Log 118

Performance of a Low-Background High Purity Germanium Detector with a Novel EndCap

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Abstract

Low background HPGe detectors have been used for many years in the measurement of low activities of radionuclides in various materials. With the increased importance of nuclear forensics, low background detectors are in increasing demand. The endcap and other materials used in low background detector construction must be selected to have the lowest activity possible. In some cases, the materials with the lowest amounts of naturally occurring radionuclides are difficult to obtain and costly. To obtain the best efficiency at all energies, low atomic number materials are needed for the endcap to ensure maximum transmission. Aluminum and magnesium are the materials used most often, with beryllium and carbon fiber being used for the low energy entrance windows. Even specially selected aluminum, magnesium and beryllium contain measurable amounts of naturally occurring radiomaterials, and beryllium has an associated health hazard. In a new approach, a new endcap has been designed completely from carbon fiber materials. This material is not mined so it does not contain any naturally occurring radionuclides. It has a low average atomic number, resulting in good transmission of low energy photons. The transmission of entrance windows below 60 keV is further improved because no support material for the entrance window itself is required. The efficiency of a large diameter and length detector with the new endcap has been measured and shows improvement over conventional endcaps for extended geometry samples. The uniformity of the sensitivity for low energies has been measured. The low background spectrum has been measured and is compared to conventional low background endcap detectors.

Introduction

In order to measure low fluxes of radiological processes or emissions from radionuclides in various materials, a HPGe detector must be constructed to minimize its contribution to the spectrum. Currently, several monitoring and nuclear forensics applications are increasing the need for low background detectors. The low-background HPGe detectors currently available are constructed from specially selected materials to reduce the naturally-occurring radionuclide content. Some materials, such as copper and magnesium, can be found with low activity content at a reasonable cost. Other materials, such as beryllium and aluminum can be refined to remove the natural radionuclides, but at a high cost and limited supply. Many low-background detectors have been made with reasonable cost materials and some detectors have been made with very carefully refined materials, however the latter materials, and hence the detectors, are expensive.

The need for low-background detectors, especially those without uranium, thorium and other naturally occurring nuclides, is increasing because of the need to identify the origin of various materials. While the detector endcap does not weigh much compared to the remainder of the detector and shield, the endcap is the closest material to the detector and there is generally no significant material between the endcap and the detector crystal. Thus the radionuclides in the endcap material can make a large contribution to the spectrum. To produce an endcap with the lowest activity one has been made entirely of carbon fiber materials. This material is naturally free of radionuclides giving the lowest background at a reasonable cost. The overall transmission is higher than a metal endcap with a carbon fiber window because there are no supports for the carbon fiber. This new endcap will provide lower detection limits than metallic endcaps.In addition, the aluminium and especially magnesium often used for endcaps can corrode and cause detector failure. Measurements of the background of the detector and its efficiency for extended sources are discussed and compared to other detectors..

The decreased attenuation by the endcap material will improve the efficiency for regular detectors. This is more pronounced in larger detectors where the endcap thickness is increased for strength.

Experimental

The detector was constructed as low background in the conventional way as shown in Fig. 1 with the exception of the endcap which is made of carbon fiber and epoxy material. The endcap material is the same composition as the carbon fiber windows currently in use on many detectors. The detector cup is made of OFHC copper. The crystal is 87 mm diameter x 84 mm long and measures 115% relative efficiency. (See Ref [5])

The low-background shield has an outer layer of 15 cm of lead with inner layers of 1 mm tin and 6.4 mm of OFHC copper. The internal dimensions of the cavity are 30.5 cm wide by 71 cm long by 51 cm deep. There was no removal of radon buildup inside the cavity. Spectra were also collected with just the tin liner and with no liner. Spectra were collected with the copper layer removed and with both the copper and tin layers removed.

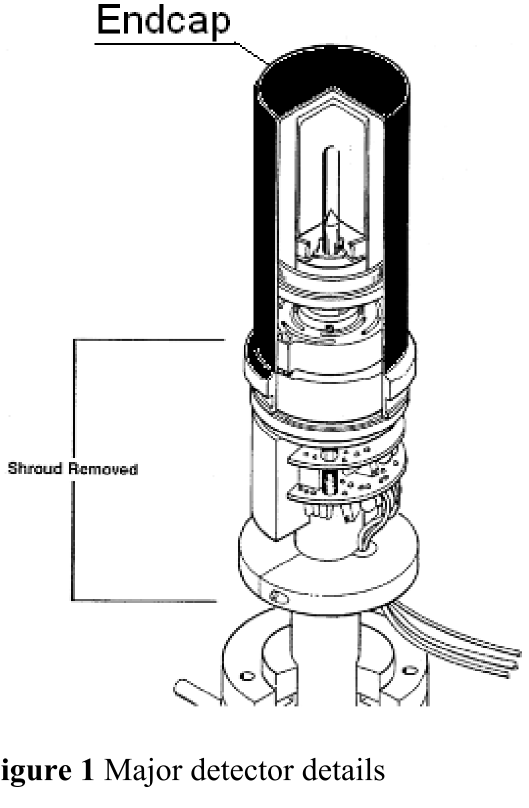

Figure 1 Major detector details

For comparison, an aluminium overcap was constructed with a top thickness of 1.5 mm and a wall thickness of 0.8 mm corresponding to the thicknesses of a conventional endcap for this size of detector. When a carbon fiber window is used, aluminum is only used in an 11 mm wide mounting flange to hold the window. Spectra were also collected with this type of endcap.

The efficiency was measured using a 10 cm diameter mixed nuclide source tracable to NIST for the carbon fiber, aluminum support for window and aluminum endcap. The source was uniformaly deposited on the filter paper. The source was placed directly on the endcap. No corrections were made for coincidence summing, which is evident in the spectrum.

The relative efficiency across the front face of the detector was also measured using an ^{241}Am pencil beam as described earlier [1]. The pencil beam was positioned at several locations on a diameter for the three combinations of endcaps.

Results

The background performance was evaluated using IEC 61976 [2] which specified certain gamma-ray peak energies and non-peak areas to be evaluated. Figure 2 shows the peak and non-peak areas for the new detector in different shields and for two aluminum endcap detectors of approximately the same efficiency and crystal dimensions. The peak regions are shown in net area counts per second and the non peak areas are shown in counts per keV per second. The spectra for the carbon fiber detector were collected for 800000 seconds and the others were collected for 100000 seconds. The overall background is lower and this lower background will give lower Minimum Detectable Limits (MDAs).

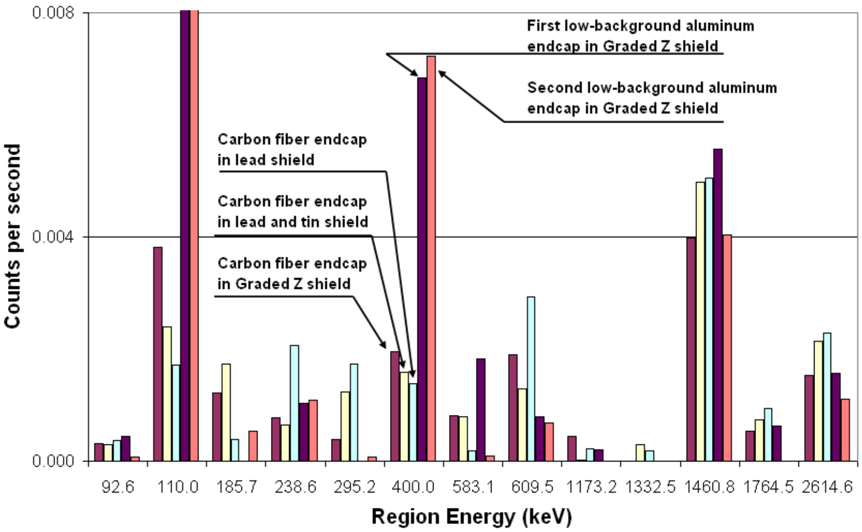

Figure 2 Comparison of Background for Different Detectors.

Peaks in the spectrum caused by cosmic ray interactions on the shielding material or on the detector itself are not included in the comparison. A list of peak energies and origins is given in refs. [2, 3].

Note that Fig. 2 shows the differences in the background for the same carbon fiber detector in the different shields in terms of background amplitude in non-peak areas. Figure 3 compares the carbon fiber detector in three shields. This result shows the background of a low-background detector depends on the shield used. This was reported previously by others [4] for NaI spectra in the case of source-induced background. The most intense peaks in the shield with lead, tin and copper are the cosmic interactions on germanium. The spectrum is similar with the copper removed, but when the tin is removed, the ^{214}Pb emissions at 295 and 351 keV are visible. Additionally, the lead X-rays (~ 75 and ~ 85 keV) are visible when the tin is removed. However, the continuum background in non-peak areas is lower without the tin or copper.

The efficiency for the 10 cm diameter filter paper source is shown in Fig. 4. As expected the higher transmission of the carbon material gives a higher efficiency. The aluminum ring and carbon fiber efficiencies are essentially the same. The shape of the efficiency curve is dominated by the dead layer of the germanium at low energies.

Figure 5 shows the shape of the curve of sensitivity vs position and it is as expected. The support ring has a small impact as indicated. The solid endcap shows the reduced count rate of about 8%. The higher efficiency will produce a lower MDA.

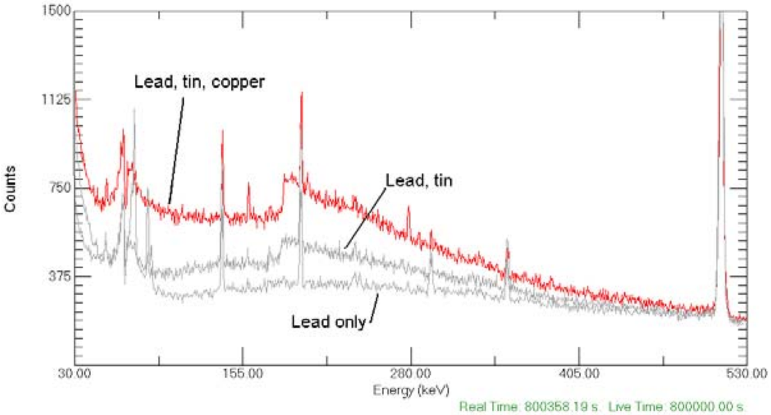

Figure 3 Comparison of background of one detector in three different shields.

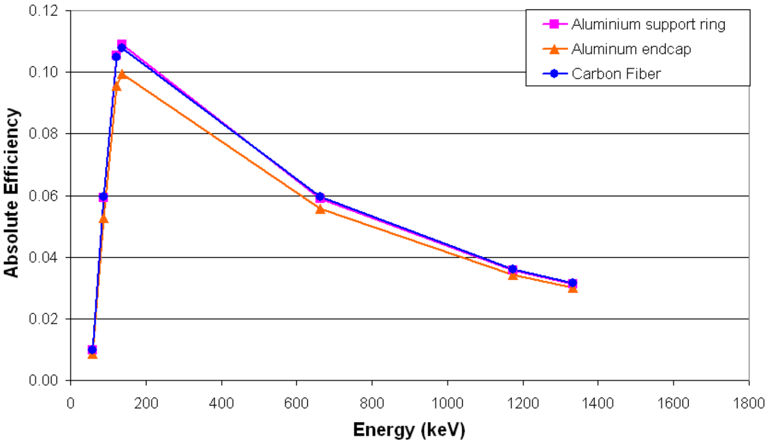

Figure 4 Comparison of efficiency for different endcaps.

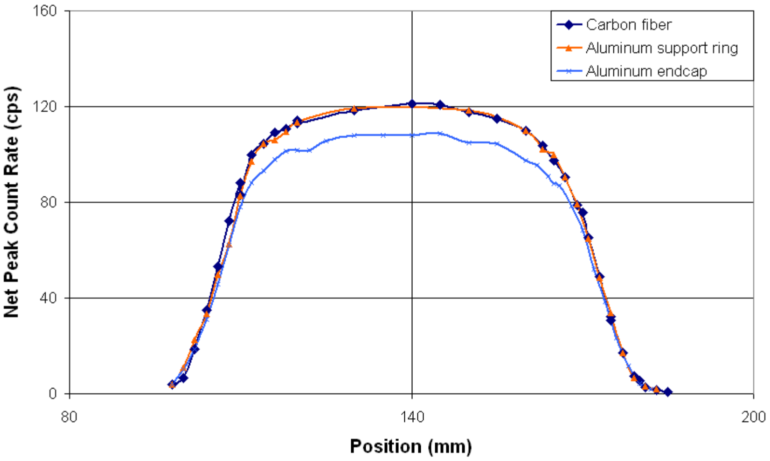

Figure 5 Comparison of the 59 keV scans of the front face of the detector for different endcaps.

Conclusion

The carbon fiber endcap has shown to have generally lower background and slightly higher transmission than similar low-background detector endcaps constructed with all aluminum or magnesium. In addition, the carbon fiber endcaps are resistant to corrosion making them less likely to be contaminated and if necessary, easier to clean. Work will continue on evaluating the long term characteristics with special emphasis on the vacuum. The carbon fiber endcap shows promise as a superior replacement for the existing low-background endcaps.

References

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