A New Segmented Gamma Scanner System - 11366

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ABSTRACT

The Segmented Gamma Scanner (SGS) system is primarily used to perform accurate quantitative assays on gamma emitting nuclides found in fission product, activation product, and Transuranic (TRU) waste. Using a modular building-block approach, the system offers tremendous flexibility for a variety of measurement situations with wide ranges of sample activities and throughput requirements, as well as the opportunity to modify the application at a later date.

For some applications, however, where the lifetime use of the system is well known, and expected to be unchanging, a simpler one-platform system is sufficient and more attractive on a cost basis. Using building blocks from the modular system, Canberra has designed and tested a new integrated SGS system which is a compact, transportable alternative to the existing design. This new system is designated the Standard SGS.

Through use of the same detector collimator and shield as well as the transmission assembly used in the Modular SGS, the new Standard SGS was shown to provide the same high-quality performance in terms of accuracy and minimum detectable activity (MDA). Based on one unified stand and using just one lift for both detector and transmission source housing, the compact size of the system allows for easy transportability within a facility (built-in fork-lift slots & capability of fitting through a standard double door). The system has a rotator built into the stand, with an optional weighing system, and the detector and transmission source housing positions can be interchanged to allow for flexibility in setup.

An overview of the new system is presented here with the measured performance results. Also illustrated is the use of the ISOCS modeling capability with this system for a difficult-to-measure situation.

INTRODUCTION

The Segmented Gamma Scanner (SGS) was introduced in the mid-1970s as an accurate, quantitative system for the nondestructive assay (NDA) of low density uranium and plutonium scrap material [1]. Since then, the SGS and its variants have been designed to accommodate a wide range of applications (safeguards, waste disposal and sorting, fuel processing, site decommissioning, etc.), nuclides, activities, sample sizes, and degrees of drum handling and automation [2-3]. For instance, in extremely high count rate situations, slit collimators have been added to the shield/detector portion of the SGS that engage at specific dose rates. For enhanced throughput, multiple detectors have been used to increase the total sensitivity and reduce the time necessary to assay the entire drum. Incorporating rollers with the drum rotator has been another option employed to mate SGS systems to an existing or planned drum conveyor network to maintain automated item handling. Very intense transmission sources with accompanying enlarged shielding and mechanical drives have been designed for items with concrete or lead lining. Having a modular approach to the SGS continues to be useful and necessary to solve a wide spectrum of assay situations.

The main motivation for a new system is to reduce a 200 liter drum SGS system to a minimum amount of complexity and footprint without sacrificing accuracy and functionality. The irreducible components of an SGS system are the following: a collimated, high-resolution gamma-ray spectrometer, mechanized frames (with a programmable logic controller or PLC) that allow for item rotation and vertical scanning, signal processing electronics, a computer, and associated software. Most SGS systems also contain a transmission source on the opposite side of the detector to perform matrix attenuation corrections. By vertically scanning items, the SGS systems can account for drums with heterogeneous matrix- and activity-distributions. By rotating the item, radial variations are averaged. For low count rate applications, a relatively lightweight, singular SGS system has been designed, tested, and deployed. For the rest of the paper, this new system will be designated as the Standard SGS.

This paper will first introduce the Standard SGS, its design features, and how it compares to Modular SGS configurations. The performance of three Standard SGS systems will then be presented and compared with a Modular SGS basic configuration.

SYSTEM DESCRIPTION

The Standard SGS has all the essential components of the Modular SGS. Figure 1 shows photographs of both systems with a 200 L drum on the rotators. The Standard SGS is not intended as a replacement, but an alternative choice for applications that do not require additional complexity or features. The main differences of the Standard SGS from the modular system are spatial, mechanical, and electrical in nature.

Figure 1. The Modular SGS system (left) and the new Standard SGS system (right). In the modular system, the detector lift is to the right of the rotator and drum. In the Standard SGS, the detector is on the left hand side of the drum, and the transmission source is on the right platform. The two pictures are not to scale.

Spatial

The required footprint and vertical extent of the main system assemblies are shown in Table I. The vertical extent is specified with the detector lift at the upper most position, and the depth of the system is measured from their widest elements. The computer is not included in these dimensions, and the electrical enclosure, which must also be taken into account, will be discussed in a later section. Although slightly larger than the modular design because of the exaggerated shelf for transmission, the direct floor footprint of the Standard SGS is much smaller, and the main frame can be transported with a single forklift. The Modular SGS requires multiple trips or lifting devices for movement. It should also be noted that the left and right shelves of the Standard SGS are symmetrical to allow for the position of the transmission and detector assemblies to be interchangeable. This addition to the overall width is included in the value of Table 1. Also, the vertical height of the Standard SGS does not include the tower of warning lights, which is often configured on the top of the vertical drive assembly. The recommended spatial clearance (4 x 3.5 x 2 in meters for Width x Depth x Height) for both systems is much larger than the actual physical footprint.

Table I. Spatial Extent of the Two SGS Systems without the Computer or Electrical Enclosure.

	Footprint Width x Depth in (cm)	Vertical Height (cm)
Modular SGS	249 x 115	196
Standard SGS	262 x 127	166

Another important spatial factor is the alignment of the detector lift, rotator, and transmission source. The Modular SGS needs careful alignment of the three subsystems to ensure accurate performance. The Standard SGS components are physically connected and do not require this alignment step during installation, although it is checked and confirmed during integration.

Mechanical
In addition to the alignment and spatial complexity, the Standard SGS's reduction in moving, mechanical parts provides improved maintainability. As seen in Figure 1, the transmission source and detector for the Modular SGS are on separate lifts with their own motors, power supplies, brakes, and drives. The maintenance and upkeep of the mechanical components include, but are not limited to the following: timing belt replacements, cleaning and lubrication of drive leadscrews, nuts, and shafts, and limit switches wear monitoring. Having fewer mechanical components also requires fewer spare parts to have on-hand and shorter assembly and integration time at the factory and on-site.

Electrical
The reduction in mechanical components of the Standard SGS also reduces the complexity of the wiring and electronics modules used in the programmable logic controller. The physical size of the mechanism control enclosure is reduced in the Standard SGS as well (Figure 2). Because of the simplicity of the mechanical movement of the single lift, the touch-pad interface was removed on the enclosure of the Standard SGS. The Modular SGS needed to have independent, manual control of the three main platforms for troubleshooting and maintenance purposes, as well as the ability to control conveyors, automatic detector attenuators, and other options in more customized systems. The Standard SGS has only three manual controls: 1) the movement of the single vertical drive, 2) the rotator, and 3) the transmission source shutter. The reduction in electrical complexity also contributes to shorter assembly and integration time.

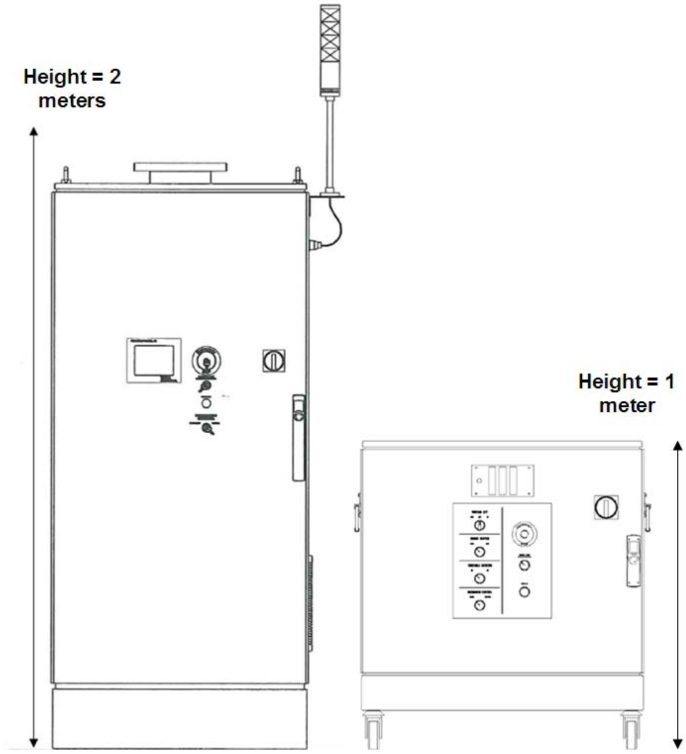

Figure 2. Modular SGS System Mechanism Enclosure (left) and the new Standard SGS enclosure (right).

Miscellaneous: Automation, Shielding, etc.

The Modular SGS does have significant benefits due to its building block approach to modify components for different applications and measurement scenarios. For example, if a pass-through automated conveyor system is needed, the only components that need to be replaced are the rotator assembly and any additional PLC modules and electronics. The Standard SGS is fairly rigid in its mechanical design and does not allow for extensive conveyor options. Both designs are typically configured with digital signal processors, such as Canberra's DSA-1000 or LYNX multi-channel analyzers (MCA).

The detector shielding design is slightly different between the two systems, but the overall lead shielding thickness is similar. The Standard SGS collimator and detector shield are made from steel weldments with poured lead. The Modular SGS uses cast and machined lead pieces for the main shielding and collimation. Both systems have cylindrical shielding and rectangular side collimation thicknesses of 4.75 cm and 5.08 cm, respectively. The top and bottom collimation has thicknesses of 7.62 cm and 5.08 cm for the Modular and Standard SGS, respectively. The increased collimator thickness in the vertical dimension for the Modular SGS is intended to accommodate high-activity drums. As we shall see in the results, this reduction in vertical shielding does not affect the performance and sensitivity of the Standard SGS (which is not intended for the extreme high-activity samples). Both systems have tin and copper liners on the inside surfaces of the shielding and collimation. Subject to the weight limits of the detector arm extension of the main frame, attenuation options are limited for the Standard SGS. Thin filters, such as tin or cadmium, can be fitted to the Standard SGS detector collimator assembly. The Standard SGS is not intended for high-count applications, where thick (~ cm), automated lead attenuators can be housed and deployed on the heavier, Modular SGS detector frame and lift.

The Standard SGS uses a high purity Germanium (HPGe) detector for nuclide identification and quantification and is typically configured with a 15 liter dewar for liquid nitrogen. This differs from the Modular SGS design (Figure 1) in that the latter is configured with a 30 liter dewar. Both SGS systems can accommodate electrical cooling systems when liquid nitrogen upkeep is impractical or prohibitibive. Both systems can also be configured with broad-energy type HPGe detectors when gamma rays below 200 keV are in abundance. When used in conjunction with appropriate isotopics codes (such as MGA or FRAM), the broad-energy HPGe detector option allows for accurate U and Pu isotopic determination.

The Standard SGS, like the Modular SGS, uses a 10 mCi Eu-152 transmission source, shielding, and shutter mechanism for wide-energy range matrix attenuation correction. Identical lead shields and tungsten shutter assemblies are used in both SGS designs. Similar to the detector portion, stronger transmission sources that require additional shielding for operational safety are subject to the weight limit of the smaller frame in the Standard SGS. These are generally needed when assaying drums of very high density matrices or drums with liners.

EXPERIMENTAL METHODS AND RESULTS

Three Standard SGS systems were constructed and tested. Because the SGS measurement and calibration procedure is a standard NDA technique [1-3], the description of the calibration and verification will be only briefly discussed. The three Standard SGS systems will be compared to both the specification sheet of the Modular SGS system, as well as a recently constructed modular system.

Standard SGS Calibrations

The three Standard SGS systems were calibrated [2, 4] with six (6) aluminum-clad rod epoxy sources of Am-241, Ba-133, Cs-137, and Co-60 with each rod having activities of 10, 10, 1, and 1 μCi, respectively [4]. One of the systems is the Standard SGS pictured in right side of Figure 1. The detectors for these systems were broad-energy type HPGe with relative efficiencies of approximately 30%. Recall that the relative efficiency of a HPGe detector is the efficiency at 1333 keV relative to a 3” x 3” Sodium Iodide scintillation detector, with a Co-60 source placed twenty-five centimeters to the endcap of the detector. They are mainly quoted to give an estimate of the sensitivity of a given detector. Efficiency curves as a function of energy and density were determined with the rod sources described above, and the drums listed in Table II. The final efficiencies used to quantify radioactivity have units of counts measured per gamma ray emitted.

Table II. Matrix Types and Densities for the 200 L Drums used in the SGS Calibrations and Verifications.

Matrix	Empty	Foam	Homasote	Particle Board	Sand
Gross Weight (kg)	26.6	31.6	109.0	173.0	352.0
Matrix Density (kg/L)	0.0013	0.024	0.396	0.704	1.564

The rods are spatially arranged within the drums to simulate a uniform source distribution and assayed to calibrate the efficiency of the system. Figure 3 shows an example of a typical multi-curve efficiency of an SGS system. In the figure, a full range of densities is used in the multi-curve calibration which can be accomplished with the ISOCS method [5] in order to extend the matrix choices available with actual calibration drums. In fact this approach can be substituted in the absence of any calibration drums, but in that case the drums serve as a reference to benchmark and validate the calibration.

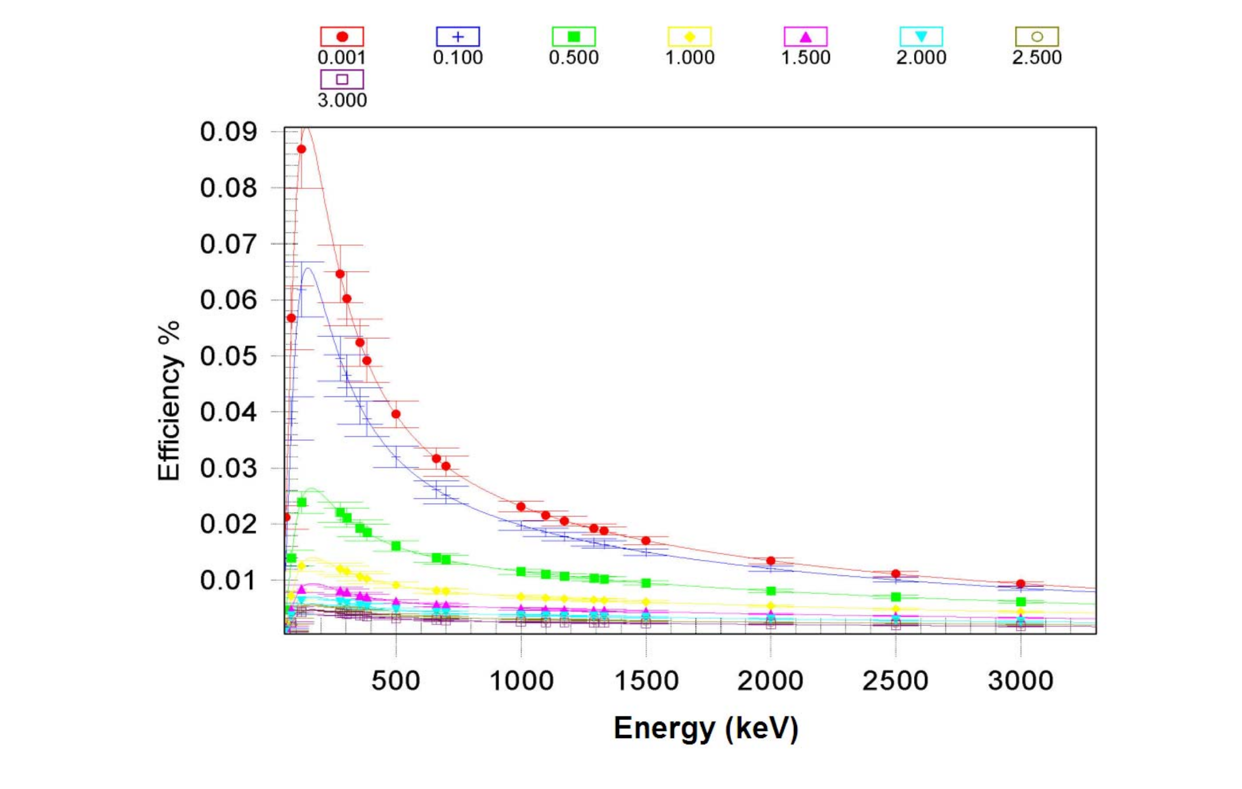

Figure 3. Multi-curve (energy and density) Efficiency of a Standard SGS system. The values of matrix densities are listed above the graph. This efficiency shown is the sum of all eight, vertical segments.

These Standard SGS systems also use a transmission source for drum matrix corrections, and the baseline of analysis is determined with an empty drum. Peak count rates of the 10 mCi Eu-152 transmission source are typically 300 – 4000 counts per second, depending on the particular gamma-ray energy and branching ratio.

In Figure 4, the top plot shows an example of the verification of one of the Standard SGS calibrations, using both the multi-curve and transmission correction analyses. The corresponding multi-curve used in the emission comparison would be very similar to the green curve in Figure 3 (solid squares, third from top). The accuracy of both the Standard SGS and the Modular SGS systems are typically ±20% or better for low to medium density drums and for energies above 150 keV. The higher recovery values for Am-241 and Ba-133 seen in the top of Figure 4 can typically be attributed to the following reasons, both associated with gamma-line energies below 150 keV. The multi-curve efficiencies at low energies (60 keV for Am-241 and 80 to 383 keV for Ba-133) are rapidly changing (as seen in Figure 3) where small biases may be seen. In addition, non-uniform source distribution and matrix attenuation effects are enhanced at gamma-ray energies below 150 keV.

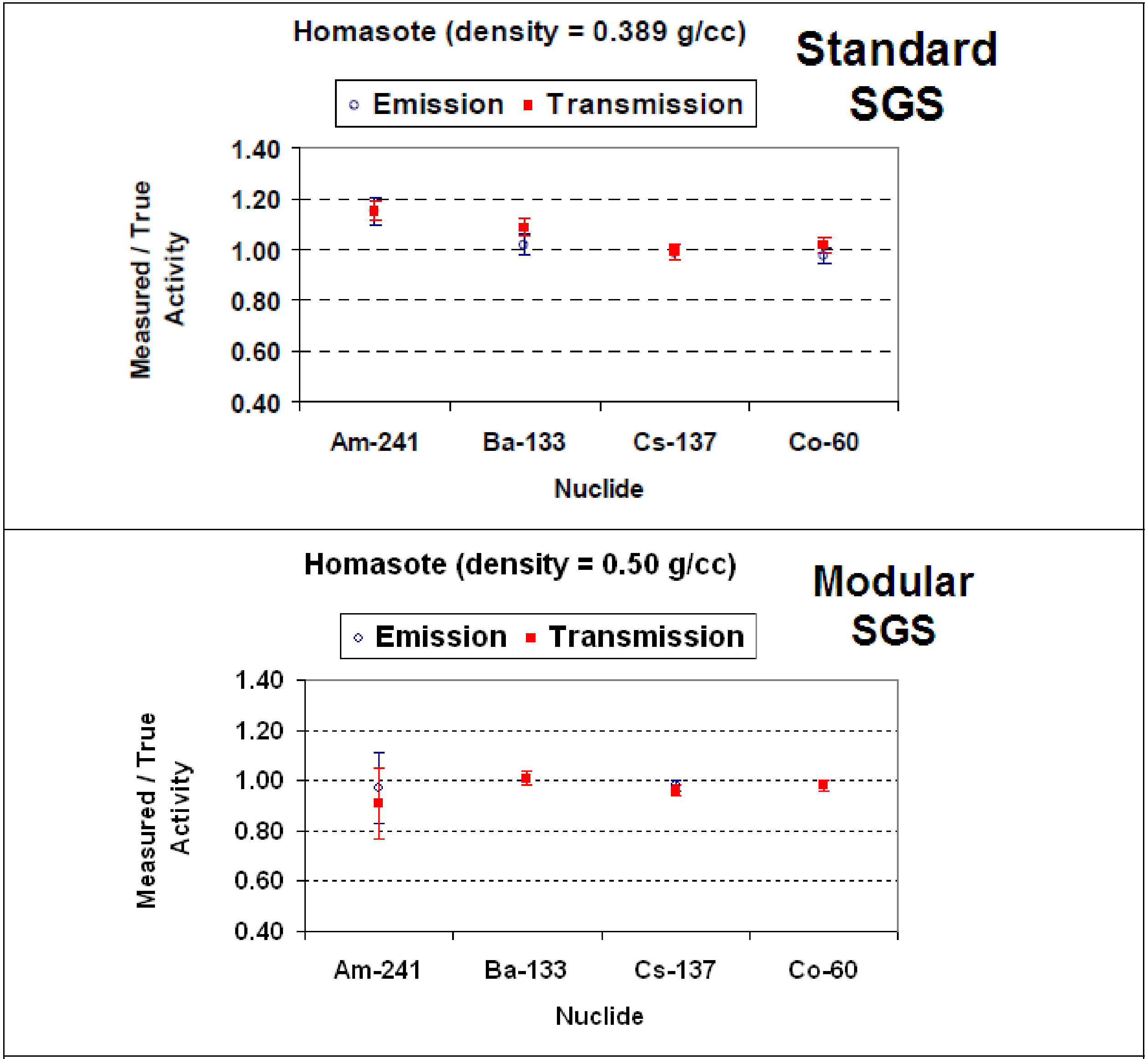

Figure 4. The calibration verification of a Standard SGS (top) is shown for the Homasote drum, where the Emission comparison (blue circles) uses multi-curve analysis and the bulk density and the Transmission comparison (red squares) is the average activity of the individual transmission-corrected segment activities. The bottom graph shows a similar calibration verification measurement for the Modular SGS system.

Modular SGS Calibration

The Modular SGS was configured with a manual rotator and a coaxial HPGe detector with 30% relative efficiency. This Modular SGS system used a LYNX as the digital signal processor and had electrical cooling of the HPGe detector, replacing the need for liquid nitrogen refilling. The efficiency of this system was calibrated with ISOCS software [5] and verified with similar drums and rods as the Standard SGS systems described above. The transmission calibration was also performed with an empty 200 L drum. Multi-curve efficiency curves similar to those shown in Figure 3 were observed, and an example of the calibration verification results is shown in the bottom plot of Figure 4. It should be noted that the Standard SGS system also is fully capable of having an ISOCS-based calibration, both reducing the need for calibration sources and drums, and allowing for the capability to calibrate a wide variety of items [5]. Verification measurements with rod sources and drums are always performed at the factory, however, in order to validate these calibrations.

MDA Comparison

The sensitivities of the four SGS systems discussed here were measured under the normal environmental background at Canberra's system testing floor and analyzed using the Currie formalism [6]. The count time was 30 minutes, and the results for a single drum are compared in Table III for all three Standard SGS systems and the Modular SGS system. The Standard SGS Systems are labeled SGS 1, 2, and 3. As expected, there is little difference between the new, Standard SGS and the Modular SGS performance and sensitivity.

Table III. Comparison of Standard SGS and Modular SGS System Sensitivities with Medium Density Matrices (0.4 – 0.5 g/cc)

Energy (keV)	Nuclide	Modular SGS MDA (μCi)	SGS 1 MDA (μCi)	SGS 2 MDA (μCi)	SGS 3 MDA (μCi)
796	Cs-134	0.09	0.07	0.09	0.07
662	Cs-137	0.11	0.09	0.11	0.08
1333	Co-60	0.06	0.06	0.08	0.06
356	Ba-133	0.13	0.08	0.11	0.07
1001	U-238	11	9	12	9
185	U-235	0.14	0.08	0.10	0.07
414	Pu-239	1,400	720	883	700

Table IV shows the empty drum MDA values of all four systems and compares these values to the specification sheet [3]. While system performance will always depend on actual measurement conditions, the specification sheet quotes MDAs under the following conditions:

- Standard 200 L (55 gal) drum,
- Density less than 0.3 g/cc,
- Background less than 0.02 mR/hr,
- No other significant nuclides present,
- 30 minute assay time.

The measured values in Table IV are lower than the specification, in part, due to the larger detectors used in the systems. The relative efficiency of the detector quoted in the specification sheet is 20%, while all four systems presented here have a relative efficiency of 30%. Also, the only drum in which the MDA was measured that is below 0.300 g/cc density was the empty drum configuration, which also has the highest intrinsic efficiency and lowest attenuation.

Table IV. Comparison of Standard SGS and Modular SGS System Sensitivities for the Empty Drum to the Specification Sheet [3].

Energy (keV)	Nuclide	Spec. Sheet MDA (μCi)	Modular SGS MDA (μCi)	SGS 1 MDA (μCi)	SGS 2 MDA (μCi)	SGS 3 MDA (μCi)
796	Cs-134	0.1	0.07	0.07	0.03	0.06
662	Cs-137	0.1	0.09	0.08	0.04	0.08
1333	Co-60	0.1	0.05	0.05	0.03	0.06
356	Ba-133	0.2	0.09	0.06	0.04	0.06

1001	U-238	20	10	9	6	9
185	U-235	0.2	0.07	0.05	0.03	0.05
414	Pu-239	12,000	633	369	174	376

CONCLUSION

A new SGS system has been developed, constructed, and tested for the measurement of various gamma-ray NDA applications. Focusing on a simpler solution for the assay of 200 L drums in low count rate, low throughput environments, a significant reduction in complexity and maintenance has been realized. By unifying the major mechanical components of the Modular SGS into a single platform, fewer moving parts and electronics are needed. The core sensing and shielding elements have not been altered. The results of this paper highlight that this simplification has not compromised the performance and versatility of the system.

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