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

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Canberra Tomographic Gamma-Ray Scanner
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)
# Can-TGS Supported Containers

<table>
<thead>
<tr>
<th>Container Description</th>
<th>Diameter</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE 3013</td>
<td>5&quot; [127 mm]</td>
<td>10&quot; [254 mm]</td>
</tr>
<tr>
<td>1 US Gal</td>
<td>7.375&quot; [187 mm]</td>
<td>7.312&quot; [185 mm]</td>
</tr>
<tr>
<td>2 US Gal</td>
<td>9.75&quot; [247 mm]</td>
<td>9.25&quot; [235 mm]</td>
</tr>
<tr>
<td>3.5 US Gal</td>
<td>11.875&quot; [302 mm]</td>
<td>10.25&quot; [260 mm]</td>
</tr>
<tr>
<td>5.0 US Gal</td>
<td>11.875&quot;[302 mm]</td>
<td>13.35&quot;[339 mm]</td>
</tr>
</tbody>
</table>
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

NDA Systems - Canberra TGS
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
Characterization of Can-TGS

TABLE VIII. Point source verification results for Walnut Matrix

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Reported Activity [μCi]</th>
<th>Uncertainty [μCi]</th>
<th>Measured / True</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle of Drum – TGS</td>
<td>20.8</td>
<td>2.3</td>
<td>0.96</td>
</tr>
<tr>
<td>Middle of Drum – SGS</td>
<td>23.3</td>
<td>0.3</td>
<td>1.08</td>
</tr>
<tr>
<td>Edge of Drum – TGS</td>
<td>23.5</td>
<td>2.5</td>
<td>1.09</td>
</tr>
<tr>
<td>Edge of Drum – SGS</td>
<td>21.2</td>
<td>0.2</td>
<td>0.98</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>21.6</td>
<td>2.3</td>
<td>21.57</td>
<td>3.24</td>
<td>1.00</td>
<td>0.18</td>
</tr>
<tr>
<td>Ba-133</td>
<td>16.6</td>
<td>0.4</td>
<td>17.14</td>
<td>0.34</td>
<td>0.97</td>
<td>0.03</td>
</tr>
<tr>
<td>Cs-137</td>
<td>87.8</td>
<td>2.3</td>
<td>90.63</td>
<td>2.19</td>
<td>0.97</td>
<td>0.03</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>23.4</td>
<td>0.1</td>
<td>21.57</td>
<td>3.24</td>
<td>1.08</td>
<td>0.16</td>
</tr>
<tr>
<td>Ba-133</td>
<td>15.4</td>
<td>0.4</td>
<td>17.14</td>
<td>0.34</td>
<td>0.90</td>
<td>0.02</td>
</tr>
<tr>
<td>Cs-137</td>
<td>90.7</td>
<td>0.6</td>
<td>90.63</td>
<td>2.19</td>
<td>1.00</td>
<td>0.02</td>
</tr>
</tbody>
</table>

*Summed Spectra Results.

TABLE IV. Matrices Description

<table>
<thead>
<tr>
<th>Matrices</th>
<th>Gross Weight [kg]</th>
<th>Density [g/cc]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty</td>
<td>2.3</td>
<td>0.001</td>
</tr>
<tr>
<td>Combustibles</td>
<td>4.8</td>
<td>0.133</td>
</tr>
<tr>
<td>Cedar Mulch</td>
<td>7.8</td>
<td>0.292</td>
</tr>
<tr>
<td>Walnut Shells</td>
<td>15</td>
<td>0.673</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>1.08</td>
<td>0.94</td>
</tr>
<tr>
<td>Ba-133</td>
<td>1.65</td>
<td>1.02</td>
</tr>
<tr>
<td>Cs-137</td>
<td>0.72</td>
<td>0.82</td>
</tr>
</tbody>
</table>
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.

\[
B = W_1B_1 + W_2B_2 \\
\sigma_B^2 = W_1^2B_1 + W_2^2B_2
\]

- 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.
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 > $L_C$?
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.

\[
MDA = C(e) \left( \frac{k^2 + 2k \cdot \sqrt{B + \sigma_B^2}}{T \cdot \text{eff}(e)_{\text{Uniform}}} \right)
\]

\[
\text{eff}[e]_{\text{Uniform}} = \frac{\sum_{i,j} F_{ij}[e]}{N_{\text{voles}}}
\]

- $F_{ij}(e)$ 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
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.