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LOS ALAMOS SCIENTIFIC LABORATORY
OF THE UNIVERSITY OF CALIFORNIA ○ LOS ALAMOS NEW MEXICO

CALIBRATION OF A MOCK FISSION NEUTRON SOURCE BY INDIUM RESONANCE MAPPING OF THE STANDARD GRAPHITE PILE

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CALIBRATION OF A MOCK FISSION NEUTRON SOURCE BY INDIUM RESONANCE MAPPING OF THE STANDARD GRAPHITE PILE

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ABSTRACT

By the integral comparison method the strength of mock fission neutron source MF23 was determined in terms of the strength of the standard Ra-Be neutron source number 44. In this laboratory mock fission sources have been calibrated heretofore by comparison of thermal activity in the standard graphite pile with that of a Ra-Be source. This method is much faster and allows much greater statistical accuracy for weak sources. However, the thermal distribution of a mock fission source differs from that of a Ra-Be source because of the neutron energy spectrum difference. This effect had been estimated to lead to a 5% correction on the relative source strength as determined by thermal activity comparisons. The present experiment was designed to calibrate the mock fission source by integrating the indium resonance activity in order to determine precisely the spectrum influence on the thermal comparison and derive constants to be used with thermal comparisons. Although MF23 blew up before the experiment was as complete as planned, the data obtained were adequate to combine with existing thermal measurements on other MF sources to derive a satisfactory set of constants for use with the thermal comparison method.

The integral comparison method for measuring the strength of an unknown natural neutron source in terms of a known natural neutron source, as used at Los Alamos Scientific Laboratory, has been described in detail elsewhere,[1] but briefly consists of the following procedure: The neutron source to be measured is placed about 2.5 ft above the bottom and on the vertical axis of the standard graphite pile, a stack of graphite 5 ft on a side and 9 ft 4 in. high. Let q(E) be the slowing-down-density of neutrons in the pile, i.e., the number of neutrons per cubic centimeter per second passing from above energy E to below energy E. If E is an energy slightly above thermal, then all neutrons from the source will pass through this energy, and the source strength, Q, is given by

$$Q = 4\pi \int_0^\infty q(E)\, r^2\, dr.$$

Since q(E) is difficult to measure, and since the method is only being used to compare this source to one already calibrated, it is sufficient to find instead a quantity proportional to q(E). The quantity, A_{res}, used here as proportional to q(E) is that part of the saturated activity of an indium foil due to its strong, narrow resonance at 1.44 ev. Then the source strength, Q_{23}, of source MF23 in terms of the source strength, Q_{44}, of the standard Ra-Be source 44 is given by

$$Q_{23} = Q_{44} \frac{\int_0^\infty A_{res}^{23} r^2 dr}{\int_0^\infty A_{res}^{44} r^2 dr} .$$

The quantity A_{res} is only that part of the saturated activity of an indium foil due to its 1.44 ev resonance. Since this level can also be excited by thermal neutrons, the saturated activity, A_{Al}, is measured for the foils irradiated in very thin aluminum trays, and the saturated activity, A_{Cd}, is measured for the foils irradiated in 0.032 in. thick cadmium trays. Previous measurements[1,2,3] have shown that 0.032 in. thick cadmium absorbs 12.0% of the 1.44 ev resonance neutrons, in addition to the thermal neutrons, so A_{res} is very nearly equal to 1.12 A_{Cd}. That A_{res} is not quite equal to 1.12 A_{Cd} is due to two causes, 1) a small fraction of the activity is produced by the absorption of high-energy neutrons, and 2) the indium foils used are not thin to either thermal neutrons or to their own beta rays.

Corrections for the absorption of high-energy neutrons have been calculated[1,2,3] from measurements of saturated activities of indium foils with the foils covered with cadmium and with boron glass. Let this correction be made by multiplying 1.12 A_{Cd} by a factor, K_1, that is a function of the distance r along the axis of the pile. Then the factor, K_1, for this correction[3] is given as a function of slot number, and consequently as a function of r, in the following table:

SLOT NUMBER	K_1
1	1.000
2	0.9966
3	0.9851
4	0.9549
5	0.9553
6	0.9840
7	0.9963
8 - 15	1.000

The correction due to the thickness of the indium foils can be made by associating[1,2,3] the measured activity with a distance, r', from the source that is slightly less than the actual distance, r, of the foil from the source. This correction, Δr, has been calculated[1,3] to be -0.65 cm, so

$$r' = r - 0.65 \text{ cm.}$$

In the following two tables, the first shows the results of mapping the standard graphite pile using Ra-Be source number 44. The second shows the results of mapping the standard graphite pile using mock fission source MF23, and all data have been corrected for decay back to 1200 on July 24, 1955. In both tables, indicated errors are probable errors.

Slot Number	r' (cm)	A_{Al} (counts/min)	A_{Cd} (counts/min)	1.12 A_{Cd} (counts/min)	A_{Al} - 1.12 A_{Cd} = A^{44}_{th} (counts/min)	1.12 K_1 A_{Cd} = A^{44}_{res} (counts/min)
1	-35.24	48760 ± 105	5299 ± 10	5935 ± 11	42820 ± 106	5935 ± 11
2	-25.07	65250 ± 98	9268 ± 13	10380 ± 15	54870 ± 99	10340 ± 15
3	-14.90	80260 ± 184	13900 ± 53	15570 ± 59	64690 ± 193	15340 ± 58
4	- 3.87	90110 ± 233	17960 ± 46	20120 ± 52	69990 ± 239	19210 ± 50
5	+ 4.15	90190 ± 141	17900 ± 53	20050 ± 59	70140 ± 153	19150 ± 56
6	+14.32	80680 ± 12	14010 ± 52	15690 ± 58	64990 ± 59	15440 ± 57
7	+24.50	65940 ± 42	9347 ± 24	10470 ± 27	55470 ± 50	10430 ± 27
8	+34.67	50660 ± 94	5440 ± 13	6093 ± 15	44570 ± 95	6093 ± 15
9	+44.84	36040 ± 133	2795 ± 14	3130 ± 16	32910 ± 134	3130 ± 16
10	+55.02	25580 ± 63	1278 ± 37	1431 ± 4.1	24150 ± 63	1431 ± 4.1
11	+65.19	17810 ± 66	579.5 ± .78	649.0 ± .87	17160 ± 66	649.0 ± .87
12	+85.53	8482 ± 28	104.2 ± .88	116.7 ± .99	8365 ± 28	116.7 ± .99
13	+105.88	4014 ± 12	17.2 ± .28	19.3 ± .31	3995 ± 12	19.3 ± .31
14	+126.23	1890 ± 2.8	5.10 ± .56	5.71 ± .63	1884 ± 2.9	5.71 ± .63
15	+146.57	884.8 ± 2.4	Too small to measure		884.8 ± 2.4	

Slot Number	r' (cm)	A_{Al} (counts/min)	A_{Cd} (counts/min)	$1.12\ A_{Cd}$ (counts/min)	$A_{Al} - 1.12\ A_{Cd} = A^{23}_{th}$ (counts/min)	$1.12\ K_1\ A_{Cd} = A^{23}_{res}$ (counts/min)
1	-35.24	52810 ± 101	5796 ± 66	6492 ± 74	46320 ± 125	6492 ± 74
2	-25.07	71720 ± 50	10360 ± 34	11600 ± 38	60120 ± 63	11560 ± 38
3	-14.90	90060 ± 175	16030 ± 256	17950 ± 287	72110 ± 336	17680 ± 283
4	-3.87	100500 ± 479	20580 ± 206	23050 ± 231	77450 ± 532	22010 ± 220
5	+ 4.15	100100 ± 152	20120 ± 280	22530 ± 314	77570 ± 349	21520 ± 330
6	+14.32	90020 ± 125	15980 ± 108	17900 ± 121	72120 ± 174	17640 ± 119
7	+24.50	73080 ± 398	10640 ± 108	11920 ± 121	61160 ± 416	11880 ± 120
8	+34.67	54300 ± 192	6008 ± 90	6729 ± 101	47570 ± 217	6729 ± 101
9	+44.84	38020 ± 111	2862 ± 16	3205 ± 18	34820 ± 112	3205 ± 18
10	+55.02	26260 ± 71	1191 ± 8.1	1334 ± 9.1	24930 ± 72	1334 ± 9.1
11	+65.19	18140 ± 47	469.6 ± 1.6	526.0 ± 1.8	17610 ± 47	526.0 ± 1.8
12	+85.53	8412 ± 9.4	56.9 ± .74	63.7 ± .83	8348 ± 9.4	63.7 ± .83
13	+105.88	3842 ± 22	7.32 ± .29	8.20 ± .32	3834 ± 22	8.20 ± .32
14	+126.23	1796 ± 29	Too small to measure		1796 ± 30	
15	+146.57	839.4 ± 20	" " "		839.4 ± 20	

By plotting $(r')^2 A_{res}$ vs r' for each source and measuring the area under each curve it was determined that

$$\frac{Q_{23}}{Q_{44}} = \frac{\int_0^{\infty} A_{res}^{23} (r')^2 \, dr'}{\int_0^{\infty} A_{res}^{44} (r')^2 \, dr'} = 1.002 \pm 0.005$$

as of 1200 on July 24, 1955. In August, 1944, the strength of Ra-Be source number 44 was measured[4] absolutely and found to be $5.92 \times 10^6 \pm 5\%$ neutrons per second. It has been calculated[5] that the strength of a Ra-Be source should grow with time according to the relation

$$Q_t = Q_o \left[1.00 + 0.10(1 - e^{-t/32})\right]$$

where t is the time, in years, after the preparation of the source. This gives, for t = 10.9 years,

$$Q_{44} = 6.09 \times 10^6 \pm 5\% \text{ neutrons per second}$$

as of July, 1955. Then the strength of source MF23 is

$$Q_{23} = 6.10 \times 10^6 \pm 5.5\% \text{ neutrons per second}$$

as of 1200 on July 24, 1955.

The calibration of a neutron source by the integral comparison method takes a number of weeks, so if many sources are to be calibrated, it is important to use a much faster method. It has been shown[6] that a thermal neutron comparison method is very fast, if a BF_3 counter is inserted in the pile and used to make the thermal measurements.

However, it was also shown that the ratio of thermal neutrons from two different types of sources was different at different distances along the pile axis, as might be expected, due to the difference in the primary neutron spectra of the two sources. It should be possible to find a set of constants, K_r, such that for a thermal comparison of a particular type of source with Ra-Be source number 44,

$$Q = \frac{Q_{44} \quad A_{th}}{K_r \quad A_{th}^{44}} \text{ .}$$

Since Q_{23} has already been determined, the constants, K_r, for MF23, presumably the same for the comparison of any mock fission source with any Ra-Be source, can be calculated from

$$K_r = \frac{A_{th}^{23} \quad Q_{44}}{A_{th}^{44} \quad Q_{23}} \text{ .}$$

The measurement of these constants, K_r, was the purpose of the experiment. Unfortunately, source MF23 blew up before the experiment was finished. More data on the mapping of the standard graphite pile with source MF23 would have been taken, although enough were taken to get an estimated ±0.5% accuracy on the strength of source MF23. A very important part of the experiment was to find the ratio of thermal counting rates for source MF23 and Ra-Be source 44, using a BF_3 counter at a number of points in the pile. Since this data could not be taken, owing to the destruction of source MF23, the thermal ratios have been found from the less accurate data taken with the indium foils. Following is a table of these results: The indicated errors are probable errors.

r' (cm)	$A_{th}^{23} / A_{th}^{44}$	$K_r^{th} = A_{th}^{23} / 1.002\ A_{th}^{44}$
4.15	1.106	1.104 ± .006
14.32	1.110	1.108 ± .003
24.50	1.102	1.100 ± .008
34.67	1.067	1.065 ± .005
44.84	1.058	1.056 ± .006
55.02	1.032	1.030 ± .004
65.19	1.026	1.024 ± .005
85.53	.9980	.9960 ± .004
105.88	.9597	.9578 ± .006
126.23	.9533	.9514 ± .015
146.57	.9487	.9468 ± .003

In order to get another value for K_r, the resonance data for source MF23 was fitted by the following equation:

$$A_{res}^{23} = 18960e^{-(r')^2/961.0} + 2414e^{-(r')^2/1764} + 180.4e^{-(r')^2/3025} \qquad (1)$$

The following table shows how close this equation comes to fitting the experimental points:

r' (cm)	A^{23}_{res} (Obs.) (counts/min)	A^{23}_{res} (Calc.) (counts/min)	ΔA^{23}_{res} (counts/min)	$\Delta A^{23}_{res}/A^{23}_{res}$ (%)
4.15	21520	21173	-347	-1.6
14.32	17640	17641	+1	0.0
24.50	11880	12025	+145	+1.2
34.67	6729	6769	+40	+.59
44.84	3205	3205	0	0.0
55.02	1334	1313	-21	-1.6
65.19	526.0	490.8	-36.8	-7.0
85.53	63.7	63.6	-.1	-.16
105.88	8.20	8.7	+.5	+6.1

This means that source MF23 could be replaced by three line sources having these resonance ranges and weights and the same resonance results would be obtained. It is possible from this to calculate the equivalent thermal ranges[1] to be 35.1 cm, 45.1 cm, and 57.4 cm and to calculate a theoretical number that should be proportional to the thermal neutrons per unit source strength at any distance from the source. Similar numbers have previously been calculated[1,3] for a Ra-Be source, so another value for K_r can be obtained. Since these values of K_r were obtained by fitting the resonance data over the entire range, they are probably more accurate than those found directly from the thermal measurements. Consequently they will be given a weight of 2 and those from the thermal data a weight of 1 when they are averaged. The results of these calculations are given in the following table:

r (cm)	K_r^{res} (Calculated from resonance data)	K_r^{th} (Calculated from thermal data)	$K_r^{ave} = \frac{2\,K_r^{res} + K_r^{th}}{3}$
4.71	1.093	1.104	1.097 ± 1%
14.88	1.095	1.108	1.099 ± 1%
25.06	1.085	1.098	1.089 ± 1%
35.23	1.076	1.065	1.072 ± 1%
45.40	1.062	1.055	1.060 ± 1%
55.58	1.045	1.030	1.040 ± 1%
65.75	1.025	1.022	1.024 ± 1%
86.09	.993	.9939	.993 ± 1%
106.44	.976	.9578	.970 ± 1%
126.79	.945	.9514	.947 ± 1%
147.13	.949	.9468	.948 ± 1%

The BF_3 counter cannot be inserted in the standard graphite pile at these values of r, so interpolation is necessary. This gives the results in the following table:

Nominal distance of BF_3 counter above source (cm)	K_r for a mock fission source
21	1.093 ± 1%
31	1.079 ± 1%
51	1.049 ± 1%
61	1.032 ± 1%
81	1.001 ± 1%
101	.976 ± 1%
121	.954 ± 1%
141	.948 ± 1%

Previous comparisons of sources MF16 and Ra-Be number 44 with a BF_3 counter had been analyzed by E. R. Graves[7] in order to estimate K_r. The best single range fit to the derivative of K_r vs r led to values of K_r at 51 cm and 61 cm of 1.07 ± 0.01 and 1.05 ± 0.01, respectively. The three range solution quoted here gives a very satisfactory fit to the MF16 thermal distribution taken with a BF_3 counter as shown in the following table:

r (cm)	$\frac{(A^{16}_{th} / A^{44}_{th})}{(A^{16}_{th} / A^{44}_{th})_{51\ cm}}$ (Experimental)	$\frac{(A^{23}_{th} / A^{44}_{th})}{(A^{23}_{th} / A^{44}_{th})_{51\ cm}}$ (Equation 1)
21	1.043	1.036
31	1.037	1.027
51	1.000	1.000
61	.9914	.9838
81	.9483	.9517

Hence it is felt that even though the experiment was terminated before completion, the values derived for K_r are reliable.

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