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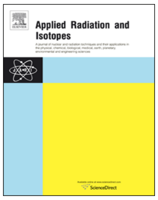

Preliminary beta spectrum measurements using a magnetic spectrometer

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HIGHLIGHTS

- We study the performance of a double focusing beta spectrometer.
- Energy calibration from internal conversion electron lines of Cs-137 and Ba-133.
- Efficiency correction was estimated using P-32 beta spectrum.
- Real data and theoretical expectation have been compared.

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ABSTRACT

We report the performances of a double focusing magnetic beta spectrometer. The energy resolution was measured using conversion peaks of Cs-137 and Ba-133 at 0.73% for 624 keV, and 1.33% for 124 keV. The counting efficiency as a function of the energy was estimated using a P-32 source and was used to correct the measured spectra of Cs-137. The result was compared with the theoretical spectrum and we found a good agreement.

1. Introduction

In the frame of our ongoing effort to simulate radionuclide calibrators (Laedermann, et al. 2004; Rault et al., 2010), we discovered that the beta spectrum shape at high energy is important when evaluating the dose calibrator response, because such electrons can directly deposit their energy in the gas chamber. Also, current theoretical beta spectrum calculations and experimental results are not available or not precise enough especially at low energy and for high forbidden orders. A precise knowledge of the spectrum would be very useful to compare with theoretical calculations and would help to improve the Monte Carlo simulation of dose calibrator response to beta emitters.

In this paper we report the study of a double focusing magnetic spectrometer used to measure the shape of beta spectra. Different isotopes, Cs-137, P-32 and Ba-133 were used to estimate the performances of the spectrometer. Our study demonstrates that we should be able to measure beta spectrum with kinetic energy up to 5 MeV.

2. Material

2.1. The magnetic spectrometer

A schematic diagram of the spectrometer is shown in Fig. 1. It was built by a company, Bruker GmbH (Karksruhe, Germany), and consists of a semicircular vacuum chamber which contains pole pieces and a pair of coils. The pole pieces are shaped to produce a magnetic field, which can focalize the electrons in both horizontal (X,Y) and vertical (X,Z) planes. The electrons are bent on a circular trajectory by the effect of the magnetic field. The curvature of the electron trajectory at the reference radius is $r_0 = 180$ mm. The detector and the source are positioned in such a way that the deflection angle is 180°. According to previous studies (Sakai et al., 1960; Siegbahn, 1965), the theoretical magnetic field needed to have this double focusing has the following components (in cylindrical coordinates):

$$B_Z = B_0\left[1 - \frac{1}{2}\left(\frac{r-r_0}{r_0}\right) + \frac{1}{4}\left(\frac{r-r_0}{r_0}\right)^2\right]$$

$$B_r = ZB_0\left[\frac{1}{2r_0} + \frac{r-r_0}{2r_0^2}\right]$$

$$B_\phi = 0 \text{ by symmetry}$$

where $r = \sqrt{x^2+y^2}$ and B_0 the nominal field for $r = r_0$ and $Z = 0$.

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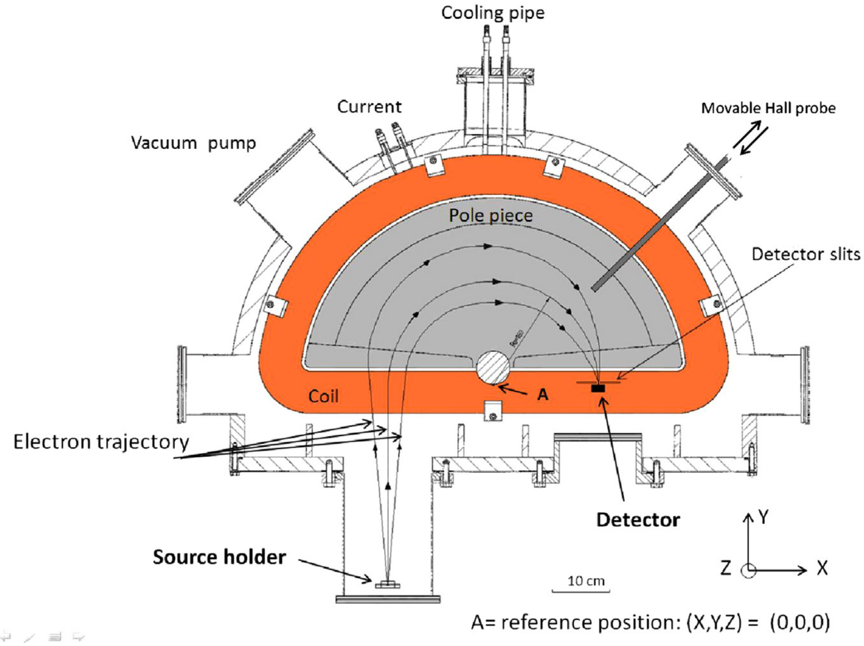

Fig. 1. Schematic top view diagram of the spectrometer.

As there is a small leakage of magnetic flux outside the chamber the detector and the source can be placed close to the spectrometer without magnetic interference. The magnetic field can be increased up to 0.1 T which allows measuring the electron kinetic energy up to 5 MeV.

The relationship between B and I determines the magnetic field value for an electron traveling at the nominal radius (reference trajectory). Then, using the trajectory equation of an electron in a magnetic field:

$$p[\mathrm{MeV}/c] = 0.3\,B[mT]r_0[m]$$

and using the relationship between the momentum p and the kinetic energy T, we obtain:

$$T[\mathrm{MeV}] = \sqrt{(0.3Br_0)^2 + m^2} - m$$

$$B[mT] = aI[A] + b$$

where m is the electron mass and a and b are parameters.

Finally, merging these two equations we obtain a direct relationship between T and I which depends on three parameters P_1, P_2 and P_3, which will be extracted from a fit.

$$T = \sqrt{P_1 I^2 + P_2 I + P_3} - m$$

Two vertical slits are positioned in front of the detector. Their aperture can be controlled, changing the measurement resolution and simultaneously decrease the signal intensity. The vacuum inside the chamber is obtained with an oil diffusion pump (allowing $P < 10^{-5}$ mbar) while the cooling of the copper coils is provided by a continuous flow of water. The current is provided by a B-EC 1 power supply controller provided by Bruker GmbH. The current can be adjusted by 0.1 mA steps either manually or remotely.

The detector is a Silicon Surface Barrier detector connected to a preamplifier model 2003BT from Canberra. The signal is sent to an Ortec 590A Amplifier and a Timing Single Channel Analyzer (TSCA) and the output logic signal is sent into a counter.

A LabView program automates the acquisition allowing the scan over the full energy range (0–5 MeV) with chosen steps.

2.2. *Source preparation*

The radioactive solutions used to prepare the sources are in hydrochloric or aqueous form with a carrier of CsCl for Cs-137, Na_2HPO_4–HCHO for P-32 and $BaCl_2$, for Ba-133. The sources were prepared by dispensing a 4 μl drop on a thin VYNS film held by a metal ring with inner and outer diameters of 1 cm and 1.8 cm respectively. The drop is deposited precisely at the center of the film using a dedicated centering piece. The diameter of the dried drop is less than 3 mm. Each source is weighted with a Mettler AE 240 balance before and after the drop deposition to know the mass of the dispensed liquid and hence its approximate activity. Then, the source is put in an air tight container with silicagel for drying. To hold the source and place it in the spectrometer, a special Plexiglas support was designed. It consists of a main holder which houses the VYNS ring and a cover with a hole of 5 mm diameter. The cover is screwed on the main holder to maintain the VYNS ring and serves as a collimator focusing the electrons through the hole around the nominal radius of the spectrometer.

Three 900 kBq Cs-137 sources, two 1.8 MBq Ba-133 sources, as well as one 780 kBq P-32 source were prepared to make the energy calibration and to estimate the counting efficiency. Cs-137 has K, L, M conversion lines at 624, 656 and 660 keV respectively, Ba-133 has K conversion lines at 124, 240, 266, 320 and 347 keV while P-32 is a pure beta emitter with a maximum energy at 1710 keV. The thickness of the sources has been estimated being to the order of a few μg/cm^2 allowing a low loss of energy.

3. Method

3.1. *Measurement protocol*

In all the measurements presented in the following the opening of the detector slits was set at 2 mm.

The acquisition is performed point by point by setting a current in the coils which determines the magnetic field intensity and then the kinetic energy of the electrons (Section 2). The minimal step is 1 mA which corresponds to about 0.25 keV with an accuracy of 0.3 mA (~0.08 keV). For each point the measured rate