Large Plastic Scintillators with Efficient SiPM Readout
Michael R. Kusner *, Peter R. Menge, Michael T. McLaughlin
Saint-Gobain Crystals, HIRAM, OH, USA
* michael.r.kusner@saint-gobain.com

Introduction
Large single pieces (~5x40x200 cm³) of plastic scintillator are routinely used for gamma ray detection of illicit nuclear materials in applications such as cargo scanning, wide area monitoring, and vehicle border crossings:
- Inexpensive
- Large efficiency solid angle products.
- Currently use several photomultiplier tubes (PMTs) for light detection
- Can a few SiPMs be used in place of PMTs?

Solution Method
- SiPMs are 3 – 5x more expensive per cm² than PMTs
- Too few SiPMs reduces light collected, gamma ray sensitivity and detectability
- Dark count noise increases with SiPM total area covered
- Advanced plastics containing high-Z additives or high fluor concentrations for fast neutron detection only add to problem
  - optical scattering increased
  - optical absorption increased
  - large detector size exacerbates total attenuation
- To enable large advanced plastic detectors a new method of scintillator light collection is needed.

Optical Simulation Results

<table>
<thead>
<tr>
<th>Configuration description</th>
<th>Configuration diagram</th>
<th>light collection efficiency, LCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x 14 x 79 in^3 PMT</td>
<td><img src="image" alt="Diagram" /></td>
<td>expected absorption length = 50 cm</td>
</tr>
<tr>
<td>standard readout = 4 PMT,</td>
<td>38.4%</td>
<td>absorption length = 350 cm</td>
</tr>
<tr>
<td>0.75 in^3</td>
<td>10.0%</td>
<td>absorption length = 1000 cm</td>
</tr>
<tr>
<td>4 WLS on long edges</td>
<td>21.7%</td>
<td>3.0%</td>
</tr>
<tr>
<td>readout of SiPM, 6x6 in^2</td>
<td>6.5%</td>
<td>4.7%</td>
</tr>
<tr>
<td>4 WLS rods threaded through bulk</td>
<td>11.4%</td>
<td>13.1%</td>
</tr>
</tbody>
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Simulations of light collection efficiency (LCE): LCE is defined as the fraction of scintillation light that reaches a photosensor (PMT or SiPM). The bulk plastic is PVT with dimensions 2½ x 14 x 70 in³ (~6x40x200 cm³ = 48 liter). Several cases of differing light absorption in the bulk plastic are tabulated. Note that as optical absorption in the bulk increases, it becomes more efficient to transport the light through wavelength shifting rods.

Experimental Results

Small Detectors
- 5cm diameter x 6cm long cylinders
- Compare readout with 2” diameter PMT vs a SiPM (6mm sq) area

Intermediate Size Detectors
- 6cm 10cm x 50cm
- Compare readout with a single 1.25” PMT or SiPMs coupled directly to the scintillator or coupled to wavelength shifting rods placed along the long edges of the scintillator

Large Sized Detectors
- 6x15x178 cm³
- Four SiPM boards mounted at each end
- Mounted inserts for SiPM boards

A plot of detectability vs energy threshold shows that the SiPM readout is as effective as a PMT for energies above 50 keV. Below that energy, dark counts in the SiPMs limit the sensitivity of the device.