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Letters to the Editors

The Thermal Capture Cross Section and Resonance Integral of Uranium-232*

The 71.7 year U^{232} is of interest in the Th^{232}-U^{233} breeding cycle because it is formed as a by-product, primarily by the sequence of reactions shown in Expression 1.

$$Th^{232}(n,2n)Th^{231}\xrightarrow[\beta^-]{25.6\ h}Pa^{231}(n,\gamma)Pa^{232}\xrightarrow[\beta^-]{31.7\ h}U^{232} \quad (1)$$

Because of the relatively short half-life of U^{232} and its daughters and the hard gammas in that decay chain, the presence of U^{232} presents significant problems in the purification of U^{233} and limits the decontamination factor that can be achieved.

Submicrogram samples of U^{232} (produced from irradiated Pa^{231}) containing about 0.75% U^{233} were irradiated for times up to about a week in the hydraulic tube of the ORR. This facility provides a thermal flux of $\approx 10^{14}$ n cm^{-2}sec^{-1} and a ratio of $(\phi_{th}/\phi_r) \approx 10$. Both cadmium-filtered and unfiltered samples were irradiated using dilute alloys of Co (0.151%) in aluminum to monitor the irradiation. The irradiated samples of uranium were assayed[a] using the two-stage mass spectrometer. Singly charged, uranium metal ions were produced by surface ionization from rhenium filaments and measured with a 14-stage electron multiplier.

The thermal flux and the resonance flux for each unit ln E were calculated from the cobalt irradiation data using 37 and 75 barns[1] respectively for the 2200 m/sec cross section, σ_0, and the resonance integral, I. The U^{232} cross sections were determined from the measured increase in the U^{233} content of the samples using previously described conventions[1]. The effect of destruction in both U^{233} and U^{232} was taken into account (using for U^{233} absorption σ_0 = 580 barns and I = 1000 barns, and for U^{232} absorption σ_0 = 560 barns and I = 800 barns). However for the relatively small flux-time product of this experiment the results were insensitive to this factor; a 50% change in the assumed cross sections of U^{233} and U^{232} gave rise to less than a 1% change in the values reported here.

The data are summarized in Table I. The weighted thermal (subcadmium) capture cross section and resonance capture integral are found to be 78 ± 4 barns and 280 ± 15 barns respectively. A '$1/v$' dependence of the cross section in the thermal region would yield a value of 75 barns for σ_0, the 2200 m/sec cross section. However there is reason to believe that the cross section does not have a '$1/v$' dependence in this case.

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[a]We are indebted to L. E. Idom for his aid in the mass spectroscopic measurements.

[1]R. W. STOUGHTON and J. HALPERIN, *Nucl. Sci. Eng.*, **6**, 100 (1959).

TABLE I

Cross Section Measurement of U^{232}

Irrad	Irrad Time $\times 10^{-5}$ (sec)	$\phi_{th} \times 10^{-13}$ n cm^{-2}sec^{-1}	$\phi_r \times 10^{-13}$ n cm^{-2}sec^{-1}	Mass Analysis[a] $(U^{233}/U^{232}) \times 10^2$	σ_{eff} (barns)	I (barns)	σ_{th} (barns)
1. Unfiltered	2.77	11.2_4		1.080 ± .006	109 ± 6		81 ± 6
Filtered			1.09_7	0.838[b] ± .001		285 ± 30	
2. Unfiltered	5.36	11.5_9		1.372 ± .005	105 ± 4		77 ± 4
Filtered			1.13_6	0.920[b] ± .002		279 ± 15	
					weighted av	280 ± 15	78 ± 4

[a]Mass analysis of unirradiated sample = 0.752 ± 0.005 percent.

[b]Mean of two samples.

The thermal fission cross section of U^{232} has been measured as 81 ± 15 barns[2] (the reported value being corrected here for the more recent U^{232} half-life of 71.7 years[3]). The fission cross section of U^{232} has been measured as a function of energy by James[4] up to 400 eV. Berreth[5] has reported upon the total cross section of U^{232} from 0.01 to 1000 eV. An analysis based upon the resonance parameters estimated by James indicates that only about 1/4 of the thermal fission cross section and 1/10 of the thermal capture cross section can be accounted for from the known resonances. This suggests the presence of a negative energy resonance, and a departure from a '$1/v$' dependence in the thermal region. The capture resonance integral estimated from the resonance parameters is 220 barns compared to our directly measured value of 280 barns. However the uncertainty in the value computed from resonance parameters is probably of the order of 50%. Our value of 78 barns for the thermal capture cross section can be compared with Elson's old estimate of 200 $^{+300}_{-200}$ barns and Berreth's total cross section of 230 barns. The large uncertainty in Elson's value limits the usefulness of its comparison here. However, subtracting 95 barns for fission and scattering from Berreth's 230 barn value yields 135 barns for the capture cross section of U^{232}.

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[2]R. ELSON, W. BENTLEY, A. GHIORSO and Q. VAN WINKLE, *Phys. Rev.* **89**, 320 (1953).

[3]J. M. CHILTON, R. A. GILBERT, R. E. LEUZE and W. S. LYON, *J. Inorg. Nucl. Chem.* **26**, 395 (1964).

[4]G. D. JAMES, "The Fission Cross Section of U^{232} from 4 eV to 400 eV," Private Communication (1964).

[5]J. R. BERRETH, M. S. MOORE and O. D. SIMPSON, *Trans. Amer. Nucl. Soc.*, **6**, 44 (1963).

Criticism of "A Note on the Measurement of the Transport Mean Free Path of Thermal Neutrons in Graphite by a Poison Method"

In a recent note[1] an attempt was made by Price to resolve the discrepancy between pulsed values of the transport mean free path, λ_t, and steady-state values in graphite. The pulsed methods were assigned an average value of 2.59 cm, and a value of 2.77 ± 0.05 cm derived from a copper-poison technique by J. M. Hendrie, *et al.*[2] was listed.

If a three-parameter fit is made to pulsed data, the decay constant α may be expressed as

$$\alpha = v\Sigma_a + D_B B^2$$
$$= v\Sigma_a + (D_0 - CB^2)B^2 \quad (1)$$

where D_B is the diffusion constant for the spectrum in the finite moderator, D_0 for the spectrum in the infinite moderator (i.e. no leakage), and C is the so-called diffusion cooling coefficient. For $\frac{1}{v}$ absorption the infinite-medium spectrum is Maxwellian at room temperature. If C is positive the spectrum is cooler than the room-temperature Maxwellian. For the copper-poison method, which is steady state, $\alpha = 0$ since there is no decay. The author assumed $B^2 = -\frac{1}{L^2}$, which is true for a steady-state infinite-medium geometry where the spectrum is warmer than a Maxwellian at room temperature. In a source-free region $\nabla^2 n - \frac{n}{L^2} = 0$. The buckling is negative and equal to the material buckling, $B_m{}^2 = -\frac{1}{L^2}$. If B^2 is set equal to $-\frac{1}{L^2}$ for a finite geometry, the tacit assumption is made that a finite steady-state system has the same spectrum as an infinite system, which is untrue.

Actually, in the case of graphite, supercooled neutrons may be obtained by passing neutrons down a narrow column. The diffusion cooling is enormously enhanced by Bragg effects. An effective 'buckling' $B_e{}^2$, must be found that goes to zero when the leakage cooling balances the diffusion heating, and becomes positive when the cooling exceeds the heating.

In the copper-poison experiments, graphite-copper stacks with an extrapolated area of 123 × 123 cm^2 were fed by a thermal column. The diffusion length was determined by the equation

$$\frac{1}{L^2} = \frac{1}{b^2} - \frac{2\pi^2}{a^2} \quad (2)$$

where b is the measured relaxation length. Of the six stacks, I would estimate that the three least poisoned cases (including pure graphite) have spectrums cooler than room temperature. A more appropriate effective buckling may be the sum of

[1]G. A. PRICE, *Nucl. Sci. Eng.* **18**, 18, 410-412 (1964).

[2]J. M. HENDRIE, J. P. PHELPS, G. A. PRICE and E. V. WEINSTOCK, "Slowing Down and Diffusion Lengths of Neutrons in Graphite-Bismuth Systems," *Proc. 2nd U. N. Int. Conf. Peaceful Uses of Atomic Energy*, Geneva, P/601 (1958).