Nonelastic Neutron Cross-Section Measurements on Li^6, Li^7, U^{235}, U^{238}, and Pu^{239} at 8.1, 11.9, and 14.1 MeV*

M. H. MacGregor, R. Booth, and W. P. Ball†
Lawrence Radiation Laboratory, University of California, Livermore, California
(Received 10 December 1962)

Nonelastic neutron cross sections have been measured for Li^6, Li^7, U^{235}, U^{238}, and Pu^{239} at 8.1, 11.9, and 14.1 MeV by means of the sphere transmission technique.

I. INTRODUCTION

THIS report summarizes neutron nonelastic cross-section measurements on lithium, uranium, and plutonium isotopes at energies between 8 and 14 MeV. Details of the experimental procedure and the UNIVAC correction problem have been published.[1]

II. MEASUREMENTS ON Li^6 AND Li^7

Neutron nonelastic cross sections were measured for Li^6 and Li^7 by means of the sphere transmission technique.[1] The Li^6 was 94.42% Li^6 by weight. The Li^7 was 98.05% Li^7 by weight. Data were taken at ten different detector biases. Corrections were applied to the data for elastic energy loss, multiple scattering, finite detector size, variation of the beam energy and intensity with angle, finite source-detector spacing, and the effect of the 15-mil Armco iron container. At 14 MeV, information on the lithium angular distribution is available.[2] At 8 MeV, the angular distribution was estimated from other light-element angular distributions. The 11-MeV correction factors were obtained by interpolation. Due to the lack of knowledge about the angular distribution, the final cross sections at 8 and 11 MeV are not very accurate. The quoted errors at 8 and 11 MeV in Table I represent an "educated guess" as to probable error limits.

The Li^7 cross section reported here is lower than that of Li^6 because inelastic scattering to the 0.477-MeV level in the case of Li^7 could not be separated from elastic scattering collisions.

TABLE I. Nonelastic cross-section values for Li^6 and Li^7 (in barns).

Neutron energy (MeV)	8.1	11.9	14.2
σ_{nx} for Li^6	0.38±0.10	0.49±0.10	0.52±0.05
σ_{nx} for Li^7	0.26±0.10	0.38±0.10	0.40±0.05

III. MEASUREMENTS ON U^{235}, U^{238}, AND Pu^{239}

Neutron nonelastic cross sections were measured for U^{235}, U^{238}, and Pu^{239} by means of the sphere transmission technique.[1] The U^{235} was 93.5% U^{235} and the rest U^{238}. The U^{238} was depleted in U^{235} and, hence, was essentially 100% U^{238}. Angular distributions for the UNIVAC correction problems were obtained by optical-model calculations, using the model of Bjorklund and Fern-

TABLE II. Nonelastic cross-section values for U^{235}, U^{238}, and Pu^{239} (in barns).

Isotope	Neutron energy (MeV)	σ_{nx}	Corrected for fission	Detector bias (% of peak pulse height) 90	86.7	85.7	83.3	80	75	71.4	66.7
U^{235}	8.1	2.90±0.15	Yes	2.89	2.87	2.89	2.92	2.92	2.93	2.95	3.03
			No	2.61	2.59	2.61	2.64	2.62	2.60	2.56	2.51
	11.9	2.66±0.10	Yes	2.64	2.65	2.68	2.66	2.67	2.66	2.71	2.67
			No	2.59	2.60	2.62	2.60	2.60	2.59	2.62	2.56
	14.1	2.84±0.10	···	2.86	2.84	2.87	2.82	2.81	2.78	2.79	2.77
U^{238}	8.1	2.95±0.15	Yes	2.91	2.94	3.02	2.93	2.94	2.92	2.94	2.92
			No	2.82	2.85	2.93	2.84	2.84	2.81	2.83	2.75
	11.9	2.83±0.10	Yes	2.83	2.79	2.83	2.83	2.83	2.81	2.83	2.84
			No	2.78	2.74	2.77	2.77	2.76	2.74	2.74	2.73
	14.1	2.95±0.10	···	3.00	2.95	2.98	2.93	2.91	2.87	2.83	2.81
Pu^{239}	8.1	3.20±0.20	Yes	3.18	3.22	3.23	3.21	3.15	3.15	3.12	3.34
			No	2.69	2.65	2.64	2.63	2.55	2.47	2.41	2.29
	11.9	2.84±0.12	Yes	2.81	2.84	2.85	2.85	2.85	2.80	2.86	2.91
			No	2.67	2.67	2.67	2.66	2.63	2.56	2.56	2.53
	14.1	2.69±0.20	Yes	2.72	2.67	2.71	2.65	2.69	2.63	2.61	2.59
			No	2.71	2.66	2.70	2.64	2.68	2.60	2.58	2.55

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Present address: Hughes Aircraft Company, Redondo Beach, California.
[1] M. H. MacGregor, W. P. Ball, and R. Booth, Phys. Rev. 108, 726 (1957).
[2] C. Wong, J. D. Anderson, and J. W. McClure, Nucl. Phys. 33, 680 (1962).
[3] F. Bjorklund and S. Fernbach, Phys. Rev. 109, 1295 (1958).

bach.[3] Data were taken at ten different detector biases. Corrections were applied to the data for elastic energy loss, multiple scattering, finite detector size, variation of the beam energy and intensity with angle, finite-source detector spacing, and fission effects. The fission correction was determined by first calibrating the detection efficiency for fission neutrons at each detector bias by using the spontaneous fissions from Pu^{240}, and then measuring the induced fission rate by means of a detector bias set above the initial neutron energy but below the upper energy limit of the fission spectrum.

Table II summarizes the results of the measurements. Fission effects on U^{235} and U^{238} at 14 MeV were negligible.

ACKNOWLEDGMENTS

We are indebted to F. Bjorklund and S. Fernbach for the optical-model calculations on U^{235}, U^{238}, and Pu^{239}.

PHYSICAL REVIEW VOLUME 130, NUMBER 4 15 MAY 1963

Search for Delayed-Neutron Emission in Br^{86} Decay*

Ellis P. Steinberg and Larry L. Schwartz
Argonne National Laboratory, Argonne, Illinois
(Received 9 January 1963).

A search for delayed-neutron activity in the decay of 54-sec Br^{86} was carried out. No statistically significant activity was observed, but an upper limit for the neutron branch of ~0.25% was set. This limit corresponds to a maximum of ~10% for the possible contribution of Br^{86} to the 55-sec delayed-neutron period observed in the thermal neutron fission of U^{235} and ascribed to Br^{87}.

INTRODUCTION

The discovery of[1] 54-sec Br^{86} presents several problems in the interpretation of observations on short-lived bromine isotopes in fission arising from the similarity in properties of Br^{86} and Br^{87}. Experiments are being carried out in this laboratory and elsewhere[2] in an attempt to characterize the decay of these nuclides sufficiently to distinguish their individual contributions to the fission product observations.

One of the prominent features of Br^{87} is its decay to an excited state of Kr^{87} above the binding energy of the fifty-first neutron in Kr^{87}, and the subsequent neutron emission from this state. This decay gives rise to the well-known 55-sec delayed-neutron period in nuclear fission. Although Br^{86} decays to the closed-shell nucleus Kr^{86} and branching to a state above the neutron binding energy (expected to be about 9.5 MeV) may not be very likely, it would be of importance to establish whether Br^{86} may be contributing to the 55-sec delayed-neutron period observed in fission. The present investigation was undertaken to establish the extent of any such contribution.

EXPERIMENTAL

The apparatus and bombardment procedure used for the previously described experiments on the discovery of[1] Br^{86} were utilized in the present investigation. About 40 cc (STP) of enriched Kr^{86} was bombarded for 40 sec with neutrons produced at the Argonne National Laboratory 60-in. cyclotron. Conditions for the bombardments were essentially identical to those for the previous Br^{86} experiments. Several runs were made to ensure that Br^{86} was produced. The decay curves observed were superposable on those of the previous experiment, and indicated the presence of Br^{86} in approximately the same intensity.

Neutrons were detected with a ring of nine BF_3 counters immersed in deuterated paraffin oil and surrounded with a shield of borated paraffin.[3] Samples were placed in the center of the ring for counting. Calibrations of the neutron counter assembly, carried out with a Cf^{252} spontaneous fission source and with the delayed neutrons from thermal fission of U^{235}, indicate an efficiency of 1.2%. In the latter case, U^{235} was irradiated in the pneumatic tube assembly ("rabbit" facility) of the Argonne CP-5 reactor in an amount calculated to give about the same disintegration rate of Br^{87} as that of the Br^{86} expected from the $Kr^{86}(n, p)$ reaction at the cyclotron (i. e., 10^5–10^6 beta disintegration/min). Counting of the delayed neutrons from fission was begun about 0.2 min after the end of irradiation. The decay curves obtained clearly indicate the 55-sec period and shorter composite periods of ~22 sec and ~7 sec which were not further resolved. Figure 1 represents a composite of 5 runs combined to obtain greater statistical accuracy. The extrapolated initial counting rate of the 55-sec period was about 700 counts/min. Within the errors of irradiation timing and uncertainty of the neutron flux, this value is consistent with expectations and indicates

---

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

[1] A. F. Stehney and E. P. Steinberg, Phys. Rev. **127**, 563 (1962).

[2] E. T. Williams and C. D. Coryell, American Nuclear Society Meeting, Boston, June, 1962 and (private communication).

[3] A. F. Stehney and G. J. Perlow, Phys. Rev. **113**, 1269 (1959).