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Thermal-Neutron Capture-Gamma Spectrum of ^{242}Pu

University of California

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THERMAL-NEUTRON CAPTURE-GAMMA SPECTRUM OF ^{242}Pu

by

P. J. Bendt and E. T. Journey

ABSTRACT

The (n, γ) spectrum from a sample of ^{242}Pu irradiated in the thermal column of the Omega West Reactor was observed from 100 to 5200 keV with both Ge(Li) and NaI(Tl) detectors. The energies and partial cross sections were determined for 407 gamma lines, using the Ge(Li) detector. The continuous spectrum observed with NaI(Tl) is displayed in 20 keV energy bins. Summing over the NaI(Tl) spectrum, an (n, γ) cross section equal to 18.5 ± 1 barns was obtained, and also a multiplicity of 4.5 ± 0.2 photons per captured neutron.

I. INTRODUCTION

The nuclear energy level scheme of ^{243}Pu up to 1100 keV was proposed by Casten, Kane, Erskine, Friedman and Gale¹, who drew upon $^{242}\text{Pu}(n, \gamma)^{243}\text{Pu}$, $^{242}\text{Pu}(d, p)^{243}\text{Pu}$, and $^{244}\text{Pu}(d, t)^{243}\text{Pu}$ reactions. For the (n, γ) investigation they used Be-diffracted reactor neutrons to produce captures predominantly in the 2.96 eV resonance of ^{242}Pu ; they determined the energy and intensity of 106 low energy gamma lines and 20 high energy gamma lines; they determined the neutron binding energy of ^{243}Pu to be 5034.2 ± 3 keV.

In the present experiment, a 106 mg sample of pure ^{242}Pu metal was irradiated in the thermal column of the Omega West Reactor. The (n, γ) spectrum was observed from 100 to 5000 keV with both Ge(Li) and NaI(Tl) detectors. The energy and partial cross sections were determined for 407 gamma lines, using the Ge(Li) detector. Of these, 216 lines are between 1200 and 3500 keV, an energy range in which Casten et al.¹ do not report measurements.

The thermal neutron capture cross section of ^{242}Pu was measured by two different methods during the last ten years. Durham and Molson² determined

the cross section by irradiating a sample of $^{242}\text{PuO}_2$ in a reactor thermal flux facility for one year. After irradiation, the plutonium and americium were separated by chemical methods, and the ratio of ^{243}Am to ^{242}Pu was obtained by absolute alpha counting. The value obtained for the neutron capture cross section at 2200 m/s was 18.7 ± 0.7 barns.

Young and Reeder³ used a PuO_2 powder sample in the neutron beam of the Material Testing Reactor's fast chopper. After correcting their results for the nuclear scattering cross section, water contamination, and scattering by small particles, they obtained 18.5 ± 2 barns for the absorption cross section of ^{242}Pu at 0.0253 eV. Young, Simpson and Tate⁴ repeated the experiment with ^{242}Pu metal samples, and combining the metal and oxide measurements, they obtained 18.5 ± 1 barns for the absorption cross section at 0.0253 eV.

By summing over the gamma spectrum measured with a NaI(Tl) detector, we obtained directly both the thermal (n, γ) cross section, and the multiplicity of prompt gamma rays per absorbed neutron. This independent determination is described below.

II. EXPERIMENTAL METHOD

The 106 mg sample of ^{242}Pu was an irregularly-shaped lump of metal, having 1 to 3 mm dimensions. The isotopic composition was $> 99.9\%$ ^{242}Pu . We tested the sample for ^{239}Pu content by searching for fission-product gammas after abruptly terminating a long thermal-neutron irradiation. No fission product gammas were detected in the geometry used for the detection of prompt radiation, and we thus believe the contribution of fission gammas to the measured (n, γ) cross section is negligible.

The sample was sealed between 2-cm-diam circular disks of 0.25 mm thick Pb foils. The Pb foils were held vertically in a graphite holder, and inserted in the gamma spectrometer channel of the OWR thermal column. The thermal neutron flux was 6×10^{11} n/cm², and approximated a Maxwellian distribution corresponding to 350 K, for which the most probable neutron velocity is 2400 m/s. The reactor and gamma spectrometer have been described elsewhere.⁵

The Ge(Li) spectrum was taken using two different modes of operation. In the low energy region, from 100 to 2400 keV, the system was operated in the anticoincidence mode; that is, pulses from the annulus (with the halves

connected together) veto storage of simultaneous pulses from the Ge(Li) detector. Since nearly all the interactions in the low to moderate energy range that produce escape radiation are Compton scatterings, the anticoincidence mode is effective for suppressing detected events that produce pulses that are not part of the full-energy peak.

In the high energy region between 2200 and 5000 keV, the NaI annulus surrounding the Ge(Li) detector was operated in the double-escape mode; that is, each half of the optically-divided annulus was required to supply simultaneously a pulse corresponding to the detection of a 511 keV annihilation quantum (actual gating was set to 500 ± 50 keV) in order to gate the pulse-height analyzer to accept a pulse from the Ge(Li) detector. This arrangement results in a dramatic background reduction, and, perhaps more importantly, in a three-fold reduction in the number of peaks in the observed spectrum, since full-energy and first-escape peaks are eliminated. Because of the rapidly increasing pair production cross section with energy, this mode of operation is useful only for $E_\gamma > 2$ MeV.

The NaI(Tl) spectrum was also taken in the anticoincidence mode. The unfolding of the pulse height distribution from the Na(Tl) detector, in order to obtain the gamma spectrum, is described in Ref. 5.

The relative efficiencies of both detectors were determined from their responses to radioactive sources having two or more gammas with known relative intensities. The NBS Mixed Radionuclide standard source was especially useful for these determinations. In the anticoincidence mode it was possible to extend the relative efficiency measurements to 2.75 MeV by using sources of ^{56}Co and ^{24}Na . In the Ge(Li) double-escape mode the entire relative efficiency curve was mapped by measuring the $^{14}\text{N}(n,\gamma)$ spectrum, which has well characterized gammas with orderly spacing that extend from 1.7 to 11.8 MeV.

III. Measurements with the Ge(Li) Detector

The energies and partial cross sections of 407 lines measured with the Ge(Li) detector are listed in Appendix 1. A section of the low energy and high energy spectrum is shown in Fig. 1.

The partial cross section of the gamma line at 287.5 keV is based on a comparison of the counts in that line to those in the hydrogen (n, γ) line at

2223 keV. A 44.2 mg sample of CH_2 was placed in the target position along with the ^{242}Pu sample and a simultaneous measurement made of both lines. The hydrogen $\sigma(n,\gamma)$ was taken to be 332 mb at 2200 m/s.⁶ The largest uncertainty in calculating the partial cross section of the 287.5 keV line is in the ratio of the detector efficiencies at these widely separated energies. We estimate this uncertainty to be $\pm 10\%$. We calculated ^{242}Pu $\sigma(287.5 \text{ keV } \gamma)$ to be 8.5 ± 0.9 barns. The cross sections of all the other ^{242}Pu gamma lines have been determined relative to the intensity of this line.

The ratio of the observed partial cross section to the total cross section (18.5 barns) does not give a correct measure of the fraction of de-exciting transitions which pass through the level at 287.5 keV. The M1 internal conversion coefficient taken from the Sliv and Band⁷ tables is 1.10, yielding a transition intensity corresponding to 17.9 barns. This value represents an upper limit on the transition intensity, since any admixture of E2 multipolarity will reduce the fraction of internal conversions. One would expect the population of the $5/2^+$ 287 keV state to be high since no lower spin states exist between it and the $7/2^+$ ground state and the compound capture state(s) have $J = 1/2^+$. The transition energy which is internally converted reappears as x-rays, except for the kinetic energy of the conversion electrons. The x-ray lines are identified in Appendix 1.

The energy-weighted sum of the partial cross sections from the 407 observed lines is 7.5 barns, or 40% of the total (n,γ) cross section obtained using the NaI(Tl) detector. This means about 40% of the ^{242}Pu (n,γ) spectrum was resolved, the remaining weaker lines forming an unresolved continuum.

IV. Uncertainties in the Gamma-Ray Energies

The energy calibration for the anticoincidence measurements was based on the well-established energies of Pu $\text{K}\alpha_1$ x-ray (103.76 keV), positron annihilation radiation (511.006 keV), ^{60}Co γ -rays (1173.21 and 1332.47 keV), ^{28}Al γ -rays (1778.70 keV), and the hydrogen (n,γ) line (2223.33 keV). The spectrometer electronic system was nonlinear at both ends of the energy range. This nonlinearity was measured and corrected to an accuracy of ± 0.3 keV. The centroids of the lines were determined with a least-squares fitting program.

The differences from the gamma energies reported by Casten et al.¹ for 97 lines below 1200 keV average +0.3 keV.

In the double escape mode, the energy scale was based on the hydrogen (n, γ) line, and on the ^{12}C (n, γ) lines at 3684.02 and 4945.42 keV. The non-linearity of the system was corrected so strong lines have an accuracy of ± 0.3 keV. Centroids of the weaker lines are somewhat less well determined because the small number of counts gives dominance to statistical uncertainty. In a separate high energy run, where the energy scale was based on the strong ^{14}N lines, the average energy of the ^{243}Pu lines was 0.3 keV lower than reported here.

By combining forty-two combinations of two lines, either to the ground state or the 287.5 keV level, we have calculated the neutron binding energy of ^{243}Pu to be 5034 ± 1 keV; Casten et al.¹ obtained 5034.2 ± 3 keV.

V. Uncertainties in the Gamma-Ray Intensities

The statistical uncertainties in the partial cross sections, plus a measurement uncertainty of $\pm 10\%$, added in quadrature, are included in the Table of gamma lines in Appendix 1. No additional uncertainty for the gamma-ray absorption corrections has been added.

The anticoincidence measurements were processed in three separate computer runs, each containing about one-third of the spectrum up to 2400 keV. These separate sections of the spectrum were normalized to the partial cross section of the 287.5 keV line. The anticoincidence and double escape mode measurements were separately normalized to the hydrogen cross section at 2223 keV. By comparing the intensity of ten overlapping lines, which were measured by both methods, we determined that the intensity calibration for the double escape mode was within 3% of that for the anticoincidence mode.

The intensities of the observed gammas were corrected for self absorption within the Pu sample, and for absorption by .025 cm of Pb, .254 cm of LiF , and 5.13 m of air. The mass absorption coefficients were taken from Storm and Israel.⁸ The largest part of the gamma absorption takes place in the heavy elements Pu and Pb. At low energy, where the transmission is low ($\sim 6\%$ at 150 keV), the uncertainty in the transmission is large. The irregular shape of the ^{242}Pu sample, which is such that no simple geometry closely approximates

the actual shape, contributes to the uncertainty in the absorption calculation. We based the absorption calculations on a spherical sample having the same mass as the actual ^{242}Pu sample.

The relative intensities of the gammas we see in the lower energy (< 2 MeV) part of the spectrum shows generally good agreement with those of Casten, et al.¹ while there is severe disagreement at the higher energies where the transitions take place between the compound excited nucleus and low-lying states. This disagreement is not surprising since different sets of levels in ^{242}Pu are sampled by the differing incident neutron energies* and each set produces its own distribution of intensities. These fluctuations in the intensities become attenuated through cascading toward lower energies, and the intensities in the low-energy portion of the observed spectrum are governed predominantly by the selection rules for transitions between the medium-to-low-lying states.

VI. Results Obtained with the NaI(Tl) Detector

The ^{242}Pu (n, γ) spectrum taken with a 6.3 cm diam by 15.2 cm long NaI(Tl) detector replacing the Ge(Li) detector and with the annulus operated in anti-coincidence, is shown in Figs 2 and 3, and tabulated in 20 keV energy bins in Appendix 2.

The neutron capture cross section in the i^{th} energy interval of the photon spectrum, σ_i , was determined by comparison with the gamma yield from $^1\text{H}(n,\gamma)$ obtained from the irradiation of a 44.2 mg sample of CH_2 in the standard target position. The ^{242}Pu (n, γ) cross section can be obtained from

$$\sigma(n,\gamma) = \frac{1}{E_n} \sum \sigma_i E_i ,$$

where E_n is the neutron separation energy for ^{243}Pu , and E_i is the energy of the i^{th} spectral energy interval, independently of any knowledge of the

* Casten et al. used the 2.96 eV resonance, while we used a thermal Maxwellian distribution.

details of the gamma de-excitation in the excited residual nucleus. Transitions that take place by internal electron conversion will contribute to the observed (n, γ) cross section only through the emission of x-rays.

The multiplicity (number of photons per captured neutron) is given by

$$M = \frac{1}{\sigma(n,\gamma)} \sum \sigma_i \quad .$$

Summing over the spectrum from 0.1 to 5.2 MeV, we obtain a neutron capture cross section of 18.5 ± 1 barns at 2200 m/s, in agreement with the earlier measurements.²⁻⁴ We also obtained a multiplicity of 4.5 ± 0.2 photons per captured neutron.

The largest contribution to the uncertainty in the cross section measurement comes from the calculation of the neutron self-absorption correction in the ^{242}Pu metal. This uncertainty results from the irregular shape of the sample. We calculated the average neutron flux to be 0.94 ± 0.04 of the incident flux, for a spherical sample containing the same mass.⁹

VII. ACKNOWLEDGMENT

We wish to thank Dr. R. E. Tate of LASL Group CMB-5 for the loan of the ^{242}Pu metal sample.

Fig. 1. A portion of the neutron-capture gamma spectrum of ^{242}Pu taken with the Ge(Li) detector in anti-coincidence mode. The four clusters of lines at the lowest energies are Pb K α , Pb K β , Pu K α , and Pu K β x-rays respectively. The most intense line is the transition from the 287.5 keV level in ^{243}Pu to the ground state.

Fig. 2. Neutron-capture gamma spectrum of ^{242}Pu taken with the (NaI(Tl) detector. The yields are displayed in 20 keV bins on a semilog scale.

Fig. 3. Neutron-capture gamma spectrum of ^{242}Pu taken with the NaI(Tl) detector. The yields are displayed in 20 keV bins on a linear scale.

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APPENDIX 1

The transition energy and uncertainty, and the partial cross section and uncertainty, of 407 neutron capture-gamma lines from the ^{242}Pu target measured with the Ge(Li) detector. Pu x-rays are identified in the table.

Trans. Energy (keV)	Uncer- tainty (keV)	Cross Sec. (barns)	Uncer- tainty (barns)	Trans. Energy (keV)	Uncer- tainty (keV)	Cross Sec. (barns)	Uncer- tainty (barns)	Trans. Energy (keV)	Uncer- tainty (keV)	Cross Sec. (barns)	Uncer- tainty (barns)
96.1	.13	1.40	.340	434.6	.10	.01	.002	663.0	.15	.11	.022
99.6	.03	8.25	.993	439.4	.10	.04	.008	675.9	.14	.11	.018
103.8	.02	12.17	1.285	444.7	.01	.12	.013	679.1	.31	.05	.013
115.2	.23	.60	.158	462.7	.16	.01	.003	683.1	.08	.08	.010
117.0	.04	4.08	.459	469.1	.09	.02	.004	685.4	.14	.04	.006
120.8	.05	1.46	.179	472.9	.17	.02	.003	687.8	.31	.02	.005
156.3	.02	.27	.028	475.1	.08	.03	.005	693.5	.13	.05	.006
159.2	.04	.12	.014	480.8	.07	.13	.017	697.0	.15	.03	.006
161.8	.09	.05	.009	483.4	.24	.04	.008	705.3	.37	.01	.004
165.4	.01	.37	.038	491.4	.08	.03	.004	707.4	.12	.03	.005
184.1	.02	.22	.023	497.7	.22	.06	.011	710.4	.16	.03	.004
192.1	.12	.11	.022	501.2	.06	.20	.024	714.7	.24	.02	.004
198.5	.10	.11	.022	503.3	.21	.06	.012	717.0	.10	.04	.005
206.2	.02	.39	.042	506.6	.25	.07	.013	724.6	.12	.04	.006
212.1	.15	.04	.011	508.6	.22	.12	.023	726.6	.20	.03	.005
219.2	.06	.13	.022	513.9	.04	.43	.047	730.1	.14	.03	.005
228.9	.03	.13	.014	516.4	.08	.13	.017	734.0	.28	.02	.004
235.7	.08	.03	.004	522.2	.03	.14	.017	738.3	.05	.10	.011
241.7	.01	.73	.075	526.3	.01	.34	.035	743.6	.08	.02	.003
261.3	.07	.11	.015	532.0	.08	.02	.003	746.4	.02	.11	.012
275.2	.16	.20	.042	534.1	.04	.06	.007	752.7	.05	.04	.005
278.1	.39	.08	.033	535.7	.05	.04	.005	757.4	.04	.05	.006
284.4	.15	.26	.046	546.7	.05	.11	.013	767.7	.14	.02	.003
287.6	.01	8.51	.874	551.6	.03	.05	.006	770.1	.11	.02	.003
296.2	.17	.06	.011	555.8	.16	.17	.031	780.9	.08	.03	.004
302.6	.21	.04	.009	558.3	.12	.23	.036	788.1	.32	.03	.006
306.9	.05	.06	.006	564.8	.02	.34	.034	791.5	.08	.09	.011
331.4	.01	.16	.016	566.4	.02	.28	.028	805.8	.08	.03	.005
343.7	.01	.26	.026	573.3	.04	.04	.005	813.9	.01	.29	.030
351.9	.10	.06	.012	589.2	.03	.14	.015	831.4	.10	.05	.008
358.0	.07	.08	.011	595.0	.33	.02	.004	837.0	.14	.03	.005
364.0	.39	.02	.003	597.6	.14	.04	.006	838.9	.13	.04	.005
368.9	.19	.03	.010	600.6	.09	.05	.007	844.9	.11	.03	.005
382.0	.11	.15	.026	602.8	.16	.03	.005	847.8	.04	.11	.012
385.9	.09	.07	.013	606.3	.17	.02	.005	850.4	.05	.08	.009
397.6	.18	.04	.008	609.9	.04	.10	.012	867.6	.05	.08	.008
400.8	.03	.32	.035	625.3	.12	.07	.014	872.4	.19	.02	.004
402.5	.03	.28	.031	631.9	.55	.03	.009	874.5	.08	.05	.007
407.4	.02	.16	.016	633.8	.31	.05	.011	880.7	.22	.02	.005
416.5	.01	1.16	.119	637.8	.15	.05	.009	884.4	.11	.05	.006
423.5	.14	.01	.002	644.0	.20	.04	.009	887.5	.06	.13	.014
426.1	.04	.03	.004	648.1	.28	.04	.008	889.5	.03	.23	.024
431.6	.15	.01	.001	656.2	.04	.10	.011	893.6	.12	.06	.008

Trans. Energy (keV)	Uncer- tainty (keV)	Cross Sec. (barns)	Uncer- tainty (barns)	Trans. Energy (keV)	Uncer- tainty (keV)	Cross Sec. (barns)	Uncer- tainty (barns)	Trans. Energy (keV)	Uncer- tainty (keV)	Cross Sec. (barns)	Uncer- tainty (barns)
895.7	.11	.06	.009	1279.5	.14	.06	.010	1628.4	.35	.03	.012
903.0	.02	.17	.018	1284.9	.19	.04	.013	1632.2	.23	.04	.012
913.4	.03	.10	.011	1289.2	.29	.01	.005	1641.3	.70	.03	.012
918.7	.09	.02	.004	1293.4	.18	.02	.005	1648.0	.53	.02	.012
931.8	.27	.03	.011	1296.1	.15	.05	.008	1666.4	.31	.07	.013
947.3	.06	.04	.010	1302.8	.64	.01	.007	1669.4	.33	.02	.009
959.4	.25	.01	.004	1304.2	.44	.01	.007	1672.3	.32	.02	.006
968.4	.24	.02	.004	1309.1	.16	.02	.004	1680.2	.36	.08	.015
970.6	.18	.04	.006	1312.9	.14	.03	.006	1682.7	.12	.05	.012
975.1	.13	.04	.006	1319.0	.08	.05	.006	1692.0	.11	.04	.006
977.0	.15	.04	.006	1325.5	.18	.02	.004	1713.7	.23	.06	.010
984.6	.10	.03	.005	1331.6	.24	.03	.005	1718.1	.33	.02	.009
988.0	.07	.06	.007	1351.0	.18	.08	.014	1720.9	.18	.01	.007
991.6	.10	.03	.005	1354.0	.27	.02	.009	1725.6	.36	.05	.017
999.4	.10	.04	.006	1357.9	.26	.02	.007	1728.7	.93	.04	.018
1009.1	.26	.04	.007	1362.0	.25	.06	.012	1767.4	.13	.06	.009
1011.3	.22	.05	.008	1369.4	.43	.01	.007	1775.1	.26	.07	.012
1015.9	.11	.06	.008	1373.4	.38	.04	.016	1779.9	.22	.03	.009
1022.6	.11	.07	.009	1381.2	.29	.04	.014	1786.2	.21	.06	.018
1028.7	.25	.01	.003	1391.2	.24	.03	.006	1789.6	1.72	.03	.027
1031.7	.11	.03	.004	1398.8	.27	.04	.011	1792.9	.62	.03	.014
1042.5	.05	.06	.007	1404.6	.65	.06	.025	1800.6	.22	.08	.014
1050.6	.12	.03	.004	1407.8	.26	.01	.009	1803.9	.34	.03	.010
1054.4	.18	.03	.005	1418.4	.34	.05	.011	1806.9	.09	.01	.005
1056.3	.19	.03	.005	1425.3	.16	.02	.004	1827.0	.35	.01	.005
1079.1	.17	.02	.004	1427.7	.11	.03	.005	1830.0	.14	.05	.008
1087.2	.15	.04	.005	1436.4	.09	.06	.012	1842.1	.22	.04	.008
1091.6	.12	.05	.006	1445.2	.22	.06	.009	1845.8	.18	.03	.007
1103.3	.12	.02	.005	1453.9	.13	.07	.009	1851.2	.14	.07	.011
1113.2	.38	.02	.005	1484.6	.08	.05	.008	1853.5	.14	.01	.006
1119.1	.25	.02	.005	1493.9	.24	.05	.009	1855.4	.41	.04	.013
1127.1	.27	.03	.007	1503.3	.33	.04	.009	1866.6	.15	.01	.003
1134.1	.24	.02	.008	1509.4	.19	.04	.008	1868.9	.15	.04	.007
1162.4	.11	.03	.006	1516.9	.10	.06	.008	1875.4	.22	.03	.007
1176.2	.04	.14	.015	1525.4	.18	.06	.013	1886.5	.22	.05	.008
1180.6	.11	.04	.006	1540.2	.17	.03	.007	1892.4	.18	.06	.010
1185.4	.11	.03	.005	1543.9	.13	.04	.011	1911.2	.21	.04	.008
1190.8	.03	.15	.015	1548.5	.15	.06	.011	1917.1	.35	.07	.015
1196.8	.05	.07	.008	1552.3	.30	.01	.006	1921.6	.41	.06	.017
1201.3	.04	.10	.011	1558.4	.31	.01	.010	1924.1	.22	.01	.005
1219.7	.16	.04	.009	1574.1	.16	.04	.008	1947.6	.16	.05	.008
1223.0	.12	.03	.005	1581.2	.42	.04	.010	1950.5	.18	.01	.009
1226.6	.21	.03	.007	1585.2	.47	.02	.007	1952.9	.36	.03	.009
1229.7	.07	.05	.007	1591.5	.57	.01	.006	1970.8	.35	.01	.007
1233.7	.10	.05	.007	1593.7	.31	.02	.006	1973.9	.27	.02	.007
1242.2	.10	.04	.006	1596.4	.16	.01	.004	2013.2	.42	.05	.015
1251.1	.38	.05	.011	1599.7	.14	.05	.008	2015.8	.19	.03	.010
1253.3	.17	.02	.008	1612.2	.41	.04	.009	2036.7	.11	.05	.010
1266.0	.07	.07	.009	1620.8	.31	.01	.008	2046.3	.12	.03	.006
1270.2	.11	.04	.007	1624.8	.46	.02	.009	2059.2	.23	.01	.004

Trans. Energy (keV)	Uncer- tainty (keV)	Cross Sec. (barns)	Uncer- tainty (barns)	Trans. Energy (keV)	Uncer- tainty (barns)	Cross Sec. (keV)	Uncer- tainty (keV)	Trans. Energy (keV)	Uncer- tainty (keV)	Cross Sec. (barns)	Uncer- tainty (barns)
2066.3	.10	.07	.009	2579.7	.29	.11	.021	3199.6	.22	.04	.006
2087.9	.32	.05	.018	2584.8	.57	.04	.012	3214.1	.24	.03	.007
2119.2	.24	.10	.014	2592.2	.20	.08	.015	3226.5	.18	.04	.006
2130.5	.34	.04	.008	2615.9	.57	.04	.016	3234.2	.25	.04	.008
2145.1	.12	.06	.007	2619.9	.43	.11	.026	3239.2	.26	.03	.007
2155.6	.68	.02	.012	2632.3	.16	.04	.010	3280.7	.41	.02	.004
2159.0	.45	.04	.016	2641.2	.80	.04	.030	3292.0	.20	.10	.016
2163.2	.37	.04	.012	2660.9	.40	.02	.008	3298.9	.33	.03	.008
2169.7	.50	.02	.008	2670.5	.15	.10	.017	3323.4	.30	.03	.007
2177.3	.16	.04	.007	2708.5	.26	.03	.006	3360.3	.30	.02	.004
2189.7	.27	.03	.005	2727.0	.93	.06	.026	3366.0	.36	.02	.004
2197.1	.46	.02	.005	2778.4	.38	.03	.009	3382.5	.16	.04	.007
2207.8	.20	.04	.006	2790.0	.25	.03	.006	3395.2	.20	.03	.005
2210.4	.18	.04	.007	2796.5	.28	.03	.007	3401.7	.26	.02	.004
2216.9	.23	.03	0.000	2802.1	.06	.19	.022	3454.5	.35	.01	.003
2222.9	.07	.10	.010	2817.3	.38	.04	.007	3463.7	.29	.02	.004
2264.1	.09	.07	.008	2821.3	.41	.03	.006	3479.0	.17	.05	.007
2291.0	.43	.07	.022	2839.1	.35	.10	.022	3482.9	.17	.04	.007
2298.8	.49	.05	.018	2852.7	.39	.03	.008	3493.0	.25	.03	.006
2307.4	.31	.10	.022	2865.7	.39	.04	.014	3519.1	.16	.05	.007
2313.3	.12	.04	.007	2875.6	.33	.10	.018	3544.7	.25	.04	.009
2324.5	.18	.03	.005	2875.6	.33	.10	.012	3573.4	.49	.01	.003
2345.0	.25	.01	.004	2907.6	.32	.05	.010	3597.8	.38	.02	.003
2352.4	.28	.02	.007	2918.8	.24	.12	.018	3601.1	.26	.07	.011
2358.1	.16	.06	.010	2948.7	.30	.05	.011	3615.3	.09	.09	.010
2378.7	.15	.07	.010	2957.4	.56	.05	.008	3648.6	.17	.05	.009
2385.0	.29	.02	.005	2972.2	.22	.05	.009	3668.3	.22	.03	.007
2388.5	.35	.01	.006	2982.4	.17	.05	.007	3735.2	.13	.03	.005
2393.7	.20	.02	.006	2992.5	.32	.02	.007	3821.1	.52	.01	.002
2412.5	.25	.03	.007	3002.1	.23	.02	.007	3845.6	.23	.01	.002
2415.3	.29	.01	.003	3012.6	.20	.04	.007	3859.4	.25	.01	.002
2423.3	.14	.04	.006	3021.9	.32	.02	.004	3906.5	.13	.03	.004
2428.2	.27	.03	.007	3030.1	.22	.04	.007	4087.4	.29	.02	.004
2438.5	.12	.07	.009	3042.5	.46	.01	.004	4130.7	.12	.04	.005
2443.2	.09	.07	.009	3053.4	.16	.07	.009	4222.8	.13	.05	.006
2454.3	.29	.02	.005	3060.0	.09	.12	.015	4227.1	.09	.07	.008
2459.7	.25	.01	.004	3069.3	.24	.03	.006	4332.3	.11	.08	.010
2463.8	.15	.04	.007	3079.8	.17	.04	.008	4360.5	.54	.01	.002
2495.8	.45	.04	.013	3095.7	.19	.05	.008	4382.7	.17	.03	.004
2537.6	.41	.05	.013	3105.3	.11	.09	.012	4589.4	.22	.03	.003
2543.0	.47	.09	.017	3118.2	.18	.03	.006	4614.2	.33	.01	.002
2552.0	.26	.15	.024	3128.4	.11	.12	.015	4644.6	.31	.01	.003
2571.4	.14	.09	.017	3158.1	.31	.02	.005				
				3169.7	.46	.02	.007				

APPENDIX 2

Photon yield from the ^{242}Pu (n,γ) reaction determined with the NaI(Tl) anticoincidence spectrometer. The data are presented in 20 keV-wide bins. Yields are in equivalent partial capture cross section, barns/MeV.

Bin No.	Center Energy (keV)	Yield (barns/MeV)	Uncertainty (b/MeV)	Bin No.	Center Energy (keV)	Yield (barns/MeV)	Uncertainty (b/MeV)	Bin No.	Center Energy (keV)	Yield (barns/MeV)	Uncertainty (b/MeV)
1	10	0.00	0.00	44	870	26.10	1.69	87	1730	22.83	1.45
2	30	0.09	0.00	45	890	26.91	1.73	88	1750	23.12	1.47
3	50	23.67	12.55	46	910	27.00	1.74	89	1770	23.47	1.48
4	70	46.89	7.67	47	930	26.47	1.70	90	1790	23.19	1.46
5	90	109.75	7.74	48	950	24.40	1.58	91	1810	23.99	1.51
6	110	123.09	8.42	49	970	22.97	1.50	92	1830	24.25	1.52
7	130	45.09	3.73	50	990	22.53	1.47	93	1850	24.67	1.55
8	150	14.99	1.79	51	1010	22.50	1.47	94	1870	24.74	1.55
9	170	18.44	1.66	52	1030	22.27	1.45	95	1890	24.47	1.53
10	190	22.49	1.93	53	1050	22.01	1.44	96	1910	24.19	1.51
11	210	28.26	2.19	54	1070	21.57	1.41	97	1930	24.00	1.50
12	230	33.67	2.46	55	1090	21.24	1.39	98	1950	23.19	1.45
13	250	42.73	2.95	56	1110	20.70	1.37	99	1970	22.45	1.40
14	270	80.99	5.13	57	1130	20.19	1.34	100	1990	22.10	1.38
15	290	161.55	9.84	58	1150	19.70	1.31	101	2010	22.16	1.38
16	310	123.01	7.53	59	1170	20.02	1.32	102	2030	21.95	1.37
17	330	44.02	2.88	60	1190	20.66	1.36	103	2050	22.12	1.38
18	350	26.92	1.87	61	1210	21.14	1.39	104	2070	22.11	1.38
19	370	26.09	1.81	62	1230	21.65	1.42	105	2090	22.03	1.37
20	390	29.32	1.97	63	1250	21.25	1.39	106	2110	21.72	1.35
21	410	39.57	2.55	64	1270	20.62	1.35	107	2130	21.42	1.33
22	430	43.81	2.79	65	1290	20.56	1.35	108	2150	20.96	1.30
23	450	34.14	2.22	66	1310	20.33	1.34	109	2170	20.32	1.26
24	470	25.21	1.70	67	1330	20.50	1.35	110	2190	19.43	1.21
25	490	27.57	1.83	68	1350	20.33	1.33	111	2210	19.44	1.21
26	510	39.77	2.53	69	1370	19.99	1.31	112	2230	19.16	1.19
27	530	50.08	3.12	70	1390	20.35	1.33	113	2250	18.71	1.16
28	550	47.72	2.98	71	1410	19.91	1.31	114	2270	18.12	1.13
29	570	39.66	2.51	72	1430	20.24	1.33	115	2290	17.61	1.10
30	590	34.11	2.18	73	1450	20.63	1.35	116	2310	17.34	1.08
31	610	28.92	1.88	74	1470	20.45	1.33	117	2330	16.99	1.06
32	630	25.19	1.66	75	1490	20.33	1.32	118	2350	16.34	1.02
33	650	24.01	1.59	76	1510	20.85	1.35	119	2370	15.88	0.99
34	670	23.41	1.55	77	1530	21.06	1.36	120	2390	15.09	0.94
35	690	22.02	1.47	78	1550	20.93	1.36	121	2410	14.57	0.91
36	710	20.91	1.41	79	1570	21.10	1.36	122	2430	14.12	0.88
37	730	20.60	1.38	80	1590	21.70	1.40	123	2450	13.55	0.85
38	750	20.75	1.39	81	1610	21.98	1.41	124	2470	12.86	0.80
39	770	21.36	1.43	82	1630	22.25	1.43	125	2490	12.30	0.77
40	790	21.46	1.43	83	1650	22.35	1.43	126	2510	12.19	0.76
41	810	22.90	1.51	84	1670	22.40	1.43	127	2530	11.81	0.74
42	830	24.55	1.60	85	1690	22.35	1.42	128	2550	11.52	0.72
43	850	25.90	1.68	86	1710	22.86	1.45	129	2570	12.00	0.75

Bin No.	Center Energy (keV)	Yield (barns/MeV)	Uncertainty (b/MeV)	Bin No.	Center Energy (keV)	Yield (barns/MeV)	Uncertainty (b/MeV)	Bin No.	Center Energy (keV)	Yield (barns/MeV)	Uncertainty (b/MeV)
130	2590	11.89	.74	170	3390	2.74	.19	210	4190	.69	.06
131	2610	11.62	.73	171	3410	2.69	.18	211	4210	.73	.07
132	2630	11.76	.74	172	3430	2.55	.17	212	4230	.69	.07
133	2650	11.50	.72	173	3450	2.56	.17	213	4250	.69	.08
134	2670	10.97	.68	174	3470	2.39	.17	214	4270	.83	.08
135	2690	10.85	.68	175	3490	2.44	.17	215	4290	.88	.08
136	2710	10.48	.65	176	3510	2.20	.15	216	4310	.84	.07
137	2730	10.16	.64	177	3530	2.25	.16	217	4330	.86	.08
138	2750	9.88	.62	178	3550	2.17	.15	218	4350	.82	.08
139	2770	10.25	.64	179	3570	2.32	.16	219	4370	.79	.07
140	2790	9.93	.62	180	3590	2.23	.16	220	4390	.65	.07
141	2810	9.92	.62	181	3610	2.12	.15	221	4410	.69	.07
142	2830	9.63	.60	182	3630	1.99	.14	222	4430	.51	.06
143	2850	9.38	.59	183	3650	1.90	.14	223	4450	.57	.07
144	2870	9.18	.57	184	3670	1.84	.13	224	4470	.47	.06
145	2890	8.65	.54	185	3690	1.79	.13	225	4490	.44	.05
146	2910	8.04	.50	186	3710	1.42	.11	226	4510	.30	.05
147	2930	7.48	.47	187	3730	1.34	.11	227	4530	.31	.05
148	2950	6.97	.44	188	3750	1.22	.10	228	4550	.21	.05
149	2970	6.63	.42	189	3770	.94	.08	229	4570	.29	.05
150	2990	6.14	.39	190	3790	.84	.08	230	4590	.25	.05
151	3010	5.95	.38	191	3810	.82	.08	231	4610	.19	.05
152	3030	6.00	.38	192	3830	.76	.07	232	4630	.21	.05
153	3050	5.92	.38	193	3850	.69	.07	233	4650	.21	.05
154	3070	5.65	.36	194	3870	.65	.07	234	4670	.33	.05
155	3090	5.38	.34	195	3890	.66	.07	235	4690	.26	.05
156	3110	5.45	.35	196	3910	.68	.07	236	4710	.19	.04
157	3130	5.05	.32	197	3930	.63	.07	237	4730	.09	.04
158	3150	5.05	.33	198	3950	.60	.06	238	4750	.11	.04
159	3170	4.58	.30	199	3970	.61	.06	239	4770	.03	.04
160	3190	4.65	.30	200	3990	.43	.06	240	4790	.16	.05
161	3210	4.14	.27	201	4010	.48	.06	241	4810	.15	.04
162	3230	3.96	.26	202	4030	.40	.06	242	4830	.06	.04
163	3250	3.70	.24	203	4050	.46	.06	243	4850	.15	.04
164	3270	3.63	.24	204	4070	.44	.05	244	4870	.13	.04
165	3290	3.42	.23	205	4090	.45	.06	245	4890	.08	.05
166	3310	3.31	.22	206	4110	.40	.05	246	4910	.05	.04
167	3330	3.17	.21	207	4130	.50	.06	247	4930	.11	.05
168	3350	3.26	.22	208	4150	.57	.07	248	4950	.12	.04
169	3370	2.82	.19	209	4170	.64	.07	249	4970	.04	.04