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Characterisation of a SAGe well detector using GEANT4 and LabSOCS

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ABSTRACT

This paper reports on the performance of a recently developed Small Anode Germanium (SAGe) well detector from Canberra Industries. This has been specifically designed to improve the energy resolution of the detector, such that it is comparable to the performance of broad-energy designs while achieving far higher efficiencies. Accurate efficiency characterisations and cascade summing correction factors are crucial for quantifying the radionuclides present in environmental samples, and these were calculated for the complex geometry posed by the well detector using two different methodologies. The first relied on Monte-Carlo simulations based upon the GEANT4 toolkit, and the second utilised Canberra Industries GENIE™ 2000 Gamma Analysis software in conjunction with a LabSOCS™ characterisation. Both were found to be in excellent agreement for all nuclides except for ^{152}Eu, which presents a known issue in the Canberra software (all nuclides affected by this issue were well documented, and fixes are being developed). The correction factors were used to analyse two fully characterised reference samples, yielding results in good agreement with the accepted activity concentrations. Given the sensitivity of well type geometries to cascade summing, this represents a considerable achievement, and paves the way for the use of the SAGe well detector in analysis of 'real-world' environmental samples. With the efficiency increase when using the SAGe well in place of a BEGe, substantial reductions in the Minimum Detectable Activity (MDA) should be achievable for a range of nuclides.

1. Introduction

High-resolution gamma (γ) spectrometry is used in a variety of research fields and industries, with applications ranging from food testing to national security. The penetrating nature of γ radiation (and the nuclide-characteristic signature of each decay) provides the opportunity to non-destructively measure and characterise radioactive material, with the levels of radiation detectable only limited by the detection systems themselves.

γ spectrometry systems suffer from three main limitations; the efficiency of the detector, the resolution of the detector, and background radiation which obscures signals of interest (including terrestrial radiation, cosmic radiation, and scattered radiation from the sample). To reduce the background, several techniques can be employed; these include Cosmic veto systems [1,2], Compton suppression systems [3,4], optimised shielding designs [5], and coincidence based systems [6,7] (which utilise multiple detectors to extract useful signals from the background continuum). These techniques however, involve the addition of both complexity and cost to the system, and do not address the sensitivity of the detector itself.

The resolution of the detector is more fundamental, and is limited by the number of charge carriers in the crystal. Efficient collection of these (through superior electrode design) has allowed resolutions to approach 0.65 keV (FWHM) at 122 keV [8] for High-Purity Germanium (HPGe) crystals. This allows previously convoluted peaks to be resolved, aiding analysis and improving sensitivity.

Efficiency is dependant on the Z value of the material and the size of the crystal that can be grown. One way to boost the detection efficiency of a HPGe crystal is to create it in the form of a well, so that the detector coverage of the source approaches 4π. While effective, this limits the amount of HPGe on each side, reducing efficiency for high-energy γ radiation. It also greatly increases the capacitance of the crystal, introducing noise and therefore degrading the resolution of the detector (a problem that worsens as the size of the well detector increases). For environmental studies requiring measurement down to the lowest possible detection limits, energy resolution is the key parameter. Inferior energy resolution has therefore until now limited the use of well detectors for the assay of radionuclides in these applications.

The Small Anode Germanium (SAGe) well detector [9] (Canberra Industries), attempts to address the resolution problems of

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traditional well type detectors, and extend the sizes of crystal available such that it can compete with traditional co-axial and broad-energy designs for a range of source types. It has a useful energy range of 20 keV–10 MeV, and is available with a large 28 mm well, with up to 425 cm^3 of active material. The resolution at low-energies (<100 keV) is comparable to that of a Broad Energy Germanium (BEGe) design, and outperforms co-axial designs across the useful energy range. One concern however, is that the crystal may prove too efficient. The geometry will cause the detector to be acutely sensitive to cascade (true-coincidence) summing, which is inherently difficult to quantify and correct for. The crystal also cannot be stored warm, as the lithium contact inside the well can drift into the HPGe, degrading low-energy sensitivity.

This paper aims to assess the suitability of the SAGe well detector for environmental samples (which often have many nuclei that require cascade summing corrections to be made), using three International Atomic Energy Agency (IAEA) reference samples, and a 'Gamma Low' Proficiency Test Exercise (PTE) source prepared by NPL (National Physical Laboratory, Teddington, UK). The efficiency and cascade summing corrections are calculated using two different methodologies (Canberra Industries LabSOCS™ and the GEANT4 [10] Monte-Carlo toolkit), and used to both identify and quantify the radiation present in the sample.

2. Experimental setup

The SAGe well detector tested during this work was provided by Canberra Industries, and is of model type GSW275L. This has the larger 28 mm diameter well (40 mm depth) with a total active volume of 275 cm^3. This is currently enclosed within a 100 mm Pb cave to minimise terrestrial radiation, which is also lined with Sn and Cu to reduce the X-ray fluorescence incident on the detector. The detector uses an ultra-low background cryostat, with the preamplifier (model 2002C) situated away from the detector. A LYNX™ Digital Signal Processor receives the preamplifier signal, and controls all further amplification, pole-zero correction and digitisation of the pulse. A schematic of the detector is shown below, in Fig. 1.

3. Measurement and analysis

All data was collected using GENIE™ 2000 Gamma Analysis software, and calibration sources were chosen to cover the 50–2000 keV energy range to fully characterise the detector. Several single γ emitters were used, as well as a NIST (National Institute of Standards and Technology) traceable complex γ source. The isotopes that comprised these were ^{241}Am (59.54 keV), ^{109}Cd (88.03 keV), ^{57}Co (122.06 keV), ^{139}Ce (165.86 keV), ^{113}Sn (391.68 keV), ^{137}Cs (661.67 keV), ^{54}Mn (834.84 keV), ^{88}Y (898.04 and 1836.06 keV), ^{65}Zn (1115.54 keV), and ^{60}Co (1173.23 and 1332.49 keV).

The IAEA reference sample contained a different range of radionuclides, and was rolled into a cylinder of 28 mm diameter (it filled the well), and 35 mm height. This was then counted in the well of the SAGe detector. The NPL PTE 'Gamma Low' sample was transferred to a liquid scintillation vial and also counted within the well. The 'Gamma Low' is a low activity mixture of four γ-emitting radionuclides in 500 g of dilute nitric acid, with activities in the range of 1–30 Bq kg^{-1}.

4. Calculating the correction factors

The high-efficiency geometry of the SAGe well detector makes the calculation of correction factors somewhat difficult, as they will be extremely sensitive to the source matrix and the intrinsic efficiency of the crystal. This is particularly true when considering cascade summing correction factors, which may approach a large multiple of the measured activity. Two tools were used to calculate these factors; the Canberra supplied LabSOCS™ characterisation in conjunction with the 3D Geometry Composer module of the GENIE™ 2000 Gamma Analysis software, and a Monte-Carlo based GEANT4 model.

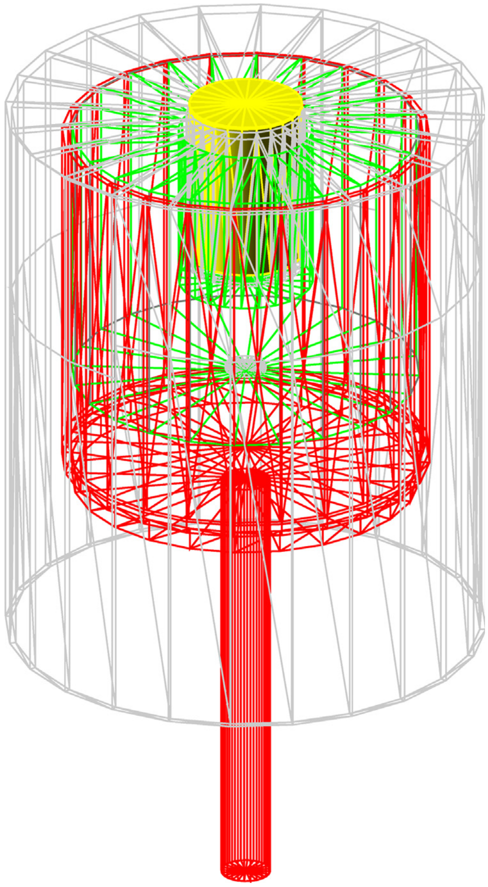

Fig. 1. A depiction of the SAGe well detector, including a sample within the well. The active HPGe crystal is shown in green, surrounded by the HPGe dead layers and insulating material (not visible in this representation). The crystal holder and copper cold finger are shown in red, along with the aluminium casings (light grey), and the source in yellow. Note that this is not an exact representation of the actual detector, and several dimensions have been modified to produce this figure. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

The former is a mathematical model based upon an initial detector characterisation, whereas the Monte-Carlo simulations are built using the manufacturer supplied detector specifications. While this means that the GEANT4 Monte-Carlo toolkit is inherently more flexible (and has the advantage of being freely available), it does require an in-depth knowledge of GEANT4 and a substantial amount of time to develop the detector model. LabSOCS characterisation (in combination with the 3D Geometry Composer module of the GENIE™ 2000 Gamma Analysis software) can be utilised by anyone via a graphical user interface, and can quickly produce efficiencies and cascade summing corrections for a wide range of pre-defined geometries.

4.1. Labsocs and 3D geometry composer

The SAGe well has been LabSOCS™ characterised, which has to be completed in the factory. This involves multiple high-accuracy measurements of the detector response to sources at different