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Si(Li) EFFICIENCY CURVE FOR X-RAY PARALLEL BEAM

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The full-energy peak efficiency of a Si(Li) detector was determined experimentally for a parallel beam in the 3–140 keV photon energy range using sources of ^{57}Co, ^{241}Am, ^{137}Cs and ^{133}Ba. The efficiency for the parallel beam was obtained from the efficiencies measured at different short distances. The experimental values were fitted to an analytical function of photon energy and a good agreement was observed over the entire range of energies. From the fitting some detector parameters were determined and are briefly discussed.

1. Introduction

The full-energy peak efficiency of a Si(Li) detector was determined experimentally for a parallel beam in the 3–140 keV photon energy range. A Si(Li) detector Mod. 7513-06165 Ortec was used with the following manufacturer specifications: 6 mm active diameter, 5.2 mm sensitive depth, 0.025 mm Be window thickness and 200 Å gold contact layer. The resolution measured at 5.894 keV (^{55}Fe) was (175 ± 5) eV. As pointed out by Gallagher and Cipolla [1] the calculated efficiency using the manufacturer specifications may be unreliable and for good accuracy it must be obtained experimentally. To measure the efficiency for a parallel beam using calibrated sources and a detector with these dimensions it would be necessary to put the sources more than 35 cm away from the detector in order to obtain an error less than 1% in comparison to a source located at infinity. This would require the use of vacuum techniques and calibrated sources of high activities which may be difficult to obtain. This work shows a simple method to obtain the efficiency curve using low activity sources and short detector–source distances.

2. Experimental

Calibrated sources of ^{57}Co, ^{241}Am, ^{137}Cs and ^{133}Ba were used for the efficiency measurements. They were prepared by dispensing weighed aliquots of the radioactive solution on mylar sheets. In order to reduce irregular crystal growths during evaporation, the sources were treated with ~20 μg of Cyastat SN and dried in a jet of warm nitrogen (~50°C). The ^{57}Co sources were prepared from a solution standardized in a 4π X–γ coincidence system. All other sources were calibrated in a Ge(Li) detector using high energy gamma lines. The uncertainties in the activities were: 1.5% (^{57}Co), 1.2% (^{241}Am), 2% (^{137}Cs) and 3% (^{133}Ba). The energies and intensities of gamma- and X-rays used are listed in table 1 [1, 2]. Some of these energies are weighted averages of two or more unresolved X-ray lines.

The efficiencies were measured at four different distances from the detector front face: 15.5, 29.2, 54.0 and 97.1 mm with an uncertainty of the order of 0.3 mm. The background under the full energy peak was assumed to be linear. It was calculated by least-squares fitting. Corrections were made for finite source size and for X- and gamma-ray attenuation in the air.

Theoretical calculation of the efficiency as a function of the distance and energy using the detector's specification given by the manufacturer showed that with a good accuracy (≲1%) it follows the relation:

$$\varepsilon(r, E) = \frac{1}{4\pi} \int_{\Omega} [1 - \exp(-\tau x)]\, d\Omega$$

$$\cong K(E)/[r + \delta(E)]^2 ,$$

where r is the distance between the source and

Table 1
Experimental results for ε_∞ and δ

Nuclide	Energy (keV)	Absolute intensity	$\varepsilon_\infty(E)$	$\delta(E)$
^{57}Co	6.46	0.5668 ± 0.0114	$2.455\times10^{-1}\pm8.9\times10^{-3}$	5.67 ± 0.14
	14.36	0.0979 ± 0.0017	$2.470\times10^{-1}\pm7.2\times10^{-3}$	5.93 ± 0.12
	121.97	0.8879 ± 0.0049	$4.489\times10^{-3}\pm1.2\times10^{-4}$	8.24 ± 0.11
	136.33	0.1186 ± 0.0030	$3.048\times10^{-3}\pm3.3\times10^{-4}$	8.99 ± 0.52
^{137}Cs	32.10	0.0556 ± 0.0018	$1.796\times10^{-1}\pm7.3\times10^{-3}$	7.97 ± 0.41
	36.60	0.0135 ± 0.0006	$1.234\times10^{-1}\pm4.7\times10^{-3}$	7.62 ± 0.09
^{241}Am	3.30	0.0635 ± 0.0060	$1.579\times10^{-1}\pm3.1\times10^{-2}$	5.37 ± 0.23
	11.88	0.00808 ± 0.00073	$2.591\times10^{-1}\pm3.2\times10^{-2}$	4.95 ± 0.44
	13.90	0.1341 ± 0.0028	$2.677\times10^{-1}\pm7.0\times10^{-3}$	6.07 ± 0.02
	17.75	0.2085 ± 0.0038	$2.539\times10^{-1}\pm7.4\times10^{-3}$	6.61 ± 0.12
	20.08	0.04971 ± 0.00096	$2.628\times10^{-1}\pm8.5\times10^{-3}$	7.35 ± 0.14
	26.35	0.0237 ± 0.0014	$2.416\times10^{-1}\pm2.0\times10^{-2}$	7.00 ± 0.59
	59.54	0.3590 ± 0.0060	$4.330\times10^{-2}\pm1.5\times10^{-3}$	8.73 ± 0.23
^{133}Ba	30.89	0.905 ± 0.055	$1.863\times10^{-1}\pm1.5\times10^{-2}$	8.33 ± 0.31
	35.29	0.210 ± 0.013	$1.553\times10^{-1}\pm1.4\times10^{-2}$	8.64 ± 0.43
	53.42	0.0199 ± 0.0013	$5.590\times10^{-1}\pm5.4\times10^{-3}$	9.43 ± 0.38
	80.90	0.317 ± 0.017	$1.663\times10^{-2}\pm1.2\times10^{-3}$	8.41 ± 0.22

detector front face, x is the distance travelled by the radiation inside the detector. $K(E)$ and $\delta(E)$ are parameters which depend only on the photon energy and can be obtained experimentally. It is easy to show that $4\pi K(E)$ is the efficiency $\varepsilon_\infty(E)$ for $r\to\infty$ (parallel beam) in units of counts/incident photon cm^2. $\delta(E)$ is the average distance travelled by the photon before being absorbed.

The experimental determination of $K(E)$ and $\delta(E)$ is performed by the least-squares fit of the following function:

$$[\varepsilon(r,E)]^{-1/2}=ar+b,$$

where $K(E)=1/a^2$ and $\delta(E)=b/a$.

3. Results

The values of $\varepsilon_\infty(E)$ and $\delta(E)$ obtained experimentally are shown in table 1. A weighted non-linear fit of $\varepsilon_\infty(E)$ as a function of E has been performed using the function taken from the work of Gallagher and Cipolla [1]:

$$\varepsilon_\infty(E)=\Omega\exp(aE^b)\,[1-\exp(cE^d)]\,.$$

The values of Ω, a, b, c and d were calculated by the computer program SAS (statistical analysis system) [3] at the IPEN Data Processing Center, and are listed in table 2.

The fitted curve is shown in fig. 1 as a full line. In this figure, the dashed line is the calculated efficiency for a parallel beam using the manufacturer's specifications for the detector. The experimental values of $\delta(E)$ are shown in fig. 2. A theoretical estimate, shown in full line in this figure, was calculated by the following relationship:

$$\delta(E)=\frac{\int_0^h x\exp(\tau x)\,dx}{\int_0^h \exp(\tau x)\,dx}+\delta_0$$

$$=\frac{1}{\tau}\left[1+\frac{\tau h}{1-\exp(\tau h)}\right]+\delta_0\,,$$

where τ is the photoelectric absorption coefficient of silicon, h is the sensitive depth of Si(Li) and δ_0 is the distance between the silicon surface and the detector front face. The latter was estimated by using the low energy $\delta(E)$ experimental values.

Table 2
Fitted parameters for the ε_∞ curve

$\Omega =$	0.2371 ± 0.0038
$a =$	-123.6 ± 480.7
$b =$	-4.631 ± 3.156
$c =$	$(-9.538 \pm 1.736) \times 10^4$
$d =$	-3.225 ± 0.040
Weighted residual =	19.78

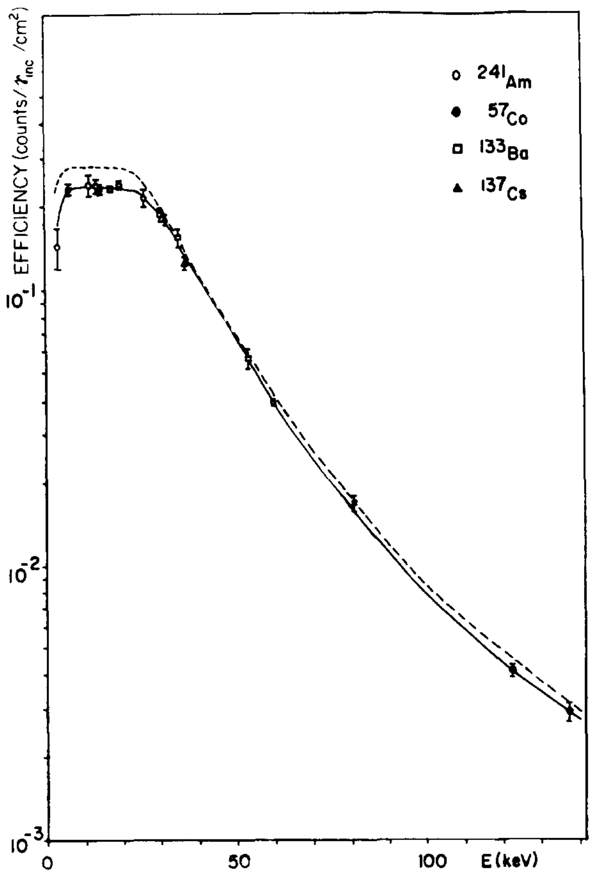

Fig. 1. Efficiency curve for parallel beam. Dashed line is the curve calculated theoretically using the manufacturer's specifications. Full line is the curve fitted to the experimental values.

4. Discussion

The fitted curve for ε_∞ agrees with all the experimental efficiencies and the uncertainty in interpolations may be essentially given by the uncertainty in the neighbouring experimental values. The parameter Ω which corresponds to the active detector area is ~20% less than the expected value and indicates a 5.5 mm active diameter instead of 6 mm as indicated by the manufacturer. The value of $d = -3.22$ agrees well with -3.1 (the slope of the plot of $\log \tau$ vs. $\log E$ for silicon). The value of b (which corresponds to the slope of the plot of $\log \mu_{att}$ vs. $\log E$, averaged for the other attenuating detector materials) has a high estimated deviation because it is given essentially by a unique point below 6 keV, namely the 3.0 keV line of ^{241}Am. Above 30 keV the dashed curve in fig. 1 is ~10% higher than the experimental one. Here there may be a combination of uncertainties in the active diameter and sensitive depth values which results in the observed difference. The source preparation method may be considered reliable above 6 keV. Below this energy the method must be checked by using other methods for preparing thin and uniform sources. The experimental values of $\delta(E)$ agree roughly with the estimated curve. The experimental value of δ_0 was (6.1 ± 0.5) mm which is in reasonable agreement with the specified value of 5 mm.

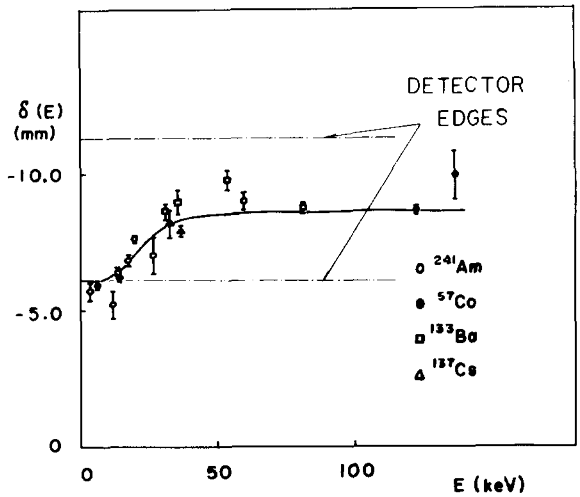

Fig. 2. Photon penetration depth, $\delta(E)$, in the detector as a function of energy. Full line is the theoretical calculation of $\delta(E)$.

References

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