Proceedings of ICEM '03:
The 9th International Conference on Radioactive Waste Management and Environmental Remediation
September 21 – 25, 2003, Examination School, Oxford, England

icem03-4658

A TOMOGRAPHIC SEGMENTED GAMMA SCANNER FOR THE MEASUREMENT OF DECOMMISSIONING WASTES

J.A. Mason- A.N. Technology Ltd., Unit 5/6,Thames Park, Lester Way, Wallingford, Oxfordshire,OX10 9TA, United Kingdom

A.C. Tolchard - A.N. Technology Ltd., Unit 5/6,Thames Park, Lester Way, Wallingford, Oxfordshire,OX10 9TA, United Kingdom

A.C.N. Towner- A.N. Technology Ltd., Unit 5/6,Thames Park, Lester Way, Wallingford, Oxfordshire,OX10 9TA, United Kingdom

K. Burke - A.N. Technology Ltd., Unit 5/6,Thames Park, Lester Way, Wallingford, Oxfordshire,OX10 9TA, United Kingdom

R.A. Price- A.N. Technology Ltd., Unit 5/6,Thames Park, Lester Way, Wallingford, Oxfordshire,OX10 9TA, United Kingdom

S. Dittrich & M Piotrowski - ANTECH Corporation, 9046 Marshall Court, Westminster, Colorado 80031

F. Zurey & D. Walraven - ANTECH Corporation, 9046 Marshall Court, Westminster, Colorado 80031

ABSTRACT

The ANTECH Tomographic Segmented Gamma Scanner (TSGS) combines: a) Conventional Segmented Gamma Scanner (SGS) analysis (compliant to ASTM C1133-96), b) Tomographic Gamma Scanner (TGS) analysis providing both attenuation and source distribution maps (effectively 3D images) of the interior of drums, and c) Isotopic ratio analysis for uranium and transuranic elements using PC-FRAM.

In SGS mode the drum is rotated and scanned segment by segment along its height. A two-pass measurement, one for transmission and one for emission, results in two spectra for each segment. An assay is made by measuring the intensity of a characteristic gamma ray from each nuclide. Corrections are made for count rate-related losses and attenuation by the item (using a transmission source). Calibration standards are used to provide the relationship between observed gamma-ray intensity and nuclide content. On completion, count rates are summed, and mass values for the nuclides of interest in the entire drum are calculated based on comparisons to appropriate calibration materials. In the case of SGS, the matrix is assumed to be homogeneous on a segment by segment basis.

TGS involves measuring drums in segments as for SGS. However, in the case of TGS, while the drum is rotated, it is also moved in the horizontal direction (translated). Also, instead of taking a single large spectrum for each segment, 150 separate spectra are taken as the drum rotates and is translated. These 150 spectra are obtained both for transmission and for emission measurements. The 150 spectra taken for transmission constitute a set of data that can be solved to yield the distribution, or map of attenuation coefficients throughout the segment of the sample or drum. The measurement equations are over specified and the solution uses a maximum likelihood analysis. This results in the determination of a map (after a geometric transformation) of attenuation coefficients in a rectangular grid suitably superimposed on each segment. The attenuation map enables the operator to 'visualise' the variation of the density (governed by the collimator size and voxel resolution) in regions of the drum. This serves a non-destructive examination function similar to 'real time radiography' but with lower resolution.

For the analysis of the emission data, the additional information obtained from the transmission data allows the emission data to be corrected for attenuation. This attenuation correction is the essential and important characteristic of TGS measurements not present in other gamma-ray measurement systems. For the first time in the case of the TGS, the map of attenuation is used to correct the measured source distribution in the matrix (segment by segment). The TSGS extends the range of gamma-ray measurement technology, as it is able to correctly determine the attenuation corrected radionuclide inventory in heterogeneous matrices where previous techniques such as the SGS are only applicable to homogeneous matrices. In the case of TGS a single calibration based on a non-interfering or empty matrix is made and then corrections relating back to this non-interfering matrix are made using the attenuation information determined from the transmission scan.

INTRODUCTION

The ANTECH TSGS and SGS range of gamma ray assay instruments consist of different instruments for different size drums and applications. The ANTECH general purpose SGS is the model 3200, which is available in 200, 320 (340) and 400 litre variants. The 320 (340) litre version will also measure 200 litre drums and the 400 litre variant will measure both 320 and 200 litre drums. All configurations will also measure smaller samples, for example product cans and bottles. The adjustment of the detector position allows the instrument performance to be optimized for the measurement of different drum sizes and of smaller containers.

The model 3800 TSGS range of gamma scanners, which include both SGS and TGS capability, also covers the same drum sizes. In addition the model 3900 Shielded TSGS is available in the 320 (340) litre configuration. This instrument has the same specification as the TSGS model 3800-320 but is contained in a 4 PI steel shield with a thickness of 100 mm. The result of shielding the TSGS is to greatly reduce the effect of background radiation and thus improve the minimum detection level (MDA). The unit will also operate in SGS mode.

GENERAL TSGS SPECIFICATION

The ANTECH Tomographic Segmented Gamma Scanner (TSGS) quantitatively determines the radionuclide content of waste drums in a size from 200 litre to 400 litre drum sizes. Detecting the range of gamma ray energies emitted by the radionuclides allows a radiological assessment and classification of the waste to be made, including determining the activity (or mass) of specific radionuclides in the drum. The ANTECH TGS is shown in Figure 1 below.

Figure 1 - The ANTECH Series 3800 Tomographic Gamma Scanner

The TSGS can operate as both a Segmented Gamma Scanner (SGS) for measuring homogeneous waste and as a Tomographic Gamma Scanner (TGS) for measuring heterogeneous waste. The TSGS also contains analysis software (the Los Alamos National Laboratory (LANL) PC/FRAM code) to determine the Plutonium isotopic ratios and the ratios of Pu to other radionuclides such as U-235.

The ANTECH TSGS is transportable and uses Los Alamos developed transmission corrected, single photon emission computerised axial tomography to determine the spatial distribution and quantity of radionuclides using high resolution gamma ray spectrometry (HRGS). The technique represents a considerable advance over the Segmented Gamma Scanner (SGS) technique through the implementation of a sample translation axis in addition to the conventional vertical scanning and rotation axes.

A gamma ray transmission source (^{75}Se, ^{75}Se/Co combination or ^{152}Eu), located in a shielded holder, is used to separately assess the absorption of the waste matrix in both SGS and TGS mode. The transmission source allows the determination of a three dimensional spatial map of the attenuation coefficient at an energy by interpolating between the gamma-ray peaks of the transmission source at several energies. Once the attenuation coefficient maps have been established for the sample, emission tomography is used to determine the distribution of selected radionuclides within the sample. Two pass (transmission follows by emission at each vertical segment) measurements are performed. This ability to produce both attenuation coefficient and source emission images for each vertical segment of the sample or waste drum is a further advantage of the TGS over the conventional SGS. Typically the spatial resolution for the emission image is ~6cm for waste drums. Also because the attenuation and source distribution matrix is known more accurately than in an SGS, biases due to matrix and source distributions are significantly reduced. As a result, a single calibration constant can be used for the determination of the nuclide mass for a wide range of material and matrix types. Isotopic ratio analysis of Pu is performed using the PC/FRAM code. A count rate loss (deadtime) source (usually ^{109}Cd) is used.

The TSGS contains a load cell to determine the drum weight and a range of cans and drums can be measured up to 320 litre (equivalent to the US 85 gallon over-pack drum). When operated in TGS mode, the instrument produces three-dimensional digital images or maps of both the density variation in the drum (from transmission tomography) and the source distribution in the drum (from emission tomography) in addition to the conventional assay result. These images or maps provide a very useful non-destructive examination (NDE) tool when characterising waste drums.

The ANTECH TSGS is constructed on a modular basis. This proven approach allows the baseline design to be readily tailored to suite specific customer requirements. The user can easily configure the measurement software for differing drum sizes, batch operations and measurement requirements.

SEGEMENTED GAMMA SCANNER

The measurements performed by the Segmented Gamma Scanner depend on measuring the intensity of characteristic gamma rays from each radionuclide. The intensity of the characteristic gamma ray is corrected for count rate losses using the dead time source and attenuation by the waste matrix using the transmission source. The relationship between the measured gamma-ray intensity and nuclide content of the waste drum is obtained from similarly corrected gamma-ray intensities using calibration standards.

The drum is rotated about its vertical axis and simultaneously scanned, segment-by-segment along the vertical axis. This method of scanning reduces the effects of non-uniformity in waste density and nuclide distribution. Corrections are made for count dependent losses from pulse pile-up and analyser dead time, as these are monitored during the measurement process.

The detector is shielded in such a manner so as to allow the waste drum to be scanned in segments (typically 10 to 16 segments for a 200 litre waste drum). For each vertical segment of the drum the average linear attenuation coefficient is calculated by measuring the transmitted intensity of an external gamma-ray transmission source. The source is mounted directly opposite the gamma-ray detector on the far side of the drum. The system normally operates in a two-pass mode (measurements made with the transmission source shutter closed, then opened, at each vertical segment).

The SGS makes the assumption that the waste has a uniform density within each horizontal segment. The energy of the transmission source is selected to match that of the gamma-ray line(s) being measured. ^{75}Se is typically used for the measurement of ^{239}Pu, while isotopes such as ^{152}Eu or ^{154}Eu, which have longer half lives and many more gamma ray lines, extend the SGS measurement to the determination of U, Co, & Cs isotopes. State-of-the-art digital counting electronics, the DSPec digital multi channel analyser is provided by ORTEC, an alliance partner of ANTECH, allow high dynamic counting rate ranges. Dead time corrections are measured with a second small, low-energy source positioned near the detector (^{109}Cd).

At the completion of the measurement of all segments, count rates are summed, and mass values for the nuclides of interest in the entire container are calculated based on comparisons to previously measured, appropriate physical standards. Counting precision data calculated for individual segments are propagated to obtain the estimated precision of the analysis based on counting statistics. This data is folded in with systematic biases to arrive at a total measurement uncertainty.

TOMOGRAPHIC GAMMA SCANNER

TGS was developed in the early 1990s by the Los Alamos National Laboratory (LANL) with funding from the Department of Energy (DOE) Office of Safeguards and Security. The technique is licensed to ANTECH Corporation.

The objective of the work was to develop a cost-effective upgrade to SGS to deal with the increasing number of large, heterogeneous samples encountered in the field. SGS was suitable for assaying samples for which the spatial variation in the gamma-ray attenuation coefficient was small. Certain waste inventory could not be assayed using SGS since the assumption of homogeneity on which SGS is based was rarely valid for these wastes.

The geometry of TGS measurements is shown in Figure 2. The main difference between TGS and SGS is the addition of a translation axis that allows the detector to view the sample along all possible lines that pass through it. TGS uses the fundamental principle of computerized axial tomography. By stacking slices (axial scanning), the spatial distribution of material within the entire sample can be recovered.

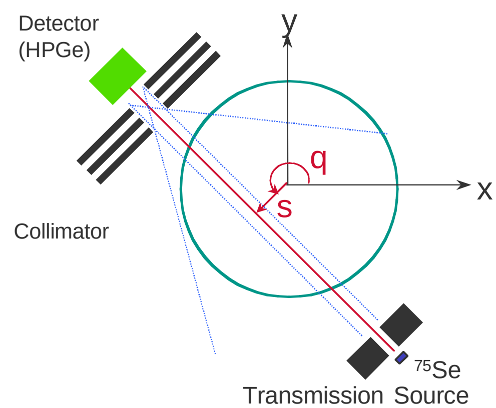

Figure 2 - TGS measurement geometry.

TGS uses transmission-corrected, single-photon emission, computerized tomography (SPECT) to determine the spatial distribution and quantity of radionuclides within a waste drum. High-resolution gamma-ray spectroscopy (HRGS) is used to make accurate measurements of individual gamma rays in complex spectra. Transmission computerized tomography is used to develop a three-dimensional spatial map of the attenuation coefficient of the sample. By using a radioisotope such as ^{75}Se or ^{152}Eu for the transmission source, gamma-ray transmission can be measured accurately at several energies. By interpolating the transmission data, spatial maps of the attenuation coefficient can be obtained at any energy.

Once the attenuation map has been determined, emission tomography is used to determine the distribution of selected radioisotopes within the waste drum. The waste drum is scanned with the transmission source shuttered off and net counts are recorded for regions of interest (ROI) about peaks corresponding to gamma rays emitted by the target isotope. For plutonium assays, ROIs are typically established for four well-resolved gamma rays: 129-, 203-, 345-, and 414-keV. Each of these gamma rays is used to develop an independent estimate of the distribution and amount of ^{239}Pu within the waste drum.

As the waste drum rotates and translates relative to the detector, the net count rate varies. The magnitude of the net count rate depends on the distance of the gamma-ray source from the detector and the intervening attenuating material. Since the attenuation map is known for the gamma ray of interest, the net count rate can be calculated for trial distributions of the emitting material for each detector location. The calculation requires knowledge of the detector spatial response function, which is determined by Monte Carlo simulations. Reconstruction of the spatial distribution of emitting material is accomplished by adjusting the trial distribution until the estimated net counts match the measurements.

By integrating the emission distribution over the volume of the waste drum, a number proportional to the amount of the selected isotope within the waste drum is obtained. Because bias caused by variations in the source position and matrix attenuation has been reduced, a single calibration constant can be used to determine the mass of the selected isotope for a much wider range of material and matrix types that was previously possible. For example, it is reasonable to use the same calibration constant for combustibles and cemented sludge. In attempting to make SGS work, count room operators would develop separate calibration constants for a large number of waste drum categories, with the hope that the variation in bias within each category would be small enough to meet accuracy requirements. Needless to say, this practice was costly and time consuming and required a valid reference technique. By eliminating the need for item categorization, TGS reduces the effort required for calibration.

In a TGS scan, the waste drum is divided into 10 to 16 axial sections (or layers), depending on the height of the waste drum. Within each layer, the waste drum is rotated and translated continuously. ROI data are acquired in uniform time intervals. The scan of a layer is broken into 150 such intervals, each associated with a narrow set of displacements and angles. Transmission and emission ROI data are stored for each interval and are later used to reconstruct the attenuation coefficient image and emission distribution. The length of each interval is typically short, no more than 0.6 s. Consequently, the entire waste drum can be covered in less than 30 min. Assuming two passes are made, one for transmission and one for emission, the total data acquisition time is less than 1 h. With this scan protocol, each layer can be represented by a coarse image with approximately 100 image elements.

The accuracy of TGS is almost always better than 10% root-mean-square (RMS) difference between measured and reference values. However, the accuracy that can be achieved depends on the density of the contents and the distance gamma rays must travel to escape the sample. For assays of plutonium in 208-L drums containing cement (~2 g/cm^3 bulk density), it has been found that the scan protocol described here yields better than 20% RMS difference. Note that for such samples, it has been found SGS to be in error by more than a factor of 5.

Because accuracy depends on waste drum size, we usually quote accuracy in terms of areal density. For example, as a rule-of-thumb we expect TGS measurements of ^{239}Pu using the 414-keV gamma ray to have better than 10% accuracy for waste drums with areal density less than 90 g/cm^2. To get bulk density, simply divide areal density by the diameter of the waste drum. Assays of 208-L drums containing metal scrap are typically accurate to within 10%. Also note that increasing the resolution of the scan along with the scan time can improve accuracy. So, in principle, the accuracy of TGS is limited only by how long the operator is willing to wait.

The precision that can be achieved by TGS varies from waste drum to waste drum and depends on the placement of the source, the distribution of attenuating material, and collimator parameters. Precision also depends on the isotope being measured. For 208-L drums, as little as 0.5 g ^{239}Pu in low-density matrices with <1-h acquisition time (this is based on actual measurements – see later for theoretical predictions on the MDA of TSGS measurements). With the typical collimator settings, a 1-h TGS scan will produce the same precision as a 20-min SGS scan. The minor loss in precision is not noticed for waste drums >10 g ^{239}Pu, and is a penalty that must be paid for increased accuracy

The advantage of TGS operation mode is that it is suitable for drums of heterogeneous waste. These can be drums with a heterogeneous distribution of the matrix or of the radioactive sources. TGS measurements involve measuring drums in layers as for Segmented Gamma Scanner (SGS) measurements. However, in the case of TGS mode, the drum is rotated, and simultaneously moved in the horizontal direction. Also, instead of taking a single large spectrum for each layer, 150 separate spectra are taken as the drum is moved. These 150 spectra are obtained both for transmission and emission measurements.

The spectra taken for transmission constitute a set of data that can be solved for the distribution or map of attenuation coefficient throughout the segment of the sample or drum. After a geometric transformation, the attenuation values of the segment, one each for a series of rectangular grid elements, is determined by maximum likelihood analysis.

A similar approach is used for the analysis of the emission data, however, the additional information obtained from the transmission data allows the emission data to be corrected for attenuation. This attenuation correction is the essential and important characteristic of TGS measurements not present in other gamma-ray measurement systems.

As a result the TGS is capable of measuring heterogeneous matrices where previous techniques such as the SGS are only applicable to homogeneous matrices. The ANTECH TGS can operate, if required, in SGS mode with drums with homogeneous waste content.

Table 1 – ANTECH TSGS Minimum Detectable Activities

Nuclide	γ Energy (keV)	Half Life (years) approx.	Branching Ratio	ANTECH 3200	SGS unshielded	ANTECH 3800	TGS unshielded	ANTECH 3900	TGS 1" Pb partial shield	ANTECH 3900	TGS 4" Steel shield
				MDA (kBq)	MDA (g)	MDA (kBq)	MDA (g)	MDA (kBq)	MDA (g)	MDA (kBq)	MDA (g)
^{137}Cs	662	30.1	0.84	3.8		3.8		1.6		0.4	
^{134}Cs	605	2.1	1	3.2		3.2		1.3		0.3	
^{60}Co	1173	5.3	1	3.2		3.2		1.3		0.3	
^{152}Eu	964	12.7	0.146			22.1		9.1		2.3	
^{152}Eu	1408	12.7	0.21	15.4		15.4		6.3		1.6	
^{239}Pu	413.7	24110.0	0.0000147	458000.0	0.2	458000.0	0.2	187780.0	0.082	46945.0	0.0205
^{235}U	186	7.04E+08	0.572	7.3	0.1	7.3	0.1	3.0	0.04	0.7	0.010
^{238}U	1001	4.47E+09	0.0059	547.7	43.7	547.7	43.7	224.6	17.9	56.1	4.48
^{241}Am	59.5	431	0.363	12.6		12.6		5.2		1.3	
^{237}Np	200	0.82	0.064	71.5	2.74E-03	71.5	2.74E-03	29.3	1.1E-03	7.3	2.8E-04

Under normal operation in TGS mode, the system will provide an attenuation map and an emission map for each segment of the drum. Typically, 200 liter drums will be mapped into 16 segments or 16 vertical sections. The spatial resolution is optimized and can be varied by modifying the collimation of the detector and the measurement time.

In TGS mode the 150 spectra taken for transmission constitute a set of data that can be solved for the distribution or map of attenuation coefficient throughout the segment of the sample or drum. The problem is over specified and the solution involves a maximum likelihood analysis, which results in the determination of the map (after a geometric transformation) of the attenuation coefficient in a rectangular grid superimposed on the segment.

As a result of the use of TGS mode, the TSGS is capable of measuring heterogeneous matrices where previous techniques such as the SGS are only applicable to homogeneous matrices. (It is important to note that the SGS has in many cases been improperly used to measure heterogeneous matrices and corrections for reducing measurement errors have been established by providing calibrations specific to each matrix type). In the case of TGS a single calibration based on a non-interfering matrix is made and then corrections relating back to this non-interfering matrix are made using the attenuation information determined from the transmission scan.

Although the TGS technique extends the envelope of the range of measurements which are possible, it has some limitations. The precision of the TGS technique depends on the degree of attenuation although compensation is made for attenuation the presence of materials with densities higher than 2000 Kg/m^3 lead to reductions in measurement precision because signal is lost as a result of the attenuation. The technique does, however, identify situations where a measurement cannot be made. For example, if a tungsten container were placed in the center of the drum, the SGS technique would fail to identify the black absorber in a drum and simply report an average attenuation for the drum segment as a whole. An SGS would not see a Pu sample placed in such a tungsten container inside a drum.

THEORY OF TGS OPERATION

The tomographic gamma scanner (TGS) method computes the total mass of the radionuclide to be assayed (e.g., ^{239}Pu) as a calibration constant multiplied by the sum of the emission-image voxel values of the TGS emission image vector. The sum, which is proportional to the mass, is referred to as the "emission image sum" (also, less formally, as the "TGS number"). The emission image is found by solving the system of equations involving a vector of measured count rates of the full-energy gamma-ray peak that the assay is based on (e.g., the 414 keV gamma ray of ^{239}Pu) and a response matrix for the sample. This matrix describes variations in both the geometric counting efficiency and attenuation losses due to the matrix as a function of the voxel and detector positions. Various image reconstruction techniques are in use for solving the equations: 1) the expectation-maximization (EM) algorithm and 2) the algebraic reconstruction technique (ART), the latter is coded in the TGS image reconstruction software.

PERFORMANCE

Minimum Detectable Activity

The minimum detectable activity (MDA) for a drum is reached when the gamma ray lines used to produce the calibration are no longer distinguishable from the background. The MDA is thus influenced by a number of factors including: 1) the background, 2) the absorption of the package, 3) the absorption within the drum waste matrix, and 4) the absorption of the drum itself. The flexibility of the TSGS allows the operator to use the higher energy lines for the isotopes.

The MDA values have been determined for 200 litre (55 gal US) drums with a matrix density of approximately 0.3 g/cc and with a background typical of a nuclear facility.

Measurement time is 30 minutes for SGS and 60 minutes for TSGS (operated in TGS mode). For both unshielded SGS (model 3200) and unshielded TGS (model 3800), the measurement data is applicable to a 50% HPGe detector. The results are shown in Table 1 above.

For the shielded TSGS model 3900 (operated in TGS mode) with the standard 100 mm. (4 inch shield) the applicable measurement time is 60 minutes and the HPGe detector efficiency is 35%. This data is presented in the last two columns of the table and is headed TGS 4" steel shield (4 π).

For comparison, data is presented in the second to last two columns of the table headed TGS 1" Pb partial shield. This data is applicable to a standard model TGS, which has been partially shielded with a lead shield of 25 mm, equivalent to 50 mm of steel. In this case the measurement data is applicable to a 50% HPGe detector and the measurement time is again 60 minutes.

It can be seen that the MDA is reduced compared to the unshielded instrument but not to the extent of the fully shielded model 3900 TSGS. In all case the 200 litre drum is measured in 16 segments. The calculation of the Minimum Detectable Activity (MDA) is usually based on the Currie formalism (reference L A Currie, Analytical Chemistry Vol 40:586 (1968)).

Comparison Between SGS and TGS Measurements

The TSGS, operating in SGS mode, was calibrated (SGS number vs. activity (μCi)) using ^{137}Cs sources in a waste matrix of density 0.3g.cm^{-3} using a ^{152}Eu transmission source. The calibration is shown in Figure 3 below.

The TGS convention has been used in quoting 'SGS numbers' in order to simplify the data handling. This quantity is directly proportional to the area under the detected gamma ray peak, which is the more conventional way of quoting the SGS data.

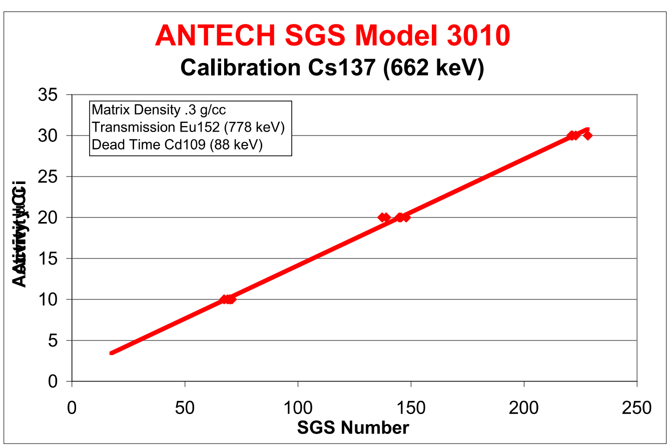

Figure 3 – Calibration of Segmented Gamma Scanner

In tomographic mode, the matrix attenuation correction of the emitted gamma rays is carried out on a voxel by voxel basis, the TGS calibration is thus matrix independent.

The TGS operating in tomographic mode was therefore calibrated (TGS number vs. activity (μCi)) using ^{137}Cs sources in an empty container. Again a ^{152}Eu transmission source was employed in the system. The calibration is shown in Figure 4 below.

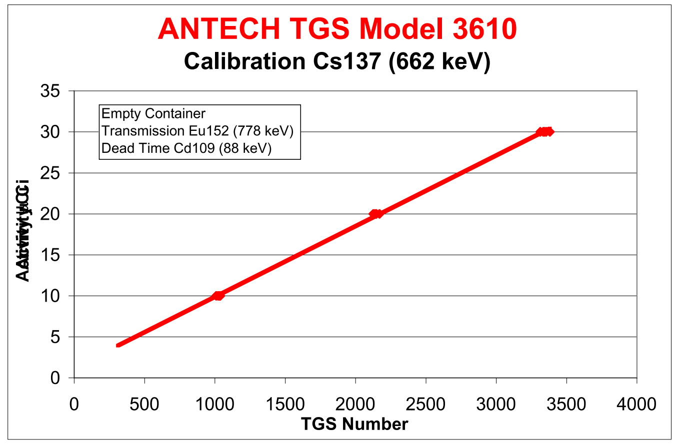

Figure 4 - Calibration of Tomographic Gamma Scanner

Replicate measurements of the 30μCi ^{137}Cs source were then conducted using the TSGS operating in a) conventional segmented gamma scanning mode, and b) tomographic scanning mode.

The source was placed alternatively at the centre and then at the edge of the waste container. The results are as shown in Figures 5 & 6 below.

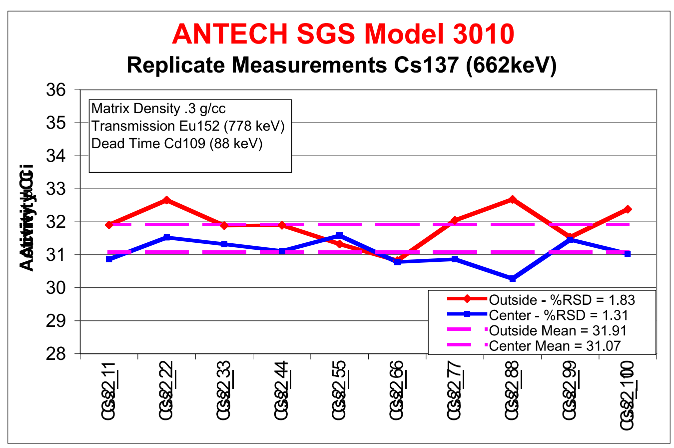

Figure 5–Replicate Measurements of a 30μCi source (SGS)

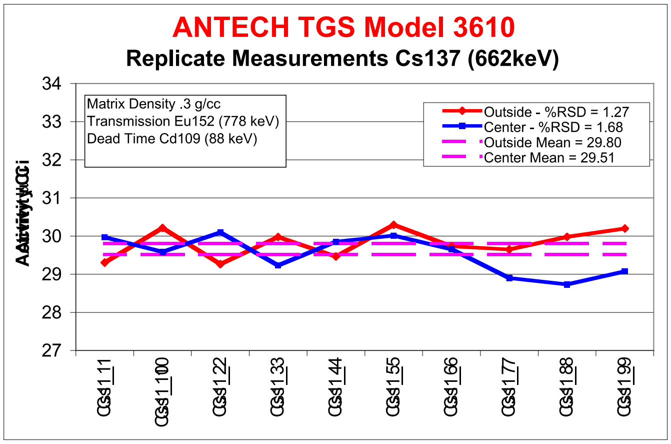

Figure 6-Replicate Measurements of a 30µCi source (TGS)

The SGS measurements show a slight radial bias. The superior performance of the tomographic gamma scanning mode lead to the TGS measurements showing an improved precision when compared with the SGS measurements.

The measurements were repeated with a 10µCi and 20µCi source and the % relative standard deviation between the TGS and SGS compared in the chart shown in Figure 7 below.

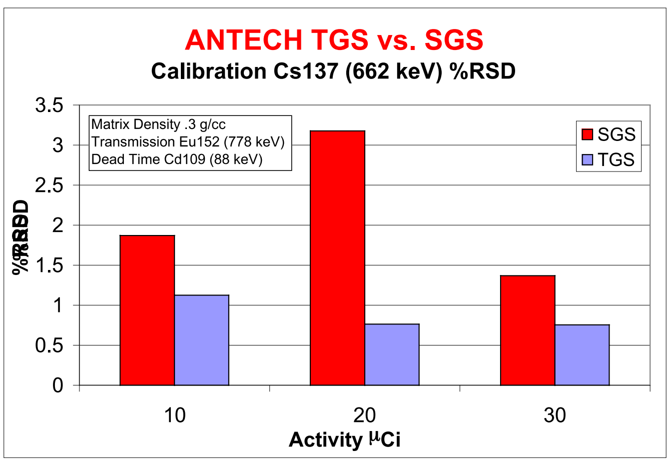

Figure 7 - % Relative Standard Deviation (TGS and SGS)

SGS measurement assumes that each segment has a homogeneous matrix density. Large errors can occur in SGS measurements if one or more segments have a heterogeneous matrix density. This situation was simulated by placing a tungsten cylinder at the edge of the TSGS measuring platform and determining the error (% difference) for replicate measurements of a ^{137}Cs source in a) SGS mode, and b) TGS mode. The data is as shown in Figure 8 below.

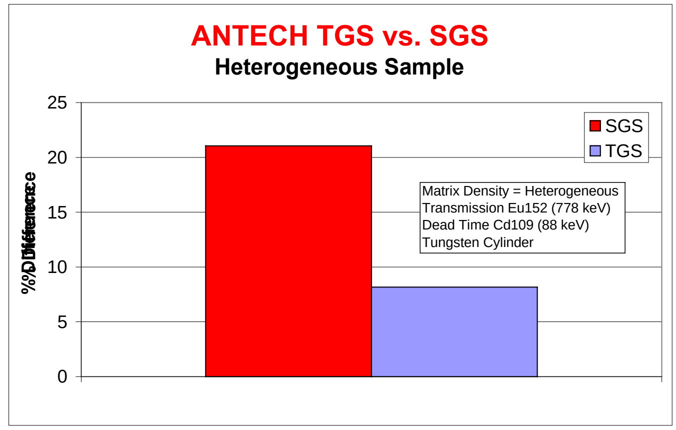

Figure 8 – TGS & SGS Errors in Heterogeneous Matrix

When the experiment was repeated with a longer count time (resulting in improved counting statistics), the error (% difference) for the SGS measurement remained the same while the error for the TGS measurement was reduced to below 5%.

TGS INSTRUMENTATION

Detector System

The ANTECH drum TSGS system uses a 50 % safeguards coaxial high purity Germanium (HPGe) detector that has a resolution at 1.33MeV of 1.8keV (typical 1.76keV). The system has a 30 litre liquid nitrogen Dewar cryostat cooling system with automatic shut down capability.

The detector and preamplifier have an appropriate lead shield and removable tungsten collimator to shield the detector system. The system can also be used with an electrical cooler such as the ORTEC X-cooler.

Drum Turntable

In TGS mode, the ANTECH TGS uses continuous scans with a short data grab time. Typically, 150 spectra are obtained each for transmission and emission measurements of the drum. Continuous scanning with the collection of single spectra is employed in SGS mode. The drum is rotated on a drum turntable. The detector mounting system is capable of being adjusted in position so that it can move close to or far away from drums being measured. The detector platform is mounted on a vertical lifting system so that it can move up and down in the vertical direction. In TGS mode, the horizontal movement of the drum is accomplished by moving the drums while the detector system remains stationary.

Initially this involves the positioning the detector to measure a particular segment of the drum. When the detector is in position, the drum is then simultaneously rotated and moved in a horizontal direction. As this scanning rotation and linear motion takes place, the detector system makes measurements of typically 150 line integrals through the drum, first for emission and then for transmission. The system is capable of delivering the very accurate position both in linear and rotational terms to accomplish this measurement. Once a particular segment is measured, the detector platform is moved to position the detector and transmission source for the measurement of the next drum or can segment. In SGS mode no horizontal movement of the drum takes place.

The motion of the drum and detector platform has a degree of accuracy higher than that required to achieve the necessary position accuracy. The ANTECH motion control system involves the use of a Parker 6K4 integrated four axes motion controller, although only 3 axes are normally used. In addition, accurate stepper or servo-control motors are used in the linear and rotational motion of the entire system. ANTECH equipment has been proven in operation and systems with broadly similar characteristics are in use at the Rocky Flats plant of the US Department of Energy and at the Los Alamos National Laboratory.

Collimators

The system is normally provided with three collimators. Two are for the TGS measurement of drums and cans. In TGS mode, the spatial resolution achievable with the drum collimator is typically 6cm x 6cm x 6cm and the spatial resolution appropriate for smaller drums and cans is typically 3cm x 3cm x 3cm. The collimators are easily interchanged by the operator and the control system senses and records electronically which collimator is inserted and that it is correctly inserted. The third collimator is for use in SGS mode.

Transmission& Deadtime Source

A ^{152}Eu transmission source is normally provided with the TSGS system. The source holder design is such that several holders can be prepared to accommodate different sources without additional operator exposure. The source shield and collimator system for use with the TSGS are inherently safe to minimize operator dose and maximize safety of operation. The system uses a fail-safe shutter design and a safe source loading system. The transmission source shield and holder are manufactured from tungsten. A ^{109}Cd deadtime source is also provided.

Electronics

The system multi-channel analyzer (MCA) is the ORTEC DSPEC plus, digital spectrometer with unique TGS mode data handling capability. The DSPEC plus has features specific to the ANTECH TSGS. The MCA contains both the high voltage and low voltage power supplies for the detector and is located less than one half meter from the detector. The system is controlled and data is transmitted from the MCA by an Ethernet data transmission system so that the analogue cables between the MCA and the detector are no more than one half meter in length.

Software

The ANTECH TSGS system uses the LANL PC/FRAM plutonium isotopic code (which also determines the presence of U and Am). In SGS mode, the data which is obtained from the emission spectra for each segment is used to provide a spectrum from which the PC/FRAM analysis determines the isotopic ratio of Pu and U and Am in the waste. In TGS mode the emission spectra for each segment are summed to provide the spectrum for PC/FRAM analysis.

As a non-destructive examination (NDE) tool the ANTECH TGS analysis software provides graphical images of each segment of the Waste Drum, based on separate images for transmission for the map of the attenuation coefficient and a map of the sources of radionuclides.

During normal operation the software provides for a periodic (typically daily) verification of the operation of the system based on the measurement of an identified calibration drum. The software also provides appropriate quality control analysis and an appropriate QC report is available from the system.

An appropriate graphical user interface is included in the system, which provides access to all the functionality of the TSGS. The TSGS can be operated locally using the ANTECH TGS MASTERSCAN software (particularly for maintenance use) or ANTECH SGS MASTERSCAN software or remotely. The local interface permits full operation of the TSGS and allows it to be configured for measurement through a set of control screens.

CONCLUSION

Since the introduction of the first commercial TSGS by ANTECH in July of 2000 in the USA, some 12,000 TGS measurements have been performed in the US DOE complex, both at Rocky Flats and Los Alamos. Several TSGS instruments have been certified to measure Transuranic Waste destined for the Waste Isolation Pilot Plant (WIPP), the US waste repository. The TGS is playing an important role in nuclear waste measurement by extending the envelope of waste types amenable to routine measurements.

REFERENCES

1. T. H. Prettyman, S. E. Betts, D. P. Taggart, R. J. Estep, N. J. Nicholas, M. C. Lucas, and R. A. Harlan, “Field experience with a mobile tomographic nondestructive assay system,” Proceedings of the 4th Nondestructive Assay and Nondestructive Examination Waste Characterization Conference, Salt Lake City, Utah (October 24-26, 1995) 109-137.

2. T. H. Prettyman, L. A. Foster, and R. J. Estep, "Detection and Measurement of Gamma-Ray Self-Attenuation in Plutonium Residues," Proceedings of INMM (1996) pp. 130-136.

3. T. H. Prettyman, S. E. Betts, A. C. Muscatello, and D. Catlett, "Final Report on the Mobile TGS Demonstration at Rocky Flats," Los Alamos National Laboratory, report LA-UR-98-4052 (1998).
4. T. H. Prettyman, R. A. Cole, R. J. Estep, and G. A. Sheppard, “A maximum likelihood algorithm for gamma-ray tomographic nondestructive assay,” Nuclear Instruments and Methods in Physics Research A **356** (1995) 470-475.
5. T. H. Prettyman, “Precision estimates for tomographic nondestructive assay,” Proceedings of the 5th International Conference on Facility Operations-Safeguards Interface (American Nuclear Society, Inc., La Grange Park, Illinois 1995), ANS Order No. 700226, pp. 191-199.
6. T. H. Prettyman, R. J. Estep, and G. A. Sheppard, “Development of a tomographic instrument for tomographic nondestructive assay,” Transactions of the American Nuclear Society **69** (1993) 183-184.
7. T. H. Prettyman, “ARC_TGS User’s Manual,” Los Alamos National Laboratory Transuranic Waste Characterization/Certification Project – Records Management, TWCP-1493 (1998).
8. R.J. Estep, T.H. Prettyman, and G.A. Sheppard, "Tomographic Gamma Scanning to Assay Heterogeneous Radioactive Waste," Nucl. Sci. and Eng., 118 (1994) p 145-152.
9. R.J. Estep, "User's Manual for TGS_FIT Version 2.0" Los Alamos Document NIS6-QAP-00.33, Rev 2.0 (December 7, 2000).
10. R.J. Estep, T.H. Prettyman, and G.A. Sheppard,, "Reduction of TGS Image Reconstruction Times Using Separable Attenuation Coefficient Models," ANS Winter Meeting Transactions, San Francisco, California (Nov., 1995).
11. R.J. Estep, T.H. Prettyman, and G.A. Sheppard, "Comparison of Attenuation Correction Methods for TGS and SGS: Do We Really Need Selenium-75?," Proceedings 37th Annual INMM meeting, Naples, Florida (July 28-31, 1996).
12. S. Dittrich, M. Piotrowski, R. J. Estep, L. Foster, "Detection of Opaque Voxels in a Heterogeneous Matrix using Tomographic Gamma Scanning," 44th Annual INMM meeting, Phoenix, Arizona (July 13-17, 2003).