Remote Reactor Monitoring

SL13-WATCHMAN-PD2Lb

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1. INTRODUCTION

The overall goal of the WATCHMAN project is to experimentally demonstrate the potential of water Cerenkov antineutrino detectors as a tool for remote monitoring of nuclear reactors. In particular, the project seeks to field a large prototype gadolinium-doped, water-based antineutrino detector to demonstrate sensitivity to a power reactor at ~10 kilometer standoff using a kiloton scale detector. The technology under development, when fully realized at large scale, could provide remote near-real-time information about reactor existence and operational status for small operating nuclear reactors.

The current project is a follow-on to the joint projects LL12 and SL12 -RxMon-PD02, which have identified a suitable deployment location for the kiloton scale detector at the Morton Salt mine near Cleveland, OH and have begun measurements of backgrounds relevant to the large underground detectors at the Kimballton Underground Research Facility (KURF) near Blacksburg, VA.

In FY14, Sandia National Laboratories led three major tasks under the WATCHMAN project; results and highlights from these three tasks are outlined in the following sections:

1. Completion of measurements of fast neutron backgrounds (>~50 MeV) underground as a function of depth using the Multiplicity and Recoil Spectrometer (MARS).
2. Preliminary engineering design of the kiloton WATCHMAN prototype detector.
3. A use case study to examine the potential nonproliferation applications of antineutrino detectors with a focus on kiloton- and megaton-scale detectors.

2. FAST NEUTRON BACKGROUND MEASUREMENTS USING MARS

Sandia National Laboratories (SNL) was responsible for the design, construction, and deployment of a fast neutron spectrometer to measure the muon induced fast neutron background as a function of depth. In FY12-FY13, the Multiplicity and Recoil Spectrometer (MARS) was designed, constructed, installed into a mobile platform (20 ft trailer), and deployed to KURF. Details of the physics and design of MARS are provided in the Detector Design Report, but briefly, the spectrometer illustrated in Figure 1 (left) determines the energy of incident neutrons by counting the number of low energy neutrons that escape out of 3,500 pounds of lead after being produced by high energy (n,kn) reactions on lead nuclei.

A description of this signature, the creation of a detector response matrix, and the process of the spectral unfolding algorithms are outlined in the FY14 fast neutron measurements report. In late FY13 and throughout FY14, MARS acquired ~6 months of data at both ~380 m.w.e and ~600 m.w.e and has been stationed at the KURF facility at 1480 m.w.e for the last 6 months. This depth was not originally anticipated to be one of the measurement locations; however it was felt that this depth will better tie these measurements to published data that extend up to this depth. Unfolded spectra from the first two locations are shown in Figure 1 (right).

[1] Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy?s National Nuclear Security Administration under contract DE-AC04-94AL85000.

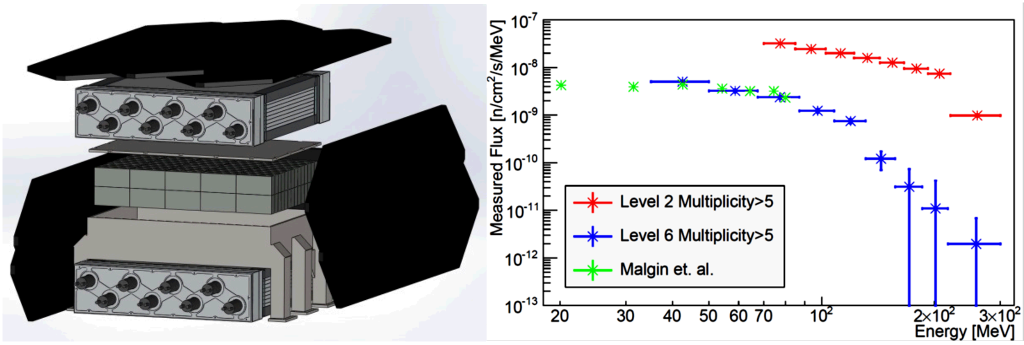

Figure 1 – (Left) Illustration of MARS including the muon veto system. (Right) Unfolded spectra from 380 m.w.e and 600 m.w.e. at KURF compared to a previous measurement atmade by Malgin et al at 550 mwe

3. WATCHMAN PRELIMINARY ENGINEERING DESIGN

Through early FY14 SNL conducted a series of detector design meetings that included many of the lead WATCHMAN collaborators; each with decades of experience in large detector design. Design components and lessons learned from detectors ranging from the Large Baseline Neutrino Experiment (LBNE) to Borexino to Super Kamiokande (Super-K) were incorporated into the WATCHMAN design. Between meetings Sandian engineers integrated suggestions and iterated on design components. Experts in various detector components (PMT mounting, electronics, cleanliness, tanks, water filtration, etc.) were assigned the task of developing a detector requirements document.

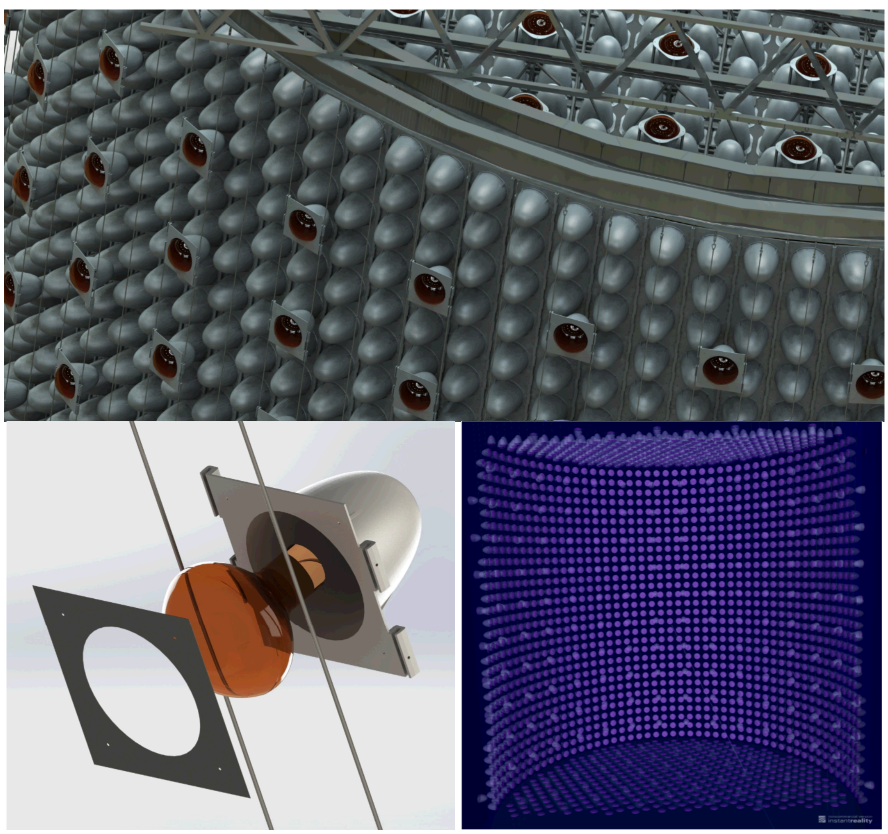

Figure 2 - WATCHMAN preliminary engineering design. (Top) CAD rendering of the backside of the PMT support structure. (Bottom left) CAD rendering of the PMT cable mounting system. (Bottom right) Visual of the Geant4 WATCHMAN detector used in simulation studies.

In parallel to the engineering design and requirements definition, a Monte Carlo simulation was developed. Designs were implemented in the BACCARAT Geant4 package both as a check against other code development (led by UC Davis) and as a means to quickly iterate between designs and predictions. Illustrations from the Monte Carlo as well as several engineered component renderings are shown in Figure 2.

4. USE CASE STUDY

In FY14, SNL and LLNL assembled a team to examine the potential nonproliferation applications of antineutrino detectors with a focus on kiloton- and megaton-scale detectors. The substantial nonproliferation expertise that exists at SNL and LLNL was leveraged by interviewing a variety of nonproliferation experts. Expert feedback was used to understand the perspectives of the nonproliferation community, to investigate needs that might be addressed by antineutrino detectors, and to examine the practicality of employing antineutrino detectors in the nonproliferation context. Based on this feedback, the team identified several nonproliferation applications for further study. The suitability of antineutrino detectors to each of these applications was determined by evaluating their performance against the core technical requirements associated with each application. These evaluations were performed in several different regimes, including cooperative and non-cooperative environments, as well as near, medium, and far standoffs. The analysis along with the evaluation of several use cases was submitted in a Use Case Study report.

5. RESULTS, DISCUSSION AND CONCLUSIONS

Preliminary results from the MARS detector are very encouraging. The depth at KURF is very similar to that at the Morton Salt Mine and will therefore have relevance both for future shallow detector deployments and the WATCHMAN demonstration detector if this project were to move forward.

The completion of preliminary engineering designs of the WATCHMAN detector has allowed us to reduce contingencies in budget estimates. For several major components such as the water tank and PMTs we were able to establish cost estimates from vendors.

The Use Case Study identified several nonproliferation applications for antineutrino detection. We believe that further study is warranted to allow pursuit of leads in the various possible user communities that have been identified in this work. Better understanding of user requirements will help inform the suitability of antineutrino detection techniques to nonproliferation needs.

6. PUBLICATIONS

Marleau, P., Gerling, M., Reyna, D., Sweany, M., Bernstein, A., Bowden, N., Dazeley, S., Roecker, C., “Multiplicity and Recoil Spectrometer for Fast Neutron Background Measurements at Depth”, SORMA 2014 conference proceedings.

Roecker, C., Marleau, P., Gerling, M., Brennan, B., “Measurements of neutron spectra underground relevant for remote detection of antineutrinos”, APS March Meeting 2014