RADIOXENON DETECTION VIA BETA-GAMMA COINCIDENCE TECHNIQUE

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Research Objectives

• Design, build, and test compact radioxenon detection systems using room-temperature semiconductor detectors (CdZnTe) through beta-gamma coincidence counting

• Advantages:
  – Better energy resolution
  – Reduced memory effect
  – Improved Minimum Detectable Concentration (MDC)
  – Reduced power, size, weight, and cost

• Several prototype detectors will be built and tested to find the best solution
Two-element Co-planar CZT Detector (TECZT)

- We started with a simple design using two fact-to-face co-planar CZT detectors
- Only coincidence events between the two detectors are processed
- Coincidence probability (entering the detectors) when the source is located at the center of a cube:
  - For 2 detectors on two sides of a cubic gas cell ~ 1/18 (5.6%)
  - For 6 detectors on all sides of a cubic gas cell ~ 5/6 (83.3%)
Two-element Co-planar CZT Detector (TECZT)

- Gas cell was built by 3D printing
- Two 10x10x10 mm co-planar CZT (CPCZT) crystals were air-sealed on two sides of the gas cell
Two-element Co-planar CZT Detector (TECZT)

- CZT detectors, 4 preamplifiers and 2 subtraction PCBs were mounted in an EMI-shielded enclosure
- Detector pulses were digitized and transferred to the PC by our 2-channel, 200 MHz digital pulse processor
Digital Trapezoidal Pulse Shaping

- Digital trapezoidal filtering was applied to detector pulses
- Flat top duration covers both single and multi-interaction events (e.g. Compton scattering) in a single detector

\[ \Delta T \approx 0.75 \, \mu\text{sec} \]

With \( V_b = 1 \, \text{kV} \), thickness = 1 cm, and \( \mu_e = 1000 \, \text{cm}^2/\text{VS} \)

- ADC Sampling Rate = 200 MHz
- Digital trapezoidal filtering was applied to detector pulses
- Flat top duration covers both single and multi-interaction events (e.g. Compton scattering) in a single detector

\[ E \mu E D D E D T D T \mu : \Delta T (T_m) \approx 1.0 \, \mu\text{sec} \]
Coincidence Detection in FPGA

- Coincidence detection was performed in hardware (FPGA)
- Coincidence events are detected when the two channels are triggered within Coincidence Time Window (CTW), adjustable from 0 to 1.275 μsec

- Coincidence Detection Unit is active in Coincidence Mode

Coincidence Time Window (0-255 clock cycles)
Coincidence Time Window

- Pulse arrival time in CPCZT is a function of interaction depth
- In coincidence mode, $^{60}$Co was placed on top of gas cell and count rates were measured with different coincidence time windows
- A flat count-rate region was observed with CTW $> 0.8 \, \mu\text{sec}$
Energy spectrum from gamma sources

- Sources were placed on the top of the gas cell
- Better resolution is expected when the detectors are exposed from the cathode side (from inside the gas cell)

Source: $^{137}$Cs

Source: $^{60}$Co
Production of $^{135}\text{Xe}$ in TRIGA reactor

- 3 ml of stable and enriched (>99%) $^{134}\text{Xe}$ was irradiated in the thermal column of the TRIGA reactor for 7 hours ($\phi = 7 \times 10^{10}$ n cm$^{-2}$ sec$^{-1}$)

- $^{135}\text{Xe}$ was injected into the gas cell after 17 hrs
### Characteristic energies for the decay of $^{131m}$Xe, $^{133m}$Xe, $^{133}$Xe, and $^{135}$Xe

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>$^{131m}$Xe</th>
<th>$^{133m}$Xe</th>
<th>$^{133}$Xe</th>
<th>$^{135}$Xe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Half-life</strong></td>
<td>11.93 d</td>
<td>2.19 d</td>
<td>5.25 d</td>
<td>9.14 h</td>
</tr>
<tr>
<td><strong>Gamma-rays (keV)</strong></td>
<td>163.9</td>
<td>233.2</td>
<td>81.0</td>
<td>250.0</td>
</tr>
<tr>
<td><strong>Gamma-ray abundance (%)</strong></td>
<td>1.96</td>
<td>10.3</td>
<td>37.0</td>
<td>90.0</td>
</tr>
<tr>
<td><strong>X-ray, K-shell (keV)</strong></td>
<td><strong>30.</strong></td>
<td><strong>30.</strong></td>
<td><strong>31.</strong></td>
<td>31.</td>
</tr>
<tr>
<td><strong>X-ray abundance (%)</strong></td>
<td>54.1</td>
<td>56.3</td>
<td>48.9</td>
<td>5.2</td>
</tr>
<tr>
<td><strong>Beta, Max Energy (keV)</strong></td>
<td>-</td>
<td>-</td>
<td><strong>346.</strong></td>
<td><strong>905.</strong></td>
</tr>
<tr>
<td><strong>Beta abundance (%)</strong></td>
<td>-</td>
<td>-</td>
<td>99.</td>
<td>97.</td>
</tr>
<tr>
<td><strong>CE, K-shell (keV)</strong></td>
<td><strong>129.</strong></td>
<td><strong>199.</strong></td>
<td><strong>45.</strong></td>
<td>214.</td>
</tr>
<tr>
<td><strong>CE abundance (%)</strong></td>
<td>60.7</td>
<td>63.1</td>
<td>54.1</td>
<td>5.7</td>
</tr>
</tbody>
</table>
2D beta-gamma spectra from $^{135}$Xe

- FPGA operation mode: coincidence (CTW=0.75 µsec)
Beta-gamma coincidence spectra from $^{135}\text{Xe}$

- FPGA operation mode: **coincidence (CTW=0.75 µsec)**
2D beta-gamma spectra from $^{135}\text{Xe}$

- FPGA operation mode: **free running**
$^{135}$Xe in ARSA Detector

- Automated Radioxenon Sampler Analyzer developed at PNNL
- It uses NaI(Tl), plastic scintillators, and 12 PMTs to detect gamma-rays and beta particles

**ARSA Detector**

$\beta$-$\gamma$ coincidence spectra from $^{135}$Xe
## TECZT and other radioxenon detectors

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</thead>
<tbody>
<tr>
<td>88 keV ($^{109}$Cd)</td>
<td>11.2</td>
<td>31.5</td>
<td>25</td>
<td>14</td>
<td>NA</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>122 keV ($^{57}$Co)</td>
<td>6</td>
<td>NA</td>
<td>24</td>
<td>NA</td>
<td>22</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>662 keV ($^{137}$Cs)</td>
<td>2.3</td>
<td>13.6</td>
<td>8.9</td>
<td>7.3</td>
<td>12</td>
<td>8.7</td>
<td></td>
</tr>
<tr>
<td>250 keV ($^{135}$Xe)</td>
<td>4.4</td>
<td>19.3</td>
<td>13</td>
<td>NA</td>
<td>9.6</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Background Rate (counts/s)</td>
<td>Total (all events)</td>
<td>0.2</td>
<td>1.26</td>
<td>3.29</td>
<td>7.5-12</td>
<td>30</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>Coincidence Events</td>
<td>0.0036</td>
<td>0.02</td>
<td>0.06</td>
<td>0.03</td>
<td>0.1</td>
<td>0.025</td>
</tr>
</tbody>
</table>

NA: data is not available


MCNP coincidence simulation

- PTRAC card was used to simulate beta-gamma coincidence events

- Visit Lily Ranjbar’s poster (poster #6) for more detail:

  *Coincidence Simulation of a Two-Channel CZT-based Radioxenon Detector*
Other ongoing projects

• A 8-channel FPGA-based DPP was designed and built
• To be used in our next generation detector with 6 CZT elements
• Will be tested during the 2nd year

8-Channel, 14-bit, 125 MHz Digital Pulse Processor
Other ongoing projects

- Depositing co-planar patterns on 20x20x5 mm CZT crystals
- Miniaturizing preamp+subtraction PCB with CZT detectors in an aluminum gas cell
Future Work

• Reduce noise level to detect 30 keV X-rays from $^{131m}\text{Xe}$, $^{133m}\text{Xe}$, $^{133}\text{Xe}$

• Test the detector with other xenon radioisotopes ($^{131m}\text{Xe}$, $^{133m}\text{Xe}$, $^{133}\text{Xe}$)

• Calculate Minimum Detectable Concentration through simulation and experiments

• Test and troubleshoot our 8-channel digital pulse processor
Conclusion

• Two-element CZT detector was designed, built, and tested by injecting $^{135}$Xe into the gas cell

• FPGA firmware (two-channel, 200 MHz) was developed to identify and capture coincidence events in real time

• Preliminary measurement results show improved energy resolution compared with other radioxenon detectors such as ARSA and SAUNA

• Compact 8-channel (FPGA-based, 14 bits, 125 MHz) digital pulse processor was designed and built
Thank You!