is at present in progress. The results of this study, combined with previous work using heavy water and graphite moderators, will add to our general understanding of lattices of this type.

The exponential assemblies are held in a 2-1/4-foot-diameter tank mounted on the thermal column of a water boiler reactor (AE-6). The thermal column is high enough so that less than 3 per cent of the thermal neutrons in the diphenyl, when no lattice is present, arise from the slowing down of epithermal neutrons entering the tank bottom. This estimate is based on a comparison of the thermal neutron fluxes in the diphenyl with and without a 1/16-inch cadmium sheet between the tank and thermal column. Lattices of one-inch-diameter uranium of enrichment 0.5, 0.7, and 0.9 per cent are being studied at spacings ranging from 1.4 to 2 inches. Lattice buckling and the thermal neutron distribution in a lattice cell are the directly measured quantities on which the analysis is based. The technique of measuring resonance escape and fast effect directly is being developed.

The lattice buckling, B^2, is obtained from the relation $B^2 = \mu^2 - \nu^2$, where μ^2, the horizontal buckling, is given by $\mu = \frac{2.405}{R}$, R being the extrapolated radius of the tank. The tank radius is 0.33 m, and the extrapolation length, $0.71\,\lambda_{tr}$, is about 0.5 cm if a value of 0.7 cm is assumed for the transport mean free path, λ_{tr}, in diphenyl. A 50-per cent error in the estimate of λ_{tr} can thus introduce an error of about 1.5 m^{-2} in the value of the buckling. This is quite a large error, since the bucklings to be measured are of the order of 20 m^{-2}. That the error in the estimated value of λ_{tr} may be large was indicated by some measurements of the horizontal distribution of thermal neutrons in the diphenyl. This distribution, for a cylindrical medium, is given by $J_o(\mu r)$, where r is the distance from the vertical axis of the tank. A fit of the measured distribution to this shape indicated an extrapolation length of 1.6 cm. This large value may in part be accounted for by epithermal neutrons leaking into the tank through the sides and thus adding to the thermal distribution near the walls but not appreciably near the axis. However, it was enough to indicate that a more precise measure of the transport mean free path in the diphenyl should be made to ensure adequate accuracy for the buckling measurements.

The best method of measuring the transport mean free path of a liquid moderator is by the boron poisoning procedure. This method has been described in detail elsewhere.* Experimentally, it consists of adding known amounts of boron (in the form of trihexylene glycol biborate in the present case) to the moderator without any lattice present, and measuring ν, the reciprocal relaxation length, after each addition. By combining the relations

$$L^{-2} = 3\Sigma_s(1 - \bar{\mu})\Sigma_a + 3\Sigma_a^2 (1 - \bar{\mu})\left(0.2 + \frac{\bar{\mu}}{1 + \bar{\mu}}\right) , \qquad \text{...(1)}$$

$$\lambda_{tr} = \frac{1}{\Sigma_{tr}} = \frac{1}{\Sigma_s(1 - \bar{\mu})} , \qquad \text{...(2)}$$

and

$$L^{-2} = \nu^2 - \mu^2 , \qquad \text{...(3)}$$

where L is the diffusion length, the Σ's are macroscopic cross sections, and $\bar{\mu}$ is the average value of the cosine of the scattering angle occurring during neutron collisions, the following relation can be found:

$$\nu^2 - 3\Sigma_a^2(1 - \bar{\mu})\left(0.2 + \frac{\bar{\mu}}{1 + \bar{\mu}}\right) = 3\Sigma_{tr}\Sigma_a(boron) + 3\Sigma_{tr}\Sigma_a(diphenyl) + \mu^2 ,$$

where now $\Sigma_a = \Sigma_a$ (boron) + Σ_a (diphenyl).

The slope of a plot of $\nu^2 - 3\Sigma_a^2 (1 - \bar{\mu})\left(0.2 + \frac{\bar{\mu}}{1 + \bar{\mu}}\right)$ against Σ_a (boron) will give the transport mean free path. The term on the left involving $\bar{\mu}$ is small, of the order of 1 per cent of ν^2, and so a rough estimate of $\bar{\mu}$ is first used. From the plotted values, a first measure of λ_{tr} is obtained. From this a better value of $\bar{\mu}$ is calculated from Eq. (2) and this is used to recalculate the left side of Eq. (4). The data after this first iteration is shown in Table I and plotted in Fig. 1. The slope gives a value of 0.80 ± 0.05 cm for λ_{tr}. The value of $\bar{\mu}$ obtained is 0.43.

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*S. W. Kash and D. C. Woods, "Measurement of the Transport Mean Free Path of Thermal Neutrons in D_2O by a Boron Poisoning Method," Phys. Rev. 90, 564 (1953).

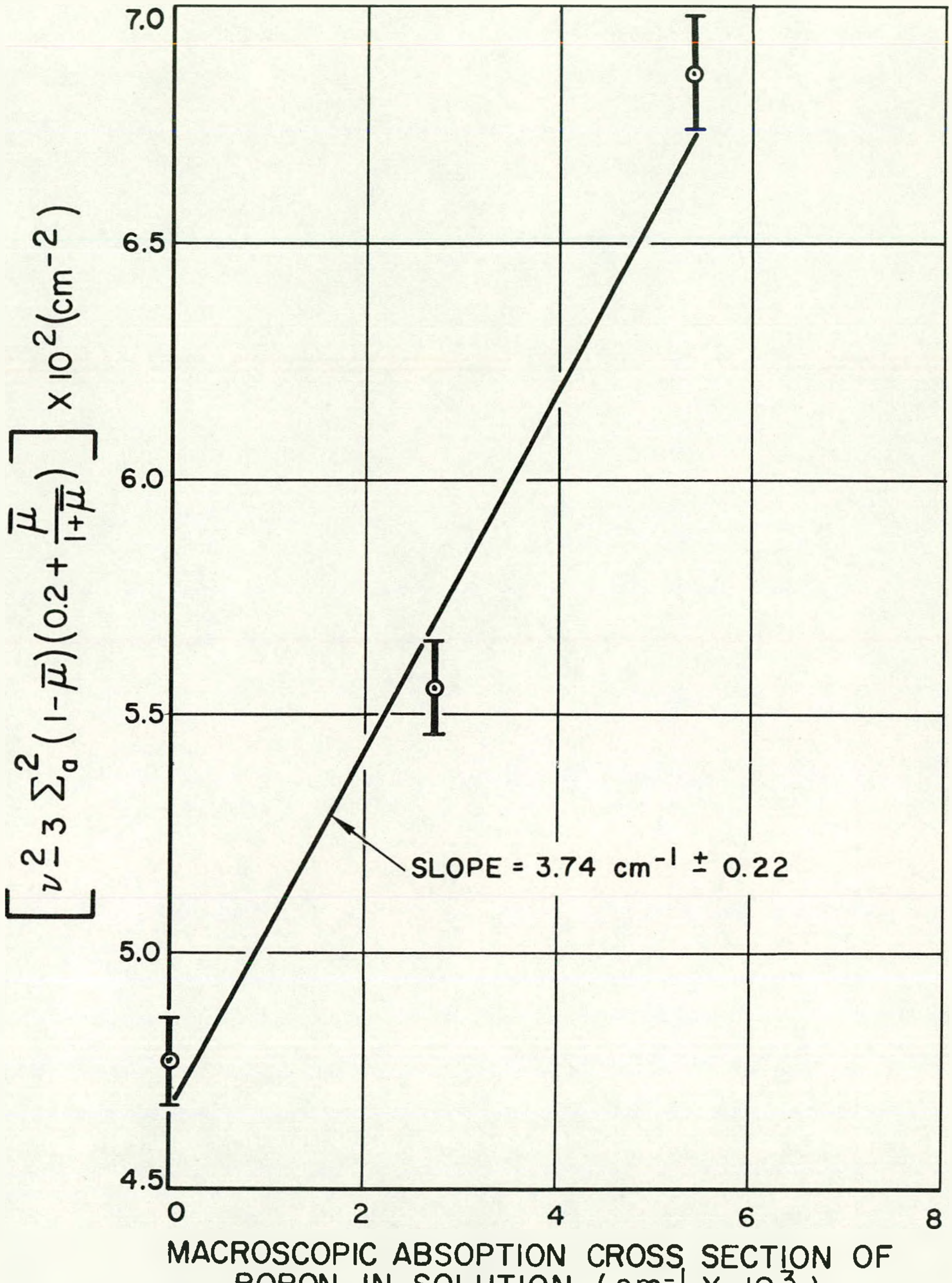

Fig. 1. Dependence of Square of Reciprocal Relaxation Length on Boron Poisoning

Measurements which will be made after one or two more additions of boron may result in a small change in the above value. However, at present it gives 0.57 ± 0.04 cm for the extrapolation length and hence a value of 47.5 ± 0.1 m^{-2} for the horizontal buckling.

TABLE I

TRANSPORT MEAN FREE PATH OF THERMAL NEUTRONS IN DIPHENYL

Concentration of Boron in Solution ($mg/liter^{-1}$)	Σ_a(boron) x 10^3 (cm^{-1})	ν^2 (cm^{-2})	$\nu^2 - 3\Sigma_a^2(1-\bar{\mu})(0.2 + \frac{\bar{\mu}}{1+\bar{\mu}})$ (cm^{-2})
0	0	0.04792	0.04774
77.6	2.682	0.05588	0.05559
158.0	5.431	0.06906	0.06864

The vertical attenuation of neutrons in two of the lattices has been measured. The values of ν^2 are given in Table II together with the lattice bucklings calculated using the above value for the horizontal buckling.

TABLE II

BUCKLINGS OF URANIUM ROD LATTICES IN DIPHENYL

Atomic Enrichment (%)	Volume Ratio of Moderator to Fuel	ν^2 (m^{-2})	B^2 (m^{-2})
0.7205	4	46.2 ± 0.8	1.3 ± 0.9
0.9124	4	29.7 ± 0.4	17.8 ± 0.5

B. COUNTING ROOM INSTRUMENTATION (W. W. Brown, M. Glaubman)

Work has started on developing the technique of measuring the resonance escape probability of lattices directly by means of U^{238} foil activation. The method depends on the use of scintillation counters. Scintillation equipment to count both beta and gamma radiation is being installed and soon will replace the Geiger counters at present used for activation analysis in the lattice studies. Initial tests show that the scintillators have less than one-quarter of the background of the Geigers and can count at rates up to 100 times that of the Geigers. Their use will thus mark a great improvement over the present counting statistics. This will be of importance in the lattices at closer spacing that soon are to be measured. Because of the limited amount of uranium on hand, these will of necessity be shorter lattices and it will not be possible to observe the neutron attenuation over as long a distance as for the two lattices measured above. To preserve even the present accuracy in the buckling measurement will therefore require activation measurements of higher statistical accuracy.