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THE NUCLEAR PARAMETERS OF SOME GRAPHITE - NATURAL URANIUM LATTICES MEASURED IN THE PCTR

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BY A E Barker DATE 7-30-81

BY J W Jordan DATE 7-30-81

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INTRODUCTION

The Physical Constants Testing Reactor, PCTR, and the method by which it can be used to obtain the nuclear properties of a multiplying material have been described in detail in a previous paper (1), hereafter referred to as I. In order to gain further insight into the operation of this reactor, and to investigate the nuclear properties of a range of graphite moderated, air cooled, natural uranium fueled systems, the infinite medium, thermal neutron multiplication factor, k_{∞}, and the thermal utilization, f, of ten such lattices have been measured. The results have been further analyzed to obtain a value of eta, the fast neutrons produced per thermal capture in natural uranium. Some comparisons are made between the results of the PCTR measurements and those obtained by other methods.

PROCEDURE

The determination of k_{∞} in the PCTR involves inserting a sample of the material to be investigated into the central region of the reactor and adjusting the can position of the region around the sample, referred to as the buffer region, until the neutron energy spectrum in the sample is the same as it would be if that sample were part of an infinite array. After the neutron energy spectrum has been adjusted, the amount of thermal neutron absorber is found which, when moved into or out of the reactor together with the test sample, will not change the reactivity of the reactor. The relationship between this mass of neutron absorber and k_{∞} of the test sample is given in I. Finally, the thermal flux is measured at various points in the sample, both in order to deduce k_{∞} from the measured mass of absorber,

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and in order to obtain the thermal utilization of the sample. In these experiments, .010" thick copper shims were used for the thermal neutron absorber, and the fluxes through the test samplewere measured with copper pins and foils. Corrections for resonance absorption in the copper were made in both applications.

Two methods have been employed in these experiments to determine that buffer configuration which will yield the correct spectrum in the test sample. The first of these is that method discussed in I which is based on the premise that when the buffer configuration is correct, the average cadmium ratio of some resonance absorber at the boundary of the test region will be the same whether the poisoned test sample is in or out of the reactor; that is, when

$$(1) \qquad \frac{(\overline{CdR})_{\text{Full \& Absorber}}}{(\overline{CdR})_{\text{Empty}}} = 1$$

where $(\overline{CdR})_{\text{Full \& Absorber}}$ is the average cadmium ratio at the boundary of the central test region measured when the poisoned sample is in that region, and $(\overline{CdR})_{\text{Empty}}$ is the same quantity measured when the region is empty. Gold foils were used in the application of the criterion of eq. (1), and since a gold foil does not absorb resonance neutrons in the same manner as does the test sample, it is necessary to assume that the shape of the neutron energy spectrum in the poisoned test sample is the same as it would be if the sample were part of an infinite array.

The second method for determining the correct buffer configuration makes use of the large number of cadmium ratios which have been obtained for graphite-natural uranium lattices from exponential experiments. (2) These cadmium ratios measured in exponential piles can be converted to those which would occur at the boundary of a poisoned sample in an infinite array by the equation

$$(2) \qquad (CdR-1)_{\infty} = (CdR-1)_{exp.}\, e^{-B_m^2 \tau}$$

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Figure 1 shows a plot of $(CdR-1)_\infty$ for .005 inch gold foils at the boundary of a test sample as a function of the carbon to uranium atomic ratio, and rod size in that sample. Thus, for a particular sample, the composition of the buffer can be adjusted until the correct cadmium ratio, as given in Fig. 1, is attained.

RESULTS AND DISCUSSION

The composition of the ten lattices studied is given in Table I. Table II lists the correct average .005 inch gold cadmium ratio at the boundary of these lattices as determined by one or both of the methods described above. An inspection of this table shows that the results obtained by the two methods are in very good agreement. Since the exponential measurements were made in relatively large samples, they undoubtedly yield cadmium ratios which, when corrected as described in eq. (2), are characteristic of an infinite array. Therefore the good agreement of the cadmium ratios in Table II tends to add confidence to the values obtained by applying the criterion of eq. (1), and indicates that the assumption concerning the shape of the neutron energy spectrum in the test sample is a valid one.

Values of k_∞ and f obtained for the ten lattices investigated are shown in Table III. The errors in the measurements of thermal utilization are all $\pm$ .006. All errors are standard deviations. Values of k_∞ deduced from buckling measurements made with exponential piles are also shown in the table. It was assumed that k_∞ and buckling are related by the equation.

(3) $k_\infty = 1 + B^2 M^2$.

The migration area, M^2, was calculated from standard formulae (4), assuming that the age of fission neutrons to thermal in graphite with a density of 1.6 gms/cm^3 is 364 cm^2. The values of k_∞ deduced from exponential experiments seemed systematically

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slightly higher than those obtained from the PCTR. However, considering the uncertainties involved in obtaining k_∞ from a value of buckling, the over-all agreement of the two sets of numbers seems quite satisfactory.

One further comparison is shown in the table. k_∞ has been obtained for the lattice indicated by applying eq. (3) to values of B^2 and M^2 measured directly at the start up of some of the Hanford production reactors. (5)

The experimental results in Table III have been analyzed to yield a value of η/ϵ, the fast neutrons produced in a rod per thermal neutron captured in that rod, for the three rod types investigated. As pointed out by Mummery (6), if values of $\ln k_\infty/f$ obtained for a given rod in various lattices are plotted vs. $\frac{U}{C\,\xi\sigma_s}$ of those lattices, where U/C is the ratio of uranium to carbon atoms in the cell and ξ and σ_s are respectively the average logarithmic energy decrement per collision and scattering cross section of the graphite in the lattice, a straight line will result whose intercept is $\ln \eta/\epsilon$ of that rod. The lines obtained for the three rod sizes considered in this work are shown in Fig. 2.

The values of η/ϵ obtained from the intercepts of these curves and the resulting values of η for natural uranium are tabulated in Table IV. The fast effect, epsilon, was measured for the 1.36" and 1.68" rods (7) with a precision of about .2 per cent. It was calculated for the .925" rod using formulae and cross sections given in the Reactor Handbook (4).

N.B. It has been assumed that the error in eta introduced by uncertainties in epsilon is negligible. Since there is no apparent trend in the value of eta with rod size, the three values were combined to yield an average value with a precision of one per cent. This error was obtained from a statistical analysis of the data shown in Fig. 2 and is a standard deviation.

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TABLE I

PHYSICAL COMPOSITION OF LATTICES STUDIED

Lattice Spacing	C/U (Atomic Ratio)	Al/U (Atomic Ratio)
.925" Diameter Rod		
5-5/8"	81.35	.634
6-1/2"	104.76	.634
7-1/2"	145.56	.634
1.36" Diameter Rod		
6-1/2"	49.93	.570
7-1/2"	69.70	.570
8-3/8"	90.77	.570
9-1/2"	112.62	.570
1.68" Diameter Rod		
7-1/2"	41.56	.078
8-3/8"	53.80	.078
9-1/2"	62.70	.078

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TABLE II

0.005 INCH GOLD FOIL CADMIUM RATIOS
AT THE BOUNDARY OF THE LATTICES

Lattice	From Eq. (1)	From Exponential Experiments
.925" Rod		
5-5/8"	4.3 ± .3	4.4 ± .2
6-1/2"	5.6 ± .3	5.3 ± .3
7-1/2"	7.1 ± .6	6.7 ± .3
1.36" Rod		
6-1/2"	3.6 ± .2	3.7 ± .2
7-1/2"	--	4.6 ± .2
8-3/8"	--	5.5 ± .3
9-1/2"	6.9 ± .2	6.4 ± .3
1.68" Rod		
7-1/2"	--	3.6 ± .2
8-3/8"	4.3 ± .5	4.4 ± .2
9-1/2"	--	4.9 ± .2

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TABLE III

VALUES OF INFINITE MULTIPLICATION FACTOR AND THERMAL UTILIZATION

Lattice	f(± .006)	PCTR	k_∞ Exponential	Production Reactors
.925" Rod				
5-5/8"	.922	1.046 ± .002	1.052	
6-1/2"	.896	1.065 ± .003	1.067	
7-1/2"	.865	1.066 ± .003	1.069	
1.36" Rod				
6-1/2"	.932	1.010 ± .001	1.010	
7-1/2"	.910	1.055 ± .002	1.057	
8-3/8"	.890	1.060 ± .003	1.075	1.063
9-1/2"	.866	1.063 ± .004		
1.68" Rod				
7-1/2"	.950	1.024 ± .003	1.019	
8-3/8"	.935	1.058 ± .004	1.070	
9-1/2"	.923	1.083 ± .004		

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TABLE IV

Rod Diameter	$\eta\epsilon$	η
.925"	1.368 ± .027	1.335 ± .027
1.36"	1.350 ± .018	1.304 ± .017
1.68"	1.374 ± .037	1.315 ± .036

$\bar{\eta} = 1.313 \pm .013$

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