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RESPONSES OF C_6D_6 AND C_6F_6 GAMMA-RAY DETECTORS AND THE CAPTURE IN THE 1.15-KEV RESONANCE OF ^{56}Fe

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Abstract: We have used the electron gamma-ray transport code EGS to calculate responses of C_6D_6 and C_6F_6 gamma-ray detectors, where the geometry of the capture experiments was carefully modelled. Very good agreement was obtained with spectra from selected resonances in the capture of neutrons by ^{207}Pb. Weighting functions based upon the calculated responses were used in measuring the capture in the 1.15-keV resonance of ^{56}Fe relative to the capture in the Au 4.9-eV resonance. The neutron width was measured to be $64.5 \pm 3.$ meV with C_6F_6 detectors, and 63.0 ± 2.5 meV with C_6D_6 detectors. These values are in good agreement with the value of 61.7 ± 0.9 meV found from transmission measurements.

(^{56}Fe, resonance capture)

Introduction

The pulse-height weighting technique has been used for more than two decades[1] to measure neutron capture cross sections. Although this technique had been extensively tested, it was reported at the Antwerp Conference[2] that when the capture in the 1.15-keV resonance of ^{56}Fe is measured relative to the capture in well known resonances of Au and Ag, the results are found to be about 20% larger than the value determined from transmission measurements or when the measurement is made relative to the thermal capture in iron. Soon after the Antwerp Conference a special task force of the Nuclear Energy Agency Nuclear Data Committee was set up to coordinate efforts to resolve this discrepancy. Although much work was stimulated by this task force,[3-8] very little progress was made in resolving the discrepancy until recently[9] when the responses of the C_6D_6 detectors used in the experiments reported at Antwerp were measured for high-energy gamma rays and found to disagree substantially with the calculated responses that had been used. These experimentally determined responses yielded a weighting function that removed the original discrepancy. It was suggested that the previously calculated responses failed to properly take into account the interaction of the capture gamma rays with material surrounding the capture samples and the detectors themselves.

In this paper we report upon the calculation of C_6D_6 and C_6F_6 detector responses using a state-of-the-art code, EGS, developed at Stanford.[10] The geometry of the capture experiments were carefully modelled. Some of these calculated responses were tested in capture experiments using observed spectra from selected resonances in the capture of neutrons by ^{207}Pb. Finally, weighting functions based upon these calculated responses were used in experiments where the capture in the 1.15-keV resonance of ^{56}Fe was measured relative to the capture in the 4.9-eV resonance of Au. The results, for both C_6D_6 and C_6F_6 detectors, were found to be in good agreement with those from transmission experiments. Complete details of the calculations and experiments will be reported elsewhere.

Calculation of the Responses

The physics of the interaction of gamma rays with matter is thought to be well understood, at least in the range of gamma-ray energies involved in neutron capture and given that a threshold of at least 100 keV is used in the detectors. Although this physics is well known, including the cross sections involved, the computation of detector responses with minimal approximations to this physics has been a great challenge. Two computer codes that represent the current state-of-the-art are widely available today. They are EGS, developed at Stanford,[10] and GEANT developed at CERN.[11] The code EGS4, interfaced with the MORSE combinatorial geometry package,[12] was used on the ORELA VAX-785 to calculate the responses of C_6F_6 and C_6D_6 detectors. Some of these responses were independently tested at ORNL with the code GEANT.[13] The integrity of the ORNL version of these codes was tested via specific computations performed by the authors of these codes[14-15] on their own versions of these codes and excellent agreement was obtained.

Great care was taken to accurately represent all of the material within a 30-cm distance of the samples and within at least 12 cm of the detectors themselves. However, a few approximations were made within these volumes. The faces of the photomultipliers, RCA 8854s, were taken to be SiO_2, when they are in fact a borosilicate glass. We also ignored the thin focussing elements between the photocathode and the first dynode.

In one set of experiments, the two C_6F_6 detectors were 10 cm in diameter and 4.0 cm deep. Their front faces were 8.72 cm from the axis of the neutron beam and facing each other. In the other set of experiments, the two C_6D_6 detectors were also 10 cm in diameter but 7.0 cm deep. Their front faces were 7.81 cm from the axis of the neutron beam. The Fe sample was 8.9 cm in diameter and 0.051 cm thick. The Au sample was also 8.9 cm in diameter but 0.0051 cm thick. The ^{207}Pb sample was only 7.62 cm in diameter but 0.32 cm thick. In calculating the responses of the detector systems the gamma rays were started uniformly through the thickness of the samples, but they followed the neutron beam profile radially since the edges of the samples were in the penumbra of the beam. For all gamma rays born in the samples, the total amounts of energy deposited in both detectors were summed since in the experiments the detectors were operated in a sum mode. Approximately 1% of the gamma rays that deposited energy in one of the two detectors also deposited some energy in the other detector.

Test of the Calculated Responses

Since some resonances in ^{207}Pb have very simple gamma-ray spectra associated with them, it is possible to test the calculated responses of the detectors in precisely the geometry they will be used in capture experiments, an important aspect since the responses to high-energy gamma rays are strongly influenced by the materials close to the sample and the detectors. Two resonances are particularly well suited for this purpose since they have small neutron widths, and, consequently, the observed spectra are not strongly contaminated by interactions of neutrons with the detectors or their surroundings. The spectrum of the 16.2-keV resonance contains only three gamma rays: a ground state transition of 7.384 MeV, and gamma rays of 2.615 and 4.769 MeV due to a cascade through the 3^- level of ^{208}Pb. The spectrum of the 30.4-keV resonance consists of the ground state transition only.

In Figures 1 and 2 we compare the observed spectra for the 30.4-keV resonance for the C_6D_6 and C_6F_6 detectors with the calculations of the responses for 7.384-MeV gamma rays. Given the statistics in these spectra, we judge the agreements to be very satisfactory. In Figure 3 we compare the spectrum obtained with the C_6F_6 detectors for the 16.2-keV resonance with the EGS calculated spectrum. We again judge satisfactory the level of agreement between the calculated and observed spectra. A similar level of agreement was found between the calculated and observed spectra of the 16.2-keV resonance for the C_6D_6 detectors.

Although our ^{207}Pb capture experiments have only allowed us to test the responses calculated with EGS for three gamma-ray energies, we feel that EGS should be able to calculate accurately the responses of our detectors at all energies needed to determine pulse-height weighting functions for use in capture experiments.

Neutron Capture in the 1.15-keV Resonance of ^{56}Fe

The capture in the 1.15-keV resonance of ^{56}Fe was measured relative to the capture in the 4.9-eV resonance of Au using the saturated resonance technique. The flight path was 24 m; the neutron flux monitor was a ^{10}B ionization chamber placed 32 cm behind the samples; the ^{10}B deposits being slightly smaller than the size of the samples. Two-dimensional data, pulse height (128 channels, 76 keV wide) vs time of flight, were acquired over a range of neutron energies around 1.15 keV and 4.9 eV. The spectra, corrected for deadtime and for sample-out backgrounds, were weighted with weighting functions obtained from the EGS calculated responses. The flux monitor time of flight spectra, corrected for deadtime, backgrounds, and transmission of the neutrons through the samples, were fitted to a power law in the vicinity of the resonances. ENDF/B-V cross sections for ^{10}B were used.

Figures 4 and 5 show the relative capture yields, obtained with the C_6F_6 detectors, as a function of energy for the 4.9-eV Au resonance and the 1.15-keV ^{56}Fe resonance. Also shown in Figure 4 is the result of a Monte Carlo calculation,[16] based upon the well known resonance parameters of the 4.9-eV resonance, normalized to the experimental data. The normalization factor so obtained was then used to normalize the results of Monte Carlo calculations for the 1.15-keV resonance of ^{56}Fe. In these Monte Carlo calculations the radiation width of the 1.15-keV resonance was kept at 573 meV, the value determined from transmission experiments,[7] and the neutron width was varied to fit the data. For the C_6F_6 detectors a value of $64.5 \pm 3.$ meV was obtained. This value is to be compared with the value of 61.7 ± 0.9 meV found from the transmission experiments. For the C_6D_6 detectors the value obtained for the neutron width of the 1.15-keV resonance was 63.0 ± 2.5 meV.

In Figure 6 we compare the pulse height spectra obtained for the Au and 1.15-keV resonance with the C_6F_6 detectors. The very different hardness of the two spectra indicates that the ratio of the capture in these two resonances will be a rather sensitive function of the weighting functions used.

Conclusions

It would seem that Corvi et al.[9] have correctly identified the source of the discrepancy in previously reported results for the capture in the 1.15-keV resonance of ^{56}Fe obtained using the pulse-height weighting method when the measurements were made relative to Au or Ag. The weighting functions used were based upon inadequately calculated responses for the detectors. Our results seem to indicate that if one carefully describes all of the material close to the samples and the detectors the code EGS4 is capable of calculating adequate responses. This is important since one may not be able to use responses obtained in a geometry which is different from the one used in the capture experiments.

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REFERENCES

1. R. L. Macklin and J. H. Gibbons: *Phys. Rev.* **159**, 1007(1967).
2. F. Corvi et al: *Proc. Int. Conf. on Nuclear Data for Science and Technology, Antwerp*: CONF-82096, (Reidel, 1982) p. 131.
3. R. L. Macklin: *Nucl. Sci. Eng.* **83**, 309(1983).
4. D. B. Gayther et al: AERE-R-11583, Atomic Energy Research Establishment, Harwell, UK (January 1985).
5. L. W. Weston and J. H. Todd: *Proc. Int. Conf. on Nuclear Data for Basic and Applied Science, Santa Fe, New Mexico* (Gordon and Breach, New York, 1986) p. 585.
6. F. G. Perey: *Ibid.*, p. 1523.
7. F. Corvi et al: *Nucl. Sci. Eng.* **93**, 348(1986).
8. R. L. Macklin: *Nucl. Sci. Eng.* **95**, 200(1987).
9. F. Corvi et al: *Nucl. Instr. and Meth.* **A265**, 475(1988).
10. W. R. Nelson et al: SLAC-265, Stanford Linear Accelerator Center, Stanford, USA (December 1985).
11. R. Brun et al: CERN/DD/EE/84-1 (1986) unpublished.
12. T. A. Gabriel et al: CALOR89, report in preparation.
13. J. R. Beene: ORNL, private communication (November 1987).
14. W. R. Nelson: SLAC, private communication (December 1987).
15. R. Brun: CERN, private communication (December 1987).
16. G. de Saussure: ORNL, unpublished code.

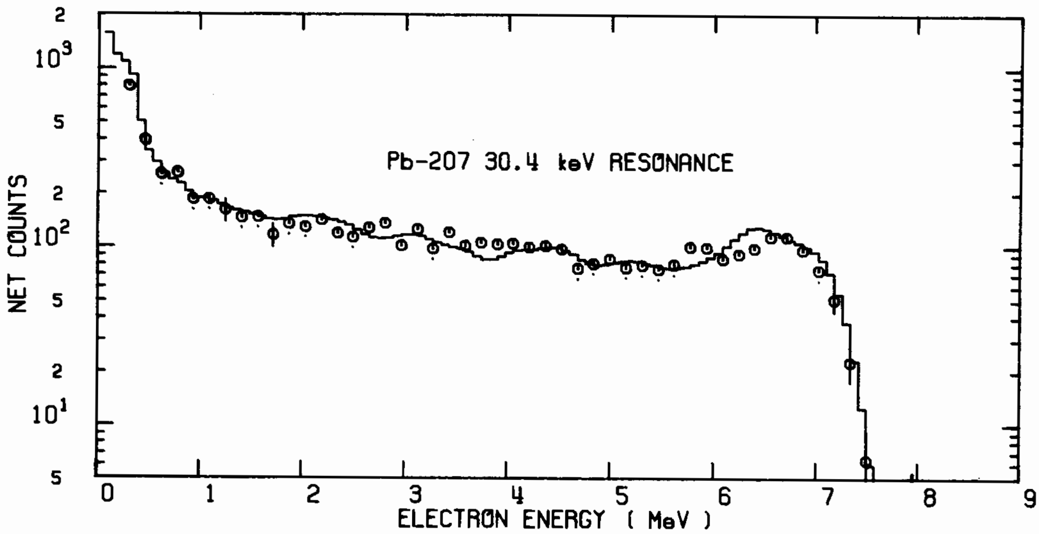

Figure 1. Comparison of the spectrum obtained with C_6D_6 detectors for the 30.4-keV resonance of ^{207}Pb with the response to 7.384-MeV gamma rays calculated with EGS. The EGS calculation was smeared with the measured experimental pulse-height resolution.

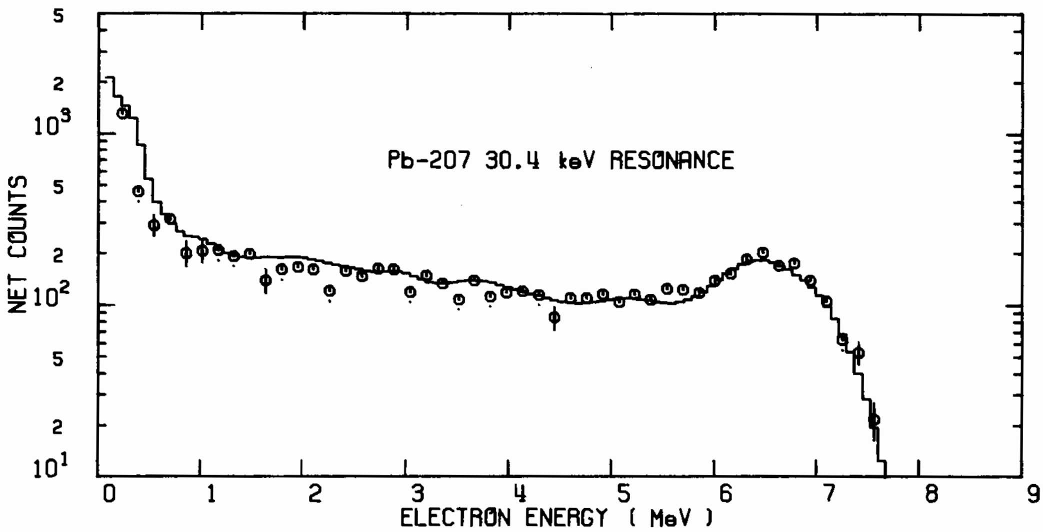

Figure 2. Comparison of the spectrum obtained with C_6F_6 detectors for the 30.4-keV resonance of ^{207}Pb with the response to 7.384-MeV gamma rays calculated with EGS. The EGS calculation was smeared with the measured experimental pulse-height resolution.

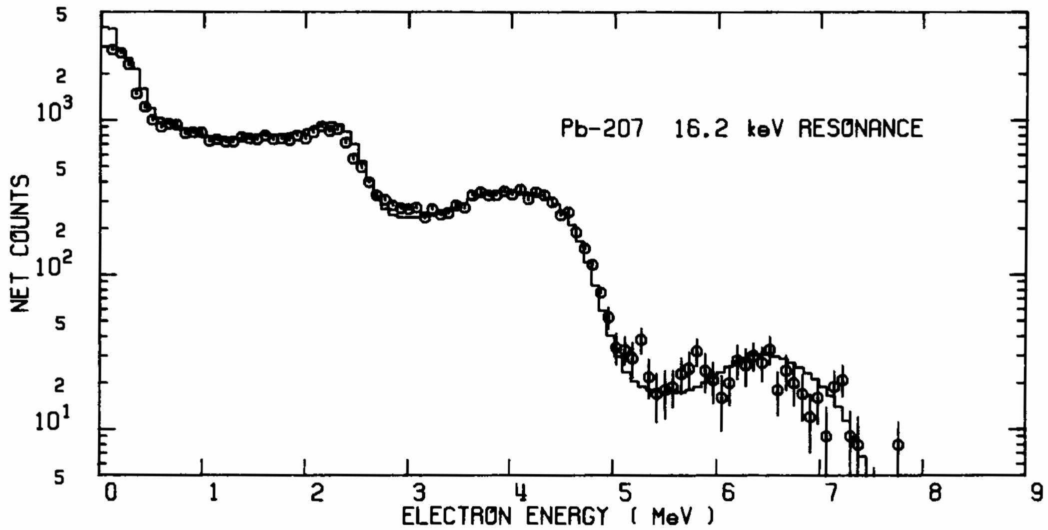

Figure 3. Comparison of the spectrum obtained with C_6F_6 detectors for the 16.2-keV resonance of ^{207}Pb with responses calculated with EGS for 7.384-, 4.769- and 2.615-MeV gamma rays. A branching ratio of 0.14 was used for the ground-state transition.

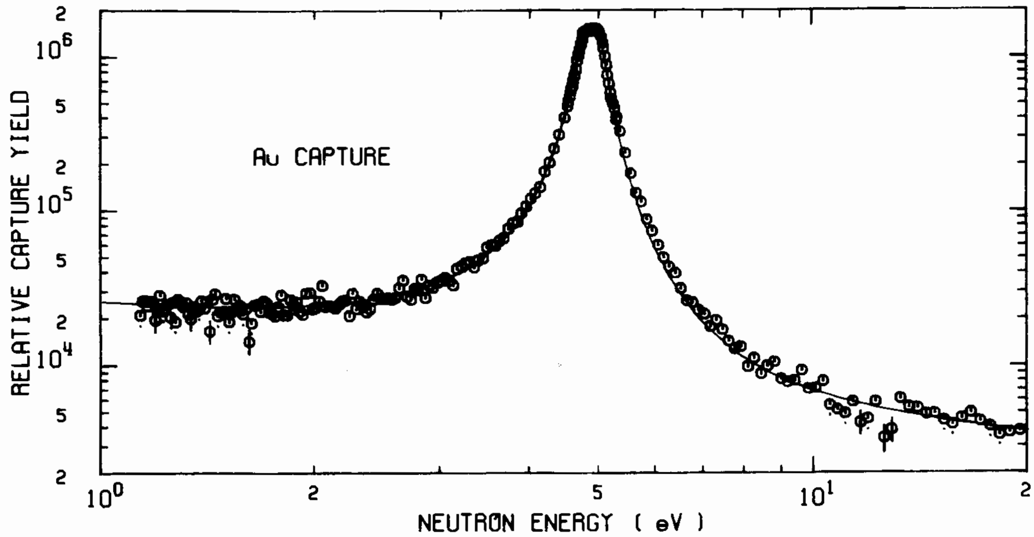

Figure 4. Comparison of the observed capture yield, with C_6F_6 detectors, with Monte Carlo calculations based upon the well known resonance parameters of the 4.9-eV resonance. A 1/v residual background with a value of 7000 at the resonance energy was added to the calculated yield in order to fit the wings of the resonance.

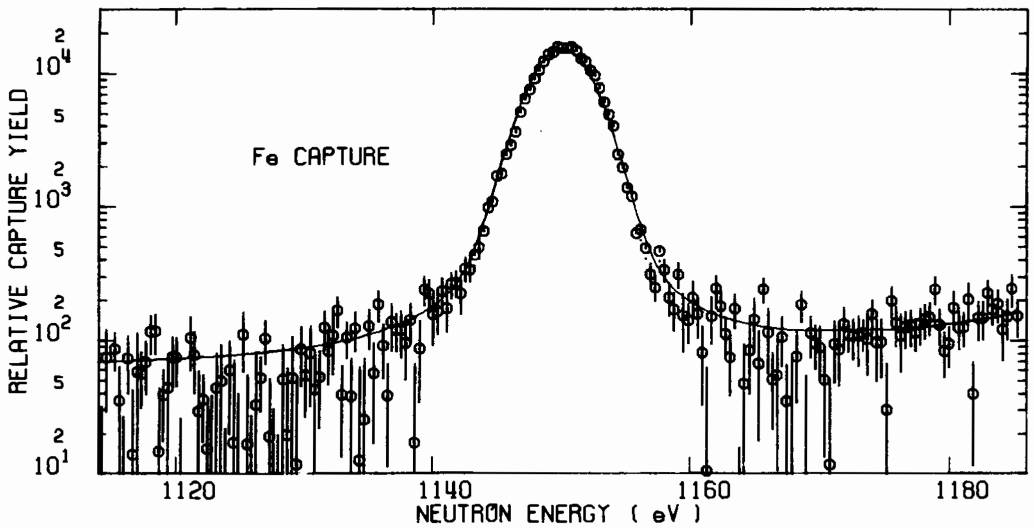

Figure 5. Comparison of the observed capture yield, with C_6F_6 detectors, with Monte Carlo calculations done with a neutron width of 64.5 meV and a capture width of 573 meV. The calculations were resolution broadened with a Gaussian resolution of 2.6 eV width, and a constant residual background of 50 was added to the calculations.

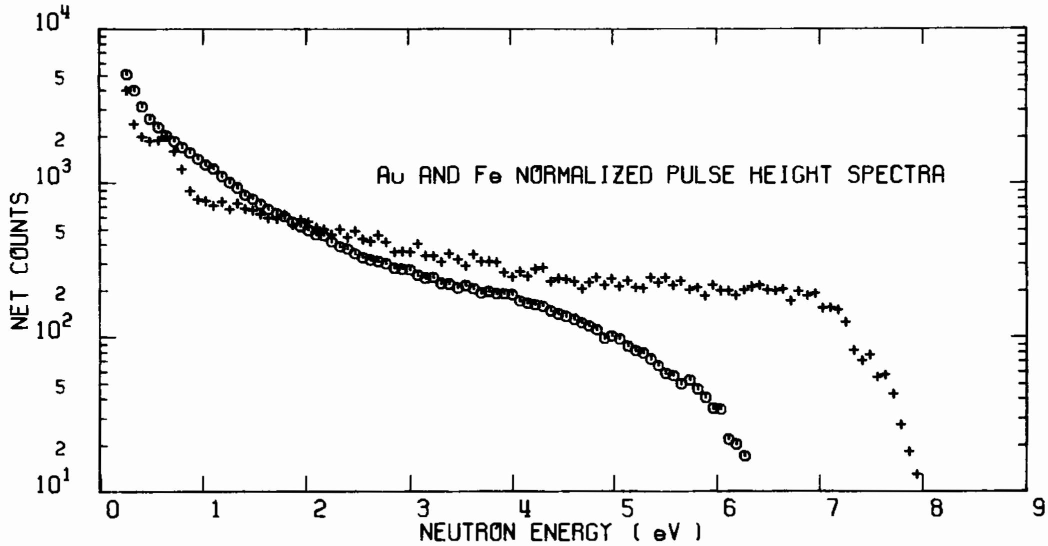

Figure 6. Comparison of the observed pulse-height spectra, with C_6F_6 detectors, for the 4.9-eV Au resonance (circles) and the 1.15-keV resonance of ^{56}Fe (crosses). The two spectra were normalized to the same total number of counts.