CEvNS for Nuclear Security

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Introduction and Motivation

• Coherent Elastic Neutrino Nucleus Scattering (CEvNS) is the new kid on the block, first measured in 2017.

• Large cross section (for neutrinos), threshold-less reaction.

• Handheld neutrino detectors?
Mission Relevance

• Small (sub-ton) neutrino detectors would greatly enhance the deployment options for reactor monitoring

• Detection of neutrinos below inverse beta decay (IBD) threshold would enhance the ability to detect reprocessing waste and plutonium breeding (Cogswell, PH, 2016)

\[ ^{238}\text{U} + n \rightarrow ^{239}\text{U} \xrightarrow{\beta^-} ^{239}\text{Np} \xrightarrow{\beta^-} ^{239}\text{Pu} \]

Emits neutrinos of 1.2 MeV – invisible to IBD detectors
Technical Approach

• Comparison with demonstrated capabilities of IBD detectors
• Use PROSPECT as benchmark
• LLNL is heavily involved in PROSPECT (co-spokesperson)
• ORNL is host to PROSPECT and COHERENT
• Major contributions by VT NSF REU student Maitland Bowen (U. Michigan)
20+ international neutrino detection experts came together to assess how current IBD technology could be used in a future nuclear agreement.

(Carr et al., 2018)
Reactor status

• Is the reactor running?
• Use PROSPECT performance as benchmark
• Includes measured backgrounds

<table>
<thead>
<tr>
<th>5MWe</th>
<th>IR40</th>
<th>ELWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2d</td>
<td>8 h</td>
<td>1.5 h</td>
</tr>
</tbody>
</table>

Time to detection at 95% C.L.
Reactor fissile inventory

• Has a high-Pu content core been swapped against a fresh one?

<table>
<thead>
<tr>
<th>BG level</th>
<th>ELWR</th>
<th>IR40</th>
<th>5MWe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>134</td>
<td>109</td>
<td>1154</td>
</tr>
<tr>
<td>0.5</td>
<td>83</td>
<td>59</td>
<td>830</td>
</tr>
<tr>
<td>0.2</td>
<td>56</td>
<td>30</td>
<td>637</td>
</tr>
<tr>
<td>0</td>
<td>45</td>
<td>16</td>
<td>527</td>
</tr>
</tbody>
</table>

Days to detection at 95% C.L.

• Requires 6 times the detector mass of PROSPECT (12t)
CEvNS

CEvNS is threshold-less

\[ \frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} N^2 M_N \left( 1 - \frac{M_N T}{2E^2_N} \right) \]

\( T \) recoil energy, \( N \) neutron number

Threshold in eV for parity in event rate per unit mass with IBD

\[
\begin{array}{cccccccc}
{^{12}}C & {^{20}}Ne & {^{28}}Si & {^{40}}Ar & {^{74}}Ge & {^{127}}I & {^{132}}Xe & {^{133}}Cs \\
790 & 770 & 702 & 672 & 491 & 353 & 347 & 343 \\
\end{array}
\]
CEvNS energy spectrum

- Different fissile produces a different neutrino spectrum
- Difference persists in detection

![CEvNS energy spectrum graph](image)
Mass advantage

• Even at 5eV threshold: 
  0.6t Xe for core swap 
  50kg Xe for reactor power 

• Assumes zero background
CEvNS background

• CEvNS at reactor yet to be observed
• Educated guess as to BG shape
• Magnitude still unknown
CEvNS with BG

- 1/E background worst case, but not unlikely
- Already for B=5S, no advantage relative to IBD
Conclusion & next steps

• CEvNS at reactors needs to be demonstrated
• Significant R&D needed to match IBD capabilities
• No handheld neutrino detectors soon!
• Evaluation of the current global detector R&D program vis a vis nuclear security applications:
  Are we looking at the right technologies?
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