Calibration of a ^{210}Po-Be Neutron Source

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Thomas Potter and Roger Caldwell

Summary

We calibrated a ^{210}Po-Be neutron source (NY-69-86, PM-4 Source Assembly) by comparing it to a ^{239}Pu-Be source, which had been calibrated at the National Bureau of Standards. To make the comparison, we used a Texas Nuclear Multisphere neutron detection system. Considering that the Pu-Be source's neutron output was 2.011×10^6 n/sec (Corrected for ^{241}Am grow-in), the Po-Be source output was 2.32×10^8 n/sec. Statistical analyses and other considerations follow.

The Multisphere Technique

The multisphere instrument was conceived by Bonner and developed by Hankins.(1) It uses polyethylene spheres of various sizes (diameter of 2, 4, 6, 8, 10 and 12 inches) to give different amounts of moderation and absorption to impinging neutrons. The spheres are placed over a small LiI thermal neutron detector, so that the detector is at the center of the sphere. Scintillations from the detector transmit by light pipe to a photomultipher. The photomultipher output feeds through a standard preamplifier and amplifier to a scaler. The efficiency of each sphere over a wide energy range is known, and by spectrum unfolding techniques, the approximate spectrum and average energy of the fast neutrons can be obtained.

For this particular calibration, after individual counting runs with different size spheres, each source was counted several times with the 10 inch sphere.

Energy Comparison of Po-Be and Pu-Be Sources

Since the counting efficiency of each sphere is energy dependent, it was necessary to demonstrate that no important differences in neutron energy existed between Po-Be and Pu-Be sources. We do this two ways:

1) Published spectra [2] can be used to compute average neutron energies for both type sources. The spectra show that the maximum energy for Po-Be is slightly greater, however, the average energy is probably a better indicator of whether counting efficiencies may be different. Tables 1 and 2 show the computation of the average neutron energies of Po-Be and Pu-Be sources respectively. These calculated average energies (3.975 MeV for Po-Be and 4.524 MeV for Pu-Be) compare well with those measured by Hess and Smith [3] (3.9 MeV for Po-Be and 4.43 MeV for Pu-Be). This difference in Po-Be and Pu-Be average energies, is small and is not likely to affect the counting efficiency by more than a few per cent.

2) The Po-Be and Pu-Be curves, generated by plotting count rate against the sphere thickness, are similar in shape, the peak counting rate occurring in each case with the 10 inch sphere. In addition, the ratio of the Po-Be count rate to the Pu-Be count rate remained nearly constant over the range of sphere sizes used (5, 8, 10 and 12 inch). These measurements demonstrated that there was no appreciable self moderation by the bulkier Pu-Be source. Self moderation probably would occur with larger Pu-Be sources, so that there is some advantage to using only a one Ci Pu-Be source to calibrate Po-Be sources.

Results

On December 3, 1968 we made five separate 10 minute counts of our one curie Pu-Be source at 1.5 meters distance. Then ten separate two minute counts of the Po-Be source were made at the same distance. Ten minute background counts were made before, between and after the source counts. Results are listed in Table 3.

TABLE 1

Average Energy, Po-Be Source, NBS 72, Figure 10

E(MeV)	N(E)	$\frac{N(E)}{\sum N(E)}$	$\frac{E\ N(E)}{\sum N(E)}$
0.5	3.0	.10	.05
1.5	3.0	.10	.15
2.5	4.0	.13	.325
3.5	5.0	.17	.595
4.5	4.5	.15	.675
5.5	3.5	.12	.66
6.5	2.5	.08	.52
7.5	1.8	.06	.45
8.5	1.3	.03	.255
9.5	0.7	.02	.19
10.5	0.4	.01	.105

$\sum N(E) = 29.7$ $\sum \frac{E\ N(E)}{\sum N(E)} = 3.975$ MeV

TABLE 2

Average En, ^{239}Pu-Be, Figure 13, NBS 72

E	N(E)	$\frac{N(E)}{\sum N(E)}$	$\frac{E\ N(E)}{\sum N(E)}$
0.5	5.0	.091	.046
1.5	4.7	.086	.129
2.5	6.5	.119	.298
3.5	8.0	.146	.511
4.5	8.5	.155	.698
5.5	6.0	.110	.605
6.5	5.0	.091	.592
7.5	6.0	.110	.825
8.5	3.0	.055	.468
9.5	2.0	.037	.352

$\sum N(E) = 54.7$ $\sum \frac{E\ N(E)}{\sum N(E)} = 4.524$

TABLE 3

Net Count Rates, Po-Be Calibration

	Po-Be Source	NBS Pu-Be	Background
	5732 c/m	49.9 c/m	2.7 c/m
	5770 c/m	47.8 c/m	2.4 c/m
	5778 c/m	51.4 c/m	1.8 c/m
	5627 c/m	48.7 c/m	
	5771 c/m	49.6 c/m	
	5700 c/m		
	5670 c/m		
	5667 c/m		
	5690 c/m		
	5727 c/m		
Average	5713 c/m	49.5 c/m	2.3 c/m

Assuming that:

$$\frac{\text{Po-Be source strength, } S_1}{\text{Pu-Be source strength, } S_2} = \frac{\text{Po-Be count rate, } R_1}{\text{Pu-Be count rate, } R_2}$$

$$S_1 = 2.011 \times 10^6 \text{ n/sec} \left(\frac{5713 \text{ c/m}}{49.5 \text{ c/m}}\right)$$

$$= 2.32 \times 10^8 \text{ n/sec}$$

If the nominal output of a one curie Po-Be source is 2.56×10^6 n/sec, then our measured source is equivalent to a nominal 90.7 Ci Po-Be source. Since 100 Ci ^{210}Po was the nominal loading, the result is in the correct range.

Statistical Analysis

The extrapolation in source strength from the Pu-Be to the Po-Be source is greater than a hundred fold. One should not make such comparisons without estimating the reliability of the extrapolation.

We ran Pearson's [4] chi-square test with both sets of counting data. Tables 4 and 5 show that our instrument exhibited only the variability expected from a reliable instrument operating on a random process.

Next we estimated the probable error of the average counting rate of each source from the relation.[4]

$$S = s \pm 0.67 \sqrt{\frac{s}{t_s} + \frac{b}{t_s} + \frac{b}{t_b}}$$

TABLE 4

Chi-square Test of Multisphere Neutron Detector
90 Ci ^{210}Po-Be Source

Test		X (Counts)	$X - \overline{X}$	$(X - \overline{X})^2$
1		11,469	39	1521
2		11,545	115	13225
3		11,561	131	17161
4		11,260	-170	28900
5		11,548	118	13924
6		11,405	-25	625
7		11,345	-85	7225
8		11,319	-111	12321
9		11,385	-45	2025
10		11,460	30	910
	Total	114,297	-3	97827

$\overline{X}$ = 11430

F = 10-1 = 9

$$X^2 = \frac{\sum(X-\overline{X})^2}{\overline{X}} = 8.56$$

P = .48 (from Figure 2.1, Chapter 27, The Atomic Nucleus)

TABLE 5

Chi-square Test of Multisphere Neutron Detector
1 Ci Pu-Be Source

Test		X (Counts)	$X - \overline{X}$	$(X - \overline{X})^2$
1		526	4	16
2		505	-17	289
3		541	19	361
4		514	-8	64
5		523	1	1
	Total	2609	1	731

$\overline{X}$ = 522

F = 4

$$X^2 = \frac{731}{522} = 1.4$$

P = .85

where:

S = average counting rate

s = observed counting rate

t_s = source counting time

t_b = background counting time

b = background counting rate

For the Pu-Be source:

$$S = 49.5 \pm 0.67 \sqrt{\frac{49.5}{50} + \frac{2.3}{50} + \frac{2.3}{30}}$$

$$= 49.5 \pm .71 \text{ c/m}$$

and the Po-Be source

$$S = 5713 \pm 0.67 \sqrt{\frac{5713}{20} + \frac{2.3}{20} + \frac{2.3}{30}}$$

$$= 5713 \pm 11.33 \text{ c/m}$$

The extrapolation of the Pu-Be source strength to estimate the Po-Be source strength involved the ratio of their counting rates. Whenever a physical magnitude Y is to be obtained by the multiplication or division of two or more physical magnitudes y_1, y_2 ....., the fractional probable error R/Y depends on the fractional probable errors r_1/y_1, r_2/y_2 ......and

$$\left(\frac{R}{Y}\right)^2 = \left(\frac{r_1}{y_1}\right)^2 + \left(\frac{r_2}{y_2}\right)^2 + \ldots\ldots + \left(\frac{r_n}{y_n}\right)^2$$

or

$$R = Y\sqrt{\left(\frac{r_1}{y_2}\right)^2 + \left(\frac{r_2}{y_2}\right)^2 + \ldots\ldots + \left(\frac{r_n}{y_n}\right)^2}$$

For the Po-Be source strength extrapolation

$$\frac{5713 \pm 11.33}{49.5 \pm .71} = 115.4 \pm 115.4\sqrt{\left(\frac{11.33}{5713}\right)^2 + \left(\frac{.71}{49.5}\right)^2}$$

$$= 115.4 \pm 1.67$$

The NBS calibration gave the Pu-Be source strength a probable error of 2% or $2.011 \pm .04 \times 10^6$ n/sec

then

$$(115.4 \pm 1.67)\ (2.011 \pm .04 \times 10^6) = 232 \pm 232\sqrt{\left(\frac{1.67}{115.4}\right)^2 + \left(\frac{.04}{2.011}\right)^2} \times 10^6$$

$$= 232 \pm 5.7 \times 10^6$$

$$= 2.32 \pm .057 \times 10^8 \text{ n/sec}$$

thus the overall probable error is

$$\frac{.057}{2.32} = .0246$$

or 2.46%

This means that half of the time, if the measurement were repeated a large number of times, a repeated measurement would fall between 2.26×10^8 and 2.38×10^8 n/sec. The standard deviation would be $2.32 \pm \frac{.057}{.67} \times 10^6$ or $2.32 \pm .085 \times 10^8$ n/sec. 95% confidence limits would be $2.32 \pm .17 \times 10^8$ n/sec. Thus, there is less than 5%/2 or 2.5% chance that the Po-Be source's output is less than 2.15×10^8 n/sec. One only needs to grant the accuracy of the NBS calibration to gain this degree of confidence in the reliability of the measurements.

REFERENCES

1. D. E. Hankins, Monitoring Intermediate Energy Neutrons, Health Physics, Volume 9, pp 31-39, January, 1963.

2. National Bureau of Standards Handbook 72 (1960). Measurement of Neutron Flux and Spectra for Physical and Biological Applications.

3. W. N. Hess and A. R. Smith, Measurement of Average Neutron Energies for (α - n) Neutron Sources UCRL-8617, April; 1959.

4. R. D. Evans, the Atomic Nucleus, McGraw-Hill, 1955, chapters 26 and 27, Statistical Fluctuations in Nuclear Processes and Statistical Tests for Goodness of Fit.