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COMPARISON OF CALCULATED AND MEASURED RESPONSE FUNCTIONS FOR GERMANIUM DETECTORS

by

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ABSTRACT

This report compares calculated and measured germanium spectra for ^{65}Zn , ^{137}Cs , and ^{113}Sn sources and uranium and plutonium spherical shells. Agreement over the full energy range of the spectra is good; deviations are explained.

I. INTRODUCTION

When sufficiently accurate Monte Carlo calculations with detailed models of detector systems are possible, expensive fabrication is not necessary to determine the response. Germanium detectors have been difficult to calculate because their high resolution requires narrow bins around peaks and the geometry of the cryostat can be complicated. Previous work at Los Alamos studied bismuth germanate and barium fluoride scintillators.¹⁻³ The present report describes some results for germanium detectors.

II. EXPERIMENTS

Two p-type closed-end coaxial high-purity germanium detectors were used. In one detector (Princeton-GammaTech Serial Number 1155) the crystal was 64.2 mm in diameter by 41.9 mm in length; the front edge was square. At 1332 keV the efficiency was 31.7% relative to a 3 inch by 3 inch NaI(Tl) detector and the resolution was 1.73 keV. In the second detector (EG&G Ortec Serial Number 25-P-1483A) the crystal was 58 mm in diameter and 54 mm in length; the front edge was rounded. The efficiency was 32.4% and the resolution was 1.66 keV.

Five radioactive sources were used. Data for three low-mass calibration sources are listed in Table I. The source strengths were determined by calibration against a mixed source of ^{125}Sb , ^{154}Eu , and ^{155}Eu from the National Bureau of Standards, with uncertainties on the line intensities of about one percent. The nominal uncertainties on the strengths of the three isotopic sources were 5%. However, the time between calibration and use in this experiment was two years for the ^{65}Zn and the ^{113}Sn and five years for the ^{137}Cs . Thus additional uncertainties were introduced

TABLE I. Characteristics of Isotopic Calibration Sources.

Nuclide	Serial Number	Source Strength μCi	Supplier
^{65}Zn	11967-13	9.2	Isotope Products Laboratories
^{137}Cs	1S661	9.6	Amersham Corporation
^{113}Sn	11967-6	0.72	Isotope Products Laboratories

because of the possible deterioration of the sources and the uncertainties in the lifetimes. The total uncertainties might have been as large as 10%. The data for two shell sources are shown in Table II.

The experiments were performed in the basement of a concrete building at Los Alamos (TA-18, Building 30, Room 1). To minimize scattering, the detector in each measurement was located 59 inches from the concrete floor and at least 90 inches from the nearest wall. The isotopic sources were suspended at 59 inches by tape from a metal rod but even farther from the nearest wall than the detector was. Similarly the shell sources were suspended by a low-mass wire. Measurements were made with each source on the axis of each of the two detectors and 45° off-axis. Thus, there were 20 experiments. The distance from the source to the center of the front surface of the detector can was 60.96 cm except for the measurements with the plutonium shell. Since the γ -ray intensity from this shell was high, it was necessary to increase the distance to 152.4 cm to reduce the dead time in the electronics. The exact geometry for each measurement was included in the calculations.

III. CALCULATIONS

Calculations of this type were pioneered by John Kriese (DIA), Bob Schrandt (Los Alamos Group X-6), and Guy Estes (Los Alamos Group X-6). Computational models of the detectors are shown in Figs. 1 and 12. The model of detector 1483A was made with SABRINA.⁴ The model of detector 1155 was contributed by Guy Estes. All calculations included the room walls. Calculations were done with the INRAD⁵ version of MCNP.⁶ The subtraction of background and collapse of the

TABLE II. Characteristics of Shell Sources.

Serial Number	WAS 114200	WAS 114100
Material	Uranium (0.2% ^{235}U)	Plutonium (6% ^{240}Pu)
Mass (g)	550	458
Inner Radius (cm)	3.3575	3.3575
Outer Radius (cm)	3.5750	3.5750
Coating Material	Stainless Steel	Stainless Steel
Coating Thickness (cm)	0.0275	0.0275

experimental results to the Monte Carlo bin width of 0.01 MeV were done with DISTJS written by Tom Seed (Los Alamos Group X-5).

IV. COMPARISON OF CALCULATION AND EXPERIMENT

Comparison of calculation and experiment is shown for detector 1155 in Figs. 2 through 11 and for detector 1483A in Figs. 13 through 22. Error bars shown on the calculated results are Monte Carlo standard deviation. The signature of less than completely successful background subtraction shows up in the experimental results only in Figs. 21 and 22. In some of the figures (for example, Figs. 4 through 9), a large peak in the experimental results has a small shoulder just below it that does not appear in the calculations. This shoulder probably belongs in the peak. If so, the agreement between the experimental and calculated shapes is excellent except for the plutonium results shown in Figs. 10, 11, 21, and 22 and discussed below. The scale factor needed to bring the experimental and calculated curves into agreement is given in Table III. For each source, this

TABLE III. Ratio Of Calculation To Experiment For Detectors 1155 And 1483A.

Source	Angle	Energy MeV	Detector	
			1155 Ratio	1483A Ratio
^{65}Zn	0°	1.10-1.12	1.3	1.1
^{65}Zn	45°	1.10-1.12	1.3	1.1
^{137}Cs	0°	0.65-0.67	1.2	1.0
^{137}Cs	45°	0.65-0.67	1.2	1.0
^{113}Sn	0°	0.38-0.40	1.0	0.9
^{113}Sn	45°	0.38-0.40	1.0	0.9
U sphere	0°	0.99-1.01	1.2	1.0
U sphere	45°	0.99-1.01	1.2	1.0

ratio is uniformly 20% higher for detector 1155 than for detector 1483A. Since the corner between the front face and the sides is square in detector 1155, the electric field gradient here is lower and might result in poor charge collection. For detector 1483A, which has a rounded corner, the ratio averages to unity.

As can be seen from Figs. 10, 11, 21, and 22, a scale factor will not work for the experiments using the plutonium sphere because the peaks are calculated higher and the areas between the peaks are calculated lower than experiment. The fact that none of the other experiments needs more than a moderate scale factor to bring the calculated and experimental results into agreement suggests that this disagreement is related to the much higher count rate for the plutonium experiments. In the analysis of all the experimental results reported here, a simple dead-time model was used, which assumes that after a γ ray reaches the detector, there is a brief time during which other incoming γ rays are ignored. Actually, the electronics are more complicated than that, and two γ rays arriving simultaneously will be counted as a single γ ray with the sum of their energies. When two γ rays arrive almost simultaneously, they may be counted as a single γ ray of an intermediate

energy, or even (because the pulse in the electronics has a negative precursor) at a slightly lower energy than either. This pile-up effect is probably not sufficiently well characterized to put into the calculations but offers a plausible explanation of the discrepancies in the plutonium experiments.

V. CONCLUSIONS

- The ^{65}Zn source seems to be some 10% stronger and the ^{113}Sn source some 10% weaker than nominal. This conclusion is not excluded by the statistics of the experiments used for their calibration.
- The plutonium sphere experiments may have been complicated by a pile-up effect.
- If the two previous conclusions are valid, the calculations for detector 1483A are in excellent agreement with experiment.
- Detector 1155 suffers from moderate charge collection problems. Some of this may well be due to the square corner between the face and the sides of the detector, but there may also be defects in the crystal.

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Fig. 1. Model of detector 1155 showing germanium crystal with central cavity, cold finger, aluminum supporting structure, electronics package, and dewar.

Fig. 2. Response of detector 1155 to a ^{65}Zn source at a distance of 2 feet on the centerline of the detector. Experiment (solid) compared with calculation (dashed).

Fig. 3. Response of detector 1155 to a ^{65}Zn source at a distance of 2 feet from the detector and 45° from the centerline. Experiment (solid) compared with calculation (dashed).

Fig. 4. Response of detector 1155 to a ^{137}Cs source at a distance of 2 feet on the centerline of the detector. Experiment (solid) compared with calculation (dashed).

Fig. 5. Response of detector 1155 to a ^{137}Cs source at a distance of 2 feet from the detector and 45° from the centerline. Experiment (solid) compared with calculation (dashed).

Fig. 6. Response of detector 1155 to a ^{113}Sn source at a distance of 2 feet on the centerline of the detector. Experiment (solid) compared with calculation (dashed).

Fig. 7. Response of detector 1155 to a ^{113}Sn source at a distance of 2 feet from the detector and 45° from the centerline. Experiment (solid) compared with calculation (dashed).

Fig. 8. Response of detector 1155 to a uranium sphere at a distance of 5 feet on the centerline of the detector. Experiment (solid) compared with calculation (dashed).

Fig. 9. Response of detector 1155 to a uranium sphere at a distance of 5 feet from the detector and 45° from the centerline. Experiment (solid) compared with calculation (dashed).

Fig. 10. Response of detector 1155 to a plutonium sphere at a distance of 5 feet on the centerline of the detector. Experiment (solid) compared with calculation (dashed).

Fig. 11. Response of detector 1155 to a plutonium sphere at a distance of 5 feet from the detector and 45° from the centerline. Experiment (solid) compared with calculation (dashed).

Fig. 12. SABRINA model of detector 1483A showing copper rod, central cavity, germanium crystal, aluminum mounting cup, and outer aluminum can.

Fig. 13. Response of detector 1483A to a ^{65}Zn source at a distance of 2 feet on the centerline of the detector. Experiment (solid) compared with calculation (dashed).

Fig. 14. Response of detector 1483A to a ^{65}Zn source at a distance of 2 feet from the detector and 45° from the centerline. Experiment (solid) compared with calculation (dashed).

Fig. 15. Response of detector 1483A to a ^{137}Cs source at a distance of 2 feet on the centerline of the detector. Experiment (solid) compared with calculation (dashed).

Fig. 16. Response of detector 1483A to a ^{137}Cs source at a distance of 2 feet from the detector and 45° from the centerline. Experiment (solid) compared with calculation (dashed).

Fig. 17. Response of detector 1483A to a ^{113}Sn source at a distance of 2 feet on the centerline of the detector. Experiment (solid) compared with calculation (dashed).

Fig. 18. Response of detector 1483A to a ^{113}Sn source at a distance of 2 feet from the detector and 45° from the centerline. Experiment (solid) compared with calculation (dashed).

Fig. 19. Response of detector 1483A to a uranium sphere at a distance of 2 feet on the centerline of the detector. Experiment (solid) compared with calculation (dashed).

Fig. 20. Response of detector 1483A to a uranium sphere at a distance of 2 feet from the detector and 45° from the centerline. Experiment (solid) compared with calculation (dashed).

Fig. 21. Response of detector 1483A to a plutonium sphere at a distance of 5 feet on the centerline of the detector. Experiment (solid) compared with calculation (dashed).

Fig. 22. Response of detector 1483A to a plutonium sphere at a distance of 5 feet from the detector and 45° from the centerline. Experiment (solid) compared with calculation (dashed).