Comparison of the simulated and measured spectra and efficiency functions for different detectors, matrices and geometries in the gamma-energy interval 50-2000 keV

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This work compares the measured and simulated gamma-ray spectra produced in different types of germanium detector with different sample geometries on the energy range 50-2000 keV.

Germanium detectors are used to determine quantitative activity concentrations of natural and artificial radionuclides in environmental samples. While the energy calibration is staight forward, much care has to be dedicated to the efficiency calibration. The calibration is correct if the radioactive standard sources, which are used for calibration, contain the same radionuclides and have the same density, geometry and chemical composition as the sample under study.

In this case the full energy peak efficiencies calculated for the calibration standards are the same as for the sample. Normally, however, these conditions are not fulfilled. Frequently, aqueous solutions with different radionuclides are used for efficiency calibration, and the efficiency curve is usually obtained by fitting a function to the calibration points. If the sample under study has a density or chemical composition different from that of the water solution, the attenuation of the photons within the source will be different and a self-attenuation correction may become necessary.

The extent of these corrections depends on the geometry of the measurement. This is particularly true for environmental samples with small activity concentrations, where large volumes are desirable to reduce measuring time. In this case it has to be checked whether a correction is necessary in order to obtain the measurment event accuracy.

Beside the "experimental" way (i.e. efficiency calibration with sources of known intensity), there is another method to attack this problem. One can use Monte-Carlo calculations to simulate the emission, propagation and detection of the gamma-rays. Sophisticated M.C. codes can treat complicated (extended) geometry and complex materials. Before using them for the analysis of real measurements, the codes have to be checked to see whether they deliver reliable results.

Therefore our first task consists of **validation of Monte Carlo calculations** by comparing their predictions with of real measurements made with sources of known activity embedded in know materials and with well-defined geometry.

The most common design of semiconductor detector used in the spectroscopy of gamma-rays is a coaxial one ("pop-top"). For this type of detector the source must be positioned outside the detector. The overall detector efficiency is reduced by the solid angle, because not every gamma-ray emitted by the source hits the detector. Even in the case when the gamma-ray enters the detector, the probability of detecting the total energy of the gamma-ray is substantially less than 100 %, and is energy dependent.

In our work we have used 2 types of semiconductor detector: Hp Ge Pop-Top and Hp Ge

LO-AX detector with a Be window. For both detectors we performed measurements using standard point sources in the energy range 50-2000 keV at different distances above the detector.

To first approximation the full-energy-peak efficiency η (E) for a specific measuring geomery is defined as:

$$\eta (E)=N(E) / (I(E) A t$$

where:

- N(E) - number of counts in the detected peak for photons of energy E,
- A - activity of the sample,
- I(E) - emission probability for photons of energy E. (fraction)
- t - measuring time

Theoretical investigations have also been made using the GEANT Monte Carlo Code (CERN). We used Monte-Carlo simulation techniques for determining the total efficiency in a well-defined measurement geometry. The z-axis of the coordinate system has been chosen to go through the detector-centre and the radioactive source. The directions of the photons (and for extended sources, the points of emission also) are generated with a random number generator, and the energy deposited by the photons in the detector is determined using GEANT. This permit the calculation of the fraction of photons of a given energy absorbed in the detector. The total efficiency can then be calculated from the number of photons generated.

We included the thickness of the dead-layer of the detector in the simulation, and we also compared the spectrum shapes.

The following cases have been studied:

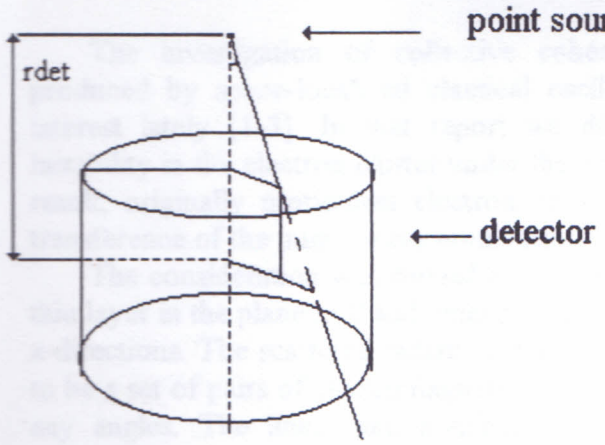
Point source centered above the detector:

The geometry of the detector-source arrangements has been built in the program, including the material surrounding, the detector (detector container, shielding, etc.). We used standard system shapes provided with the main GEANT program.

The geometry is assumed to be axially symmetric with a point source at a distance *rdet* from the detector (Fig. 1.). The detector itself is of cylindrical shape. Its geometrical parameters are stored in the array *xyzdet* (inner radius *xyzdet(1)=0*, outer radius *xyzdet(2)*, length *2*xyzdet(3)*). In the simulation photons are emitted isotropically in the 4π solid angle. This has been accomplished with the following program segment:

```
cth=1.-2*rndm()
sth=sqrt(1.-cth*cth+1.e-8)
phi=2.*acos(-1.)*rndm()
```

The rndm() function of GEANT generates a random number equally distributed in the interval (0,1). The first line transforms it to an equally distributed random number in the (-1,1) interval, which is used later as the cosine of the polar angle in a spherical coordinate system. Using this, the second line calculates the sine of the same polar angle with the well known trigonometrical formule. Finally, the third line uses again the rndm() function to generate the evenly distributed asimuthal angles in the $(0,2\pi)$ interval.
(Note: π =acos(-1.))



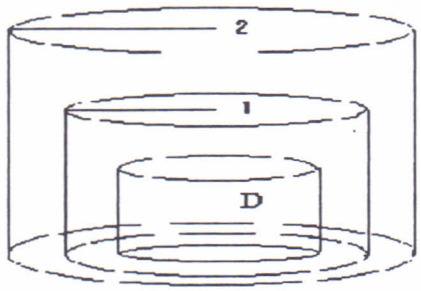
The Monte Carlo results describe the experimentally observed energy spectra very well. In our poster the simulated efficiency will also be shown. We compared the simulated and measured efficiency curves and found that the simulated curves for both detectors were above the measured ones. This problem hs not been solved completely, so far.

After these results we studied extended sources using the Monte Carlo method. The main goal of these invesigations was to determine peak efficiencies for large volume sources taking into account self-attenuation. We made measurements using Marinelli backer and aqueous solution (water, liquid sources), and an environmental sample: soil 6 (IAEA-standard) with known composition.

These measurements were also simulated by GEANT including the exact experimental geometry.

Marinelli beaker on the top of the detector:

In the simulation we built up the Marinelli beaker from two TUBEs, which is a standard system shape (Fig 2. the numbers 1, 2 represent the Marinelli beaker, D is the detector). Here we had to generate not only a random direction, but also the position of the emitted gamma ray distributed evenly in an extended source, (i.e. within the Marinelli beaker). To accomplish this we used the rejection method, by including the following lines in the main program. The dimensions of the Marinelli beaker are stored in the 3-dimensional arrays *xyzhe1* and *xyzhe2*. For both of them the first coordinate gives the inner radius, the second the outer radius and the third the half length of the correspondig TUBE. The Descartes-coordinates of the randomly generated emission point of the gamma ray is stored in the array *vert* . (*he1kz* is the displacement of the center of the Marinelli backer from the center of the Master coordinate system.)




```
10          continue
    vertdx=(1.-2.*rndm())*xyxhe1(2)
    vertdy=(1.-2.*rndm())*xyzhe1(2)
    vert(1)=vertdx
    vert(2)=vertdy
    vert(3)=he1kz+(1.-2.*rndm())*xyzhe1(3)
    vertro=sqrt(vertdx*vertdx+vertdy*vertdy)
    if(vertro.lt.xyzhe1(2).and.vertro.gt.xyzhe1(1)) go to 12
    if(vertro.lt.xyzhe1(1).and.vert(3).gt.he2kz-xyzhe2(3)) go to 12
    go to 10
12  continue
```

The main idea behind the program: first we generate an equally distributed random number in a paralellepiped which contains the cylindrical beaker, and then we reject those events where the point is not inside the beaker (the point is tested if it is between the inner and outer radii of the tubes.)

From the results of the simulation and measurements the correction factor for the efficiency function, for extended sources has been determined.

The advantage of this method (provided that the problem of discrepancy between the measured and the simulated efficiencies can be resolved):

- No time-consuming efficiency calibration measurements are needed (with the same composition and the same geometry as the sample to be studied)
- By running the simulation program the full energy peak detection efficiency can be determined quickly for an environmental material of known chemical composition as a function of gamma-ray energy.
- Knowing the efficiency the absolute activity of the sample can be easily deduced from the measurement.

Therefore time can be saved, and the gamma-ray spectra of extended radioactive sources can be easily and more precisely analysed.