

THE UPDATED BESGE SPECTROMETER FOR PURE BETA ACTIVITIES IN ENVIRONMENTAL MATRICES

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Abstract—This work describes an updated version of a beta spectrometer that measures pure beta emitter activities. The detection system consists of a plastic scintillator surrounded in a 4π geometry by large anticoincidence NaI(Tl) scintillators. A thin silicon detector, inserted between the plastic and the sample, helps to reduce the gamma background. A Monte Carlo code, used to calculate the quite complex spectrometer response function to any isotope, is also described. *Health Phys.* 66(4):454–457; 1994

Key words: environmental impact; radiation, beta; spectrometry, beta; detector, scintillation

INTRODUCTION

THE FIRST version of a pure beta spectrometer constituted by a plastic scintillator surrounded in all directions by large NaI(Tl) anticoincidence detectors has been previously described (Palazzolo et al. 1992).

In the present Beta Spectrometer of the University of Genoa (BESGE) setup, a thin silicon detector between the sample and the plastic has been added. This new detector is operated in coincidence with the plastic scintillator and significantly increases the gamma rejection efficiency. Due to the BESGE complexity, we have developed a Monte Carlo code to simulate the response function to the various decay schemes.

The BESGE arrangement is shown in Fig. 1. The silicon has a 900-mm² active area and a 300 μ sensitive depth.[†] The silicon surface is covered with a 0.185- μ -thick aluminum layer to protect the silicon under various conditions of use. Signals, from the cemented plastic and NaI(Tl) scintillators, are analyzed in order to discriminate between events occurring in the plastic and in the NaI(Tl). Furthermore, the electrons emitted by the sample cross the silicon, leaving in it a small fraction of their energy (≈ 150 keV), and enter the plastic. Pulses from the plastic scintillator are distinguished when they are a) recognized as generated only by the plastic scintillator; b) in coincidence with the

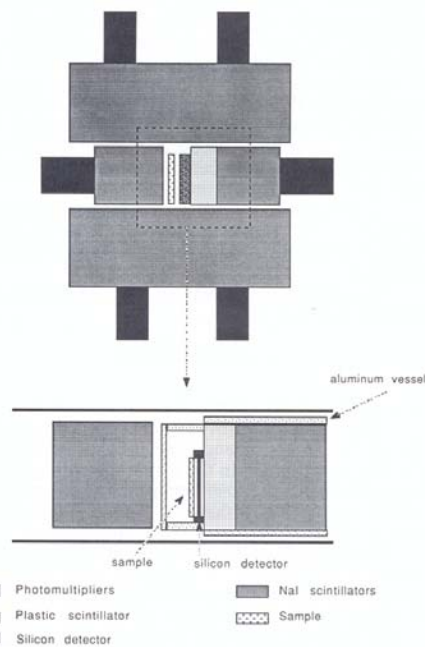


Fig. 1. Spectrometer geometry.

silicon diode; and c) in anticoincidence with all the other NaI(Tl) detectors.

SPECTROMETER PERFORMANCE

The silicon detector produces three effects on the spectrometer performances: a) efficiency reduction for pure beta emitters; b) spectra distortion; and c) background attenuation.

The measured spectrum of a ⁹⁰Sr + ⁹⁰Y source is shown in Fig. 2 with and without the silicon detector. The threshold on the silicon discriminator is set im-

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mediately over its noise level, i.e., at ≈ 30 keV. The detection efficiency (η_B) was 14% in the first and 43% in the second case (with an energy threshold of 60 keV). Moreover, the spectrum shape is quite different in the two cases. A large fraction of the low-energy ^{90}Sr electrons is stopped in the silicon, and in the plastic scintillator spectrum the characteristic double beta shape is lost. The efficiency reduction and the spectral shape distortion are compensated (at least for $^{90}\text{Sr} + ^{90}\text{Y}$ analysis) by the background reduction.

The "residue" of each beta-gamma emitter is defined as the ratio between its counts per second in the plastic spectrum and its activity. In the same way, the "residual spectrum" is the counts distribution in the plastic. Some typical cases are reported in Table 1. The ^{137}Cs residue is quite high because, due to its decay scheme (Oak Ridge National Laboratory 1973), it is "seen" by the spectrometer as a pure beta emitter. The main ^{137}Cs beta decay produces ^{137}Ba in a metastable state (half-life 156 s); the beta and the attendant gamma have not, therefore, any time correlation.

In the previous detector arrangement the background rate (B) is 0.33 ± 0.01 cps. With the silicon detector coincidence this figure decreases to 0.0090 ± 0.0001 cps.

The minimum pure beta activity, σ , detectable with BESGE, can be evaluated as

$$\sigma = \frac{3 \times \text{sqrt}(B/T)}{\eta_B}, \quad (1)$$

where T is the count time.

Also, with the improved gamma rejection obtained by the silicon coincidence, the residual beta-gamma emitters' contribution in the plastic spectrum may still be significant. If the total beta-gamma activity in the sample is much higher than the $^{90}\text{Sr} + ^{90}\text{Y}$, the residual spectra should be evaluated and subtracted.

The residual spectra can be directly measured (Palazzolo et al. 1992) in coincidence with a selected gamma peak on the NaI(Tl) detectors; however, this possibility is time consuming especially if many residual spectra must be measured. Moreover, if the NaI(Tl) spectrum has overlapping peaks, or if more beta decays produce the same gamma ray, this method may be inaccurate. We have, therefore, developed a Monte Carlo code to get a library of residual spectra.

MONTE CARLO SIMULATION

General description

Our code is written in FORTRAN and uses the GEANT 3 package (Brun et al. 1987), developed at the European Center for Nuclear Research (CERN) in Geneva, Switzerland, to describe the detector geometry and composition and to calculate the energy losses in all the materials.

The user can simulate any kind of radioactive decay. The code outputs are the spectra on the plastic, silicon, and the NaI(Tl) detectors. All the logical con-

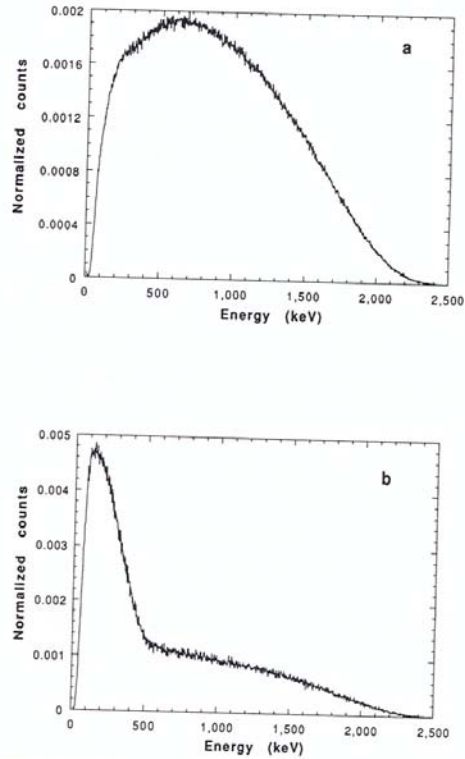


Fig. 2. Energy spectrum of a $^{90}\text{Sr} + ^{90}\text{Y}$ source: a) with, and b) without the silicon between the source and the plastic. The spectra are normalized to the same area.

Table 1. Residues for some typical beta-gamma emitters with and without the silicon.

Isotope	Residual counts with silicon (%)	Residual counts without silicon (%)
^{203}Hg	$(2.4 \pm 0.3)10^{-2}$	$(1.8 \pm 0.1)10^{-1}$
$^{137}\text{Cs}^a$	$(1.4 \pm 0.4)10^{-2}$	$(3.0 \pm 0.2)10^{-1}$
^{137}Cs	$(4.1 \pm 0.2)10^{+0}$	$(3.4 \pm 0.2)10^{-1}$
^{60}Co	$(2.0 \pm 0.1)10^{-2}$	$(5.4 \pm 0.2)10^{-1}$
^{88}Y	$(1.6 \pm 0.1)10^{-3}$	$(2.8 \pm 0.2)10^{-1}$

^a Only gamma component.

ditions used during the true measurements (i.e., the generation of the acquisition trigger) can be reproduced. In particular, the residual spectra of each isotope can be obtained. The calculated spectra are folded with an

energy-dependent Gaussian curve in order to consider the statistical character of the signal's generation. The energy loss of the electrons in the sample is also considered.

Shape of the beta spectra

The energy of the electrons and positrons emitted in beta and beta-gamma decays is randomly extracted, according to the Monte Carlo method, following the shape of the emission spectrum of each isotope. It is well known that the Fermi approximation of the beta spectrum shape is accurate only in a limited number of cases. Following the common terminology, derived from the Gamow-Teller theory (see, for example, Wu 1960 and Konopinski and Uhlenbeck 1941), we have grouped the beta transitions in three classes adopting for each of them a proper shape:

1) Allowed transitions—we have used the standard Fermi relation (Fermi 1934):

$$N(p)dp = Cp^2E(E_{\max} - E)^2F(z, E)dp, \quad (2)$$

where C is a normalization constant and the other symbols are well known.

2) First forbidden unique transitions—eqn (2) has been multiplied by the corrective factor (Langer and Price 1949)

$$(E^2 - 1) + (E_{\max} - E)^2. \quad (3)$$

The $^{90}\text{Sr} \pm ^{90}\text{Y}$ case belongs to this group (Jensen and Jackson Laslett 1949)

3) First forbidden not unique and higher-order forbidden transitions—we used eqn (2) according to the experience of several researchers (see Cross et al. 1983). On the average, this kind of transition has shapes quite similar to the allowed shapes. We used a different approach only for the very interesting twice forbidden transition of ^{137}Cs . In this case, we multiplied eqn (2) by the experimental corrective factor (Hsue et al. 1966):

$$3(E^2 - 1)^2 + (E_{\max} - E)^4 + 10(E^2 - 1)(E_{\max} - E)^2. \quad (4)$$

Folding of the spectra

In order to compare the code results with the measurements, it is necessary to fold the simulated spectra with a Gaussian function. The Gaussian variance, σ_g , is an energy-dependent function and must be determined for the specific apparatus by ad hoc measurements. The results were

$$\sigma_g = 146.7 - 22.4E^{0.5} + 0.9E - 8.8 \times 10^{-5}E^2. \quad (5)$$

Using this relation, the simulated spectra can be compared with the measured ones. We always obtained, as shown in Figs. 3a and b, a satisfactory agreement between Monte Carlo and measurements, both in efficiency and in spectral shape. In Fig. 4, the simulated spectrum of the $^{90}\text{Sr} + ^{90}\text{Y}$ is shown; it must be compared with Fig. 2b.

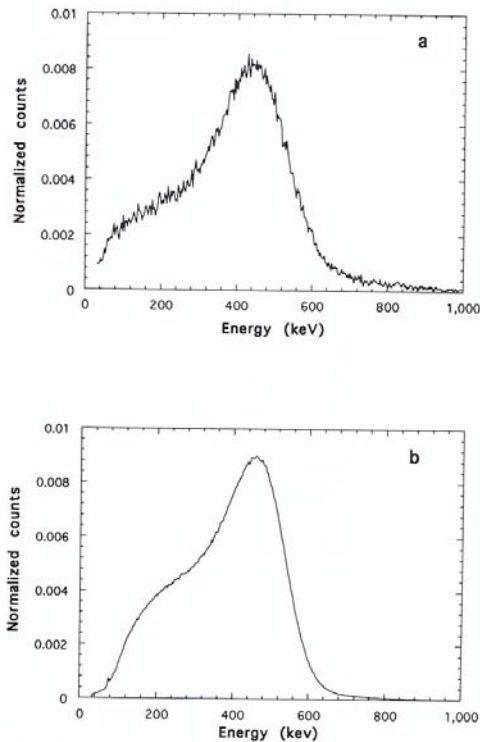


Fig. 3. Simulated (a) and measured (b) residual spectrum of a ^{137}Cs source. The spectra are normalized to the same area.

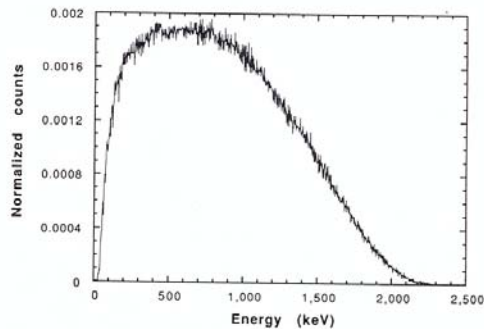


Fig. 4. Simulated energy spectrum on the plastic of a $^{90}\text{Sr} + ^{90}\text{Y}$ source normalized to the same area of the spectra in Fig. 2.

CONCLUSIONS

A previous beta spectrometer based on a plastic scintillator operated in anticoincidence with 4π NaI(Tl) detectors has been improved using a thin silicon detector.

In this new configuration, called BESGE, the sensitivity in ^{90}Sr measurements is not reduced while the gamma rejection is significantly improved. ^{90}Sr activities as low as 10^{-2} Bq can be measured in a few hours.

A Monte Carlo code has been written mainly to calculate the residual spectra of the beta-gamma emitters. The code can be used to build a library of residual spectra. When using such a library, the data reduction time is substantially negligible.

A further development could be achieved by the substitution of the NaI(Tl) scintillator, which closes the hole in the anticoincidence, with a germanium detector. The better energy resolution of the germanium detector should improve the analysis of the gamma components in the sample. The large NaI(Tl) could be used as in the present detector configuration and, at the same time, as anti-Compton active shielding for the germanium detector. In this case, BESGE could be a new, sensitive and compact simultaneous beta and gamma spectrometer. This arrangement could be very useful where many samples must be analyzed in short time frames. Obviously, the expected gamma rejection effi-

ciency will be lower than in the present setup, and its decrease should be evaluated.

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