55Fe Measurements in Radioactive Waste with a Triple GEM Detector

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Materials in accelerator environment are activated by radiations\(^1\)

In order to treat this materials after the decommissioning, it is necessary a characterization to know the nuclide population

Gamma emitters are easily recognised by \(\gamma\) spectrometry

The challenge is to measure the \(^{55}\)Fe amount

A detector with high efficiency to \(^{55}\)Fe and high \(\gamma\) rejection to is needed

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\(^1\): F.P. La Torre et al. Radiological Hazard Classification of materials in CERN’s accelerators, CERN technical note 2012 1184236
**GAS ELECTRON MULTIPLIER**

- Autoshielding: only surface contributes to x-ray emission when for $\gamma$ is the whole volume
- Efficiency for x-ray and $\gamma$ rejection unknown

Characterization with calibration sources

F. Sauli NIM A386 531
M. Alfonsi et al., The triple-Gem detector for the M1R1 muon station at LHCb, N14-182, 2005 IEEE-NSS
X-ray source: $^{55}\text{Fe}$

- $^{55}\text{Fe} \rightarrow ^{55}\text{Mn} * \rightarrow (~28\%)$  
  $^{55}\text{Mn} + 6\text{keV}$
- Not negligible attenuation in air
- Conversion in gas mixture through photoelectric effect
- Avalanche produced by low energy electron $\sim 200\text{ e-}$ created in the drift
- Conversion efficiency until 9 mm of ArCO$_2$: 39%
MATERIAL BUDGET AND MEASUREMENT WITH SOURCES

<table>
<thead>
<tr>
<th>Width</th>
<th>Density (g/cm³)</th>
<th>1.17MeV Length (cm)</th>
<th>1.33MeV Length (cm)</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0.0012</td>
<td>14077</td>
<td>14858</td>
<td>0.0090%</td>
</tr>
<tr>
<td>Mylar</td>
<td>11.5 μm</td>
<td>1.4</td>
<td>11.8</td>
<td>0.0007%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>0.5 μm</td>
<td>2.7</td>
<td>6.3</td>
<td>0.0097%</td>
</tr>
<tr>
<td>ArCo2 70/30</td>
<td>0.3 cm</td>
<td>0.0018</td>
<td>9890</td>
<td>0.0200%</td>
</tr>
<tr>
<td>Copper</td>
<td>5 μm</td>
<td>8.9</td>
<td>2.1</td>
<td>0.0400%</td>
</tr>
<tr>
<td>Kapton</td>
<td>50 μm</td>
<td>1.4</td>
<td>11.7</td>
<td>0.0097%</td>
</tr>
</tbody>
</table>

Gamma source: $^{60}$Co

- $^{60}$Co $\rightarrow ^{60}$Ni $^* + \beta + \bar{\nu} \rightarrow (100\%) ^{60}$Ni $+ (1.17 MeV) + (1.33 MeV)$
- Almost no attenuation in air or gas mixture
- Conversion through Compton effect in producing a MIP e-:
  $\gamma + e^- \rightarrow \gamma' + e^- (MIP)$
- Conversion efficiency until 9 mm of ArCO$_2$: 1.14%
- Electrons from $\beta$ decay
CHARACTERIZATION WITH SOURCES

Solid angle: \( \Omega = 2\pi \left( 1 - \frac{d}{\sqrt{d^2 + r^2}} \right) \)

Efficiency: \( \varepsilon = \frac{\text{rate/Clsz}}{\text{Activity}} \times \frac{4\pi}{\Omega} \)

<table>
<thead>
<tr>
<th>Photons</th>
<th>9 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working point</td>
<td>960</td>
</tr>
<tr>
<td>Efficiency (^{55}\text{Fe})</td>
<td>39%</td>
</tr>
<tr>
<td>Efficiency (^{60}\text{Co})</td>
<td>1.14%</td>
</tr>
<tr>
<td>Rejection Factor</td>
<td>34</td>
</tr>
</tbody>
</table>
MEASUREMENTS WITH SAMPLES: PROCEDURE

Distance Detector-Sample: 2 cm  
WP: 960 V  
Gate: 1000 ms  
Efficiency X: 39%  
Efficiency gamma: 1.14%

- First measurement with the sample in front of the detector

- Second measurement with a shielding made with 0.4 mm of Al in order to shield x-rays and to get the amount

- Several measurements of background
Sample from STS pipes with well known isotope composition from radiochemical analysis and gamma spectroscopy.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Surface cm²</th>
<th>Volume cm³</th>
<th>Co-60 Bq/gr</th>
<th>Fe-55 Bq/gr</th>
</tr>
</thead>
<tbody>
<tr>
<td>149</td>
<td>20.6</td>
<td>15.5</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>62</td>
<td>19.2</td>
<td>6.79</td>
<td>66</td>
<td>24</td>
</tr>
<tr>
<td>63</td>
<td>20.3</td>
<td>8.26</td>
<td>57</td>
<td>22</td>
</tr>
</tbody>
</table>
### Measurements with Samples: STS Pipe Samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>No Shielding</th>
<th>Shielding</th>
<th>Gamma Norm Vol</th>
<th>X rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>149</td>
<td>0.63</td>
<td>0.46</td>
<td>0.01</td>
<td>0.17</td>
</tr>
<tr>
<td>62</td>
<td>3.22</td>
<td>2.57</td>
<td>0.31</td>
<td>0.65</td>
</tr>
<tr>
<td>63</td>
<td>2.73</td>
<td>1.94</td>
<td>0.19</td>
<td>0.79</td>
</tr>
</tbody>
</table>

\[ \gamma = \frac{Sh - Bck}{Sample\ Volume} \]

\[ X = No\ Sh - Sh \]

**Graphs:**
- **Gamma rays: GEM vs Gamma spectro**
  - y-axis: Hz/cm³
  - x-axis: Bq/g

- **X-Rays: GEM vs RC Analysis**
  - y-axis: Hz
  - x-axis: Bq/g
MEASUREMENTS WITH SAMPLES: SC (SYNCHROCYCLOTRON) SAMPLE

SC sample STS
Screenshot after 120 events
WP 960 V

Only results from gamma spectroscopy

<table>
<thead>
<tr>
<th>Sample from SC</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface cm²</td>
<td>7.07</td>
</tr>
<tr>
<td>Volume cm³</td>
<td>2.8</td>
</tr>
<tr>
<td>Co-60 Bq/gr</td>
<td>4</td>
</tr>
<tr>
<td>Fe-55 Bq/gr</td>
<td>?</td>
</tr>
</tbody>
</table>
Lead collimators in front of the sample. Hole diameter 0.2 cm
Thickness 0.23 cm
WP=960 V

STS sample from SC – Attenuation in air

<table>
<thead>
<tr>
<th>Shielding</th>
<th>0.39</th>
</tr>
</thead>
<tbody>
<tr>
<td>No shielding</td>
<td>0.43</td>
</tr>
<tr>
<td>Gamma norm vol (Hz)</td>
<td>0.05</td>
</tr>
<tr>
<td>X rays (Hz)</td>
<td>0</td>
</tr>
</tbody>
</table>
MEASUREMENTS WITH SAMPLES: SAMPLE IN TAPE

- Sample in powder
- Higher granularity
- Higher contribution from $^{55}\text{Fe}$

<table>
<thead>
<tr>
<th>Sample</th>
<th>GEM Rate (Hz)</th>
<th>Spectro Co-60 (Bq/gr)</th>
<th>Spectro Fe-55 (Bq/gr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>0.28±0.02</td>
<td>3.0</td>
<td>14.0</td>
</tr>
<tr>
<td>149</td>
<td>0.27±0.02</td>
<td>3.0</td>
<td>14.0</td>
</tr>
<tr>
<td>52</td>
<td>0.24±0.02</td>
<td>7.8</td>
<td>7.1</td>
</tr>
<tr>
<td>62</td>
<td>0.33±0.03</td>
<td>66.0</td>
<td>24.0</td>
</tr>
<tr>
<td>ISR 71</td>
<td>0.25±0.03</td>
<td>2.1</td>
<td>?</td>
</tr>
</tbody>
</table>
CONCLUSIONS

- A fully characterization of a 9 mm drift camera has been done:
  - \( \varepsilon_x = 39\% \)  
    - Rejection: 34
  - \( \varepsilon_\gamma = 1.14\% \)
- Several radioactive samples have been measured with several procedures
- **PROBLEM:** since the attenuation length in waste material is 8 \( \mu \)m for x rays, while for \( \gamma \) is 23 cm, the x-rays intensity is always extremely low
- We started to work with other detector as GEMPix and to scratch the waste to obtain a powder in order to have more granularity