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Letters to the Editors

Total Neutron Cross Section of Pa^{233} from 0.01 to 1.0 eV*

In the design of thorium breeder reactors, the neutron cross section of protactinium-233 (Pa^{233}) is of primary importance. Because of the high radiation field involved and the short half-life of this isotope, its cross section measurements are much more difficult than for nonradioactive samples. The Materials Testing Reactor (MTR) fast chopper has capabilities of making measurements on such highly radioactive samples[1,2]. In addition, the facilities for producing Pa^{233} were available at the MTR site.

The Pa^{233} sample was produced by irradiating 280 grams of thorium-232 (Th^{232}) in the Engineering Test Reactor (ETR) for one cycle (approximately four weeks). At the completion of the irradiation, the irradiated material was transferred to the chemistry alpha-cave for chemical separation, which yielded approximately 900 mg of Pa^{233}. The details of the chemical preparation of this unique sample (the largest ever separated in solid form) will be given in a separate publication[3]. The sample consisted of approximately 15 000 curies and read approximately 25 000 R/h at one foot. The oxide sample was pressed in an aluminum matrix for cross section measurements.

The total neutron cross section of Pa^{233} was measured on the MTR fast chopper from 0.01 to 20.0 eV[4]. The present letter is a report of the data between 0.01 and 1.0 eV (of greatest interest to thermal reactor design); the data above 1.0 eV will be reported at a later time, after complete analysis for the resonance parameters. Figure 1 shows the total neutron cross section between 0.01 and 1.0 eV. The data points are tabulated, for greater convenience in use, in Table I. The sample thickness at the time of the first measurements was approximately 300 barns/atom. The data shown are an average of five different runs taken over a period of seven days. The individual measurements each took about eight hours of running time, and agreement was obtained within the counting statistics of approximately ± 0.6 barns for each run. A gold sample was cycled in series with the Pa^{233} sample and used as a standard for checking the performance of the equipment. The 0.4 and 0.8 eV resonances can be attributed to Pa^{233}, since they appear to decay with the proper half-life. A second-order-polynomial least squares fit to the $\sigma_T\sqrt{E}$ curve between 0.01 and 0.1 eV gives a 2200 m/sec total cross section value of 56.7 ± 0.4 barns. However, other uncertainties, such as the errors in the original number of atoms of Pa^{233} at the time of chemical separation, the assigned error to the uranium-233 (U^{233}) cross section (which was the major contaminant), the error in the decay

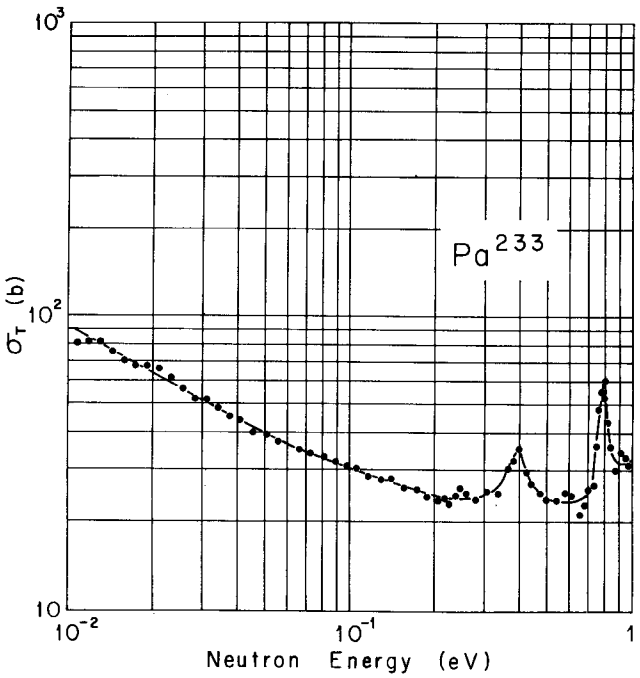

Fig. 1. The total neutron cross section as a function of neutron energy for Pa^{233} from 0.01 to 1.0 eV.

*Work performed under the auspices of the USAEC.

[1] F. B. SIMPSON and R. P. SCHUMAN, *Proc. Symposium Neutron Time-of-Flight Methods, Saclay, France, 24-27 July*, Session II, 85-91, (1961).

[2] F. B. SIMPSON and R. P. SCHUMAN, *Trans. Am. Nucl. Soc.* 6, 1, 43 (1963).

[3] J. W. CODDING *et al.*, to be published.

[4] F. B. SIMPSON *et al.*, *Bull. Am. Phys. Soc.* 9, 433 (1964).

TABLE I

Total Neutron Cross Section *vs* Neutron Energy for Pa^{233} from 0.01 to 1.0 eV

E(eV)	σ(*b*)	*E*(eV)	σ(*b*)	*E*(eV)	σ(*b*)
0.0109	81.04	0.0889	32.10	0.4476	26.73
0.0120	81.64	0.0977	30.51	0.4682	27.57
0.0132	81.29	0.1071	30.44	0.5021	23.80
0.0145	74.65	0.1179	28.38	0.5529	24.25
0.0160	70.05	0.1300	27.80	0.5989	24.41
0.0176	66.54	0.1428	27.47	0.6289	20.36
0.0193	67.22	0.1569	26.25	0.6515	21.32
0.0213	64.49	0.1725	25.67	0.6755	22.48
0.0234	61.43	0.1895	24.19	0.7008	25.72
0.0257	56.48	0.2040	23.51	0.7275	26.33
0.0283	54.02	0.2145	23.79	0.7485	35.48
0.0311	51.18	0.2260	23.01	0.7630	48.16
0.0343	47.78	0.2371	24.01	0.7780	53.57
0.0377	45.25	0.2490	25.66	0.7934	53.30
0.0414	44.30	0.2619	24.61	0.8093	61.04
0.0455	40.39	0.2807	23.51	0.8257	42.64
0.0501	39.01	0.3091	25.37	0.8425	35.91
0.0552	37.13	0.3419	24.86	0.8689	29.65
0.0606	36.97	0.3675	29.90	0.9059	34.07
0.0666	34.96	0.3853	31.98	0.9453	36.24
0.0734	33.85	0.4046	35.33	0.9874	31.14
0.0807	32.71	0.4253	29.02	1.0207	35.97

time, and the error in the half-life of Pa^{233}, increases the error to ± 1.6 barns. There are also other errors which may exist which have not been taken into consideration, such as sample nonuniformity and possibly small unknown contaminants. The final result of this determination gives a value for the 2200 m/sec total cross section of Pa^{233} as 57^{+3}_{-4} barns.

As an independent check on the original amount of Pa^{233} present in the sample at the time of chemical separation, measurements were taken on the sample after about three half-lives of decay. At this time, approximately 90% of the Pa^{233} had decayed to U^{233}. Figure 2 shows the U^{233} total cross section data obtained from this measurement. A least squares fit to these data gives a thermal total neutron cross section value of 589 barns which is in agreement with other values[5,6,7].

It is of interest to compare the present results with previously obtained integral measurements of the Pa^{233} cross section. The present 2200 m/sec value of 57^{+3}_{-4} barns for the total cross section agrees favorably with the 41 ± 5 barns and 39 ± 5 barns for the absorption cross section recently

[5]O. D. SIMPSON, M. S. MOORE and F. B. SIMPSON, *Nucl. Sci. Eng.* **7**, 187 (1960).

[6]R. C. BLOCK, G. G. SLAUGHTER and J. A. HARVEY, *Nucl. Sci. Eng.* **8**, 112 (1960).

[7]G. J. SAFFORD, W. W. HAVENS and B. M. RUSTAD, *Phys. Rev.* **118**, 799 (1960).

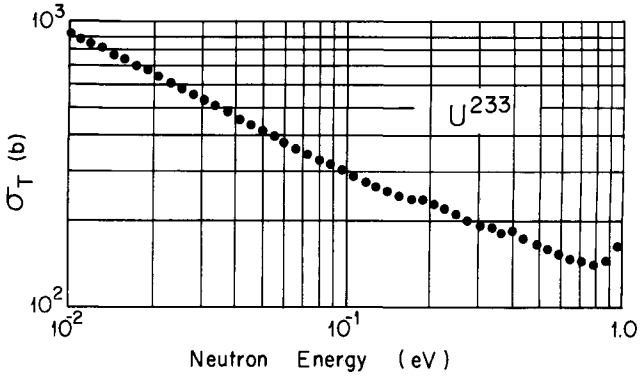

Fig. 2. The total neutron cross section as a function of neutron energy for U^{233} from 0.01 to 1.0 eV obtained from the Pa^{233} sample after about three half-lives of decay.

obtained by Halperin *et al.*[8] and by Eastwood and Werner[9] by activation and mass-spectrographic techniques respectively. However, it is a little lower than the value of 68 ± 6 barns obtained by Smith *et al.*[10] for the absorption cross section. It might also be noted that the resonance absorption integral estimated from preliminary resonance parameters obtained in the present work agrees, within the quoted errors, with resonance absorption integrals measured by activation[9] and mass-spectrographic techniques[11].

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[8]J. HALPERIN *et al.*, private communication.

[9]T. A. EASTWOOD and R. D. WERNER, *Can. J. Phys.* 38, 751 (1960).

[10]R. R. SMITH *et al.*, IDO-16226 (1955).

[11]J. HALPERIN *et al.*, ORNL-3320, 1 (1962).

Inelastic Neutron Scattering by some Hydrogenous Moderators

In the Fermi pseudopotential approximation[1] the differential scattering cross section for a system of nuclei which is isotropic with respect to the direction of the incident neutron can be written:

[1]P. A. EGELSTAFF, "Inelastic Scattering of Neutrons in Solids and Liquids," IAEA, Vienna 25 (1961).