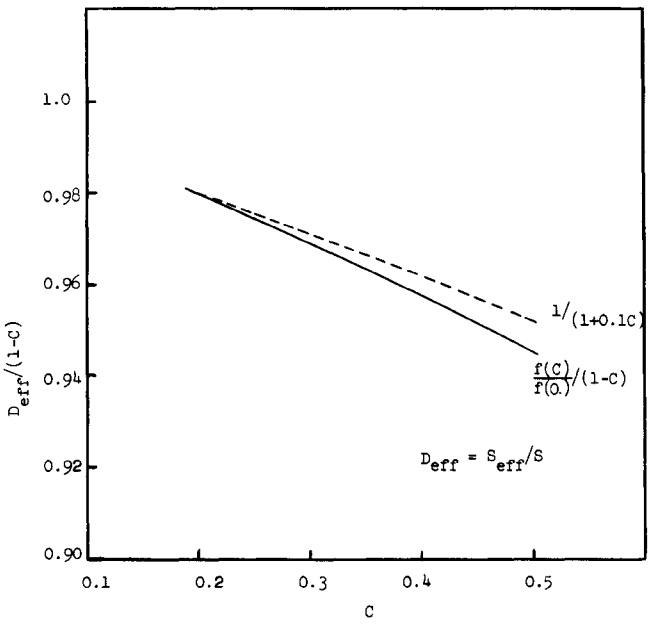

Fig. 2. Effective surface for a resonance without Doppler broadening (cylindrical lump).

36.8 eV, respectively, at the temperature of zero K. At 293 K, these become about 12% and 7%, respectively. The dependence of the correction factor on ℓ_0 is not distinct for the range of $\Sigma_{p0}\ell_0 = 0.16 \sim 0.64$, where Σ_{p0} is the macroscopic potential scattering cross section of UO_2, although a slight increase is seen in the correction factor with the increase of ℓ_0 which is expected from Figure 1.

Calculations for all resolved levels were run at 293 K to obtain the relation between D_{eff} and C in total resonance absorption in U^{238}. The results again show that (2) is a good approximation. The ten per cent correction of C for D_{eff} is considered as the average for all resonance levels.

As a conclusion, Levine's relation, (1), is well suited to the calculation of D_{eff} for square and hexagonal lattices for the normal absorber radius although it is questionable to extend this to an unpractically large absorber, say over 1 in $\Sigma_{p0}\ell_0$, as can be inferred from the curve in Figure 1. It is recommended, however, to use the classical factor $(1-C)$ for D_{eff} in slab geometry.

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Fast Fission Factors in Slightly Enriched Uranium, Light-Water-Moderated Slab Lattices*

The fast fission factor of reactor core assemblies is usually inferred from measurements of the ratio of U^{238} to U^{235} fission rates in the fuel of the lattice ($= \delta_{28}$). These measurements are generally normalized to the results of an auxiliary experiment, the so-called double-fission-chamber experiment[1], whose uncertainty heavily contributes to the overall margin of error of the data.

The present note describes a measurement of δ_{28} in slightly enriched uranium/light-water-moderated slab lattices, performed by a technique which differs to some extent from the methods currently used[1,2,3] and yields data of satisfactory accuracy.

The lattice investigated consisted of an array of bare U metal slabs enriched to 1.25% U^{235}. The slabs were arranged in rows of continuous sheets, 0.122 in. thick, spaced to give the desired volume ratios. The water-to-uranium volume ratios investigated were nominally 4:1, 3:1, 2:1, 1.5:1, and 1:1.

The facility used was a miniature assembly, measuring 16 in. high by 12 in. wide by 12 in. long, contained in an aluminum tank surrounded on all sides, except the top, by $\frac{1}{16}$ in. of cadmium sheet and 3 in. of paraffin. The whole assembly was irradiated in the tunnel under the Brookhaven National Laboratory graphite reactor. Previous work had proved the feasibility of such small-size assemblies for measurements of microscopic lattice parameters[1].

The ratio of U^{238} to U^{235} fission rates in the uranium was deduced from the fission-product activities of two uranium foils, one enriched to 1.25% U^{235} and one depleted to about 3 parts/10^6 U^{235}, irradiated bare at equal flux positions in the fuel of the lattice. The foils were rectangular (0.005 in. thick by 0.122 in. wide by 0.500 in. long) and were inserted into the slab sandwiched between 0.001 in. Al catchers, as shown in Figure 1. The irradiation time was 40 min.

The induced gamma activities of the detectors were measured by a 2 in. dia. × 2 in. high NaI(Tl) single-channel analyzer. The beta background was eliminated by a $\frac{1}{8}$ in.-thick pure Al shield. Discrimination against the activity from the U^{238} capture products (U^{239} and Np^{239}) was achieved by

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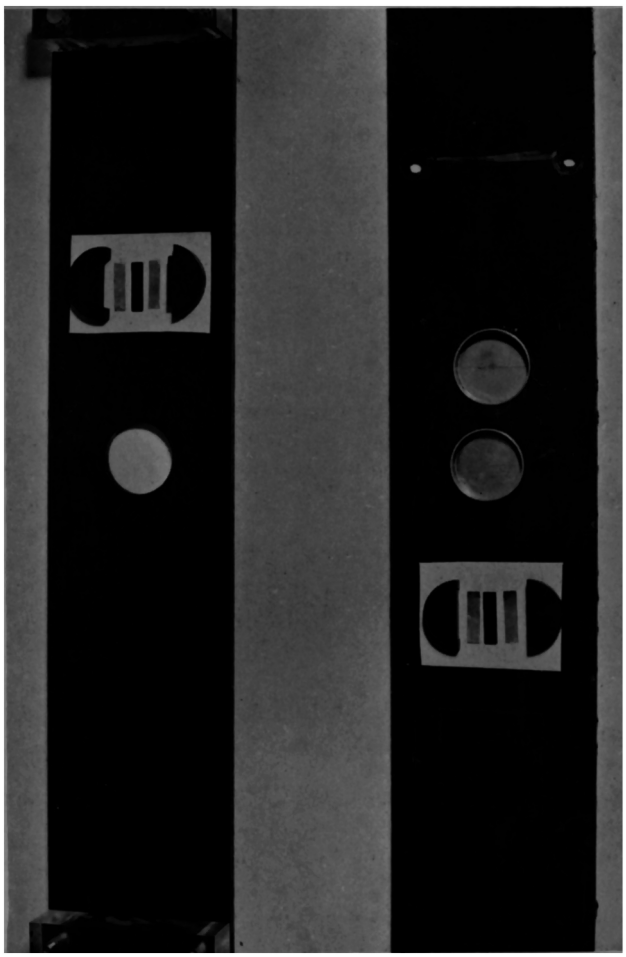

Fig. 1. Detectors arrangement in the uranium slabs, for the measurement of δ_{28} and δ_{25}.

setting the baseline of the counting equipment at 0.730 MeV (i.e., above the energy of the gamma rays from Np^{239} as well as of the Bremsstrahlung from the Np^{239} beta particles), and by starting to count when the 23-min activity of U^{239} had decayed to a negligible value. For reasons of convenience counting began about 10 hours after the end of the irradiation.

Standard corrections for room background, U natural activity, counter dead time, etc., were applied to the count rates, which yielded, after some obvious manipulation, the ratio of the activities from U^{238} and U^{235} fission in the fuel.

Such a ratio was related to the parameter of interest--the ratio of U^{238} to U^{235} fissions--by an auxiliary measurement, giving the quantity k = (U^{238} fissions/ U^{235} fissions)/ (U^{238} fission-product activity/U^{235} fission-product activity).

This measurement was performed by a double-fission-chamber technique. Two uranium foils, one depleted and one enriched in U^{235}, identical to those used for the measurement in the lattice, were waxed to the two cathodes of the chamber. The chamber was surrounded by a cadmium sheet and irradiated in a flux spectrum typical of that in the lattice investigated.

The fissions in the two halves of the chamber were separately recorded during the exposure by standard counting equipment, yielding the numerator of the above expression. The denominator was obtained from the induced activities of the same two foils. Since the quantity k is in general a function of the irradiation time, of the time elapsed after the irradiation, of the counting equipment and of the counting technique, all these parameters were chosen the same as for the lattice measurement.

Because of the appreciable thickness of the uranium foils used, the fission products emitted in the chamber are characterized by a continuous energy distribution. However, since the fission product range in uranium is of the order of 13 mg/cm^2, both this distribution and the rate of fission-product emission are independent of the foil thickness for the thickness considered. The assumption that the fission-product escape probability and energy distribution are identical for U^{235} and U^{238} fission is adequate for the interpretation of the present experiment, as shown by an analysis of the data in Reference 4.

As a consequence of the continuous energy distribution of the emitted fission products, the counting system does not exhibit a discriminator plateau, and the count rate decreases steadily as the discriminator setting is increased. Since this could make the count rate sensitive to small electronic instabilities, a very stable high-voltage supply unit was used, and the counting set-ups were interchanged between the two sections of the chamber several times during the exposure by a switch placed between the chamber and the preamplifiers. The α background was easily eliminated by a proper choice of the discriminator setting. When this procedure was used, the counting stability was found to be satisfactory.

Since irregularities and oxidation of the surface of the foils might have an effect on the fission-product emission, the surfaces of the foils were rectified and etched with a diluted HNO_3 solution immediately before irradiation; further oxidation during the measurement was retarded by the flow of argon through the chamber. The equivalence between the two halves of the chamber was tested by interchanging the enriched and depleted U foil positions.

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The curve of k versus time—between 9 and 12 hours after irradiation—as obtained from the results of seven independent measurements using different U foils, is shown in Figure 2. The experimental error for points 30 minutes apart is less than ± 1%, appreciably lower than that reported from previous measurements by different techniques[2,3,5]. This error includes the contributions to the spread in the results due to surface irregularities and oxidation of the foils, counting instabilities and slight differences in the efficiencies of the two halves of the fission chamber.

There is therefore evidence that the method is rather insensitive to the effect of these anomalies, provided adequate precautions are taken in selecting the experimental set-up and technique. Due to the linearity and the small slope of the curve in Figure 2, the normalization of the data from the lattice measurements can be advantageously performed using an average value of k over the counting time for the activities induced in the detectors.

The modified double-fission-chamber experiment described above is more straightforward than the usual technique using microthin fission plates, and also avoids the uncertainty associated with the determination of the amount of U deposited on the plates.

The measured values of δ_{28} are listed in the first column of Table I. The quoted errors are the standard deviations of the mean of the results of 4-6 independent measurements, including the contribution of the uncertainty from the double-fission-chamber experiment.

In the second column of Table I are listed the corresponding values of δ_{28} calculated by the Monte Carlo method by H. Rief[6]. These values have been substantially confirmed by recent calculations, using a more up-to-date set of cross sections[7]. The agreement with the experimental

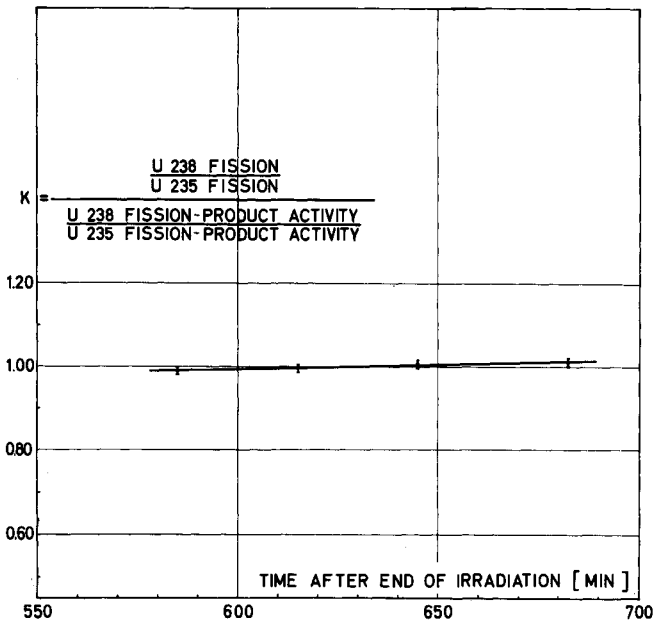

Fig. 2. The normalization curve as obtained from the double-fission-chamber experiment.

results is satisfactory, except for the lattices with $\frac{W}{U}$ volume ratios 2:1 and 3:1 where the theoretical values are somewhat higher. The reason for the discrepancy was not investigated.

Since it was considered of some interest for comparison with theory, to separate the thermal and epithermal components of the U^{235} fissions in the expression for δ_{28}, the ratio of epicadmium to subcadmium U^{235} fissions in the fuel of the lattices investigated ($= \delta_{25}$) was also measured by the cadmium-ratio technique described in Reference 8.

The results of this measurement are listed in the last column of Table I. The quoted errors are the standard deviations of the mean of the results of 4 independent measurements.

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TABLE I

Ratios of U^{238} Fission to U^{235} Fission (δ_{28}), Fast Fission Factors (ϵ) and Ratios of Epi-Cadmium to Sub-Cadmium U^{235} Fission (δ_{25}) in 1.25% Enriched Uranium/Light-Water-Moderated Slab Lattices

Slab Thickness	$\frac{W}{U}$	δ_{28} Experimental	δ_{28} Calculated	ϵ Experimental	δ_{25} Experimental
0.122 in.	1.025	0.163 ± 0.002	0.166	1.115	0.258 ± 0.001
	1.537	0.1285 ± 0.0015	0.128	1.090	0.170 ± 0.001
	2.049	0.1020 ± 0.0025	0.108	1.072	0.1306 ± 0.0007
	3.074	0.0775 ± 0.0015	0.083	1.054	0.0871 ± 0.0005
	4.098	0.0640 ± 0.0010	0.064	1.045	0.0654 ± 0.0004

The fast fission factors have been inferred from the measured δ_{28}'s through the usual equation[1]:

$$\epsilon = 1 + \left(\frac{\nu_{28}}{\nu_{25}} - \frac{1 + \alpha_{28}}{\nu_{25}}\right) \delta_{28} \ ;$$

where

$$\alpha_{28} = \frac{\int_{E_0}^{\infty} \sigma_c^{238}(E)\phi(E)dE}{\int_{E_0}^{\infty} \sigma_f^{238}(E)\phi(E)dE} \ ,$$

E_0 is the U^{238} fission threshold energy, and the other symbols have their standard meaning. The values of ϵ listed in Table I correspond to taking $\alpha_{28} = 0.107$ (calculated by numerical integration of the above expression over the fission-neutron energy spectrum[1]), $\nu_{28}/\nu_{25} = 1.16$[9], $\nu_{25} = 2.43$.

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