Precise Efficiency Calibration of an HPGe Detector from 50 keV to 1836 keV

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An essential requirement of our program to measure precise *ft*-values for the superallowed $0^+ \rightarrow 0^+$ beta transitions from light $T_z = -1$ nuclei [1] is the ability to determine their branching ratios with a precision approaching ±0.1%. The only approach potentially capable of reaching this level of precision is to measure their β-delayed γ-rays in a detector whose detection efficiency is known to the same precision. However, calibration of a detector's efficiency to this level is extremely challenging since very few sources provide γ-rays whose intensities (relative or absolute) are known to better than ±0.5% [2].

Our approach is to combine a wide variety of source measurements with Monte Carlo calculations performed for the exact known dimensions and composition of our 70% HPGe detector. Only sources emitting two or more γ-rays with well established relative intensities are being used. In the best cases, these relative intensities are known to ±0.2%. When a number of these independent calibration sources are used in combination with concurrent Monte Carlo calculations, we anticipate that we will obtain better than ±0.2% precision on relative efficiencies at all energies within the range spanned by the sources.

We will convert these relative efficiencies to absolute values using the superallowed emitters themselves. Since the β-transition from ^{22}Mg to the ground state of ^{22}Na is second forbidden unique, that transition is suppressed by some ten orders of magnitude relative to the allowed and superallowed branches to excited states in ^{22}Na. Thus, effectively all β-transitions from ^{22}Mg give rise to γ-rays, which means that branching ratios from that nucleus can be determined entirely from relative intensity measurements – since the total of all observed transitions must equal 100%. However, we also measure directly the exact number of ^{22}Mg nuclei in our sample [1]. By combining the observed γ-ray peak intensities, the deduced branching ratios and the measured sample size, we can establish our absolute detection efficiency under standard experimental conditions – conditions identical to those that will also be used to study other decays like that of ^{30}S, which does exhibit a ground-state β-branch without subsequent γ-ray emission.

Since the study of ^{22}Mg decay requires γ-ray efficiencies down to 73 keV, our key long-lived calibration source is ^{133}Ba, which provides γ-rays spanning energies from 53 to 384 keV. Although the relative intensities of the γ-rays from ^{133}Ba have been well established [1], other details of its decay scheme are more ambiguous. These details are important to us since our in-beam experiments require a measurement in relatively close geometry (source-detector distance, 15.0 cm), where the summing of coincident γ-rays is not negligible. We undertook a complete evaluation of the ^{133}Ba decay scheme, including the effects of electron conversion and electron capture on γ-γ and γ-X-ray summing. A program was written to incorporate these effects in a statistically consistent manner, thus allowing us to analyze a measured ^{133}Ba γ-ray spectrum and derive relative detector efficiencies with appropriate uncertainties.

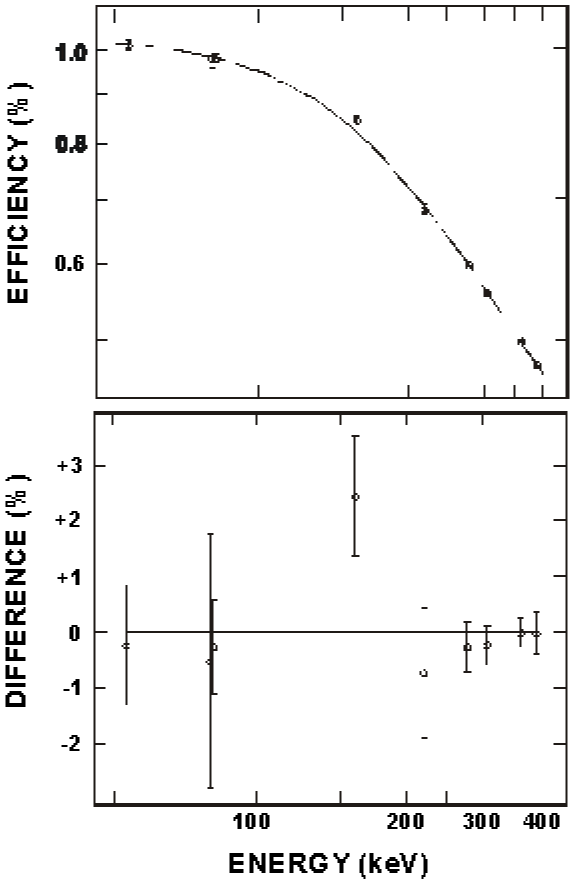

Figure 1: (top) Detector efficiency measured with ^{133}Ba source, compared with Monte Carlo calculations; (bottom) percentage difference between measured and calculated efficiencies.

Monte Carlo calculations were performed with the electron and photon transport code CYLTRAN from the Integrated Tiger Series, ITS, set of codes [3]. This code has already been demonstrated to be highly effective for HPGe detectors at energies above 400 keV [4]. In running this code, we have been able to incorporate detailed specifications for our HPGe detector provided through the kind co-operation of PerkinElmer Instruments (Ortec Product Line). A comparison between the results from this code and the efficiencies we measured with a ^{133}Ba source appear in Fig. 1. For all γ-rays, except those at 161 and 223 keV, our precision is limited by uncertainties in the ^{133}Ba decay scheme, not by counting statistics or other experimental uncertainties. In the figure, the calculations have been normalized to the 356 keV peak; the normalization factor was 0.964. It should be noted, however, that the activity of our ^{133}Ba source, as provided by Nycomed Amersham, is only quoted to ±3% uncertainty. In essence, then, the Monte Carlo calculations not only show excellent agreement for the relative efficiencies between 53 and 384 keV but are within experimental uncertainties on the absolute efficiencies as well. Similar agreement also exists in the more tractable higher-energy region above 400 keV.

The results in the figure indicate that our relative efficiencies are now known to about ±0.3% for energies above, say, 250 keV but are less well defined at 73 keV, where one of the γ-ray peaks from ^{22}Mg occurs. To secure this region, we have performed a measurement on a cascade of γ-rays (332, 215 and 93 keV) from the decay of 5.5 hr ^{180m}Hf [5].

This work is continuing.

References

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