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Large area alpha sources with a lip: Integral counting and spectral distortions

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HIGHLIGHTS

- Analysis method for proportional counter data for alpha sources with a lip.
- Monte Carlo analysis reproduces low-energy scattering shape and efficiency.
- Electric field calculations explain peak shift to higher energy.

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ABSTRACT

The detection efficiency for large area alpha sources with adjustable heights of a raised lip around the edge were measured by 2π gas-filled proportional counter. The variations in low-energy spectral shape were modeled using a Geant4 radiation and charge transport Monte Carlo simulation, to enable extrapolation of the spectrum to zero energy. COMSOL Multiphysics finite-element analysis was used to explore changes in the spectrum gain in the presence of a lip. It qualitatively reproduced an increase in peak height due to an increasing height of the source lip. A spectrum analysis procedure was developed to perform integral counting on sources with a lip. The experimental results were used to validate the model, which was then used to predict the changes in 2π counting efficiency for other source-lip geometries.

1. Introduction

Calibration of large area sources for surface emission of alpha and beta particles is essential for measuring performance of deployed instruments used in radiological protection, such as those used to monitor contamination resulting from nuclear accidents or release of radioactive materials (ISO, 1988; Unterweger and De Felice, 2015). Predominantly, such calibration sources are flat and either circular or rectangular, with radii or sides of a few centimeters and thicknesses of a few millimeters. The National Institute of Standard and Technology (NIST) large area proportional counters that are used for calibrations were themselves characterized, and are periodically validated, using sources of similar, flat geometry, making these detectors appropriate for calibrating flat sources. However, recently sources that have been sent to NIST for calibration sometimes take the form of a circular disc having a raised lip around the edge of several millimeters in height, simulating a cupped planchet used for smear counters (c.f. EAB-PL from Eckert and Ziegler, Berlin Germany).[1] Measurements of 2π alpha emission rates of these sources produced energy spectra (Fig. 1) that differed significantly from spectra of flat sources, in that an additional count peak appeared in the low-energy portion of the spectrum (Fig. 1, region A), which is usually a local minimum. It was assumed that the additional counts were alphas emitted in the upward 2π hemisphere that then scattered off the lip, so that including the new peak in the integral counting would recover most or all of the 2π count rate. The present work is intended to discern any quantitative effect on the emission-rate measurements for these sources, by designing and measuring an alpha source geometry with a removable lip of adjustable height.

The analysis method normally used at NIST for surface emission rate measurements relies on horizontal extrapolation of the spectrum beginning at the spectral count minimum (Fig. 1, region A), above the low-energy noise. However, that procedure would miss significant portions of the scattered spectrum for sources with a lip. Thus, a new procedure is required.

To develop and study a new procedure, a flat cylindrical Pu-239 source was used, to which rings could be added around the edge to

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[1] Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

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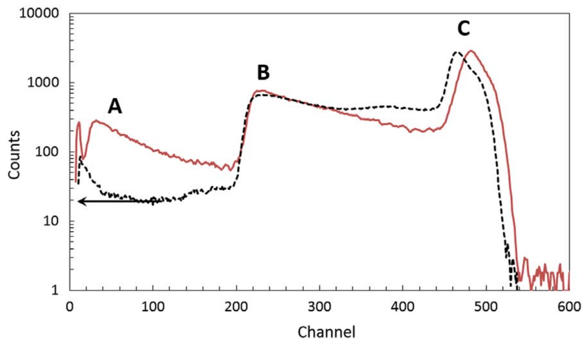

Fig. 1. Spectra for an Am-241 planchet source with a lip (solid red line) compared to a flat Pu-239 source (dotted black line). For the source with a lip, Region A represents alpha particles that hit the lip. Shoulder B represents alpha particles that are emitted vertically and thus hit the top of the detector. Peak C is the full-energy peak, which is shifted in gain due to changes in the electric field caused by the lip. The black arrow indicates the usual horizontal extrapolation of the alpha tail to channel 0 for integral counting. See Section 2.1 and Fig. 2 for details of the detector.

produce lips of various heights. A new extrapolation method that would work for any ring height was devised and tested. Radiation transport modeling was validated by experiment and then used to predict detector response for other geometries.

During the study, it was found that adding lips to the source produced a secondary effect of increasing the spectrum gain (see high-energy peak in Fig. 1). Although this gain increase did not have a significant effect on the integral counting, it could be important for spectroscopic studies. Therefore, the effect of the lip height of the electron multiplication of the detector was simulated using finite element analysis of the electric field in the detector for various source geometries.

2. Equipment and methods

2.1. Experimental

The detector, electronics, and basic analysis method have been described by Hutchinson and Bright (1987) and Hutchinson (2004). In short, the 2π multi-wire proportional counter was run with flowing P-10 gas (standard 90% argon / 10% methane mixture by volume), at a nominal pressure of 0.1 MPa. The detector contains 19 wires (33 μm diameter, 30 cm length, 9.7 mm separation), which are electrically connected to form a single anode with voltage set at $V_0 = 750$ V. The source and all walls of the detector form the cathode at ground potential. The anode signal is processed by a preamplifier and shaping amplifier and fed into a multichannel analyzer to record pulse-height spectra.

The radioactive source used for this work was a commercial wide area Pu-239 reference source, Fig. 2. The nominal 2π alpha emission rate from the top surface of the source was 51 s^{-1}. The source is contained in an anodized aluminum foil of diameter 36 mm, embedded in the top surface of an aluminum disc of diameter 47 mm. The thickness of the anodized aluminum layer is about 5 μm.

To create sources with a lip, a set of aluminum rings were made having 8 different heights, h, between 0.6 mm and 9.5 mm. These rings were mounted one at a time, or else stacked, on the disc source. The inner diameter of the rings was chosen to leave a small gap of width, w, up to 4 mm, between the active area of the source and the ring. Fig. 2 shows a schematic of the detector containing the source with a ring.

Data were acquired for the same source with and without the rings. Typically, 5 repeat measurements of 1000 s each were recorded. Additional longer runs lasting 20,000 s were taken for the source without rings. Background spectra were also recorded. Spectra were corrected for background before performing further analysis. First the typical integral-spectrum-counting analysis method was performed (Hutchinson, 2004), which involves placing a low-energy cut on the spectrum above the detector noise floor and then extrapolating the low-energy tailing of the alpha peak to channel zero using a linear function of slope 0 (horizontal) or else one that slopes down to the origin. In this work, a horizontal extrapolation was used, with the count level set by averaging over about 20 channels in the region of local count minimum below the alpha shoulder (See Fig. 1). Then an alternative method was developed to extrapolate the low-energy tail using an exponential function. Each spectrum was analyzed separately and the results for a given geometry were then averaged.

The alternative method of extrapolation was devised specifically for the spectra that these lipped sources generate. Here it was assumed that all the counts in region A (Fig. 1) were from alpha particles emitted in the forward 2π hemisphere that hit the lip, still depositing some energy in the P-10 gas. The hypothesis was that an exponential extrapolation of the tail of this scattering peak from around channel 20 downward to channel 0 would recover the true 2π emission rate, as measured by the usual procedure with no lip. An exponential function was fit to the tail of the low-energy peak. This equation was used to predict how many counts would be in the channels from the line back to channel zero, eliminating low-energy noise. The area in question was small relative to the total spectrum, e.g. about 0.5% for $h = 0$.

2.2. Modeling

To better understand the spectral distortions caused by sources with a lip, and to be able to predict the effect on integral counting results, computer models were constructed.

Preliminary calculations indicated that the increase in counts in the low-energy spectrum were due to alpha particles hitting the lip, which was then simulated with a Geant4 radiation transport model (Agostinelli et al., 2003). The model was made using Geant4.9.5, with the standard electromagnetic physics package. Particle production cuts were set to 10 μm and the step limit was 10 μm in the detector gas and 0.2 μm in the source. The geometry was set based on measurements of the detector and technical drawings of the source and rings. The general shape of the Pu-239 depth distribution in the source was taken from Berger et al. (1996), with the parameters tuned to the specifications of this source and to match the tailing of the spectra. The simulation was run for $1 \cdot 10^6$ decays of Pu-239 for each experimental geometry, as well as for other geometries not measured experimentally. The Monte Carlo random number generator was constructed to produce the same set of

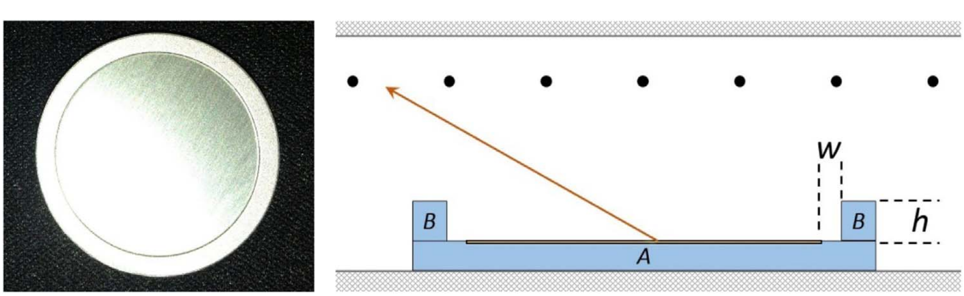

Fig. 2. (Left) Photograph of Pu-239 source. (Right) Zoomed-in side-view of the 2π proportional counter, shown to scale except for the wire diameter, which is actually 33 μm. A lip is created by placing a ring, B, of height, h, (4 mm as shown) on top of the Pu-239 disc source, A. There is a radial gap of width, w, between the active area of the source (yellow inset in A) and the inner surface of the lip. All surfaces except the wires are at ground potential. The wires are at potential V_0. The entire detector contains 19 wires, but only the central 7 are shown. An example Pu-239 alpha track is illustrated by the orange arrow.