Snowmass2021 - Letter of Interest

ROADSTR: a Mobile Antineutrino Detector Platform for enabling Multi-Reactor Spectrum, Oscillation, and Application Measurements

Neutrino Frontier Topical Groups:	(NF02) Sterile neutrinos (NF03) Beyond the Standard Model (NF07) Applications (NF09) Artificial neutrino sources

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In this Letter of Interest, we describe the Reactor Operations Antineutrino Detection Surface Testbed Rover (ROADSTR) project. Our goal is to develop and demonstrate enabling technologies for readily mobile antineutrino detectors able to make precision measurements at essentially any reactor facility. Efforts underway include development of Pulse Shape Discrimination capable scintillators, particularly ^{6}Li-doped plastic, mobile detector implementations, and correlated background studies. While readily mobile detectors have obvious appeal for reactor monitoring applications, they would also allow measurements at multiple reactors using the same detector. Such measurements with common detector response systematic uncertainties could be beneficial for short baseline oscillation studies, will help to constrain flux and spectrum predictions, and provide benchmark measurements for applications.

Relevant Snowmass 2021 Letters of Interest:

- *Prediction and Measurement of the Reactor Neutrino Flux and Spectrum*
- *Mutual Benefits derived from the Application of Neutrino Physics to Nuclear Energy & Safeguards*
- *Neutrino Physics and Nuclear Security Motivations for the Continued Development of Organic Scintillators with Pulse Shape Discrimination Capability and ^{6}Li-doping*

Introduction

In this Letter of Interest, we describe the Reactor Operations Antineutrino Detection Surface Testbed Rover (ROADSTR) project, which is supported by the LLNL LDRD program. Our goal is develop and demonstrate enabling technologies for readily mobile antineutrino detectors able to make precision measurements at essentially any reactor facility with little to no overburden. There are several elements of the project that support this goal. A versatile mobile platform is being constructed to facilitate testing and demonstration of detector(s) and multi-site background measurements. A major focus is the further development of Pulse Shape Discrimination (PSD) capable scintillators, particularly ^{6}Li-doped plastic. Several Inverse Beta Decay (IBD) detector implementations are being studied through simulation and prototyping. Finally, we are performing studies and measurements to understand how well correlated background rates can be predicted *a priori*. It is our intention to benefit ongoing reactor antineutrino detection efforts and to provide enabling capabilities for future experiments, especially those seeking to operate at multiple locations. We encourage input and cooperation from the neutrino physics community in this effort.

Scientific and Application Motivations

The ability to perform precision antineutrino measurements at arbitrary reactor facilities without the need for overburden would be of mutual benefit to neutrino physics and potential reactor monitoring applications of neutrino detection technology. Furthermore, it is notable that to date no detector has made measurements at more than one reactor. Our motivation is to provide capabilities that enable:

- **Multi-reactor measurement of antineutrino spectra.** As noted in [1–3], measurements with common detector response systematics at reactors with differing fission fractions would provide a powerful means to validate prediction methods, to which combined analysis of such spectra could themselves contribute. Furthermore, a set of multi-reactor measurements would provide a valuable set of templates for reactor monitoring applications.
- **Multi-reactor and multi-baseline oscillation measurements.** Baseline and energy resolved antineutrino measurements over a broad baseline range are the preferred method for probing the existence of $1-10$ eV^2 scale sterile neutrinos using reactor antineutrinos [3–5]. Measurements at research reactors provide the greatest sensitivity at higher values in that range due to smaller accessible baselines and compact core size. Measurements at $10-30$ m from larger core commercial reactors provide the best sensitivity at ~ 1 eV^2 due to very high statistics that can be collected. Mobile systems would allow measurements with common detector response systematics to be performed at both reactor types, improving the sensitivity that can be achieved. Measurements at different baseline at the same reactor provide a cross-check of systematic uncertainty estimates, especially in the case of a claimed observation.
- **Reactor monitoring demonstrations.** Systems capable of operation at any reactor have obvious appeal for applications [6]. Mobile systems able to operate without overburden would greatly simplify deployment, enabling access to a much broader range of facilities. As noted above, multi-reactor spectral measurements could find use as templates and aid in providing precision flux and spectrum predictions.

Mobile Detector Platform

A number of past efforts have used containers, trucks, or trailers as a deployment platform for antineutrino detectors [7–10]. For this project we are constructing a versatile mobile platform based around a custom trailer to further illustrate the attractive features of mobility and provide a convenient means to demonstrate detector designs and perform measurements at multiple locations. This platform will feature re-configurable fast and thermal neutron shielding surrounding a flexible vibration isolated ~ 1 cubic meter deployment volume. Cabling, data acquisition, environmental control, power conditioning, and other experimental services will be installed to support multiple prototype systems or a single large detector.

Development of PSD Capable Materials and Detector Concepts

Results from the PROSPECT experiment demonstrate that the combination of PSD capable organic scintillators doped with ^{6}Li and detector segmentation can provide very strong rejection of aboveground cosmogenic backgrounds [4, 5, 11]. We therefore focus on the development of such materials and detector concepts that employ them.

Priorities for the development of PSD-capable organic scintillators are summarized in more detail elsewhere [12]. Since materials development is inherently risky, we are considering several options. Plastics will be the major focus of this effort, given the expertise of our group and logistical simplifications these materials provide in the context of mobile systems. In the recent years, significant progress has been made in synthesizing stable PSD plastic scintillators [13] and incorporating ^{6}Li [14]. Techniques for scaling to larger elements sizes and improved ^{6}Li-doping approaches have recently been been established [15, 16]. Under this project we are working to produce to meter-scale elements and improve light yield and optical transmittance. An additional option to incorporate ^{6}Li for capture of the IBD neutron is the use of ^{6}LiZnS inorganic scintillator on the edges of an organic scinitillator element [10, 17–19]. Green emitting scintillators able to wavelength shift (WLS) the blue ^{6}LiZnS scintillation are an efficient way to readout large volumes of this inhomogeneous arrangement. Therefore, PSD-capable green WLS plastics will also be investigated, since in combination with ^{6}LiZnS they would provide the desired particle identification capabilities, albeit with lower efficiency than homogenously doped materials. Finally, the ^{6}Li solubilization techniques used for doped plastics will also be applied in the context of liquid organic scinitillators.

Detector concepts are being studied to use these materials. The primary focus is on two-dimensional segmentation, as described in e.g. [17, 20] and successfully demonstrated by PROSPECT. Simulation studies are being conducted to assess the effect of variations in parameters like total system size, segment size, material scintillation, and optical performance. Combined with results from materials development and testing, one or more prototype scale detectors will be constructed, characterized and used for background measurements.

Another feature of segmented ^{6}Li-doped scintillator detectors is that they are in principle able to indicate the direction of incoming antineutrinos [5, 21]. Directionality could assist with background reduction and, of course, indicate the direction of an unknown reactor. The very finely segmented SANDD detector concept [21–23] will be exercised under this project to explore what can be achieved in this respect.

Background Measurements and Modelling

The key challenge of reactor antineutrino measurement is the reduction and subtraction of neutron capture correlated background events. The typical approach is to measure the correlated background rate during reactor off periods. The ability to predict such backgrounds could help in situations where reactor off measurements are infrequent, e.g. refuelling outages at commercial power reactors, or at reactors that are refuelled online and only shut down after long periods for essential maintenance. Several advanced reactor concepts fall into this later category, as do CANDU reactors. We will use our mobile platform and prototype detectors to perform multi-site background measurements that will inform and validate a background prediction model. The goal will be to understand the level of fidelity with which the local environment needs to be represented in order to predict variations in background rate and the level of precision that can likely be achieved. We anticipate detailed background modelling of this type being an important capability for mobile, multi-site reactor antineutrino measurements like those described above.

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