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CALCULATION OF THE PEAK EFFICIENCY OF EXTENDED RANGE HIGH PURITY GERMANIUM DETECTOR FOR DIFFERENT COUNTING GEOMETRIES

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ABSTRACT

The full - energy peak detection efficiecy (Ep) has to be introduced in the relevant equations for neutron activation analysis for determination of the analyte concentration, and also for flux ratio and the deviation parameter determination as well as the true - coincidence correction.

In the present work a technique is outlined for the calculation of the full - energy peak efficiency of cylindrical gamma - detector (ER -HPG) for point, disk and cylinder sources, positioned at any source - detector distance. Moreover attention was paid to true - coincidence effects. An overall uncertainty of 3 to 4% was achieved.

INTRODUCTION

Although at present most users of germanium γ - ray detectors show interest only in such data as resolution and conventional relative efficiency. I suppose that this will change in the future. Indeed, the advent of the hyperpure germanium detectors with their more easily accessible dimensions has prompted many researchers to reconsider their tedious procedures for detection efficiency determination and to explore the possibilities of computational techniques.

Gamma - ray spectrometry is extensively used as a powerful tool for research and control both in fundamental and applied physics. Application fields are, for instance, activation analysis, geology, radiation protection and nuclear medicine. The samples to be studied show various shapes and activity levels. In reactor technology research, for instance, highly active fuel rods have to be checked, whereas in environmental radioactivity monitoring, large liquid samples with low activity have to be measured.

For point geometry at large source - detector distance (e.g. 15 cm or more) it has become a standard procedure to determine experimentally the efficiency curve (i.e. Ep versus gamma ray energy, E_γ). This can readily be performed by measuring calibrated multigamma point sources. Using some additional calibration sources for the low and high energy region, it is possible to construct a calibration curve with an overall uncertainty of about 2 to 3% in the 70 to 3000 - keV energy region, and Of 2 to 5% for lower energies down to 70 keV.

When samples have an extended geometry - as is often the case in practice - and counting close to the detector is required to obtain sufficiently high count rates, mononuclidie multi-gamma-ray point sources can no longer be used. Indeed true coincidence loss would lead to systematic errors whereas it is obvious that only calibaration sources reproducing the sample geometry and composition (gamma - ray attenuation) can yield the relevant efficiency curve; the latter prerequisite is particularly hard to fulfil when solid samples are measured. True coincidence could be avoided by using sources of non-coincident gamma - rays, but in spite of the larger efforts the accuracy of the efficiency curve would decrease due to the limited number of calibaration points.

Based on different principles, models and assumptions, numerous papers can be found in the Literature [1 - 13] dealing more or less successfull with the theoretical or semi-empiric peak - or total - efficiency calculation. Lin Xilel [14] proposed a new semi-empiric computational technique which was shown to yield accurate peak - efficiency curves (3 to 4%) when applied to Ge (Li) detectors. It seems likely that extended range high purity germanium detectors (ER-HP-Ge) will replace Ge(Li) detectors in the future. Therefore the applicability and the accuracy of this technique to the calculation of the peak efficiency of ER-HP-Ge detectors will be experimentally tested in this work.

THEORETICAL

In order to count an event under the full energy peak, a gamma - photon, emitted from the source, should satisfy three conditions:

1) It should hit the active zone of the detector without having undergone any energy degradation in the source itself or in the interacent materials.

2) It should interact with the detector material in another way than by coherent scattering.

3) The interacting photon should transfer its total energy to the detector material thus giving rise to a count under the full energy peak.

Summarizing, the method calculates the full-energy-peak efficiency for a giving gamma - ray energy and for a counting geometry denoted as " x " , from:

$$E_{p,x} = E_{p,ref}\,.\ \bar{\Omega}_x / \bar{\Omega}_{ref}\,.\ (p/t)_x / (p/t)_{ref} \text{----}$$

where $\bar{\Omega}$ is the effective solid angle subtended at the source by the detector. The parameter p/t is the virtual peak - to total ratio. As beared out by experimental test, it can be assumed that p/t is a constant of a detector or crystal and thus is independent of source geometry and composition as well as of source - detector distance; similar conclusions were drawn earlier for Nal (Tl) detectors [15]. Thus Eq.1 can be simplified to:

$$E_{p,x} = E_{p,ref}, \quad \bar{\Omega}_x / \bar{\Omega}_{ref} \qquad \text{----------} \; 2$$

The basic concepts, formula and calculation methods of the effectivs solid angle $\bar{\Omega}$ were extensively discussed elsewhere [14]. It was shown that only simultaneous treatment of geometry, detector response and gamm - attenuation is principally correct. The efficiency curve for the reference geometry (Ep,ref) must be determined experimentally, which however is a simple task and is commonly done in most nuclear laboratories.

EXPERIMENTAL

The ER-HP-Ge detector investigated here was fabricated by the TENNELEC with 22% relative efficiency and i.8 keV resolution for the 1332.5 -keV line of ^{60}Co was used.

Testing the proposed computational technique can be performed by controlling the validity of Eq. 2, rearranged to:

$$E_{p,x} / E_{p,ref} = \bar{\Omega}_x / \bar{\Omega}_{ref}$$

Therefore experimentally determined Ep ratios were compared to calculated ratios. As a reference (index ref) point source geometry at 18.35 cm from the detector crystal (active zone) was used. Different geometries (index x) were studied:

1) Point sources were measured at 4.32 cm and at 1.51 cm from the crystal.

2) Aqueous radionuclide solutions were measured at different counting distances.

MEASUREMENTS

To avoid pulse pile-up, measurements were performed at low count rates. Using a plxiglass support the sources could be positioned reproducibly.

In experiment (1) the point sources were measured at the reference distance and at both studied distances, which directly yields the required efficiency ratios. In principle the point sources used in experiment (2) should be measured in the reference position as well. However to avoid supplementary long counting periods they were measured at the close - in positions calibrated in experiment (1).

RESULT AND DISCUSSION

In Fig. 1 experimentally determined Ep,x / Ep,ref values are compared to calculated $\bar{\Omega}_x / \bar{\Omega}_{ref}$ curves plotted on a semi-logarithmic scale; for convenient interpretation a + 3% range is added to the calculated curves. On the experimental points error bars corresponding to a 67% confidence level are quoted (student - t factor for two degrees of freedom).

In general the agreement between experiment and calculation is fully satisfactory. Occasionally small systematic errors seem to exist, which however are always below 3%. In order to convert both calculated ratios and experimental Ep ratio to actual efficiencies, the peak efficiency for the reference position was determined experimentally using calibrated multi-gamma point sources (Fig. 2a).

Figure 2 shows the final calculated efficiency curves for the geometries studied in this work together with the experimental check points, for comparison the experimental efficiency curve for the reference position is added.

Finally I should say clearly that the applied computational technique can only be used when the detector dimensions are known

CONCLUSION

It was shown that the applied semi - empiric computational technique makes it possible to calculate the full energy peak efficiency for extended range high purity germanium detectors.

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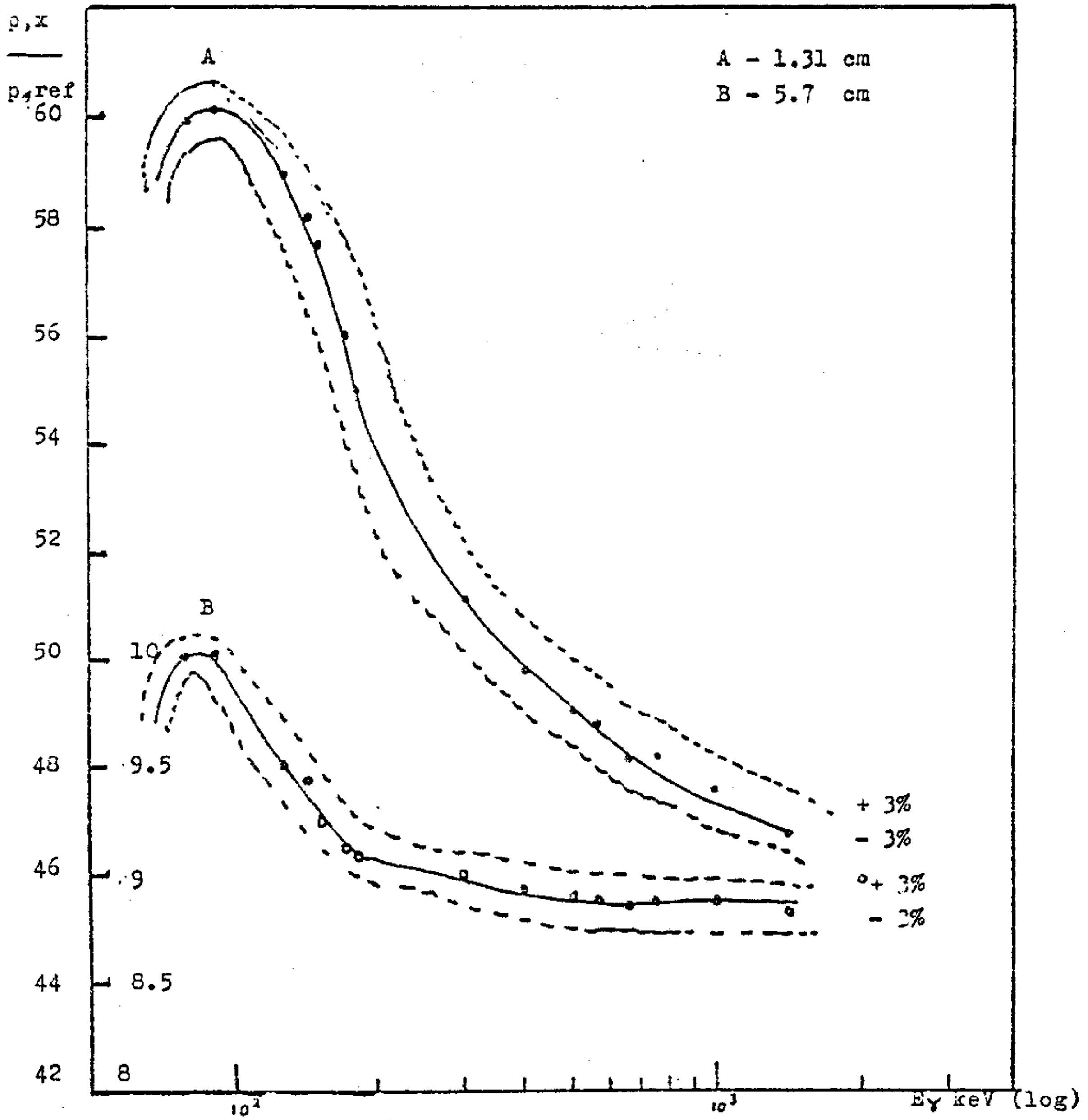

Fig.1 Comparison of calculated and experimental efficiency ratios
x = point geometry at 1.31 cm; o at 5.7 cm; ref = 18.3 cm

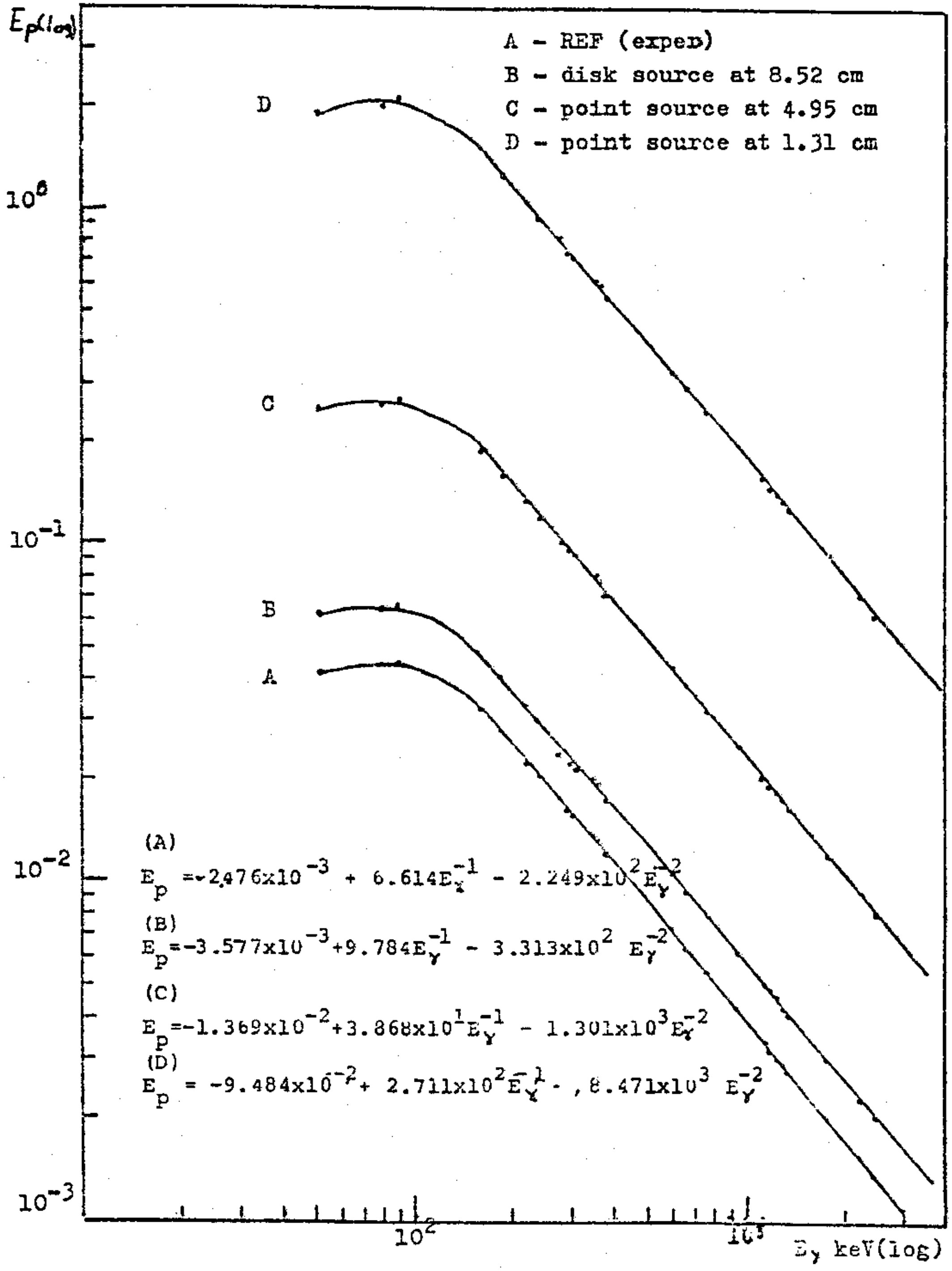

Fig.2 Calculated peak - efficiency curves and experimental check points.

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حساب كفاءة القمه لكاشف الجرمانيوم عالى النقاوة واسع المدى لهندسيات عد مختلفة

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ان كفاءة الكشف عن قمم الطاقة ذات صلة وثيقة بمعادلات التحليل التنشيطى بالنيوترونات لتعيين تركيز العناصر ونسب الفيض النيوترونى ومعامل انحراف الفيض الفوق حرارى عن الحالة المثالية وذلك بالاضافة الى معالجة تأثيرات الموافقة الحقيقية لأشعة جاما المتتابعة فغ هذه الدراسة أسلوب تقنية أوجز لحساب كفاءة الكشف عن قمم الطاقة لكاشف الجرمانيوم عالى النقاوه واسع المدى أسطوانى الشكل لمصادر على شكل نقطة - قرص - أسطوانه وضعت فى مكان معين وعلى أى بعد من الكاشف وعلاوة على ذلك كان هناك اهتمام أكثر بتأثيرات الموافقة الحقيقية حيث أمكن تحقيق دقه عالية فى القياسات