of nuclide abundance or level parameters, resonance I dominates the shape of the flux near the resonant energy. Then a simple estimate of the capture rate in resonance II may be obtained by integrating the capture cross section from resonance II times the flux determined by the presence of resonance I in the absence of resonance II.

The procedure is to express the capture cross section in resonance II in terms of the line shape of resonance I and a modifying function. We use unbroadened line shapes and expand σ_{a_2} in the difference $x_1^2 - x_2^2$, where $x_i = 2(E-E_{r_i})/\Gamma_i$; E_{r_i} is the resonance energy and Γ_i is the total width.

For the flux we use the intermediate representation of Goldstein and Cohen[3] and introduce their parameter β_λ given by

$$\beta_\lambda^2 = 1 + \frac{\sigma_0}{s+\lambda\sigma_p}\,\frac{\Gamma\gamma + \lambda\Gamma_n}{\Gamma},$$

where

the resonance parameters are those of the dominant resonance (I)

σ_0 is the peak cross section of resonance I,

s is the effective moderator scattering per atom of type I

σ_p is the total potential scattering per atom of type I

λ is the intermediate representation parameter.

Performing the integration by a contour integral[a]

$$RI_2 = \frac{\Gamma_1}{2E_{r_1}}\int_{-\infty}^{\infty}\psi_1\,\sigma_{a_2}\,dx_1,$$

where RI_2 is the resonance integral for the second resonance

$$\psi_1 \approx (1+x_1^2)/(\beta_\lambda + x_1^2),\quad \sigma_{a_2} = \frac{\Gamma_{\gamma 2}}{\Gamma_2}\,\frac{\sigma_{0,2}}{1+x_2^2},$$

we find

$$RI_2 = I_{0,2}\,\frac{E_2}{E_1}\times \times\left[1 + \frac{(1-\beta_\lambda^2)\Gamma_1}{\beta_\lambda}\,\frac{\Gamma_2 + \beta_\lambda\Gamma_1}{(\Gamma_2+\beta_\lambda\Gamma_1)^2 + 4(E_2-E_1)^2}\right],$$

where $I_{0,2}$ is the infinite-dilution resonance integral.

Consider as an example a mixture of $H:U^{238} = 1$ and estimate the depression in the response of a gold foil from the interference between the 6.68 eV resonance of U^{238} and the 4.91 eV resonance in gold. We have for resonance I:

$E_1 = 6.68$ eV

$\sigma_0 = 2.192 \times 10^4$ barns

$\Gamma_1 = 0.0264$ eV

$\sigma_s = 20$ barns

$\lambda = 0$

$\beta_\lambda^2 = 954.$

For resonance II:

$E_2 = 4.91$ eV

$\Gamma_2 = 0.1406$ eV.

By substitution we find $\frac{RI_2}{I_{0,2}} = 0.69$; the largest part of the ratio, 0.734, comes from the term E_2/E_1. It may be fairly argued that the ratio E_2/E_1 should be omitted, since it comes from neglecting the $1/E$ dependence of the flux. In fact, if we put $\beta_\lambda = 1$ (no resonance flux depression) we find $RI_2/I_{0,2}$ given by: $RI_2/I_{0,2} = E_2/E_1$. We therefore suggest modifying the formula given above by dropping the ratio E_2/E_1. When this is done for the example cited, $RI_2/I_{0,2} = 0.94$. An exact calculation[1] gives a value of 0.92 for this ratio.

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Resonance Integrals for U^{233} Fission and Th^{232} Capture

The resonance integrals for U^{233} fission and Th^{232} capture have been measured relative to the resonance capture integral of Au^{197} by means of the cadmium-ratio-activation technique[1]. Dilute detector foils were irradiated in an 11.5 cm diam water hole at the center of the TRX critical facility[1]. The TRX is a water-moderated lattice of cylindrical, slightly enriched uranium metal and UO_2 fuel rods. The epithermal flux spectrum in the water hole was approximately proportional to $1/E$ except for the flux peak above 25 keV.

Figure 1 shows the disc-shaped cadmium box.

[a] Suggested by E. Pennington, ANL. The contour lies in the upper half plane.

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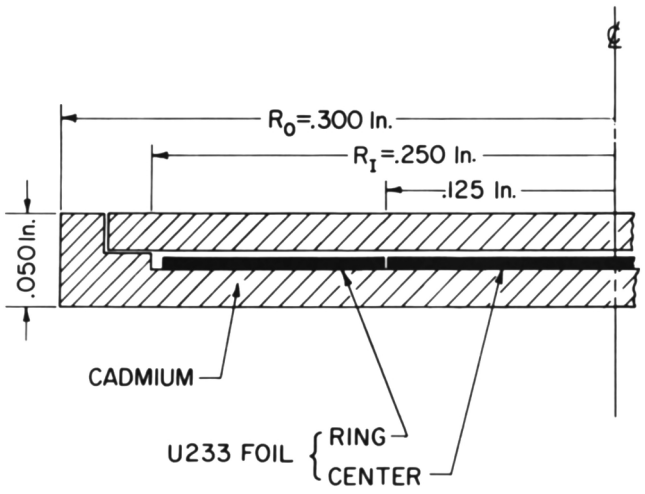

Fig. 1. Cadmium box.

The γ activities of the foils were measured by means of a NaI scintillation counter. Details of the foils and γ counting are summarized in Table I.

The neutron flux spectrum was calculated in P_1 approximation assuming one-dimensional, cylindrical geometry by means of the P3MG program[2]. This calculation employed one thermal-energy group and 54 groups from 0.625 eV to 10 MeV. The thermal-flux spectrum was obtained in 40 groups up to 1.4 eV by means of a space-independent calculation[3], assuming the existence of a pure buckling. This was normalized to the one-group thermal flux from the P3MG calculation up to 0.625 eV. The spectrum is shown in Fig. 2.

The cadmium cutoff energy ϵ^j for each detector was calculated, assuming infinite slab geometry, from the expression[1]

$$\int_{\epsilon^j}^{5\text{eV}} \phi(E)\, \sigma^j(E)\, dE = \int_0^{5\text{eV}} \phi(E)\, \sigma^j(E)\, E_2(X)\, dE, \tag{1}$$

where $X = \sum_a^{\text{Cd}}(E)\, t.$

The resonance integral I^j above the cutoff energy was obtained from the relation (terms are defined in Table II)

$$I^j(\epsilon^j) = I^{\text{Au}} \frac{(\text{C R} - 1)^{\text{Au}}}{(\text{C R} - 1)^j} \frac{\sigma_0^j}{\sigma_0^{\text{Au}}} \frac{F^j}{F^{\text{Au}}}. \tag{2}$$

Calculated corrections were applied where necessary to account for departure from $1/v$ dependence of the detector subcadmium cross sections and for slight foil self-shielding in this range. Corrections were also applied for self-shielding of the epicadmium detector activations and for departure of the epithermal flux spectrum from the $1/E$ shape. For U^{233}, a correction to account for edge effects in the cadmium box was obtained by comparing the activations of the ring and center portions of the foil (see Fig. 1). These corrections are incorporated in the F factors of Eq. (2). The results, as well as details of the calculations, are spelled out in Table II.

Natural activities of U^{233} and Th^{232} were subtracted. Perturbation of the results by aluminum or nickel activities was found to be negligible. Half-lives of Au^{198} and Pa^{233} were consistent with accepted values within the statistical accuracy of the counts. All uncertainties are compounded as though they were random. The U^{233} result includes 1% to account for uncertainty of the cutoff energy.

The value for Th^{232} is in agreement with that obtained by Brose[4] using the cadmium-ratio technique. His result of 82.7 ± 1.8 barn when put on the same basis as the present value (namely I^{Au} = 1555 barn and σ_0^{Th} = 7.33 barn) becomes 80.8 ± 1.8

[2]H. BOHL, Jr., *et al.*, "P3MG-1—A One-Dimensional Multigroup P-3 Program for the Philco-2000 Computer," WAPD-TM-272, Bettis Atomic Power Laboratory (1963).

[3]W. W. CLENDENIN, "MAGMA—A Philco 2000 Program for the Calculation of Scattering Kernels, Neutron Spectra and Few-Group Parameters for Thermal Neutrons," WAPD-TM-373, Bettis Atomic Power Laboratory (1964).

[4]M. BROSE, Thesis, Technische Hochschule Karlsruhe (1962).

TABLE I

Details of Detectors and γ Counting

	U^{233}	Au^{197}	Th^{232}
Foil Composition	2.8 wt% U^{233}-Al	0.25 wt% Au-Ni	2.9 wt% Th-Al
Foil Diameter (in.)	0.488	0.387	0.387
Foil Thickness (in.)	0.006	0.002	0.004
Activity Counted	Fission Products	Au^{198}	Pa^{233}
Half-life (day)	- - - -	2.7	27.4
Window	400 keV int.	360-460 keV	50 keV int.

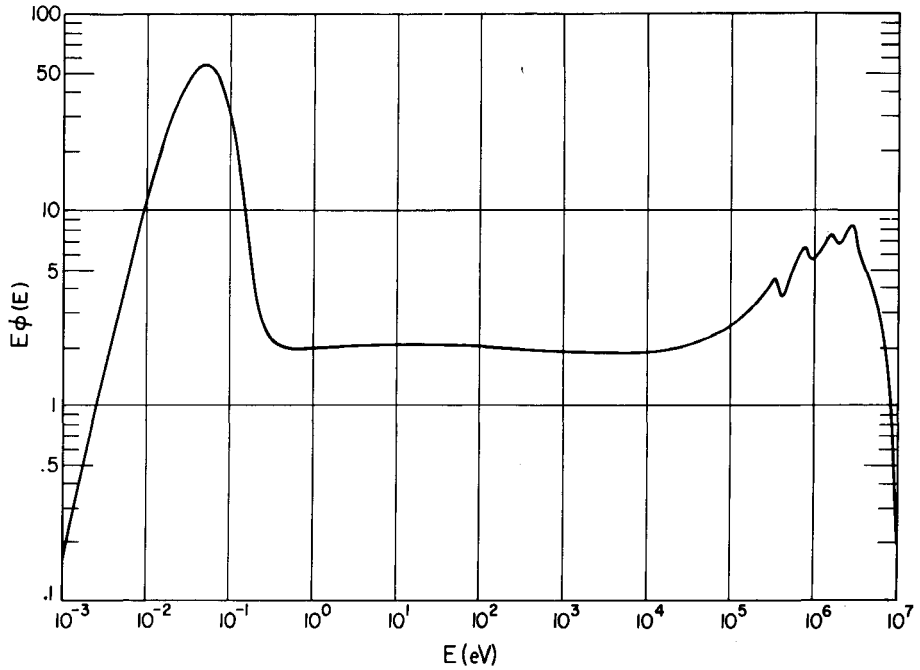

Fig. 2. Flux spectrum.

TABLE II

Experimental Results

Detector, j	Au^{197}	Th^{232}	U^{233}	
Cadmium thickness, t (in.)	0.0205	0.0205	0.0215	0.0320
Measured cadmium ratio, C R	3.918 (0.5%)[b]	5.105 (0.6%)	31.20 (0.5%)	32.11 (0.5%)
Calculated cadmium cutoff energy, ϵ^j (eV)	(0.5)[c]	(0.5)[c]	0.62	0.75
Cross section at 0.0253 eV, σ_0^j (barn)	98.8 (0.3%)	7.33 (1.6%)	526 (0.6%)	
Calculated subcadmium non-$1/v$ correction, Δ_1	+0.006	-0.005	-0.004	
Calculated subcadmium self-shielding correction, Δ_2	0	0	-0.006	
Calculated epicadmium self-shielding correction, Δ_3	+0.014	+0.010	0	
Calculated correction to $1/E$ epicadmium spectrum, Δ_4	0	+0.021	+0.005	
Measured correction to infinite slab geometry for cadmium box, Δ_5	0	0	-0.010	
Total correction factor, $F^j = 1 + \Delta_1 \ldots + \Delta_5$	1.020 (1%)	1.026 (1.3%)	0.985 (0.8%)	
Resonance integral above ϵ^j, I^j (barn)	1555 (2.6%)[a]	82.5	771	748
Calculated correction to ϵ^j = 0.5 eV (barn)			+27	+49
% uncertainty assigned (excluding σ_0's and I^{Au} uncertainties)		2.0%	1.8%	
% uncertainty assigned (including σ_0's and I^{Au} uncertainties)		3.6%	3.3%	
Resonance integral above 0.5 eV (barn)		82.5 ± 3.0	798 ± 26	

[a] Resonance integral standard[14,15].

[b] Errors quoted for cadmium ratios are % standard deviations obtained from the spreads of the individual measurements.

[c] Nominal values.

barn, compared with 82.5 ± 1.7 barn. It is not known how close to $1/E$ was the spectrum in which the measurements of Brose were made. Johnston, *et al.*[5], Tiren and Jenkins[6] and Sampson[7] have obtained values in the vicinity of 83 barn by activation techniques.

The situation with regard to U^{233} is less clear. Halperin, *et al.*[8] obtained 875 ± 40 barn above 0.5 eV by radiochemical separation and counting of selected fission product activities. Bigham[9] gets 739 ± 36 barn by counting fission product activity, whereas the present experiment yields 798 ± 26 barn. The reasons for these discrepancies are not apparent.

Integration of differential U^{233} fission cross section data has yielded results of 789 barn[10], 775 barn[11] and 772 barn[12], all consistent with the present value. In the case of Th^{232}, however, some adjustment of the resonance parameters is necessary in order to obtain a value in the vicinity of 83 barn[13,14].

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