C. Roca, on behalf of the ROADSTR Near-Field Working Group:


presents:

DESIGN, TEST AND PRODUCTION AT LLNL OF:

NOVEL PSD PLASTIC SCINTILLATOR TECHNOLOGIES FOR NEUTRINO DETECTION

Snowmass Summer Meeting 2022 - 25.VII.2022
There is a strong interest in readily mobile precision neutrino flux detectors.

**STATE OF THE ART: ABOVEGROUND REACTOR NEUTRINO DETECTION**

**PROSPECT** has demonstrated first high sensitivity aboveground detection and identified important capabilities.

- Segmentation
- Li doped scintillator
- PSD capabilities
MOTIVATIONS FOR READILY MOBILE ABOVEGROUND DETECTION SYSTEM

- Potentially useful tool for negotiation and verification of nuclear agreements.
- Advanced reactors may be difficult to safeguard with conventional approaches.

PROSPECT aboveground demonstration has inspired new use cases studies.

- Readily mobile systems have several motivations
  - Benchmarks for applications
  - Validating flux & spectrum predictions against diverse fuel types.

There is a strong interest in readily mobile precision neutrino flux detectors
PSD PLASTIC MATERIALS: HOMOGENOUS $^6$LI-DOPING

- Building on more than a decade of effort at LLNL by N. Zaitseva, A. Mabe & M. Ford
- Eljen Technology has started mass-producing PSD plastic bars with lab’s formulation.

Developing formulations and production processes

Transferring technology for commercial production

Exploring solubility of multiple Li bearing compounds and their stability

Evaluating light yield, attenuation length, PSD properties

Build up a characterization setup to test bars as they are produced

Advancing PSD plastic materials with the goal of matching demonstrated performance of liquids to enable easily mobile systems.
Primary and secondary dyes are responsible for PSD and wavelength shifting.
Lithium salts are added to ensure correlated event selection through n-capture process.
BASICS OF PSD PLASTIC CHEMISTRY

Addition, mixing and curing of components require very strict condition controls
Good $^6\text{Li}$ solubility is paramount, so a variety of Li salts are being studied dissolved at different temperatures.
For commercial production we have proceeded with an aliphatic \( ^{6}\text{Li} \) salt.

**Advantages**
- Good solubility of \( ^{6}\text{Li} \) salt
- Good stability

**Disadvantages**
- Difficult to produce
- Lower light output

**Advantages**
- Simple synthesis of \( ^{6}\text{Li} \) salt
- Good light output

**Disadvantages**
- mTP required for high LO
- Lower Figure of Merit
Co-monomer addition to main matrix element in order to dissolve $^{6}$Li salt
SOLUBILITY OF $^6\text{Li}$ SALTS

$65\, ^\circ\text{C}; ^6\text{LiO}$

Styrene:MAA:

90:10  89:11  88:12  87:13  85:15

High MAA content reduces light output - but lower MAA requires higher processing temperatures
There is a critical mass fraction from which light output declines rapidly. This point has not been reached using MMA.
There is a critical mass fraction from which light output declines rapidly. This point has not been reached using MMA.
When using mTP as primary dye instead of PPO, critical point is for declining LO is not reached.

Non-bonding interactions of $^6$Li salt and MAA with PPO - would not occur with mTP.
BASICS OF PSD PLASTIC CHEMISTRY

Dyes used during the production may impact the long way stability of the plastics
mTP and MDAC (actual antioxidant) show promising results regarding long term stability.
Higher temperatures and air are clear reasons for early degradation.

**STABILITY OF PLASTICS**

- **85:15 PS:PMMA**
- **PMMA**
- **Contain 6LiBSA**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Light Output (arb. units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>20</td>
</tr>
<tr>
<td>49 days at RT in air</td>
<td>15</td>
</tr>
<tr>
<td>+7 days at 50 °C in air</td>
<td>10</td>
</tr>
<tr>
<td>+7 days at 60 °C in N₂</td>
<td>5</td>
</tr>
<tr>
<td>+1 week at 60 °C in air</td>
<td>2</td>
</tr>
</tbody>
</table>
Initial attempts to fabricate plastics at larger scale had defects, discoloration and opacity.
FROM LAB TO COMMERCIAL PRODUCTION

External collaborator is consistently producing batches of 5.5x5.5x50 cm bars for testing.
External collaborator is consistently producing batches of 5.5x5.5x50 cm bars for testing
A MOBILE ANTINEUTRINO DETECTOR

ROADSTR

TESTING NEW PSD PLASTIC TECHNOLOGY
Building from recent advances, our goals are to develop and demonstrate enabling technologies for mobile antineutrino detectors.

**Areas of development**

- **PSD Plastic Scintillators**
- **Segmented geometries**
- **Mobile deployment engineering**

**Background prediction**

- **ROADSTR**
- **ROADSTR + Concrete Wall**
- **ROADSTR + Lead shielding**
Characterization setup allows for multi-bar testing using different collimated sources placed at varying positions remotely controlled.

- Hosts up to 4 segments with double PMT readout.
- Linear stage allows precise position-scan.

Testing different wrappings

- Calibration source placed inside lead collimator
- Collimator moves across the setup thanks to linear stage
- Lead collimators
LINEARITY TEST USING DIFFERENT SOURCES

- Position scan displays long attenuation lengths ~80 cm
- Multi-source measurements show good linearity and effective light yield of ~500-600 PE/MeV
- After characterization, bars are stored in vacuum to avoid deterioration.
- Control bar left in contact with air to test stability of material

All bars tested to this moment have display consistent results in terms of attenuation length and light output
PSD CAPABILITIES USING CF252

- The plastics show excellent PSD capabilities.
- Clear and distinct n-capture island.
- Figure of Merit ~ 1.2 between nuclear and electronic recoils (work in progress)

Reconstructed Energy [MeV]

PSD Factor []

Figure of Merit ~ 1.2 between nuclear and electronic recoils (work in progress)
**SUMMARY**

✦ The **PROSPECT aboveground** detection is an important capability demonstration for reactor monitoring applications and other reactor neutrino studies.

✦ **Mobile** aboveground systems that maintain high sensitivity are a clear next step along the technology development path.

✦ The **ROADSTR** program at the **LLNL** is advancing PSD Plastic Scintillator technology:
  - Different 6Li salts (Aliphatic / Aromatic), solubility monomers (MMA / MAA) and primary dyes (PPO/mTP, MDAC) considered.
  - Plastic elaboration approach is extensible to large scale and it’s been transferred for external production.
  - Long-term and stability effects on the plastics still under research.
Thanks for your attention!