# Upgrading VLAND to VSplat

For the reactor-based oscillation and $\sin^2\theta_W$ experiments, it would be very useful to have a measurement of the spallation-produced isotopes coming from cosmic rays. The VLAND detector could be upgraded and used to provide this measurement. Simultaneously, it could be used for R&D for the reactor experiment, specifically on phototubes and Gd-doping.

## 1 Motivation

VSplat is motivated by the need to understand "spallation background" in reactor-based experiments such as CHOOZ and Braidwood. Interactions of cosmic-rays with oil can produce radioactive isotopes in a number of ways, but for the sake of this discussion, we will lump all production together and call it "spallation." Typically when such muon interactions occur, neutrons are produced along with the radioactive isotopes. Most isotopes decay producing $\beta$'s and $\gamma$'s over a period of seconds. A few produce a correlated neutron with the day, in particular $^9$Li and $^8$He.

These isotope decays represent a significant background for physics at a reactor experiment. Those which produce only a $\beta$, with an endpoint above 3 MeV, are a background to the $\sin^2\theta_W$ measurement. Those which produce a correlated neutron are a background to the $\theta_{13}$ measurement.

Rates for isotopes produced by 200 GeV muons have been measured in experiment NA54 [1], to an error which is typically 1%, depending on the isotope. However, cosmic muons cover a range of energies and thus extrapolating these results to the expectation in a reactor experiment is tricky. It would be very valuable to these experiments to measure the rate of these isotopes per incident cosmic muon, at a typical depth for a reactor experiment, as a full-blown test of the model.

For the reactor experiment to extend to $\sin^2 2\theta_{13} < 0.01$, an analysis which compares the shape of energy distributions in near and far detectors is necessary. The sensitivity of such an experiment is limited by the fact that the $^9$Li and $^8$He production rates have been measured together, in experiments like NA54, but not separately. The best data separating the two comes from KamLAND and is shown in Figure 1 [2]. This seems to indicate that most of the rate is from $^9$Li and not $^8$He. One can see that a higher statistics measurement is needed.

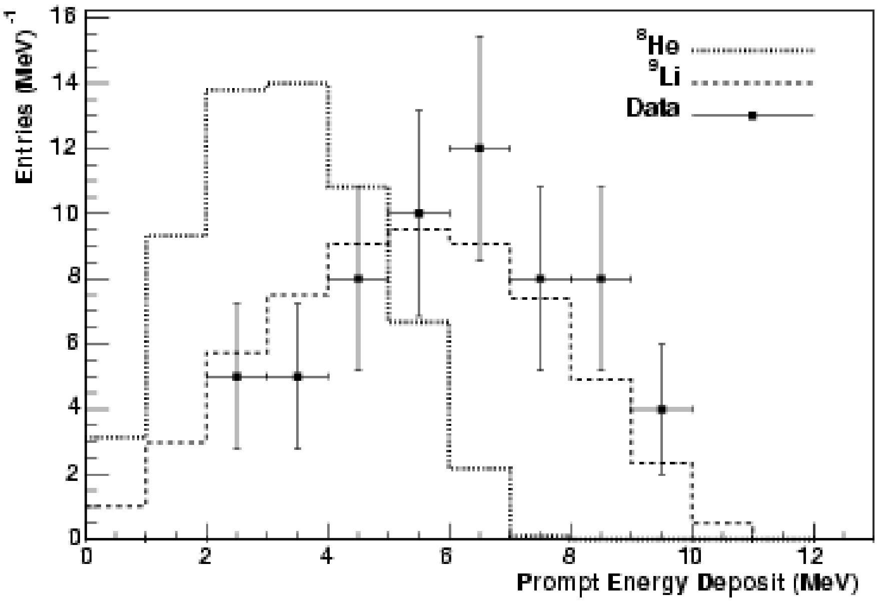


Figure 1: KamLAND measurement of $\beta$ decays with a correlated neutron. The results favor $^9$Li over $^8$He as the source of these events.

At the reactor experiment, a muon-neutron veto can be introduced to remove some of these decays. The idea of this veto is to search for neutrons produced in coincidence with the cosmic, since most spallation reactions release neutrons. It is unclear what dead time such a veto would produce. Also, it is unclear how efficient such a veto would be, since the neutron capture signal might be "hidden" in the light from the muon event. A measurement giving information on the performance of such a muon-neutron veto would be useful.

# 2 Addressing these Issues with an Upgraded VLAND

Here is my understanding of the VLAND design. The purpose of VLAND is neutron detection for homeland security. The detector is cylindrical, 2m in diameter and 2 m long, like an upright soup-can. In its initial phase it will be lined with 50 Hammamatsu 5912 8-inch phototubes, which gives 25% photocathode coverage in its initial phase. An LSND/MiniBooNE electronics card will be used for readout, which has 128 channels, of which only 50 will be used. A present the plan is to use scintillator oil, although the VLAND group is interested in investigating Gd-doping. If the analysis cuts 30 cm from the tubes, which have faces 20 cm from the tank, then this represents a fiducial volume of 3.24 m$^3$ or 2.7 tons. By late autumn 2005, the VLAND tests related to Homeland security will be complete.

Once VLAND becomes available, it could be upgraded and used to measure the rate of spallation-produced isotopes, as well as to study the efficiency for a muon-neutron veto. VLAND can be enhanced by adding 50 more Hammamatsu 5912 phototubes. This represents 50% photocathode coverage, which should provide very good energy resolution.

The remaining 28 channels of electronics could be used for a muon tracker system which would be installed above and below the detector. Above the tank, there would be two tiers of tracker separated by about 50 cm. Each plane would consist of six scintillator bars which are 125 cm long and set-up to be overlapping so that array is 125 cm wide. Each tier consists of an $X$ and $Y$ array. Below the detector are two square solid scintillator planes, which will be used to identify through-going muons. The NuTeV 5×5 counters would be ideal This uses 26 of the 28 readout channels, leaving two open as trigger bits.

The physics trigger would be an incoming cosmic ray muon as identified by the high number of hits in the tank. In the analysis we will look for low energy followers coming within $\sim 1$ s of the incoming muon. For the depths under consideration, the through-going muon rate is about 1 Hz (assuming a 2 m$^2$ detector cross section), so there is a high probability of multiple muons appearing in the window. In this case, the decaying isotope will be associated with the muon which is physically nearest to the event. The position of the muon will be determined by the tracker. Going deeper, to $\sim 450$ mwe, would reduce the muon rate to about 0.5 Hz, but also increases the running time

| | 25 mwe | 50 mwe | 300 mwe | 450 mwe |
|---|---|---|---|---|
| muons ($m^{-2}$ $s^{-1}$) | 88.3 | 24.6 | 0.53 | 0.19 |
| neutrons ($ton^{-1}$ $day^{-1}$) | 11360 | 4942 | 322 | 145 |
| $^{9}$Li+$^{8}$He | 5.3±0.9 | 2.3±0.3 | 0.15±0.02 | $(6.6\pm0.7)\times10^{-2}$ |
| $^{8}$Li | 10.±5. | 4.4±1.9 | 0.28±0.11 | 0.13±0.05 |
| $^{6}$He | 40.±12. | 17.±4.5 | 1.1±0.2 | 0.50±0.07 |
| $^{9}$C | 12.1±5.3 | 5.2±2.1 | 0.34±0.11 | 0.15±0.05 |
| $^{8}$B | 17.9±6.4 | 7.7±2.5 | 0.50±0.12 | 0.22±0.05 |

Table 1: Isotopes with energy endpoint $>$ 3 MeV for various overburdens. Rate for the isotopes is in decays/ton/d.

to acquire spallation events by a factor of two. A random strobe trigger will measure the environmental backgrounds to allow subtraction.

Gd doping is preferable for the experiment. This reduces the pathlength to only 6 cm, thus fewer neutrons will exit. Also, it will allow us to efficiently tag neutrons because the energy for Gd capture is $\sim$ 8 MeV rather than 2.2 MeV. During the VLAND running, we may be able to gain useful information the Gd to H capture ratio. Also, this may contribute to R&D on clean Gd doping, which is very important to the $\sin^2\theta_W$ measurements. Thus this work would have a double-use.

A location for the tests must be identified with a depth of at least 300 mwe (115 m of dirt) is needed. Most practical would be a location underground at Los Alamos, if a suitable place exists. This would allow for easy maintenance of the experiment (see below). However, the detector can be transported. Therefore we can investigate opportunities at locations such as WIPP or Soudan. WIPP has a flat overburden, which is very attractive for matching the Braidwood conditions. Luckily, because the detector is small, it is relatively straightforward to transport it on a flatbed truck and does not require a large niche. So one hopes this is not too expensive.

# 3 Expectations

Table 1 shows the expected rates for spallation products with decay endpoint greater than 3 MeV, a region of particular interest to the $\sin^2\theta_W$ study. The rates are given in decays/ton/day. Based on these rates, at 300 mwe, we expect about 2.4 events/ton/day above 3 MeV (and many more below). With 2.7 tons, this gives 6.4 events/day, or 10k events in about 1500 days. Thus, in 4 years, we achieve a 1% (statistical) measurement of the spallation rate. This matches the error from the NA54 measurement, but is a more applicable result for the reactor experiments since it properly folds in the cosmic-ray spectrum.

There would be over 600 $^9$Li and $^8$He events in the sample. Thus one can achieve over an order of magnitude better result than the KamLAND study. This will be valuable to the $\theta_{13}$ shape analysis.

Four years of running would mean that results would be available in 2010. This is timely, since the proposed reactor experiments expect to begin in 2008-9 and require at least three years of data taking to achieve their goals.

At this point in time, there may also be information from other spallation related experiments, however the results of VSplat will be complementary to these results rather than redundant. For example, KamLAND is likely to continue to take data, and could obtain about five times the statistics presented in the McKinny thesis. However, this provides a date point on spallation production at depths of xxx mwe – much deeper than the region where the new reactor experiment will run. Also, an experiment using muons in the NuMI line is under consideration. This experiment's goal is to achieve a high statistics measurement of the $^9$Li and $^8$He. However, the VSplat results on these isotopes will provide a useful cross check on systematics associated with the result, since the muon energy spectrum is significantly different.

# 4 Practicalities

The cost for the upgrades to VLAND is expected to be about \$100,000, **not** including any related to the detector hall or the price of Gd for the oil. Of this total, \$40,000 is for the 50 tubes, based on the price per tube charged to MiniBooNE; \$50,000 is for the muon tracker system, based on the cost of purchasing the scintillator for the NuTeV upstream veto (unless we can find one to borrow); and \$10,000 is for other materials and computing. The Gd could be quite expensive – I have to look into this. My hope is to find an existing area to use as a detector hall.

The experiment will probably need to run for 4 years, thus this makes a location at Los Alamos desirable because the people with knowledge of the electronics are local. Other groups could plan to provide a student who would periodically come to LANL to share in running shift.

Based on LSND and MiniBooNE, the detector should need little maintenance and the plan would be to use an LSND-style pager system to run shifts. Therefore, it is also feasible to run the experiment at a remote site like WIPP or Soudan. However, this means that when something goes wrong which cannot be fixed remotely, someone will have to drive or fly to the site and investigate. This could result in a as much as a week of downtime. But since past experience with these detectors shows they are quite hearty, this is not expected to happen often and thus does not represent a major loss of statistics.

# References


[1] T. Hagner *et al.* Astropart. Phys., **14** 33–47, 2000.

[2] K.S. McKinny, "A Search for Astrophysical Electron Antineutrinos at KamLAND," Thesis, University of Alabama, 2003.