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Evidence for revision of the evaluated half-life of ^{207}Bi

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HIGHLIGHTS

- Differences in ^{207}Bi half-life values.
- High purity germanium (HPGe) detectors for gamma-ray spectrometry measurements.
- Comparison of HPGe efficiency measurements using ^{207}Bi half-life published values.

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ABSTRACT

The National Institute of Standards and Technology (NIST) compared the measured full-energy peak efficiency obtained from a large set of sources to that of a ^{207}Bi source obtained using three different half-life values. The values of the half-life used for this comparison are published in the Decay Data Evaluation Project (32.9 ± 1.4) years and the Evaluated Nuclear Structure Data File (31.55 ± 0.04) years, and in a recent NIST publication (31.20 ± 0.05) years (or (11395 ± 18) days).

1. Introduction

In 1973 the National Institute of Standards and Technology (NIST) developed a standard reference material (SRM) for ^{207}Bi. SRM point sources were prepared as part of that work. One of these sources was used over the years to calibrate the NIST high purity germanium (HPGe) detectors' efficiency as a function of photon energy. This source was consistently used since the year 2000 to calibrate different HPGe detectors at different source-to-detector distances. The ^{207}Bi source is part of a set of sources that NIST uses for calibration of all the HPGe detectors that are part of the NIST gamma-ray spectrometry system.

In order to use an HPGe detector for activity and impurity measurements of unknown samples, it is first necessary to calibrate these instruments using known reference sources. These detectors are normally calibrated by determining the full-energy peak efficiency and total efficiency as a function of photon energy. The determination of the full-energy peak efficiency for an HPGe detector relies on available nuclear decay data. In particular, the radionuclide half-life and the gamma-ray emission intensity (or emission probability) for each gamma-ray energy. NIST uses nuclear decay data obtained from two databases, these are the Decay Data Evaluation Project (DDEP) (DDEP, 2017) and the Evaluated Nuclear Data Structure File (ENSDF) (ENSDF, 2017). The uncertainty and accuracy of the measured detector efficiency strongly depends on the nuclear decay data used.

During the calibration of several of the NIST HPGe detectors it was observed that the NIST ^{207}Bi SRM source measurements were not agreeing with the values obtained from other radionuclides for similar gamma-ray energies. As a result of further investigations it was determined that the published half-life value for ^{207}Bi was causing these discrepancies. This paper will discuss the differences observed for the measurements when using different half-life values and suggest a possible solution to the observed discrepancies.

A new half-life value cannot be reported as part of this work because it is not possible to estimate systematic effects as measurements were performed with numerous detectors and source geometries over many years. Only an estimated average half-life value can be provided.

2. Experimental setup

The gamma-ray spectrometry system at NIST is composed of five different HPGe detectors, the relative efficiency of these detectors range from 10% to 60%. These detectors are calibrated using various gamma-ray emitting sources with energies ranging from 45 keV to 2.6 MeV. Depending on the energy range and type of detector the calibration is sometimes extended from 14 keV to 3.6 MeV. The full-energy peak efficiency as a function of energy for each of these detectors is measured at a reproducible distance and geometry for a large set of sources that changes with time as the short-lived radionuclides decay away. The

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measurement distances ranged from 25 cm to 100 cm; due to the detector efficiencies at these measurement distances, the true coincidence summing corrections are negligible (the corrections are less than 0.05%). This set of sources includes a NIST ^{207}Bi SRM point source. Since 2000 the calibration of these instruments was performed in a consistent manner. A total of twelve different efficiency calibration measurements for the different detectors were performed from 2000 to 2010. For the original measurements and before the DDEP (Bé et al., 2010) data were available, the ENSDF nuclear data values (Schmorak, 1984; Kondev and Lalkovski, 2011) were used for measurement of the full-energy peak efficiency. When the DDEP (Bé et al., 2010) data became available, the efficiency curves were revised and the new measurements were performed using these DDEP half-life values.

In 2015, a new detector geometry was calibrated using this same ^{207}Bi SRM point source and a discrepancy was noted when measuring the full-energy peak efficiency as a function of photon energy. In addition to the ^{207}Bi source, several other SRMs that included different radionuclides with photon energies ranging from 45 keV to 2.6 MeV were used to perform this calibration. For this particular measurement, the half-life that was initially used to decay correct the activity of the ^{207}Bi source was obtained from DDEP (Bé et al., 2010), which provides a value for the half-life of (32.9 ± 1.4) years. In the process of trying to understand the discrepancies observed in the efficiency values obtained using ^{207}Bi and other radionuclides, with photon energies close to the ^{207}Bi values, a separate independent value of the half-life of (31.55 ± 0.04) years published in the ENSDF data evaluation (Kondev and Lalkovski, 2011) was used to perform the decay correction. During this time, NIST re-evaluated many of the half-life measurements for long-lived radionuclides and reported a new half-life for ^{207}Bi of (11395 ± 18) days (Unterweger and Fitzgerald, 2014) (i.e., (31.20 ± 0.05) years) measured using an ionization chamber. This new NIST value was also used to evaluate the efficiency values.

3. Results and discussions

The observed differences in the values of the half-life led to the revision of all the efficiency curves measured from 2000 to 2016. In the process of doing so it was noted that the ^{207}Bi measured efficiency values agreed better with the efficiency values obtained using other radionuclides when the NIST half-life value of (11395 ± 18) days was used.

The high energy region of the efficiency curves for the different HPGe detectors was fitted using a quadratic function (excluding the ^{207}Bi values) and the measured ^{207}Bi efficiency values, using the different half-life values, were compared to the fitted values. Fig. 1 shows an example of the full-energy peak efficiency measurements and fitting curve for one HPGe detector geometry. Fig. 2 shows the associated residuals from the quadratic fit for this HPGe detector geometry range from 0.06% to 1.3%. For this particular detector, the measurements were performed in 2010. The uncertainties of the measured full-energy peak efficiencies for the different detectors range from 0.4% to 0.9%. An average half-life value of (11373 ± 120) days (coverage factor of k = 1), i.e., (31.14 ± 0.33) years, was obtained from the fitted efficiency values for the ^{207}Bi 569.698 keV line for the twelve different efficiency calibration measurements for the five different detectors.

The percent differences, between the measured ^{207}Bi efficiency for the 569.698 keV line and the fit to the measured efficiency curve, when using the DDEP half-life value ranged from 2.5% to 5.5% (depending on the year when the measurements were performed) while the percent difference using the ENSDF value range from 0.5% to 2%. The percent differences when using the new NIST half-life value ranged from 0.2% to 1%. Fig. 3 shows the percent difference between the fit and the measured ^{207}Bi efficiency for the different half-life values. The

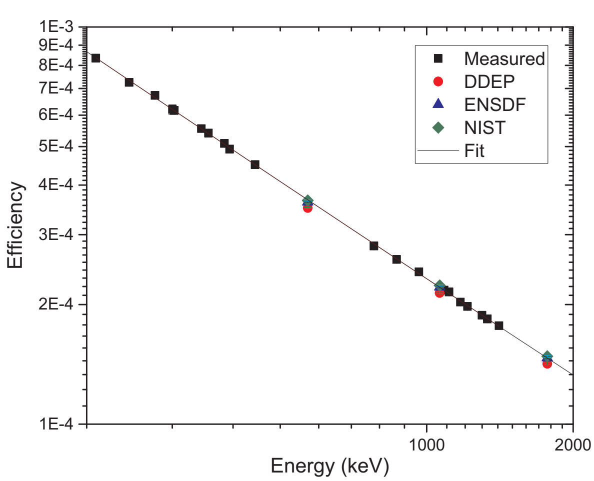

Fig. 1. Efficiency measurements for one HPGe detector with sources placed at a distance of 40 cm from the front face of the detector. The squares represent the measured values for the NIST source set, the circles, triangles and diamonds represent the measured ^{207}Bi values using the DDEP, ENSDF and NIST half-life value respectively. The solid line represent the quadratic fit to the measured values. Uncertainties are smaller than the size of the symbols.

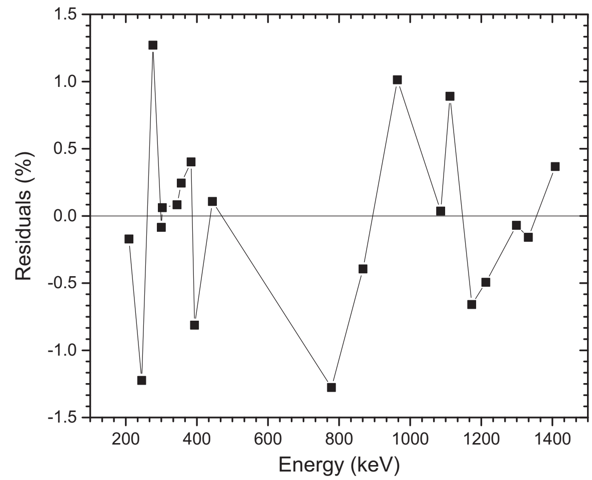

Fig. 2. Residual from the fit to the data (excluding the ^{207}Bi values) using a quadratic function.

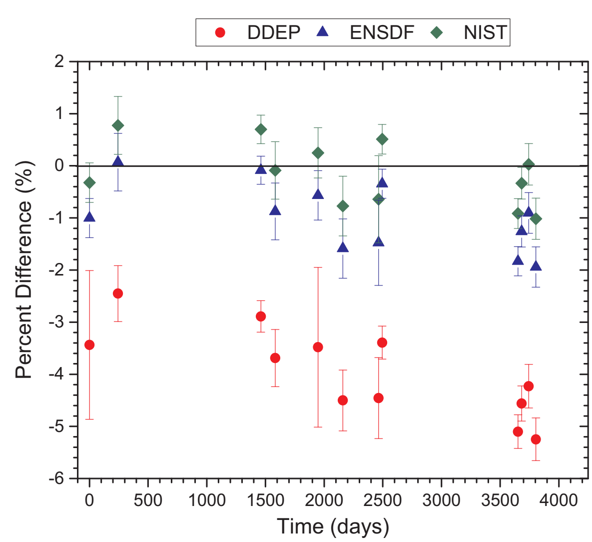

Fig. 3. Percent difference between the measured and fitted efficiency values for the 569.698 keV line for the different half-life values. The circles, triangles and diamonds represent the percent difference between measured ^{207}Bi values and the fit using the DDEP, ENSDF and NIST half-life value respectively. Uncertainties are given with a coverage factor of k = 1.