EXPERIMENTALLY DETERMINED NEUTRON
AND GAMMA-RAY SPECTRA FROM AN
ENCAPSULATED Cm_2O_3 POWER SOURCE

R. M. Freestone, Jr.

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Neutron Physics Division

Experimentally Determined Neutron and Gamma-Ray Spectra

From an Encapsulated Cm_{23}O_3 Power Source

R. M. Freestone, Jr.

Work Done By:

R. M. Freestone, Jr.

K. M. Henry, Jr.

J. L. Hull

J. J. Manning

J. N. Money

F. J. Muckenthaler

MARCH 1974

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ABSTRACT

The experimentally determined neutron and gamma ray spectra of a Cm_2O_3 spontaneously fissioning source are presented. The neutron spectrum is given for the energy range 30 keV to 10 MeV, while the gamma ray spectrum spans the energy range 205 keV to 12 MeV.

I. INTRODUCTION

A measurement of the neutron spectrum of a Cm_2O_3 source, encompassing an energy range from 7 keV to 10 MeV, and a companion measurement of its gamma ray spectrum from 0.205 to 12 MeV, have recently been completed by the staff of the Oak Ridge National Laboratory Tower Shielding Facility (TSF). These spectra are of interest primarily because of the potential of the material as an isotopic power source, in addition to its obvious value as a compact, high-yield, neutron and gamma ray source.

II. SOURCE DESCRIPTION

The source consisted of a Cm_2O_3 pellet, encased in a double stainless steel capsule. A sketch of the source construction is shown as Figure 1. Because of physical difficulties and differing instrument sensitivities, it was not possible to perform all neutron measurements at the same point. However, all data have been normalized to a source-detector separation of 12 in. by the usual R^2 method for this presentation.

III. NEUTRON INSTRUMENTATION

The system of neutron spectrometers used to obtain the results described below is that currently in use at the TSF in various radiation shielding studies, and requires the use of several detectors in order to cover the desired energy range. For the energy range from 0.8 to 14 MeV, the system used is basically that described by Burrus and Verbinski,¹ utilizing a nominally 2- by 2-in. cylindrical NE213 organic scintillator, with pulse shape discrimination against gamma rays. This spectrometer has been proved in a variety of tests since its conception circa 1966, one of the most useful being the work of Straker, et al.,² who used a similar system to make direct and simultaneous comparisons with time of flight data.

The energy range from about 90 keV to 1.4 MeV is covered by a set of 3 spherical proton recoil counters, modeled after the design of Benjamin, et al.,³ filled to pressures of 1, 3, and 10 atm. of hydrogen. The basic idea behind the use of 3 counters is that for any given filling

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DIMENSIONS IN INCHES

TOTAL POWER OUTPUT 69 ± 1 WFig. 1. Sectional View of the Curium Oxide (Cm_2O_3) Source.

pressure there exists a lower energy limit, above which gamma-ray effects are negligible, and a high energy limit below which wall effects, due to high-energy proton recoils escaping from the counter before losing all energy, are not intolerable. This system has been well proven by experience at the TSF, where experimental results are compared with predicted results for simple shields of a single element (e.g., iron, sodium).

Finally, the energy range from about 8 or 10 keV to 140 keV is covered by a Benjamin-type proton recoil counter filled to 3 atm. with a mixture of 85% H_2 , 10% CH_4 , and 5% N_2 . Gamma ray discrimination with this counter is based upon the observation that pulses resulting from gamma-ray-induced electron events have a low initial rate of rise when compared with pulses resulting from neutron-induced proton recoil events producing equal total ionization. The technique, which has been variously exploited,^{4,5,6} is to accumulate in a two-dimensional array specific ionization (rate of raise divided by ionization) vs. ionization. A typical specific ionization curve obtained during the present work is shown as Figure 2. The rather broad distribution on the left of the figure represents electron events, while the sharp peak at the right represents proton events. As is evident, the tail of the electron peak extends well under the proton peak, and must be extracted before the proton peak is integrated to produce a point in a pulse height spectrum suitable for unfolding to a neutron spectrum. Currently at the TSF two methods are used to remove the gamma-ray background. The one method involves normalization and subtraction of separately obtained ^{60}Co specific ionization curves, while a second method utilizes for the subtraction curves obtained with a thick LiH, lithiated paraffin, or water plug between the source and the detector. Neither method produces an exact fit to the gamma distribution obtained in the "foreground" measurements.

The system just described is that with which we have had the least experience, and at the present time our confidence in the accuracy of the data from 10 to 140 keV is less than in the remainder of the energy range.

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Fig. 2. Typical Specific Ionization Curve.

IV. NEUTRON SPECTRA

The neutron spectrum is presented in Fig. 3 and in Tables 1, 2, and 3. The separation reflects the use of the three distinct spectrometry techniques in obtaining these data. Figure 4 offers a comparison of the present work with the ^{244}Cm spectrum measured by Stoddard.⁷ In this figure the spectra have been normalized over the interval from 2 to 6 MeV, the region where the shape agreement is nearly exact. As Fig. 4 shows, we are in good agreement with the Stoddard spectrum above 2 MeV, but find fewer neutrons from 30 keV to 2 MeV.

The neutron spectrum from 0.1 to 12 MeV has been integrated to form a 13-group array and converted to units of absolute abundance ($\text{n. sec}^{-1} \cdot \text{W}^{-1}$) to obtain the result offered as Table 4.

In concluding the neutron portion of this paper, a word or two concerning errors is necessary. In the region above 0.8 MeV (the NE213 domain) the experimental pulse height curves are unfolded with the Burrus FERDOR code,¹ and the vertical bars representing the 68% confidence interval include both counting statistics and unfolding errors. For the rest of the data (the 3-counter and 2-parameter domains) the errors shown are those due to counting statistics only. An additional and undisplayed error remains. In the series of unfolding processes required to produce the spectrum of Figure 3, the output of one unfolding becomes the input to the next. Thus the output from the NE213 unfolding is input to the 10 atm. proton recoil unfolding, which in like fashion becomes the input to the 3 atm. unfolding. The 3 atm. output is input for the 1 atm. unfolding, and all of this becomes input to the 2-parameter counter unfolding. Obviously, errors generated at any stage are propagated all the way to the lowest energy. No attempt has been made to estimate the magnitude of this error propagation. Prudence would probably suggest at least a doubling of the errors quoted in the low energy region of the spectrum.

Fig. 3. Neutron Spectrum of the Curium Oxide (Cm_2O_3) Source.

Fig. 4. Comparison of Neutron Spectrum Observed in the Present Work With Spectrum of Stoddard (Ref. 7).

Table 1. Curium Source Neutron Spectrum (NE213 Results)
Source-Detector Separation (12 in.)

Energy (MeV)	Flux (neutrons·cm ⁻² ·MeV ⁻¹ ·Min ⁻¹)			
	Lower Bound	Upper Bound	Mean Value	Running Integral
0.80	3.73(5) ^a	4.83(5)	4.28(5)	0
0.90	3.59(5)	4.89(5)	4.24(5)	4.24(4)
1.00	3.49(5)	4.42(5)	3.95(5)	8.19(4)
1.10	3.56(5)	4.28(5)	3.92(5)	1.21(5)
1.20	3.66(5)	4.24(5)	3.95(5)	1.61(5)
1.30	3.90(5)	4.38(5)	4.14(5)	2.02(5)
1.40	4.00(5)	4.52(5)	4.26(5)	2.45(5)
1.50	3.83(5)	4.38(5)	4.11(5)	2.86(5)
1.60	3.59(5)	4.11(5)	3.85(5)	3.24(5)
1.70	3.56(5)	4.04(5)	3.80(5)	3.62(5)
1.80	3.49(5)	3.94(5)	3.71(5)	3.99(5)
1.90	3.42(5)	3.80(5)	3.61(5)	4.35(5)
2.00	3.27(5)	3.63(5)	3.45(5)	4.70(5)
2.10	3.14(5)	3.45(5)	3.30(5)	5.03(5)
2.20	3.09(5)	3.38(5)	3.24(5)	5.35(5)
2.30	3.05(5)	3.29(5)	3.17(5)	5.67(5)
2.40	3.01(5)	3.22(5)	3.12(5)	5.98(5)
2.50	2.99(5)	3.18(5)	3.09(5)	6.29(5)
2.60	3.00(5)	3.16(5)	3.08(5)	6.60(5)
2.70	2.96(5)	3.10(5)	3.03(5)	6.90(5)
2.80	2.76(5)	2.90(5)	2.83(5)	7.19(5)
2.90	2.43(5)	2.59(5)	2.51(5)	7.44(5)
3.00	2.17(5)	2.25(5)	2.21(5)	7.66(5)
3.20	1.83(5)	1.92(5)	1.87(5)	8.03(5)
3.40	1.65(5)	1.74(5)	1.69(5)	8.37(5)
3.60	1.50(5)	1.57(5)	1.53(5)	8.68(5)
3.80	1.39(5)	1.46(5)	1.43(5)	8.96(5)
4.00	1.23(5)	1.29(5)	1.26(5)	9.21(5)
4.20	1.11(5)	1.17(5)	1.14(5)	9.44(5)
4.40	1.01(5)	1.06(5)	1.04(5)	9.65(5)
4.60	8.49(4)	9.00(4)	8.74(4)	9.82(5)
4.80	7.15(4)	7.56(4)	7.36(4)	9.96(5)
5.00	5.96(4)	6.33(4)	6.14(4)	1.01(6)
5.20	5.13(4)	5.51(4)	5.32(4)	1.02(6)
5.40	4.69(4)	5.07(4)	4.88(4)	1.03(6)
5.60	4.11(4)	4.42(4)	4.26(4)	1.04(6)
5.80	3.63(4)	3.97(4)	3.80(4)	1.05(6)
6.00	3.31(4)	3.59(4)	3.45(4)	1.05(6)
6.20	3.00(4)	3.27(4)	3.13(4)	1.06(6)
6.40	2.75(4)	2.99(4)	2.87(4)	1.06(6)

Table 1 (Cont'd.)

Energy (MeV)	Flux (neutrons·cm ⁻² ·MeV ⁻¹ ·Min ⁻¹)			
	Lower Bound	Upper Bound	Mean Value	Running Integral
6.60	2.41(4)	2.65(4)	2.53(4)	1.07(6)
6.80	1.98(4)	2.19(4)	2.09(4)	1.07(6)
7.00	1.57(4)	1.77(4)	1.67(4)	1.08(6)
7.20	1.23(4)	1.42(4)	1.33(4)	1.08(6)
7.40	1.08(4)	1.26(4)	1.17(4)	1.08(6)
7.60	1.10(4)	1.27(4)	1.18(4)	1.08(6)
7.80	1.05(4)	1.21(4)	1.13(4)	1.09(6)
8.00	8.42(3)	9.79(3)	9.10(3)	1.09(6)
8.20	6.26(3)	7.50(3)	6.88(3)	1.09(6)
8.40	5.37(3)	6.54(3)	5.96(3)	1.09(6)
8.60	5.00(3)	6.09(3)	5.54(3)	1.09(6)
8.80	4.28(3)	5.30(3)	4.79(3)	1.10(6)
9.00	3.53(3)	4.48(3)	4.00(3)	1.10(6)
9.20	3.17(3)	4.07(3)	3.62(3)	1.10(6)
9.40	2.93(3)	3.80(3)	3.36(3)	1.10(6)
9.60	2.74(3)	3.53(3)	3.14(3)	1.10(6)
9.80	2.52(3)	3.28(3)	2.90(3)	1.10(6)
10.00	2.10(3)	2.85(3)	2.48(3)	1.10(6)
10.20	1.77(3)	2.43(3)	2.10(3)	1.10(6)
10.40	1.46(3)	2.12(3)	1.79(3)	1.10(6)
10.60	1.10(3)	1.74(3)	1.42(3)	1.10(6)
10.80	8.62(2)	1.48(3)	1.17(3)	1.10(6)
11.00	7.84(2)	1.37(3)	1.08(3)	1.10(6)
11.20	5.89(2)	1.16(3)	8.74(2)	1.10(6)
11.40	3.63(2)	9.04(2)	6.33(2)	1.10(6)
11.60	3.53(2)	8.66(2)	6.09(2)	1.10(6)
11.80	4.18(2)	9.10(2)	6.64(2)	1.10(6)
12.00	3.87(2)	8.49(2)	6.18(2)	1.10(6)
12.20	3.83(2)	7.87(2)	5.85(2)	1.10(6)
12.40	3.80(2)	7.63(2)	5.72(2)	1.10(6)
12.60	2.65(2)	6.43(2)	4.54(2)	1.10(6)
12.80	5.81(1)	4.08(2)	2.33(2)	1.10(6)

^aRead as: 3.73×10^5 .

Table 2. Curium Source Neutron Spectrum (3-Counter Benjamin Data) Source-Detector Separation (12 in.)

Energy Boundary (MeV)	Flux (n/cm ² /MeV/Min)	Error (%)
0.0488-0.0576	0.129(7) ^a	7.38
0.0576-0.0665	0.525(6)	21.02
0.0665-0.0789	0.435(6)	20.38
0.0789-0.0931	0.368(6)	24.37
0.0931-0.1091	0.383(6)	23.98
0.1091-0.1286	0.224(6)	37.86
0.1286-0.1517	0.411(6)	19.70
0.1517-0.1783	0.425(6)	18.66
0.1622-0.1889	0.378(6)	8.77
0.1783-0.2084	0.406(6)	19.42
0.1889-0.2244	0.356(6)	8.02
0.2084-0.2457	0.346(6)	20.07
0.2244-0.2644	0.410(6)	7.32
0.2457-0.2900	0.475(6)	13.32
0.2644-0.3089	0.476(6)	6.62
0.3089-0.3622	0.462(6)	6.48
0.3622-0.4289	0.396(6)	6.80
0.4289-0.5044	0.481(6)	6.68
0.4452-0.5279	0.448(6)	6.28
0.5044-0.5933	0.417(6)	6.22
0.5279-0.6197	0.473(6)	2.28
0.5933-0.7000	0.454(6)	5.23
0.6197-0.7298	0.452(6)	2.27
0.7298-0.8584	0.469(6)	2.15
0.8584-1.0052	0.426(6)	2.34
1.0052-1.1889	0.408(6)	2.13
1.1889-1.4000	0.409(6)	2.04

^aRead as: 0.129 x 10⁷.

Table 3. Curium Source Neutron Spectrum (2-Parameter Data)
Source-Detector Separation (12 in.)

Energy Boundary (MeV)	Flux (neutrons $\cdot$ cm $^{-2}$ $\cdot$ MeV $^{-1}$ $\cdot$ Min $^{-1}$)	Error (%)
0.0271-0.0308	6.146(5) ^a	27.69
0.0300-0.0336	6.456(5)	20.47
0.0308-0.0350	6.981(5)	22.24
0.0336-0.0385	3.662(5)	30.67
0.0385-0.0446	3.542(5)	28.88
0.0446-0.0495	4.510(5)	32.38
0.0495-0.0569	3.963(5)	26.87
0.0569-0.0642	3.971(5)	30.54
0.0642-0.0740	3.124(5)	31.85
0.0740-0.0838	4.501(5)	25.38
0.0838-0.0948	4.252(5)	26.44
0.0948-0.1082	4.583(5)	21.79
0.1082-0.1229	5.311(5)	19.20
0.1229-0.1400	5.222(5)	18.17

^aRead as: 6.146 x 10⁵.

Table 4. Binned Energy Distribution of Neutrons
from the Cm_2O_3 Source

Energy Boundary	Abundance
(MeV)	(n.sec ⁻¹ .W ⁻¹)
0.1-0.2	1.032(5) ^a
0.2-0.5	4.653(5)
0.5-1.0	6.373(5)
1.0-1.5	5.724(5)
1.5-2.0	5.301(5)
2.0-2.5	4.540(5)
2.5-3.0	3.976(5)
3.0-4.0	4.653(5)
4.0-5.0	2.665(5)
5.0-6.0	1.300(5)
6.0-8.0	1.088(5)
8.0-10.0	2.594(4)
10.0-12.0	6.711(3)

^aRead as: 1.032×10^5 .

V. GAMMA RAYS FROM ^{244}Cm

Figure 5 shows the experimental configuration for the gamma-ray measurements. Background data were obtained by positioning a 6-in. lead slab against the detector side of the LiH slab.

The TSF gamma-ray spectrometer, utilizing a 5- by 5-in. cylindrical NaI(Tl) scintillator at the center of a massive spherical shield, has previously been described by Muckenthaler, et al.⁸ Spectra are obtained by unfolding the pulse-height data with the FERD code developed by Burrus.⁹ The quoted errors represent both counting statistics and unfolding errors.

The results of the gamma-ray measurement are presented in Table 5, and integral fluxes over various energy intervals are given in Table 6. The data are plotted in Figure 6. The known 0.210- and 0.278-MeV gamma rays from ^{243}Cm , and the 0.570- and 0.825-MeV gammas from ^{244}Cm are clearly resolved. The minor peak at ~ 1.27 MeV probably results from the decay of ^{154}Eu , a fission product.

The present measurement is compared, on an absolute basis, with the predictions of Stoddard⁷ in Table 7.

Fig. 5. Experimental Setup for Gamma-Ray Spectrum Measurements.

Fig. 6. Gamma-Ray Spectrum of the Curium Oxide (Cm_2O_3) Source.

Table 5. Curium Source Gamma-Ray Spectrum

Photon Energy (MeV)	Flux (g/cm ² /MeV/Sec)		Photon Energy (MeV)	Flux (g/cm ² /MeV/Sec)	
	Lower Limit	Upper Limit		Lower Limit	Upper Limit
2.050(-1) ^a	5.957(0)	6.500(0)	8.900(-1)	8.250(0)	8.639(0)
2.150(-1)	9.650(0)	1.021(1)	9.100(-1)	7.254(0)	7.592(0)
2.250(-1)	8.946(0)	9.489(0)	9.300(-1)	6.688(0)	7.008(0)
2.350(-1)	5.326(0)	5.814(0)	9.500(-1)	6.607(0)	6.934(0)
2.450(-1)	4.954(0)	5.518(0)	9.700(-1)	7.009(0)	7.328(0)
2.550(-1)	1.194(1)	1.263(1)	9.900(-1)	7.367(0)	7.666(0)
2.650(-1)	2.203(1)	2.285(1)	1.010(0)	7.063(0)	7.371(0)
2.750(-1)	2.293(1)	2.374(1)	1.030(0)	6.187(0)	6.446(0)
2.850(-1)	1.422(1)	1.481(1)	1.050(0)	5.272(0)	5.521(0)
2.950(-1)	6.843(0)	7.288(0)	1.070(0)	4.840(0)	5.084(0)
3.050(-1)	4.221(0)	4.592(0)	1.090(0)	4.960(0)	5.208(0)
3.150(-1)	3.528(0)	3.906(0)	1.110(0)	5.300(0)	5.540(0)
3.250(-1)	3.324(0)	3.686(0)	1.130(0)	5.488(0)	5.710(0)
3.350(-1)	3.345(0)	3.702(0)	1.150(0)	5.442(0)	5.687(0)
3.450(-1)	3.506(0)	3.869(0)	1.170(0)	5.412(0)	5.625(0)
3.550(-1)	3.635(0)	3.995(0)	1.190(0)	5.577(0)	5.842(0)
3.650(-1)	3.577(0)	3.931(0)	1.220(0)	6.484(0)	6.819(0)
3.750(-1)	3.361(0)	3.712(0)	1.260(0)	8.065(0)	8.397(0)
3.850(-1)	2.959(0)	3.600(0)	1.300(0)	7.868(0)	8.163(0)
3.950(-1)	2.666(0)	3.535(0)	1.340(0)	5.927(0)	6.168(0)
4.100(-1)	2.923(0)	3.806(0)	1.380(0)	5.081(0)	5.295(0)
4.300(-1)	3.760(0)	4.257(0)	1.420(0)	5.632(0)	5.844(0)
4.500(-1)	4.351(0)	4.822(0)	1.460(0)	5.443(0)	5.653(0)
4.700(-1)	5.223(0)	5.707(0)	1.500(0)	4.643(0)	4.828(0)
4.900(-1)	6.719(0)	7.234(0)	1.540(0)	4.562(0)	4.744(0)
5.100(-1)	8.281(0)	8.821(0)	1.580(0)	5.130(0)	5.310(0)
5.300(-1)	1.005(1)	1.061(1)	1.620(0)	5.209(0)	5.384(0)
5.500(-1)	1.212(1)	1.270(1)	1.660(0)	4.615(0)	4.776(0)
5.700(-1)	1.243(1)	1.300(1)	1.700(0)	4.206(0)	4.359(0)
5.900(-1)	1.244(1)	1.298(1)	1.740(0)	4.159(0)	4.307(0)
6.100(-1)	1.154(1)	1.205(1)	1.780(0)	4.068(0)	4.211(0)
6.300(-1)	9.066(0)	9.528(0)	1.820(0)	3.771(0)	3.906(0)
6.500(-1)	7.705(0)	8.096(0)	1.860(0)	3.489(0)	3.617(0)
6.700(-1)	7.359(0)	7.736(0)	1.900(0)	3.402(0)	3.528(0)
6.900(-1)	7.699(0)	8.148(0)	1.940(0)	3.478(0)	3.602(0)
7.100(-1)	8.532(0)	9.026(0)	1.980(0)	3.584(0)	3.706(0)
7.300(-1)	9.254(0)	9.741(0)	2.020(0)	3.586(0)	3.705(0)
7.500(-1)	9.562(0)	1.005(1)	2.060(0)	3.394(0)	3.507(0)
7.700(-1)	9.528(0)	1.001(1)	2.100(0)	3.188(0)	3.297(0)
7.900(-1)	1.053(1)	1.107(1)	2.140(0)	3.177(0)	3.285(0)
8.100(-1)	1.308(1)	1.364(1)	2.180(0)	3.279(0)	3.385(0)
8.300(-1)	1.405(1)	1.457(1)	2.220(0)	3.256(0)	3.358(0)
8.500(-1)	1.223(1)	1.270(1)	2.260(0)	3.034(0)	3.135(0)
8.700(-1)	9.885(0)	1.030(1)	2.300(0)	3.817(0)	2.911(0)

Table 5 (Cont'd.)

Photon Energy (MeV)	Flux (g/cm ² /MeV/Sec)		Photon Energy (MeV)	Flux (g/cm ² /MeV/Sec)	
	Lower Limit	Upper Limit		Lower Limit	Upper Limit
2.340(0)	2.695(0)	2.784(0)	5.000(0)	1.795(-1)	1.923(-1)
2.380(0)	2.611(0)	2.695(0)	5.080(0)	1.689(-1)	1.817(-1)
2.420(0)	2.535(0)	2.616(0)	5.160(0)	1.534(-1)	1.649(-1)
2.460(0)	2.446(0)	2.523(0)	5.240(0)	1.393(-1)	1.489(-1)
2.500(0)	2.388(0)	2.462(0)	5.320(0)	1.277(-1)	1.376(-1)
2.540(0)	2.375(0)	2.447(0)	5.400(0)	1.208(-1)	1.308(-1)
2.580(0)	2.341(0)	2.412(0)	5.480(0)	1.103(-1)	1.189(-1)
2.620(0)	2.265(0)	2.334(0)	5.560(0)	9.606(-2)	1.049(-1)
2.660(0)	2.181(0)	2.247(0)	5.640(0)	8.890(-2)	9.712(-2)
2.700(0)	2.122(0)	2.186(0)	5.720(0)	8.504(-2)	9.295(-2)
2.740(0)	2.088(0)	2.149(0)	5.800(0)	8.164(-2)	8.906(-2)
2.780(0)	2.027(0)	2.089(0)	5.880(0)	8.194(-2)	8.914(-2)
2.830(0)	1.872(0)	1.941(0)	5.960(0)	8.434(-2)	9.140(-2)
2.890(0)	1.689(0)	1.752(0)	6.040(0)	8.464(-2)	9.116(-2)
2.950(0)	1.581(0)	1.639(0)	6.120(0)	7.997(-2)	8.600(-2)
3.010(0)	1.487(0)	1.543(0)	6.200(0)	7.083(-2)	7.666(-2)
3.070(0)	1.381(0)	1.433(0)	6.280(0)	6.060(-2)	6.620(-2)
3.130(0)	1.299(0)	1.349(0)	6.360(0)	5.025(-2)	5.574(-2)
3.190(0)	1.259(0)	1.308(0)	6.450(0)	3.898(-2)	4.421(-2)
3.250(0)	1.215(0)	1.260(0)	6.550(0)	2.934(-2)	3.412(-2)
3.310(0)	1.142(0)	1.185(0)	6.650(0)	2.344(-2)	2.771(-2)
3.370(0)	1.064(0)	1.107(0)	6.750(0)	2.026(-2)	2.428(-2)
3.430(0)	9.890(-1)	1.028(0)	6.850(0)	1.689(-2)	2.077(-2)
3.490(0)	9.261(-1)	9.648(-1)	6.950(0)	1.231(-2)	1.588(-2)
3.550(0)	9.025(-1)	9.368(-1)	7.050(0)	9.865(-3)	1.295(-2)
3.610(0)	8.694(-1)	9.033(-1)	7.150(0)	9.188(-3)	1.196(-2)
3.670(0)	8.050(-1)	8.386(-1)	7.250(0)	7.258(-3)	9.820(-3)
3.730(0)	7.387(-1)	7.687(-1)	7.350(0)	4.595(-3)	7.020(-3)
3.790(0)	6.855(-1)	7.184(-1)	7.450(0)	3.254(-3)	5.450(-3)
3.850(0)	6.520(-1)	6.822(-1)	7.550(0)	2.418(-3)	4.555(-3)
3.910(0)	6.257(-1)	6.557(-1)	7.650(0)	1.460(-3)	3.547(-3)
3.970(0)	5.925(-1)	6.299(-1)	7.750(0)	1.140(-3)	3.134(-3)
4.040(0)	5.645(-1)	5.933(-1)	7.850(0)	1.648(-3)	3.450(-3)
4.120(0)	5.345(-1)	5.601(-1)	7.950(0)	1.958(-3)	3.653(-3)
4.200(0)	4.890(-1)	5.161(-1)	8.050(0)	1.732(-3)	3.439(-3)
4.280(0)	4.460(-1)	4.757(-1)	8.150(0)	1.255(-3)	2.903(-3)
4.360(0)	4.106(-1)	4.476(-1)	8.250(0)	7.509(-4)	2.250(-3)
4.440(0)	3.613(-1)	3.872(-1)	8.350(0)	2.593(-4)	1.623(-3)
4.520(0)	3.054(-1)	3.280(-1)	8.460(0)	-6.916(-6)	1.325(-3)
4.600(0)	2.642(-1)	2.854(-1)	8.580(0)	1.088(-4)	1.422(-3)
4.680(0)	2.356(-1)	2.553(-1)	8.700(0)	3.666(-4)	1.460(-3)
4.760(0)	2.163(-1)	2.339(-1)	8.820(0)	3.982(-4)	1.348(-3)
4.840(0)	1.943(-1)	2.098(-1)	8.940(0)	2.347(-4)	1.083(-3)
4.920(0)	1.826(-1)	1.947(-1)	9.060(0)	-7.364(-5)	7.353(-4)

Table 5 (Cont'd.)

Photon Energy (MeV)	Flux (g/cm ² /MeV/Sec)		Photon Energy (MeV)	Flux (g/cm ² /MeV/Sec)	
	Lower Limit	Upper Limit		Lower Limit	Upper Limit
9.180(0)	-2.234(-4)	4.357(-4)	1.062(1)	-1.379(-4)	3.074(-4)
9.300(0)	-1.852(-4)	3.715(-4)	1.074(1)	-1.405(-4)	2.696(-4)
9.420(0)	-1.686(-4)	4.177(-4)	1.087(1)	-2.023(-4)	2.722(-4)
9.540(0)	-1.946(-4)	3.918(-4)	1.101(1)	-1.888(-4)	2.720(-4)
9.660(0)	-2.086(-4)	2.544(-4)	1.115(1)	-2.281(-4)	2.522(-4)
9.780(0)	-2.564(-4)	2.430(-4)	1.129(1)	-1.501(-4)	1.928(-4)
9.900(0)	-1.881(-4)	3.424(-4)	1.143(1)	-9.093(-5)	3.162(-4)
1.002(1)	-3.744(-5)	5.377(-4)	1.157(1)	-2.599(-5)	3.244(-4)
1.014(1)	1.042(-4)	6.549(-4)	1.171(1)	1.882(-6)	2.549(-4)
1.026(1)	1.398(-4)	7.008(-4)	1.185(1)	-1.336(-4)	2.663(-4)
1.038(1)	8.588(-5)	5.984(-4)	1.199(1)	-2.149(-4)	2.933(-4)
1.050(1)	-6.099(-5)	4.211(-4)	1.213(1)	-1.732(-4)	3.346(-4)

^aRead as: 2.050×10^{-1} .

Table 5. Curium Source Gamma-Ray Spectrum
Integrated Over Selected Intervals

Energy (MeV)	Integral (g/cm ² /Sec)	Error (g/cm ² /Sec)
0.210-0.400	1.457(0) ^a	4.958(-2)
0.400-0.600	1.621(0)	5.593(-2)
0.600-0.900	3.033(0)	7.040(-2)
0.900-1.200	1.852(0)	4.098(-2)
1.200-1.600	2.401(0)	2.755(-2)
1.600-2.000	1.626(0)	2.829(-2)
2.000-2.500	1.513(0)	2.443(-2)
2.500-3.000	1.019(0)	1.626(-2)
3.000-3.500	6.086(-1)	1.445(-2)
3.500-4.000	3.790(-1)	8.213(-3)
4.000-5.000	3.553(-1)	1.158(-2)
5.000-6.000	1.188(-1)	4.619(-3)
6.000-7.000	4.431(-2)	2.466(-3)
7.000-8.000	5.438(-3)	1.139(-3)
8.000-10.000	1.285(-3)	9.359(-4)
7.500-9.500	2.605(-3)	1.291(-3)
7.000-7.500	4.085(-3)	6.533(-4)
6.000-7.000	4.431(-2)	2.466(-3)
5.000-6.000	1.188(-1)	4.619(-3)
4.000-5.000	3.553(-1)	1.158(-2)
3.000-4.000	9.874(-1)	1.967(-2)
2.600-3.000	7.789(-1)	1.266(-2)
2.200-2.600	1.076(0)	1.693(-2)
1.800-2.200	1.397(0)	2.381(-2)
1.350-1.800	2.209(0)	4.044(-2)
0.900-1.350	2.954(0)	6.383(-2)
0.400-0.900	4.657(0)	1.263(-1)
0.205-0.400	1.495(0)	5.095(-2)

^aRead as: 1.457 x 10⁰.

Table 7. Comparison of Measured with Predicted Gamma-Ray Flux
from Cm_2O_3 Source

Energy (MeV)	Abundance ($\gamma \cdot \text{sec}^{-1} \cdot \text{W}$)		Ratio (2/1)
	Measured (1)	Predicted ^a (2)	
0.5-1.	4.58(6) ^b	2.0(7)	4.4
1.0-2.	2.53(6)	4.8(6)	1.9
2.0-3.	8.46(5)	1.6(6)	1.9
3.0-4.	2.66(5)	1.9(5)	0.7
4.0-5.	8.35(4)	6.4(4)	0.8
5.0-6.	2.54(4)	3.4(4)	1.3
6.0-7.	8.62(3)	5.8(3)	0.7

^aFrom Table X, Ref. 7.

^bRead as: 3.41×10^6 .

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