Application Note

The SAGe Well: A New Revolution in Well and Environmental Counting

Introduction

This application note introduces the new SAGe™ Well Detector[1] and describes its benefits for several radiochemistry laboratory counting applications. The Canberra™ SAGe Well is a product of sustained investment in the area of High-Purity Germanium (HPGe) detector research and development and represents a new type of HPGe detector for laboratory counting, the first since the introduction of the Broad Energy Germanium (BEGe) detector in 1997. Like the BEGe detector, the SAGe Well offers excellent energy resolution performance over an energy range of 20 keV – 3 MeV. In addition to this, it delivers the efficiency benefits associated with counting inside the well without compromising energy resolution. Furthermore, the detector is manufactured with an aspect ratio of a Standard Electrode Germanium (SEGe) coaxial detector to allow excellent efficiency performance for standard laboratory geometries such as Marinelli beakers or other large sample containers. The result is a versatile detector that can deliver reductions in count time, through improvements in Minimum Detectable Concentration/Activity (MDC/MDA), for a range of sample sizes and geometries counted inside the well, on the end cap or in Marinelli beakers.

A revolution in energy resolution performance

Traditional HPGe Well Detectors have been available for many years, but have enjoyed only limited adoption for radiochemistry laboratory applications. This is mainly due to the relatively poor energy resolution for this type of detector (which is particularly poor for larger well diameters). The counting applications have therefore been limited exclusively to small samples (<15 cc) where the inferior energy resolution is overcome by the extremely high detection efficiency inside the well, leading to a net improvement in MDC for these small samples. For larger sample volumes the poor energy resolution of the traditional Well detectors renders them inferior to BEGe and coaxial detectors.

Figure 1 shows an overlay of two low-energy spectra taken with a traditional Well and a SAGe Well, clearly demonstrating the significant improvement in resolution. Figure 2 compares the energy resolution performance of the SAGe Well Detector with those of other detector types over an energy range of 20 keV – 3 MeV. The detector has similar resolution performance to the BEGe detector, but offers significant improvement over the SEGe (Coax) and traditional Well detectors. For this reason, the SAGe Well Detector becomes the optimum choice for a range of sample counting applications. Three example applications are described in this note.

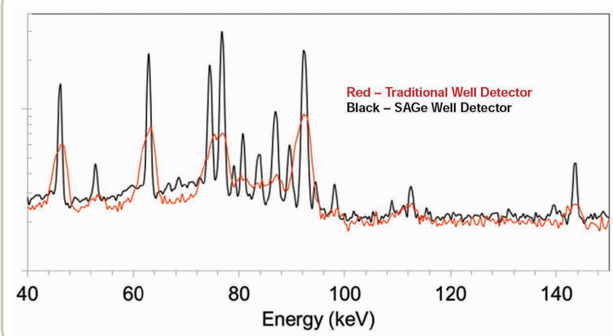

Figure 1:
Spectrum overlay of a traditional Well detector compared to a SAGe Well

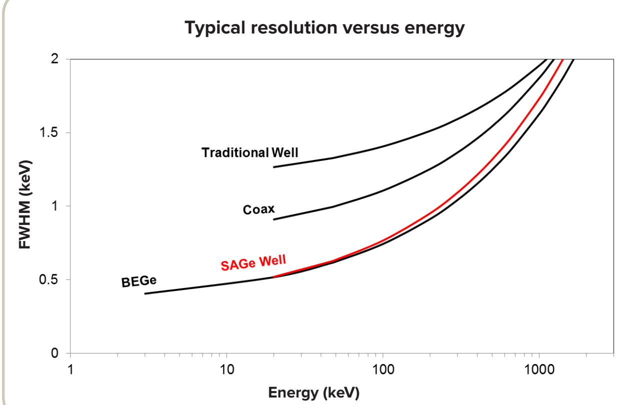

Figure 2:
Energy resolution (FWHM) as a function of energy for different detector types

Larger well size, without compromising performance

There are six different models of the SAGe Well Detector available and these are identifiable by their active volume (see Table 1). Typically, the lower active volumes are used where the gamma ray energies are relatively low (such as Pb-210 measurements with the key gamma energy of 46 keV). The larger active volumes are usually selected for the measurement of nuclides emitting higher-energy gamma rays, such as Cs-137 and Co-60.

[1] Patent pending

Table 1:
Dimension and energy resolution specification for the SAGe Well Detector models

Model	Min. Active volume (cc)	Well diameter (mm)	Well depth (mm)	1332 keV FWHM (keV)	122 keV FWHM (keV)	Endcap diam. (inch)
GSW120	120	16	40	2.2	0.75	3.25
GSW200	200	16	40	2.2	0.75	3.5
GSW300	300	16	40	2.2	0.75	4.25
GSW350	350	16	40	2.2	0.75	4.5
GSW425	425	16	40	2.2	0.75	4.5
GSW275L	275	28	40	2.2	0.75	4.25

Figure 3 shows the absolute efficiency as function of energy for a point source located at the bottom of the well for four different SAGe Well Detector models, including the GSW275L with 28 mm diameter well. This figure can be used as a guide to select the best suitable detector model as a function of the desired efficiency in the energy region of interest.

Note that the SAGe Well has a larger (28 mm) well diameter model (denoted by the suffix "L"). The new design of the SAGe Well is such that this larger well model has the same excellent energy resolution performance as the other models. This is a significant step forward over traditional Well Detectors where the supply of larger well diameters was inhibited by the poor energy resolution. Although the outer dimensions of the GSW275L and GSW300 models are similar, the absolute efficiency of the GSW275L is lower because more active germanium material is removed to manufacture the large well. However, the 28 mm well can fit three times more sample material than the 16 mm version. Therefore, the massimetric efficiency (sample mass * efficiency) is actually higher, improving measured MDC values. Also, having a larger diameter well means a wider range of samples can be counted inside the well (soil core samples, food, enriched uranium,...).

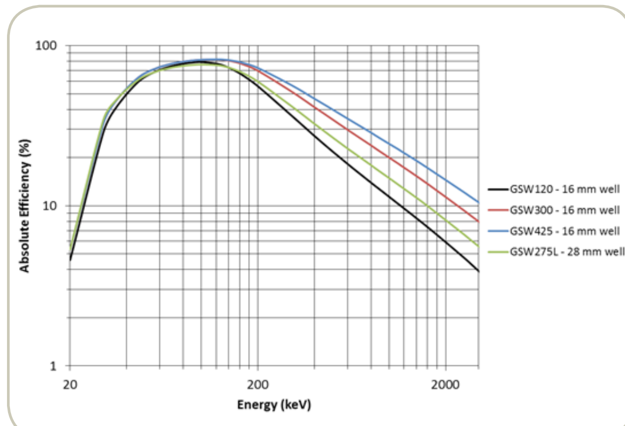

Figure 3:
Absolute efficiency as function of energy for a point source located at the bottom of the well

Table 2:
SAGe Well Detector Compatibility with Marinelli beakers

	Beaker Class	Well ID inches (mm)	Sample Volume at 1" FB (liters)	GSW120	GSW200	GSW275L	GSW300	GSW350	GSW425
Model 463316	Mini	3.32 (84)	0.18	√					
Model 533N-E	0.5 L	3.30 (84)	0.40	√					
Model 590G-E	0.5 L	3.60 (91)	0.45	√	√				
Model 538G-E	0.5 L	3.78 (96)	0.58		√				
Model 133N-E	1 L	3.33 (84)	0.84	√					
Model 190G-E	1 L	3.58 (91)	1.0	√	√				
Model 132G-E	1 L	3.32 (84)	1.1	√					
Model 138G-E	1 L	3.8 (96)	1.60		√				
Model 233N-E	2 L	3.30 (84)	1.65	√					
Model 445N-E	4 L	4.44 (113)	3.0			√	√		
Model 448G-E	4 L	4.79 (121)	3.0					√	√
Model 438G-E	4 L	3.78 (96)	3.2		√				
Model 433N-E	4 L	3.33 (84)	3.67	√					

Compatibility with Marinelli Beakers

The detector geometry is such that the SAGe Well accepts standard Marinelli beakers. The detector aspect ratio coupled with the excellent resolution performance leads to a significant improvement in MDC performance for these geometries, and therefore shorter counting time when compared to a standard coaxial detector. Table 2 shows the compatibility of the various SAGe Well Detector models with a wide selection of GA-MA & Associates Marinelli beaker models.

A solution for True Coincidence Summing (a first for Well Detectors)

The typical life time of excited states in a nucleus is in the picosecond time scale. For photon detectors a typical response time, i.e. the time between two photons that is needed for the detector to recognize that the deposited energy comes from two photons, is on the order of microseconds. This is several orders of magnitude longer than the life time of the excited states. For decays where more than one photon is emitted there is a probability that both photons will interact in the detector and deposit energy in the detector. Since the time between the photons is much shorter than the response time for the detector it is not possible for the detector to distinguish between the two photons and only one pulse (with the sum of the deposited energies) will be generated. This effect is known as True Coincidence Summing and it can result in significant under-estimation of activity results (up to 30% is typical). The level of impact is strongly dependent upon the sample and detector geometry and is greatest for well detector geometries. In these geometries the detection efficiency is high and the sample is almost completely surrounded by the detector, resulting in an enhanced probability that two or more gamma rays in a cascade will be detected simultaneously.

For traditional Well Detectors there is no satisfactory solution for correcting for the effects of True Coincidence Summing. For the SAGe Well Detector, corrections become easy since full LabSOCS™ support is available. Accurate corrections can be made by simply defining a LabSOCS geometry for the measurement using the 3D Geometry Composer (note that the detector must be factory characterized as is the case for standard detectors). LabSOCS modeled efficiency calibrations are also possible both inside and outside the well. For the first time this becomes a viable option to source calibrations for well detectors.

Three key advantages

As discussed above, the SAGe Well Detector combines the following aspects in order to deliver the best available counting performance for a range of samples:

(a) Excellent energy resolution over 20 keV – 3 MeV (similar to a BEGe detector),

(b) A larger well size (28 mm) without compromising resolution performance,

(c) An aspect ratio similar to coaxial detectors and compatible with Marinelli beakers and other large sample containers.

The SAGe Well Detector therefore has three main application advantages:

1. **Traditional Well Applications:** The step-change in energy resolution performance over traditional Well Detectors (for example around a factor of 3 improvement at 50 keV – see Figure 2) means that MDC values are significantly improved leading to large reductions in counting times. As Figure 1 shows, the improvement is most pronounced in the low energy region. In this note, an analysis of the Pb-210 dating application (with the key gamma energy of 46.5 keV) shows that a **factor of 10** improvement in count time can be gained with the SAGe Well Detector.
2. **New Well Applications:** As previously described, the poor energy resolution of traditional Wells has inhibited a wider use for laboratory counting applications. The drastic improvement in energy resolution coupled with the larger well diameter accepting more sample means that the SAGe Well Detector becomes the best choice for a broader range of applications. The example chosen in this application note is the measurement of Ra-226 / Ra-228 in drinking water. Typically the sample is precipitated on a filter paper and counted on the detector end cap. The application study shows that counting the filter paper inside the well of a SAGe Well Detector can lead to a **factor of 50** improvement in counting time. Due to the poor resolution it would be impractical to count these types of samples on a standard Well detector.
3. **Measuring Larger Samples:** In addition to measuring samples inside the well, the geometry of the SAGe Well detector is such that it is compatible with Marinelli beakers (see Table 2) and large sample containers. Figure 2 shows that the energy resolution performance is superior to standard coaxial detectors (particularly in the low-energy region); so significantly reduced count times can be achieved when comparing with SEGe detectors of a comparable size.

An example application is described for each of these cases.

Traditional Well Application: Pb-210 Dating Example

Pb-210 dating is a technique to determine the age of a sample of soil by comparing the ratio of Pb-210 to another daughter product of uranium. Pb-210 (half-life of 22.3 years) is a naturally occurring radioactive form of lead and is one of the last nuclides created by the U-238 decay chain. When in equilibrium, the U-238 decay products are produced with known quantities (since successive isotopes in the decay series will have the same activity). This is only true of a closed system, however, and one of the products in the U-238 decay chain is Rn-222, a gas which can partially escape to the atmosphere before decaying into Pb-210. The radon that is trapped in the soil will be in equilibrium with the other decay products (this is called the supported component). The radon that escapes into the atmosphere and decays will not be in equilibrium with the other decay products (this is the unsupported component). The supported and unsupported components correspond to two distinct contributions to the Pb-210 activity concentration. These two contributions are shown graphically below and the difference between them allows determination of the age of the soil sample and thus forms the basis of the dating method.

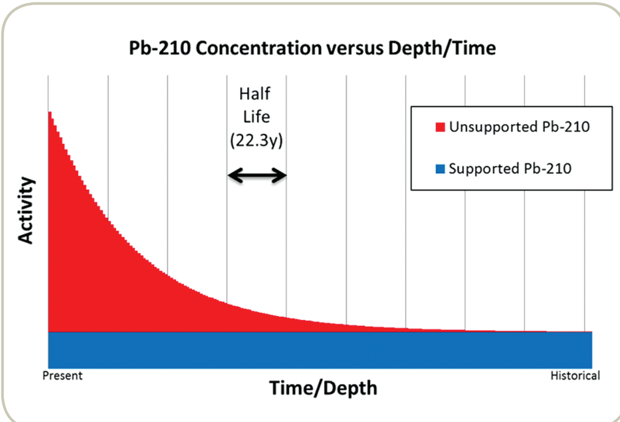

Figure 4:
Evolution of the supported and unsupported Pb-210 contribution as function of time/depth

Samples are obtained by extracting a sediment core sample in the location of interest. These samples are then sectioned into consecutive segments to be analyzed independently. Generally, this leads to a minimization of the sample size to allow the maximum spatial (and therefore temporal) resolution. In practice, the MDC for the measurement system determines the age of the oldest samples that can be evaluated and up to now the best sensitivity has been achieved with traditional Well Detectors (due to their excellent peak efficiency). The SAGe Well detector has greatly improved energy resolution, offers a larger well size to accept more samples and delivers the same excellent peak efficiency of traditional wells. It therefore provides the best possible measurement performance for Pb-210 dating applications. As presented below, the improvement in counting time over traditional well systems is pronounced.

Consider a typical, limited size soil core sample with a density of 1.6 g/cc. This sample could be counted in any of the following geometries:

- Traditional Well Detector with 16 mm Well (Maximum Sample Volume ~ 8 cc) – model GCW4522
- SAGe Well Detector with 16 mm Well (Maximum Sample Volume ~ 8 cc) – model GSW120
- SAGe Well Detector with 28 mm Well (Maximum Sample Volume ~ 24 cc) – model GSW275L

It should be noted that the traditional Well Detector has a volume of 230 cc which is almost twice as large as the GSW120 (120 cc) and almost as large as the GSW275L (275 cc).

The MDC performance for each of these three scenarios is compared in Figure 6. At count times exceeding three hours (which are typical for the application) the MDC values for GSW120 (the SAGe Well detector with the 16 mm hole) are better by 30-40% when compared with the GCW4522 (the traditional Well Detector with the same hole diameter). This equates to a factor of 2 improvement (i.e. reduction) in counting time. It must be noted that this is true even though the SAGe Well Detector volume is significantly smaller (by almost a factor of 2) and is therefore significantly less expensive than the traditional Well Detector against which it is compared.

Counting with the GSW275L (the SAGe Well detector with the 28 mm) allows more sample (factor of 3) to be placed inside the well which provides additional MDC benefits. An improvement in MDC of greater than a factor 3 is achieved for this detector, which provides a reduction in count time of a factor 10 when compared against the traditional Well Detector, assuming that the larger sample volume is available.

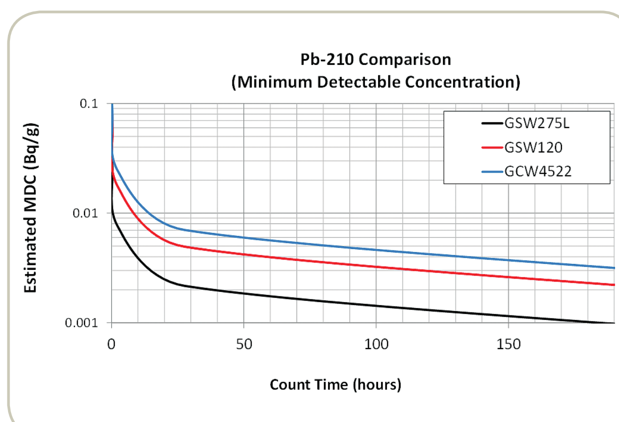

Figure 6:
Estimated MDC performance for three soil core sample measurement scenarios

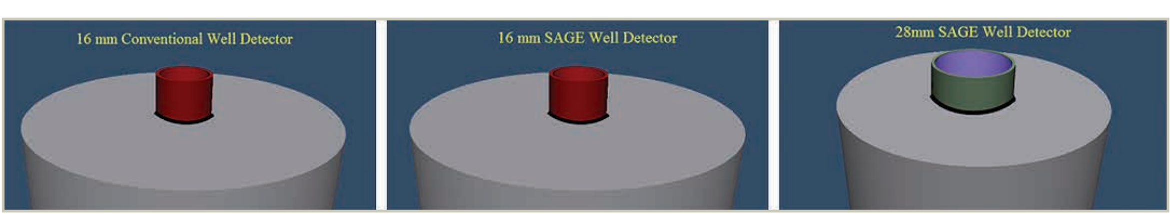

Figure 5:
Three different well detector measurement scenarios for soil core sample measurements

New Well Applications: Radium in Drinking Water Example

Radium is found at low concentrations in soil, water, plants and food, but the greatest potential for human exposure to radium is through drinking water. Since radium is chemically similar to calcium, it can cause harm by replacing calcium in bones. As a result, the US EPA has established regulations for reporting the amounts of two isotopes, Ra-226 and Ra-228, that can be found in drinking water supplies.

The original EPA-approved method for quantifying Ra-226 and Ra-228 was both time consuming and complex, taking as much as eight hours to complete the method for both radionuclides. In 2002, the Georgia Tech Research Institute advanced a simplified procedure that was later approved by the EPA, greatly reducing the preparation time. The procedure calls for a precipitation of the radium onto a filter paper that is then analyzed with a high-resolution gamma spectrometer. While the technician time required for this new method has been greatly reduced, the counting time is now typically the limiting factor to the throughput capacity of the laboratory. Counting filter samples inside the well of a SAGe Well dramatically improves the count time required for this analysis.

Up to now the best possible detection sensitivity is achieved by counting the filter directly on the end cap of a BEGe detector. The energy resolution of the SAGe Well is comparable to that of a BEGe, but the peak efficiency for a sample inside the well is much higher than for a sample on the endcap. Therefore the use of a SAGe Well can dramatically improve the counting time to achieve a given MDC. For this comparison, the following two viable scenarios have been selected.

- 47 mm filter measured on the end cap of a BEGe detector – model BE3830
- 47 mm filter measured inside the well of a SAGe Well detector – model GSW120

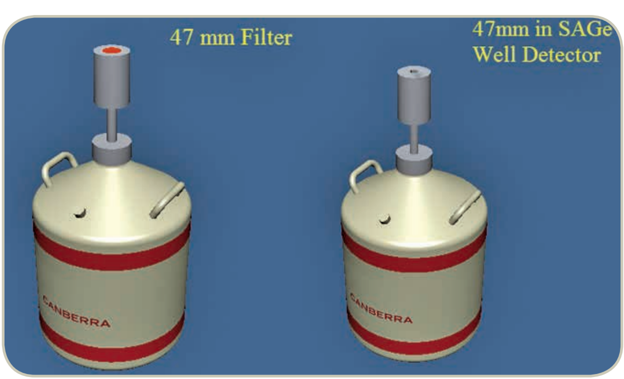

Figure 7:
Two different measurement scenarios for radium in drinking water (precipitated onto a filter)

Figure 8 compares the Ra-226 MDC results for the two scenarios. The two detectors will achieve comparable energy resolution performance but the peak efficiency achieved for the sample inside the SAGe Well is significantly greater than that achieved on the end cap of the BEGe. The result is a factor of 7–8 improvement in MDC, thus providing an improvement (i.e. reduction) in count time of around a factor 50. This significantly improves the productivity of laboratories performing this type of sample counting.

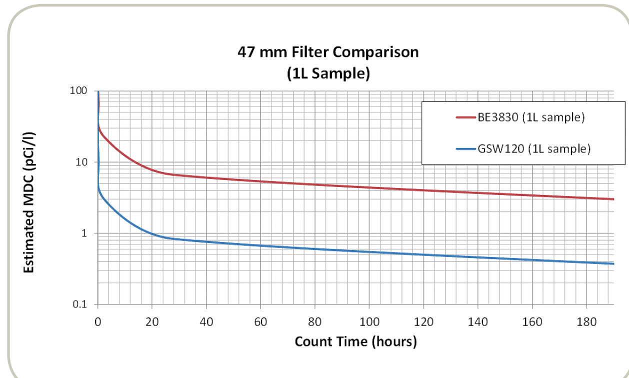

Figure 8:
Estimated Ra-226 MDC performance for two measurement scenarios for radium in drinking water

Measuring Large Samples: Radioiodine Contamination in Milk Example

The recent events in Fukushima Japan have renewed the interest in measuring I-131 in milk samples. These samples are representative of the numerous liquid samples that are best measured in a large volume beaker counted on the face of the detector.

The major advantage of the SAGe Well Detector (as demonstrated in the previous two examples) is for the measurement of small samples inside the well. However, there are many laboratories that are required to carry out this type of small sample counting in addition to counting large volume liquid samples such as milk. Both of these very different needs can be satisfied with a SAGe Well Detector. This versatility is due to its excellent energy resolution both inside and outside the well and performance exceeds that of standard coaxial detectors for the measurement of Marinelli beakers.

Figure 9 presents a comparison of the MDC performance for the smallest SAGe Well detector (GSW120) with that of a typical coaxial detector. Both detectors have approximately the same active volume. The MDC performance is a factor 2 better for the SAGe Well Detector. The result is a reduction in count time of a factor 5 for this example.

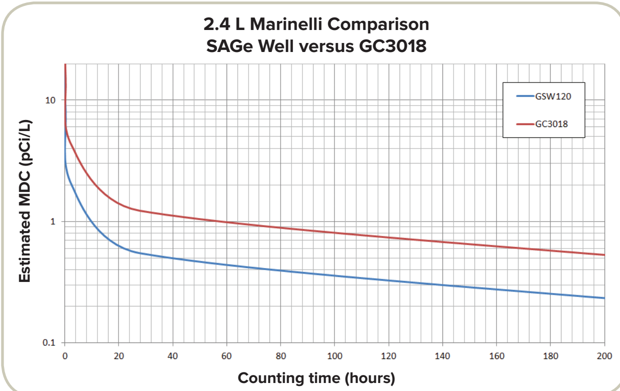

Figure 9:
Comparison of MDC for I-131 in milk measured in a 2.4 L Marinelli beaker

A comparison is also made for a 400 mL liquid sample positioned on the end cap of the following three detectors:

- SAGe Well Model GSW120
- BEGe model BE2825
- Standard coaxial GC1520

These detectors are selected to have similar detector volumes.

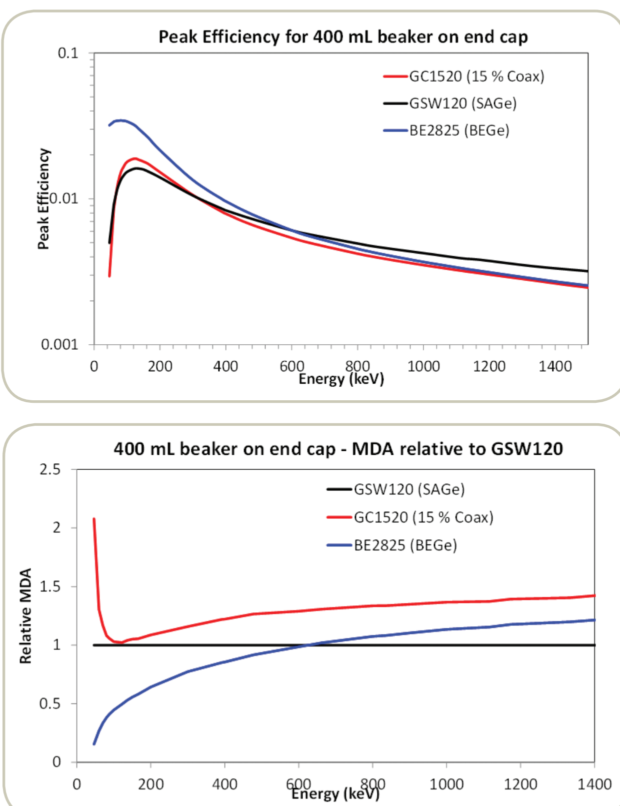

Figure 10:
Peak Efficiency for three detectors for a 400 mL beaker sample (top) and relative MDA normalized to the SAGe Well detector (bottom)

The top panel of Figure 10 shows that the peak efficiency of the coaxial detector and the SAGe Well detector are similar. The peak efficiency of the BEGe detector is superior at energies <600 keV. Given that the SAGe Well and BEGe detector have similar energy resolution performance (Figure 1) the MDA/MDC performance of the BEGe for this type of sample geometry is superior to the SAGe Well detector for these energies (bottom panel of Figure 10). As Figure 10 demonstrates, the MDA/MDC performance of the SAGe Well is superior to that of the standard coaxial detector for the full energy range. This is due to the superior energy resolution performance.

The results in Figure 10 show that the SAGe Well, while very good, is still not the absolute best for all applications. Not surprisingly, the BEGe performs best for samples on the endcap (like a beaker or a filter paper), particularly at low to medium energies.

Conclusion

The traditional Germanium Well Detector has had a very limited role in the radiochemistry laboratory. While it has significant advantages in efficiency for small samples under ~ 8 cc that can fit inside the well, there are no other sample types for which it is suited mainly due to the poor spectral resolution.

The SAGe Well detector offers two major advantages for in-well counting. First, the vastly improved resolution greatly enhances detection sensitivity for nuclides (particularly below 100 keV in energy). This can reduce counting times by half while increasing nuclide identification capability. Second, the optional 28 mm well size is the largest of any Germanium Well detector in the industry. And the SAGe Well detector design is such that this larger well model has the same excellent spectral resolution as the rest of this new detector range. By allowing more sample to be counted, in addition to the energy resolution gains described above, the counting time can be reduced ten-fold as compared to a traditional Well Detector.

However, improved well counting is just the beginning of the advantages of the SAGe Well detector. The SAGe Well is no longer a dedicated detector for very small samples. It can count samples on or near the face of the detector, or even in a Marinelli beaker, with the same or better count time performance as compared to a standard coaxial detector.

The SAGe Well's versatility is unmatched among all types of Germanium detectors. Well detector users should greatly appreciate the enhancements the SAGe Well brings to their applications. And count room managers who have ever wanted to count well-sized samples but could not justify the cost of a dedicated detector no longer have to choose. The SAGe Well does it all and does it well!

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