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Calculation of electron deposition in proportional counters

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Abstract

Efficiency extrapolation is a common technique in the standardization of radionuclides by the technique of $4\pi\beta$–γ coincidences. It can be achieved in two ways: adding thin films onto the radioactive source or by electronic discrimination in a pressurized $4\pi\beta$–γ system. The last case is the most extensively used actually in metrology laboratories. There is a need to know the electron energy loss inside the proportional counter as a function of the electron energies and working pressures.

Calculations of electron energy loss have been performed for electron energies in a range from a few keV to 2 MeV in a mixture of Ar(90%) CH_4(10%) and for pressures ranging from 100 to 2000 kPa in a 5 cm radius proportional counter. Wall effects, such as electron backscattering, are included in the calculations. Results are provided in the form of graphs and some recommendations are given about the optimal values of the energies that can be used to perform the extrapolation in the standardization of some radionuclides.

Keywords: Proportional counters; Energy deposition

1. Introduction

About 4π proportional counters are commonly used for the standardization of radionuclides by the $4\pi\beta$–γ coincidence technique. Some properties, like low noise and low γ efficiency, make them very attractive electron detectors. Different designs have been in use for long times, especially gas flow detectors at atmospheric pressure and high pressure proportional counters, ranging up to 7500 kPa. They are typically operated with CH_4 or Ar–CH_4 (9/1). At low gas pressure, energetic electrons deposit only a small fraction of their energy in the sensitive volume and so this system operates just as a counter of events. At higher pressure, the deposited beta electron spectrum better reproduces the emitted spectrum in the low energy range.

The $4\pi\beta$–γ equations for complex decay involve many parameters. The true disintegration rate is obtained from an extrapolation to 100% beta efficiency (Baerg, 1973). Possible methods to change the beta efficiency are the variations of:

(1) self-absorption,
(2) foil absorption,
(3) threshold level.

In general, measurements with atmospheric counters use method (2) for efficiency variation while method (3) is more typical for pressurized counters. Both methods are not theoretically equivalent, but experimentally there are no significant differences. Method (3) is only available in the low energy region of the measured spectrum when the full energy of electrons is deposited in the counting gas. Pressures in the order of several MPa are necessary to guarantee this condition. In general, pressures in the order of 1000 kPa are high enough to extrapolate correctly by threshold variation for most of the beta emitters, but calculations are necessary to establish the threshold limits.

While existing tabulations of linear energy transfer for electrons in a particular medium could assist in finding with low accuracy the discrimination range, a Monte Carlo routine allows simulating the deposited energy spectrum,

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thus improving our knowledge on the available discrimination range. The results of such simulations are presented in this paper. Graphs of the energy deposited by electrons from beta spectra are included.

2. Experimental

2.1. Detector

The proportional counter is of the pill box type, made of aluminium and with a sensitive volume of 5 cm in diameter and 5 cm height. The anodes are made of gold-covered stainless steel wires, with a diameter of 30 μm. The counter wall thickness has been designed to withstand pressures up to 2000 kPa.

The working voltage in the proportionality region varies with the gas pressure. The velocity of the secondary charged particles depends on the ratio E/p, where E is the electric field and p is the pressure. For good transit times, the voltage should be as high as practicable. The simulations do not take into account the electric field inside the sensitive volume. They only cover the deposition of energy in the sensitive volume of the detector.

Proportional counters can work at pressures up to 2000 kPa and are operated under flow conditions, usually with 9/1 Ar–CH_4 gas. The simulation has been performed reproducing that mixture of gases. Some studies of gases like CH_4 and Xe have been included.

The selection of the operating pressure is basically a function of the energy of the emitted electrons. The energetic range to perform the discrimination will be longer as the pressure increases. Simulations have been performed for various energy ranges and pressures. The energies of the monoenergetic electrons analyzed covered the region from 10 keV to 3 MeV, including practically all possible radioactive electron emissions through beta decay.

2.2. Simulation

The PENELOPE code (Baró et al., 1995) has been used to run the simulations. This code is useful to simulate electrons, positrons and photons transport. The simulation of the transport of electrons and positrons is much more difficult than that of neutral particles because the average energy loss per interaction is very small and, as a consequence, especially in high energy particles, there is a large number of interactions before the particle is absorbed. In general, most of the Monte Carlo codes have recourse to multiple scattering theories which allow the simulation of the global effect. Strictly speaking, detailed simulation will only be possible with energies up to 100 keV. For larger initial energies, detailed simulation will be very inefficient. Penelope uses a scattering model that combines numerical cross sections with analytical differential cross sections for different interaction modes (Fernández-Varea et al., 1993). It is applicable for electron energies ranging from 1 keV to 1 GeV.

Different pressures have been simulated modifying the density of the gas inside the chamber. But some relativistic effects induce changes in the interaction cross sections as a function of the density. They are taken into account in the simulation program.

The proportional counter has been modelled as a body confined by four objects: two cylindrical bases of 5 cm diameter and two cylinders of 5 and 7 cm defining the internal and external diameter of the aluminium walls, respectively, whereas the cylindrical volume inside defines the sensitive volume. The source of electrons is supposed to be punctual, located in the central point along the symmetry axis. Source crystals and absorbing foils have not been taken into account. The results of the simulation show the spectrum of deposited energy inside the sensitive volume and the deposited energy into the walls and includes many other parameters, as the number of absorbed and transmitted particles, kind of interactions, etc.

The Ar–CH_4 (9/1) counting gas has been simulated as a proportional mixture of three kinds of atoms. A few simulations with CH_4 and Xenon have also been made. Electron multiplication, charge collection and the effect of the electronic chain have not been simulated. Therefore, full energy peaks are described by a line spreading over a few channels.

Interactions, at all pressures, are predominantly elastic and inelastic. Bremsstrahlung emissions are only important for very high energies, in general more than 10 MeV for this kind of media. The number of primary particles simulated for each energy and pressure is in the order of 2×10^5.

3. Results

The first group of simulations were performed at a pressure of 100 kPa. In the region from 10 to 50 keV the

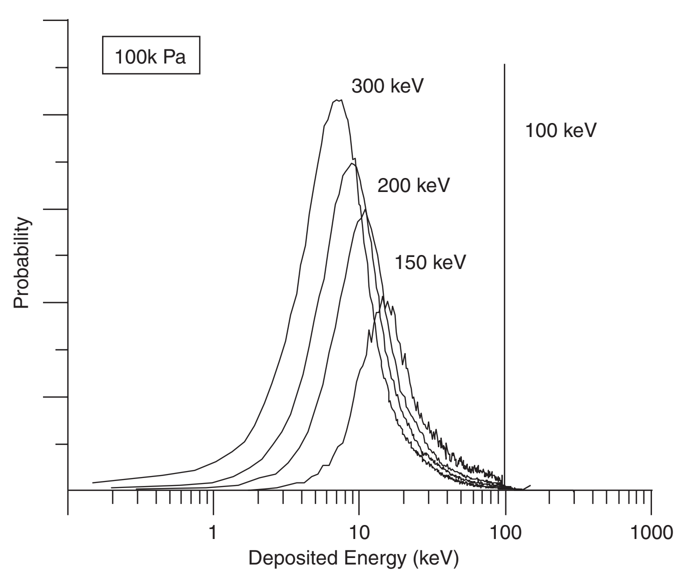

Fig. 1. Deposited energy spectrum of electrons in an atmospheric 5 cm diameter Ar–CH_4 proportional counter.