Studies of poly(ethylene naphthalate) for use as a structural scintillator in low background experiments

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LRT Conference, Jaca
Thanks
What is PEN?

○ Commercially available
○ Brandnames: Teonex
○ Relatively cheap
○ Experience in manufacturing
○ Transparent plastic
○ Known to scintillate [arXiv:1903.10736]
  ○ Self-veto?
○ PEN as low background material?

Top: Structural formula of PEN.
Bottom: Custom molded PEN capsule parts
Radiopurity Screening

- Low-background experiments need low-background material
- Commercially available PEN granulate gamma screened at LNGS
- Two types: TN8050, TN8065
- Reference measurement: GERDA HV-capacitor [arXiv:1903.10736]
Radiopurity Results

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<tbody>
<tr>
<td></td>
<td>[mBq/kg]</td>
<td></td>
<td></td>
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<tr>
<td>Ra-228</td>
<td>&lt; 0.15</td>
<td>&lt; 0.15</td>
<td></td>
</tr>
<tr>
<td>Th-228</td>
<td>(0.23 ± 0.05)</td>
<td>&lt; 0.13</td>
<td>&lt; 1.4</td>
</tr>
<tr>
<td>Ra-226</td>
<td>(0.25 ± 0.05)</td>
<td>&lt; 0.11</td>
<td>&lt; 2.0</td>
</tr>
<tr>
<td>Th-234</td>
<td>&lt; 11</td>
<td>&lt; 15</td>
<td></td>
</tr>
<tr>
<td>Pa-234m</td>
<td>&lt; 3.4</td>
<td>&lt; 3.0</td>
<td></td>
</tr>
<tr>
<td>U-235</td>
<td>&lt; 0.066</td>
<td>&lt; 0.054</td>
<td></td>
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<tr>
<td>K-40:</td>
<td>1600 ± 400</td>
<td>1000 ± 400</td>
<td>&lt; 3.6</td>
</tr>
<tr>
<td>Cs-137</td>
<td>&lt; 0.057</td>
<td>&lt; 0.064</td>
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Measurement by M. Laubenstein (68 % C.L.)

- Commercially available pellets have comparable counts to materials in use
- Surface contamination
- Reduce levels in PEN by synthesis
Material Properties

- Very resistant to most acids and alcohols
  - Can be cleaned aggressively
- 3 point bending test of material at room temperature and in LN2
- High structural stability
- Structural, transparent material ✓

Three-point bending flexural test results with PEN samples

(15 \times 30 \times 3 \text{ mm}^3)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>PEN at 296 K</th>
<th>PEN at 77 K</th>
<th>Copper at 296 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{el}$ [MPa]</td>
<td>108.6 ± 2.6</td>
<td>209.4 ± 2.8</td>
<td>100</td>
</tr>
<tr>
<td>$E$-Modulus [GPa]</td>
<td>1.855 ± 0.011</td>
<td>3.708.1 ± 0.084</td>
<td>128</td>
</tr>
</tbody>
</table>

[www.memsnet.org/material/coppercubulk/]
Molding PEN Parts
Light Yield Measurements

- Scintillation yield measured in electron spectrometer
  [doi:10.1088/1748-0221/10/09/P09008]
- Electron energies between 0.4 - 1.6 MeV used
- Compared to a PS, SuperNEMO

Set up used for light yield measurements
PS and PEN light output when excited with mono-energetic electrons (FWHM = 1.0 ± 0.2 % at 1 MeV)

- Light yield for PEN around 2/3s of PS
- Lower yield than literature, self produced tiles
- Trade off: cleanliness vs light yield
Emission Spectra

- PEN emits blue light, no extra fluors
- Good match to commercial PMTs and SiPMs
- Emission spectrum measured with spectrograph
- BC-408 and PS similar yields, use BC-408 as reference
- Excited by monochromatic 380 nm light
- Drawback: limited absorption length
Emission Spectra Results

Emission Spectra of PEN, BC-408 and PMMA tiles (30 x 30 x 3 mm$^3$)

- Blue emission from PEN
- Lower yield than BC-408
Wavelength Shifting

- Measured emission spectrum from wavelength shifting, not scintillation
- Can PEN shift VUV?
- 126 nm light from LAr source
- Compare efficiency of tile coated with TPB and PEN

PEN exposed to UV
Wavelength Shifting Results

Left: Ratio of PMT anode currents (blue line) PEN/TPB Right: VUV/UV emission spectrum of liquid argon [arXiv:1511.07718]

- Efficiency of wavelength shift around 50% of TPB at 126 nm
- Optically active without scintillation
- Enhanced efficiency of liquid argon vetoes
- Consistent with DEAP: arXiv:1806.04020
PEN is a commercially available plastic, relatively radiopure

- Good structural properties, suitable as a support material
- Both scintillates and wavelength shifts
- Emission peak suitable for many photo-detectors
- Scintillation yield lower than other plastics, attenuation limits part size
- Demonstrated to wavelength shift liquid argon peak emission to blue
- PEN is already in consideration for future low-background experiments, such as DarkSide, DUNE, LEGEND, KAMLAND-ZEN