Canberra's Tomographic Gamma-Ray Scanning (TGS) System for small containers

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Canberra Tomographic Gamma-Ray Scanner

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Can-TGS for small containers

- **Canberra invested in the Can-TGS as an R&D tool.**
  - To conduct TGS related studies, new developments
  - Serves as a test bed for testing hardware and software upgrades
  - Used as a training tool for Canberra personnel, and for customer demos.
  - Can be operated in the SGS mode too

- **Recent measurements on the Can-TGS**
  - Characterized the system using representative matrices and point sources; assayed heterogeneous matrices; compared SGS vs. TGS
  - Exploring the limits of TGS sensitivity and Minimum Detectable Activities (in progress)
  - QA testing updated version of NDA2000 software for TGS functionalities (in progress)

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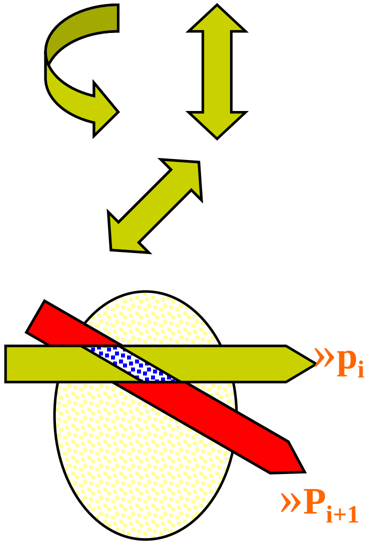
Can-TGS Supported Containers

Container Description	Diameter	Height
DOE 3013	5" [127 mm]	10" [254 mm]
1 US Gal	7.375" [187 mm]	7.312" [185 mm]
2 US Gal	9.75" [247 mm]	9.25" [235 mm]
3.5 US Gal	11.875" [302 mm]	10.25" [260 mm]
5.0 US Gal	11.875”[302 mm]	13.35”[339 mm]

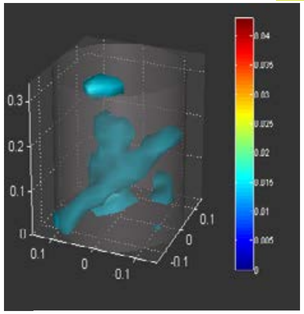
Quality of assays and images

TGS Technique

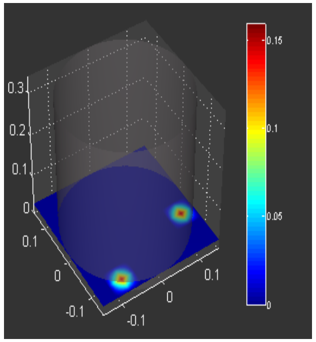
- Combines high resolution gamma spectroscopy with image reconstruction techniques
- Solves for photon attenuation and radionuclide distribution on a voxel (volume element) by voxel basis
- Uses both gamma ray transmission + passive emission measurement



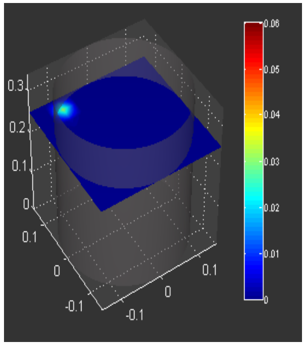
- Scans performed with three degrees of freedom
  - Rotation
  - Elevation
  - Translation – breaks axial symmetry and ensures equal weighting for all voxels



»Attenuation of 662 keV Cs-137

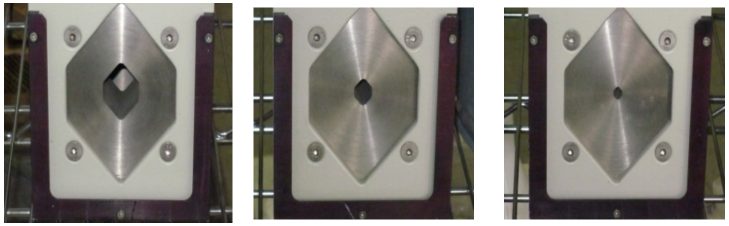


»Emission of 662 keV Cs-137



»Emission of 1332 keV Co-60

- TGS collimator options



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Main Components

- Detector – Canberra BE3825 (other detector options available)
- Acquisition Electronics – LYNX DSA, Pulser
- Rotator-Translator –
- Collimator(s)
  - TGS: Diamond shaped with apertures: 0.635 cm, 1.27 cm, 2.54 cm
  - SGS: Rectangular shaped: 1.9 cm vertical and 10.0 cm horizontal
- Transmission Source – 15 mCi Eu-152 (other sources such as Ba-133 can be used)
- Automation Control (PLC) –
- Acquisition and Analysis Software - NDA2000

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Characterization of Can-TGS

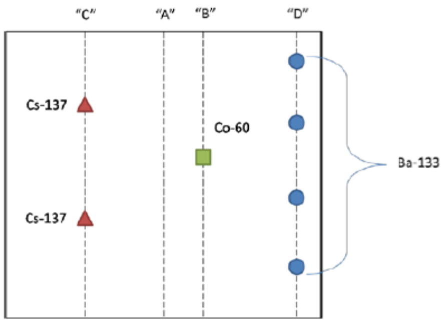


TABLE IV. Matrices Description

Matrices	Gross Weight [kg]	Density [g/cc]
Empty	2.3	0.001
Combustibles	4.8	0.133
Cedar Mulch	7.8	0.292
Walnut Shells	15	0.673

TABLE VIII. Point source verification results for Walnut Matrix

Test Case	Reported Activity [µCi]	Uncertainty [µCi]	Measured / True
Middle of Drum – TGS	20.8	2.3	0.96
Middle of Drum – SGS	23.3	0.3	1.08
Edge of Drum – TGS	23.5	2.5	1.09
Edge of Drum – SGS	21.2	0.2	0.98

Fig. 4. Matrix photographs. Clockwise, from bottom-left: Empty, Cedar Mulch, Combustibles, Walnut shells.

TABLE VI. 5 Gallon Pail, 2.54 cm collimator TGS verification results for empty drum

Nuclide	Reported Activity [µCi]	Uncertainty [µCi]	True Activity [µCi]	Uncertainty [µCi]	Measured / True	Uncertainty
Co-60	21.6	2.3	21.57	3.24	1.00	0.18
Ba-133	16.6	0.4	17.14	0.34	0.97	0.03
Cs-137	87.8	2.3	90.63	2.19	0.97	0.03

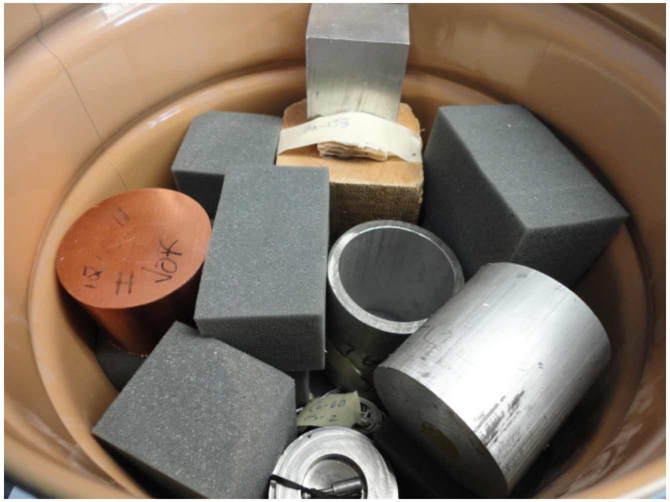
TABLE VII. 5 Gallon Pail, 1.9 cm collimator SGS verification results for empty drum

Nuclide	Reported Activity† [µCi]	Uncertainty [µCi]	True Activity [µCi]	Uncertainty [µCi]	Measured / True	Uncertainty
Co-60	23.4	0.1	21.57	3.24	1.08	0.16
Ba-133	15.4	0.4	17.14	0.34	0.90	0.02
Cs-137	90.7	0.6	90.63	2.19	1.00	0.02

†Summed Spectra Results.

TGS vs. SGS

Nuclide	Measured / True [SGS]	Measured / True [TGS]
Co-60	1.08	0.94
Ba-133	1.65	1.02
Cs-137	0.72	0.82



- **TGS accuracy is better than SGS**
  - **For matrices that are heterogeneous**
  - **For source distributions that are non-uniform**

Sensitivity Limits of TGS

- The TGS Analysis is ROI based using two continuum regions, bounding the peak ROI for the background determination.
- The extent of these regions may be different and are therefore weighted.

$$B = W_1 B_1 + W_2 B_2$$

$$\sigma_B^2 = W_1^2 B_1 + W_2^2 B_2$$

- Where B_1 and B_2 are the counts in the left and right background ROIs.
- Following the Currie formalism, the Critical Limit (the limit below which a signal cannot be reliably detected) is given by:

$$L_c = k\sqrt{B + \sigma_B^2}$$

- k is the abscissa of the Gaussian distribution corresponding to a given confidence level.

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Exploring the sensitivity limits of TGS

- Critical Limit L_C established (at 95% confidence level) by measuring item with non-radioactive matrix.
  - Diamond collimator with 1 inch aperture used in measurements
  - 1 hour assay (30 minute emission scan)
  - 5 gallon pail with walnut shell matrix (0.67 $g.cm^{-3}$)
- Next, assays were performed with a single point source of a given radionuclide (^{133}Ba, ^{137}Cs, ^{60}Co) with progressively diminishing activities.
  - 20 assay trials with each point source
  - For each assay, determine the net counts in the peak ROIs of the given nuclide.
  - Check if Net Peak ROI Counts > L_C. If True, the peak is detected. If FALSE, the peak is not detected.
  - Of the 20 trials, what is the % of the trials for which Net peak Count > L_C?

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Exploring the sensitivity limits of TGS – Some results

- ^{133}Ba Point Source measurements
  - 0.237 µCi – 356 keV – Net peak > L_C for 80% of trials
  - 0.48 µCi – 356 keV – Net peak > L_C for 85% of trials
  - 0.68 µCi – 356 keV – Net peak > L_C for 90% of trials
  - 1.40 µCi – 356 keV – Net peak > L_C for 100% of trials
- ^{137}Cs Point Source measurements
  - 0.26 µCi – 662 keV – Net peak > L_C for 75% of trials
  - 0.55 µCi – 662 keV – Net peak > L_C for 100% of trials
  - 0.732 µCi – 662 keV – Net peak > L_C for 95% of trials
  - 0.902 µCi – 662 keV – Net peak > L_C for 100% of trials
- ^{60}Co Point Source measurements
  - 0.25 µCi – 1332 keV – Net peak > L_C for 85% of trials
  - 0.5 µCi – 1332 keV – Net peak > L_C for 100% of trials
  - 0.793 µCi – 1332 keV – Net peak > L_C for 100% of trials
  - 0.997 µCi – 1332 keV – Net peak > L_C for 100% of trials

More work is needed…

- Examine the emission images for the various activity level sources of a given nuclide (@ a given emission energy)
  - Does the emission image progressively become fuzzier? Does it maintain its voxel location as the activity decreases and the statistics become poorer?
  - Examine the statistical significance of the sensitivity measurements
- Determine the Detection Limit L_D, and the MDA.

$$MDA = C(e) \bullet \frac{\left(k^2 + 2k \cdot \sqrt{B + \sigma_B^2}\right)}{T \bullet eff(e)_{Uniform}} \qquad eff[e]_{Uniform} = \frac{\sum_{i,j} F_{ij}[e]}{N_{voxels}}$$

- $F_{ij}(e)$ are the attenuation corrected efficiency matrix elements for emission peak e. The efficiency is averaged over all voxels.
- There is a need to rigorously examine methods to estimate MDA for TGS

Summary

- Canberra’s Can-TGS is proving to be a valuable R&D tool to conduct Physics studies, testing and qualification of software and hardware upgrades.
  - Outcome of Physics studies will be reported at WM2015 and INMM 2015 conferences.
- Used for training /familiarize Canberra scientists and engineers on the TGS techniques.
- Could be potentially useful for collaborative R&D with Universities and National Laboratories.
- Available as a product for purchase by customers

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