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APPLICATION OF Ge SEMI-CONDUCTOR DETECTOR TO WHOLE-BODY COUNTER

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Abstract

Peak efficiencies of a Ge semi-conductor detector for point sources and volume sources were evaluated by Monte Carlo simulation and experiment. It was found that the calculated results are in good agreement with the experimental values. Consequently, the simulation method for peak efficiencies was validated. In addition, an optimum design for whole-body counter with Ge semi-conductor detectors was examined by simulation. A whole-body counter offering a uniform response to several ^{137}Cs distributions was obtained conceptually.

1 Introduction

A precision whole-body counter installed at the Japan Atomic Energy Research Institute (JAERI) have used thallium activated sodium iodide [NaI(Tl)] scintillation detectors, since these detectors have many advantages of intrinsic detection efficiency, availability in sufficient size and at acceptable cost, energy resolution and long term stability of operation[1∼5]. However, the whole-body counter has a problem awaiting solution - the ability to distinguish between γ rays that have similar energies. In the near future, germanium (Ge) semi-conductor detectors are to come into for the whole-body counter at JAERI so as to solve the problem.

In general, a Ge semi-conductor detector has higher energy resolution than a NaI(Tl) scintillation detector. However, a Ge semi-conductor detector can not attain the size as large as a NaI(Tl) scintillation detector, has lower peak efficiency than a NaI(Tl) scintillation detector and thus can not be located in the positions of NaI(Tl) scintillation detectors used for a whole-body counter. Therefore, it is necessary that peak efficiencies of a Ge semi-conductor detector, quantity and optimum siting of Ge semi-conductor detectors be simulated for designing a precision whole-body counter.

While various computer codes of Monte Carlo simulation have been developed and used to determine peak efficiency of Ge semi-conductor detector[6∼9], very little work is currently available in the published literature on designing a whole-body counter using Monte Carlo simulation.

The objective of the present study is to develop a reliable means for designing a whole-body counter equipped with Ge semi-conductor detectors using Monte Carlo simulation.

2 Materials and Methods

2.1 Whole-body counter with a Ge semi-conductor detector

To make a preparatory experiment for designing a precision whole-body counter, a Ge semi-conductor detector was installed in a whole-body counter at JAERI. A P-type high-purity Ge (HPGe) closed-ended coaxial detector (80% relative efficiency) was chosen as the detector. The calculation geometry of the Ge semi-conductor detector is shown in Fig.1. The geometry was assumed to be composed of multilayer cylinders by adopting the factory information.

2.2 Validation of peak efficiencies by Monte Carlo simulation

Peak efficiencies of a Ge semi-conductor detector for point sources and volume sources were evaluated by Monte Carlo simulation and experiment. The point sources were positioned 25 cm from the endcap face of the detector. The volume sources - two water-filled block-shape phantoms containing ^{137}Cs and ^{40}K, respectively - were positioned on a bed, as shown in Fig.2. The distance between the endcap face of the detector and the bed was 50 cm.

The peak efficiency is the ratio of the number of counts in the photopeak to the number of γ rays emitted from the source. The photon energy range of interest was 60 - 1,836 keV, since the range covered photon energies for typical radionuclides, *i.e.* ^{241}Am, ^{57}Co, ^{137}Cs, ^{60}Co, ^{40}K and ^{88}Y, supposed to be measured with the whole-body counter.

Monte Carlo simulation was carried out using the EGS4 code system[10] in conjunction with a user code for general purpose (UCGEN) [11]. The photon cross sections for materials were taken from PHOTX[12]. The number of the history of the simulation was determined to be ten million in order to reduce statistical uncertainties below 5%.

2.3 A whole-body counter offering uniformity of response

The deployment of Ge semi-conductor detectors in relation to the phantom, giving a response which is adequately independent of the distribution of five ^{137}Cs point sources within the phantom - an optimum siting of detectors, was determined using Monte Carlo simulation. A 'stretcher' geometry, with the subject in a supine posture and several detectors distributed about the body, was adopted for the design, since in the precision whole-body counter at JAERI the stretcher geometry has been adopted with five NaI(Tl) scintillation detectors.

3 Results and Discussion

3.1 Validation of peak efficiencies by Monte Carlo simulation

The calculated and measured peak efficiencies for the point sources are plotted against photon energy in Fig.3. The error bars indicate the experimental uncertainties for the measurements of peak efficiencies. The calculated results are in fairly good agreement with measured data in the energy range of 60-1,836 keV. The discrepancies between the calculated and measured peak efficiencies may be attributed to an inaccurate dead layer thickness that is assumed to be 0.7mm based on the factory information and used in the Monte Carlo simulation. It is difficult to know the actual accurate thickness of the dead layer of a Ge semi-conductor detector by only the factory information.

Figure 4 shows the calculated and measured peak efficiencies for the water-filled block-shape phantom. The calculated peak efficiencies for the phantom agree well with the measured ones.

Consequently, the Monte Carlo simulation method for the peak efficiencies was validated.

3.2 A whole-body counter offering a uniform response

Figure 5 shows a whole-body counter offering a uniform response to several ^{137}Cs distributions. The optimum distance between the endcap face of the detectors and the bed was determined by Monte Carlo simulation. The whole-body counter uses three units with six Ge semi-conductor detectors. Geometrical means are calculated using count rates of a pair of detectors above and below the phantom.

The variations in the response of the whole-body counter are shown in Figure 6. The distributions of five ^{137}Cs point source are assumed to be on the front, the axis and the back of the phantom respectively, as shown in Figure 7. The response is normalized to the average response of the units for the axis. From Figure 6 it can be stated that the whole-body counter has offered improved uniformity of response.

4 Conclusions

We have shown that the peak efficiencies of the whole-body counter with a Ge semi-conductor detector can be calculated using Monte Carlo simulation. The adopting of Monte Carlo simulation in designing a precision whole-body counter was found to be effective.

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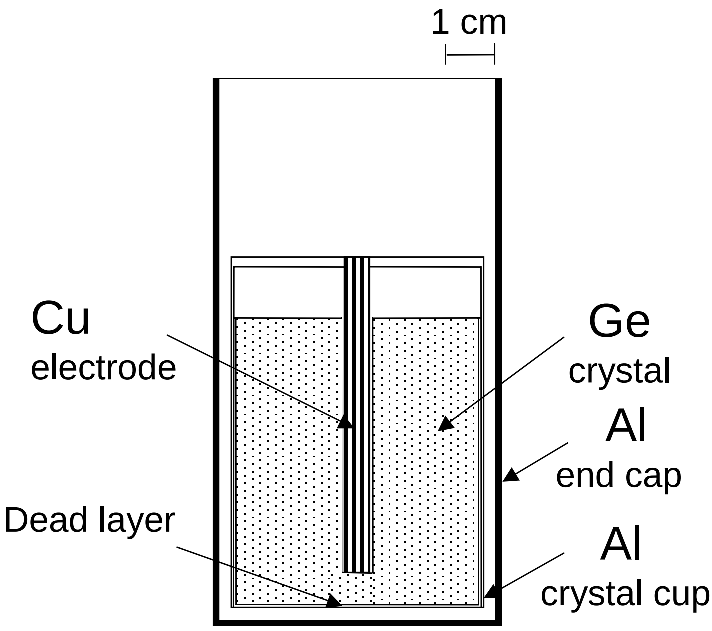

Figure 1: Structure of the germanium semi-conductor detector.

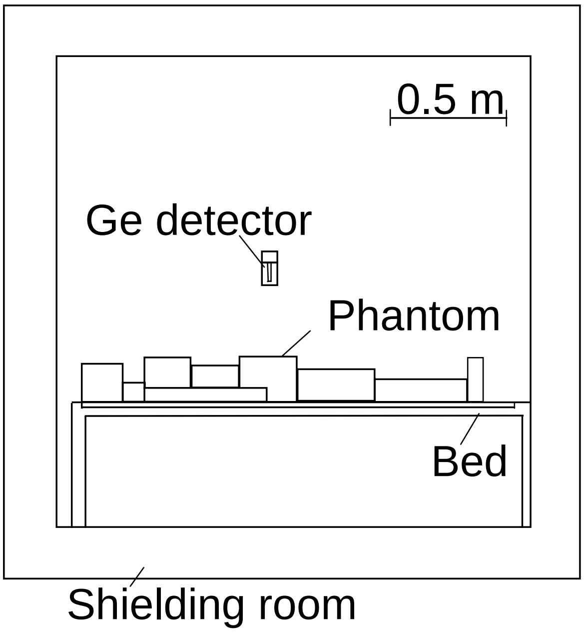

Figure 2: Geometry of the detector and the water-filled block-shape phantom.

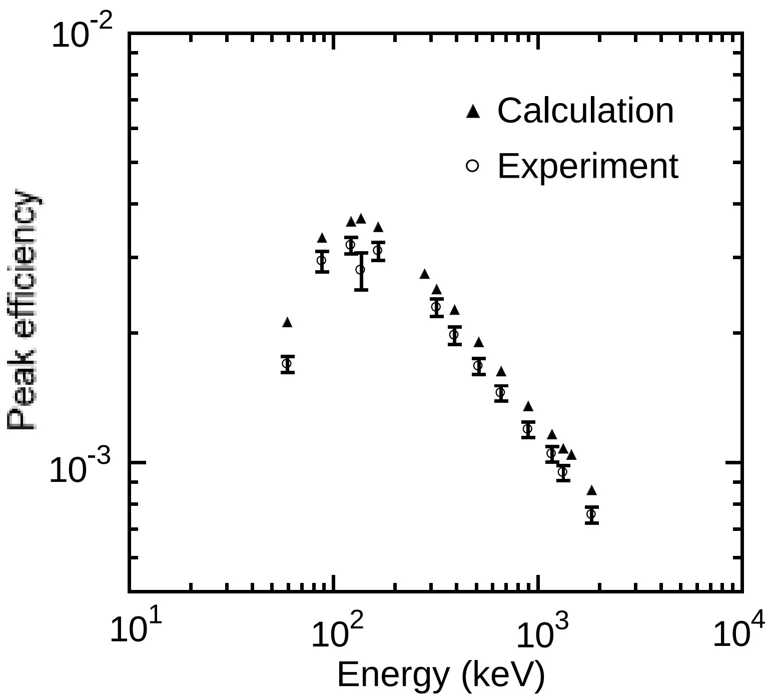

Figure 3: Peak efficiencies for point sources.

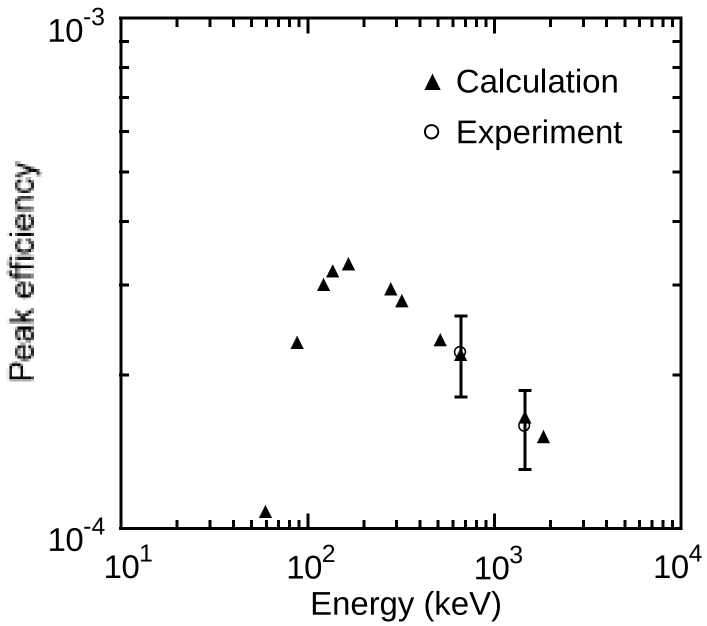

Figure 4: Peak efficiencies for the water-filled block-shape phantom.

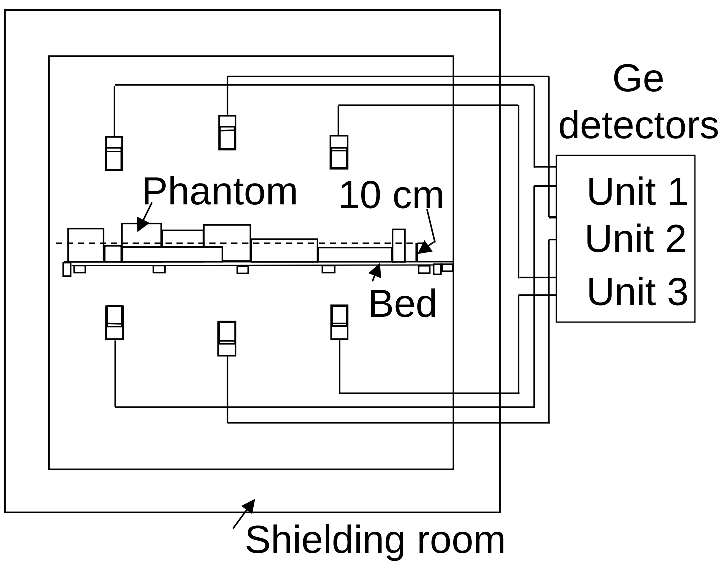

Figure 5: A whole-body counter offering uniformity of response.

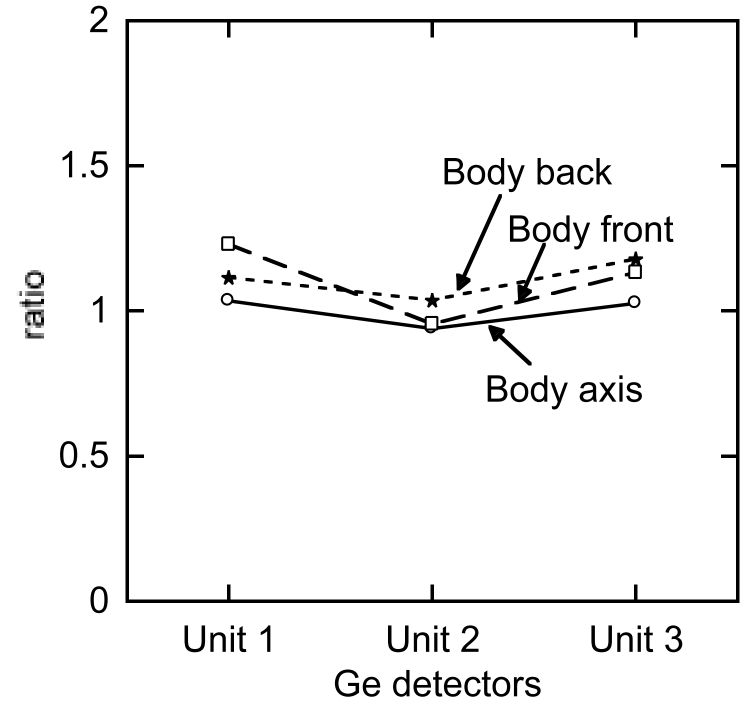

Figure 6: Response of the whole-body counter regarding ^{137}Cs distribution.

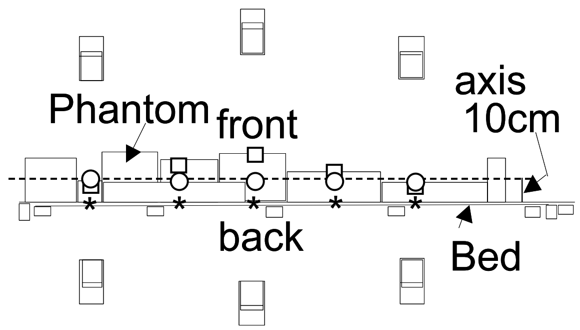

Figure 7: Distributions of five ^{137}Cs point source on the water-filled block-shape phantom.