UCSB High Energy Physics Detector R&D Final Technical Report DE-SC0013892

Benjamin Monreal (CoPI), Harry Nelson (CoPI), David Stuart (PI)

June 30, 2017

The major efforts of the UCSB Detector R&D program in the 2015–2017 period were to develop a liquid scintillator based detector to be used for characterizing radioactive impurities in samples for rapid and effective screening of low background materials for direct dark matter detection experiments; complete engineering and simulation work investigating the feasibility of constructing large detectors in salt caverns; and provide engineering innovation for development of new ideas. We summarize each of these efforts below.

Liquid Scintillator Screener

When developing the LZ Outer Detector (OD), Prof. Nelson and his group realized that the very low-background photomultiplier tubes (PMTs) available for the LZ liquid xenon (LXe) TPC readout could be utilized to detect the light from a small liquid scintillator (LS) detector. For most liquid scintillator systems, the PMTs have radioactivity in the realm of several Becquerel (Bq), but the LZ LXe tubes have about 1000 times less radioactivity. Acrylic, generally used to contain LS, is one of the most radiopure substances available, and has been used to build the Sudbury neutrino observatory, and the DEAP dark matter detector.

Taking advantage of this radiopurity, a small (roughly 1 cubic foot) chamber of liquid scintillator can provide a low-background detector capable of competing with high purity germanium detectors, at a fraction of the cost. The disadvantage of the liquid scintillator is that it has very poor energy resolution. However, for assurance that a particular sample is radiopure, tagging the precise parent isotope is unnecessary.

We have designed, constructed, and operated a LS screener. Our engineers, Susanne Kyre and Dean White, performed the mechanical design and procurements from Reynolds Polymer Technology for the "LS Screener" shown in Fig. 1. Funds for fabrication were provided by UCSB.

Graduate student Scott Haselschwardt assembled and commissioned the device. He then operated it within the low-background environment of the former LUX water shield in the Davis Laboratory at the Sanford Underground Research Facility and measured the level of a variety of radioimpurities by collecting pulse area spectra and comparing them to simulations. He has proven that the gadolinium-loaded liquid scintillator produced by Brookhaven

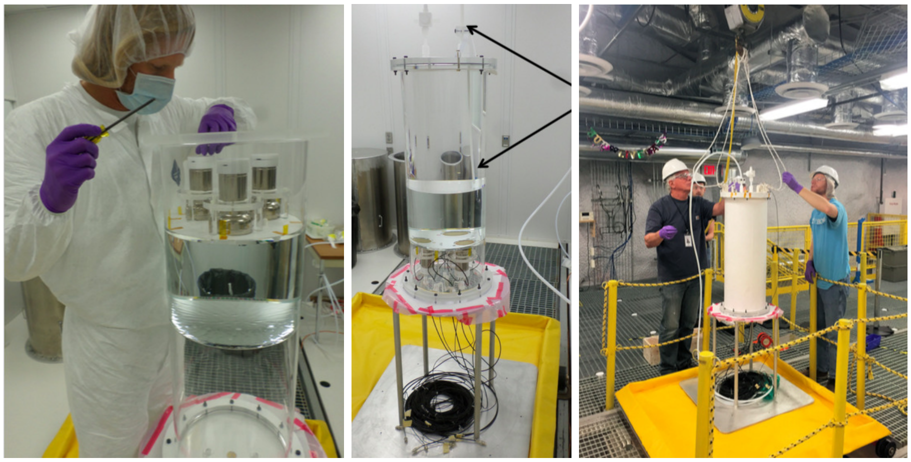

Figure 1: (a) Photo of the LS Screener PMTs being mounted by S. Haselschwardt. (b) Photo of the filled screener; the arrows point to a teflon tube used for thoron calibration. (c) Deployment of the LS Screener in the LUX water by UCSB engineer Dean White (left) and graduate student S. Haselschwardt (right).

National Laboratory meets the LZ project requirements. He presented these results at the Conference on Science at the Sanford Underground Research Facility in May 2017 and will describe the device in his doctoral dissertation.

Investigation of solution-mining for constructing large underground salt caverns

Prof. Monreal proposed and studied the idea of excavating large underground salt caverns with solution-mining (arXiv:1410.0076). As part of this detector R&D project, he worked with UCSB postdoc Luiz de Viveiros and undergraduate William Luszczak to develop a new kind of time projection chamber with special features, in particular the ability to detect scintillation and Cerenkov light without photomultiplier tubes, that make it feasible at very large scales and, apparently, low cost. This is described in "Sub-Penning gas mixtures: new possibilities for ton- to kiloton-scale time projection chambers", arXiv:1512.04926.

Mechanical engineering support for development of new ideas

The detector R&D grant provided partial support for two senior Development Engineers, Dean White and Susanne Kyre. We have relied on a small team of excellent mechanical engineers who have made critical contributions over the past 20 years to our construction projects for the BaBar silicon detector, CDMS, CMS, LUX, KATRIN, and LZ. They have provided a foundation of technical expertise that we have relied on to both develop and execute detector projects. The majority of their support comes from project funds related to their work on execution of the LZ and CMS upgrade projects, but the partial support through this R&D budget allowed them to contribute to development of new ideas on future detector projects.

Their specific contributions include:

- Design of the mechanical structure for LS Screener described above.
- Designed a methodology to measure the radon contamination in the nitrogen volume

above the LUX water shield. This is a small addition to the LUX detector system that was understood during operation to be an important auxiliary measurement; no contamination was detected.

- Design of the acrylic vessels, Gd-loaded liquid scintillator and water tank for the LZ outer detector.

- Work with Prof. Stuart on the initial design of a mechanical support structure and calculation of cooling requirements for the milliQan experimental proposal development. (arXiv:1607.04669)

Support from R&D funds for the design work in the last two items was important for development of new ideas, before project funding can be obtained after successful reviews.