CVT Workshop

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Stilbene Cell for Radioxenon Detection

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Introduction and Motivation

• Comprehensive Nuclear-Test Ban Treaty bans nuclear testing worldwide

• Established a verification regime consisting of 4 continuously monitoring technologies:
  – Seismic
  – Infrasound
  – Hydro acoustic
  – Radionuclide

International Monitoring System: Radionuclide Stations

67 radionuclide stations worldwide (red)
80 total radionuclide stations planed (grey)
25 radioxenon stations (R+)
Radioxenon for Nuclear Explosion Monitoring

- Noble gases can reach the surface even in underground explosions making clandestine testing difficult
- Radioxenon has the highest cumulative fission yield of the noble gases produced
- Radioxenon has been measured from a variety of sources such as Chernobyl, Fukushima, and DPRK nuclear tests
Current Method to Measure Radioxenon


<table>
<thead>
<tr>
<th>Isotope</th>
<th>Electron Energy (keV)</th>
<th>Photon Energy (keV)</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{131m}\text{Xe}$</td>
<td>129</td>
<td>$\sim30$</td>
<td>11.84 d</td>
</tr>
<tr>
<td>$^{133m}\text{Xe}$</td>
<td>198</td>
<td>$\sim30$</td>
<td>2.198 d</td>
</tr>
<tr>
<td>$^{133}\text{Xe}$</td>
<td>346 (endpoint)</td>
<td>$\sim30$ and 80</td>
<td>5.248 d</td>
</tr>
<tr>
<td>$^{135}\text{Xe}$</td>
<td>950 (endpoint)</td>
<td>250</td>
<td>9.14 h</td>
</tr>
</tbody>
</table>

Simulation of the 4 radioxenon isotopes of interest
Current Limitations to Radioxenon Detection

- Xe-133 interferes with metastable isotopes complicating source characterization

- Radon interferes with all ROIs and its removal is a major system component

- Memory Effect: Radioxenon diffuses into plastic raising the background of subsequent measurements and decreasing detector sensitivity
Advantages of Stilbene

• Improved energy resolution
  – Decreases ROI bounds leading to increased sensitivity

• Pulse Shape Discrimination
  – Discrimination of radon alphas and xenon betas

• Decreased memory effect
  – Improves detector sensitivity and extends measurement time

• Alternative scintillator
  – Maintains geometry and efficiency
Overview of PNNL Experimental Campaigns

• Side by side plastic and stilbene experiments
  – Gas line connected to both detectors
  – Stilbene cell volume is 20% larger
  – Solid angle difference

• Experimental Campaign 1
  – Tested vacuum stability of cell

• Experimental Campaign 2
  – Full characterization campaign
Results: Xe-135 Measurement

- Ratio of coincidence to singles counts is less for stilbene compared to plastic suggesting gamma efficiency drop
Results: Xe-133m and Xe-131m Measurements

- Beta spectra gated on 30-keV
- 45-keV broadened for stilbene
Results: Detector Characterization

- Stilbene resolution slightly improved
  - 2.2 keV FWHM decrease

- Stilbene efficiency decreased
  - Average 15% decrease

- Efficiency decrease for stilbene cell leads to increased minimum detectable concentration
  - Average 0.1 mBq/m³ increase
Results: Radon Pulse Shape Discrimination

• The use of stilbene allows for the identification of alpha particles emitted by radon which can be used to mitigate interference

• Results in 1% decrease in MDC for Xe-135 and can be used for environmental monitoring applications
Memory Effect Experiment

- Testing for residual activity remaining in cells
- Xe-133 was measured for 3 days
Results: Memory Effect Analysis

- Residual activity remaining: 4.5% plastic and 0.043% stilbene
- Memory effect is approximately 100-times smaller
- IMS stations would have extended time to measure atmospheric samples = increased sensitivity
CVT Impact

- Numerous internships and experimental campaigns at PNNL

- Participation in the 2017 CTBT Science and Technology conference in Vienna, Austria

- Presentation at the International Noble Gas Experiment Conference sparked interest from CTBT partners

- Research resulted in National Laboratory Impact Award
Conclusion

• The almost negligible memory effect of the stilbene cell can improve the overall sensitivity of the verification regime

• A balance between light collection and ruggedness is needed for in-field use of the stilbene cell to maximize performance

• Future work includes field measurements with the stilbene cell
Acknowledgements

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