Light Collection Measurements and Simulations of Wavelength Shifting Plates for Water-Cherenkov Detectors

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Introduction

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Research Focus Area: Radiation Detection
Planned Graduation: December 2022

Special thank you to:
The WATCHMAN Collaboration
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Marc Bergevin
Antineutrinos in support of international safeguards?

Large-scale water-based detectors may be able to detect, exclude, or verify the presence or operation of a nuclear reactor within a 1-100km radius.

Large (ton to kiloton scale) detectors with diameters of tens of meters need to use water-based media due to its longer attenuation length compared to scintillator.

Exclusion of unknown reactors over such a large area is not currently possible through any other detector technology and can help detect and deter the illicit generation of special nuclear materials.
Background: Antineutrino Detection

An antineutrino interacts in the detector via **Inverse Beta Decay**, producing a positron and a neutron.

- The positron immediately produces **prompt Cherenkov light** as it travels through the medium.
- The neutron is absorbed at a later time on gadolinium and produces gamma rays, resulting in **delayed Cherenkov light**.

Cherenkov light is collected by **photomultiplier tubes (PMTs)**, which convert it into an electric signal, which can then be used to reconstruct the antineutrino interaction.

The Issue:
The Cherenkov process produces little light; we need to maximize light collection for performance!
Research Goals

Guiding Question:
Can WLS plates improve the performance of large water-based Cherenkov detectors by increasing light collection and energy resolution?

WLS plates collect additional light that would have missed a PMT and redirect it towards the PMT for detection.

Cherenkov light is mostly created in the UV spectrum, and the plates shift Cherenkov light to visible blue light, where PMT quantum efficiency is higher.

But WLS plates degrade position reconstruction resolution, creating a trade-off that will be studied in future works.
Experimental Tests

Need to experimentally test the light collection of a WLS plate to see how much additional light can be captured.

PMT: 10 in. Hamamatsu R7081 PMT
WLS Plate: EJ286 WLS Plate with Reflector
LED: Moveable Collimated LED
Experimental Results

**Findings:**
Largely constant collection efficiency across the plate surface, except at plate-PMT interface.

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Simulation Results

• Results consistent between experiment and simulations
• Larger plates allow for linear light collection improvement, but results with Cherenkov light will be different (somewhat lower) than experiments with an LED

Next, simulations were validated with the experimental results and used to test plate sizes that were not available in the lab.

<table>
<thead>
<tr>
<th>Reflector</th>
<th>Light Increase</th>
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<tbody>
<tr>
<td></td>
<td>Experimental</td>
</tr>
<tr>
<td>Yes</td>
<td>7.4 ± 0.7%</td>
</tr>
<tr>
<td>No</td>
<td>-0.08 ± 0.7%</td>
</tr>
<tr>
<td>Yes &amp; using Optical Grease</td>
<td>16.2 ± 0.7%</td>
</tr>
</tbody>
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Future Work

Preparations for in-water testing of WLS plates and PMTs in a one-ton detector are ongoing; test will use both an LED and Cherenkov light from cosmogenic muons to better represent real detector performance.

Results will validate full-detector simulations to predict plate behavior in a large-scale detector.

8 PMTs total, 4 will be mated to WLS plates.
The NSSC Experience

Favorite Opportunities:

• Research at LLNL
• Deputy Director at NPWG
• Keepin Summer Program at LANL
• Policy boot camp at GWU

Lawrence Livermore National Laboratory

Los Alamos National Laboratory

GW Boot Camp on Nuclear Security Policy
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