This is a proposal to upgrade the existing VLAND detector to measure spallation-produced isotopes coming from cosmic rays in an apparatus which is of very similar design to the proposed reactor experiment detectors [2]. This is important input for proposed $\sin^2 2\theta_{13}$ and $\sin^2\theta_W$ studies at a reactor. Additional physics may also be possible, in particular we are investigating the feasibility of a search for new physics using orthopositronium decay. Because of the similarities to proposed reactor-based detectors, VSPLAT could be also used for tests and R&D for the reactor experiment. In this proposal we specifically consider phototube response, long term stability of Gd-doping, and U and Th cleanliness during construction.

The VSPLAT group consists of experimenters from VLAND and the Midwest reactor collaboration. Because of the interesting projects and small group size, VSPLAT is ideal for participation by high school and undergraduate students. Our request in this proposal is for equipment funds totaling $xxx, provided over a period of 3 years. Funds to support the experimenters will come from other sources.

1 Primary Motivation for VSPLAT

Recent neutrino oscillation experiments have provided exciting and unexpected results. The atmospheric and solar neutrinos results have now been substantiated by terrestrial experiments. Precision constraints on the oscillation parameters are beginning to become available. However, one mixing parameter, θ_{13}, is still unknown and is limiting both theoretical and experimental progress. For this reason, there is a strong consensus in the community that a measurement at the $\delta \sin 2(2\theta_{13}) \approx 0.01$ level is a high priority goal[1]. A two detector reactor oscillation experiment[2] holds the promise of reaching this goal in timely and cost effective way but only if the systematic uncertainties can be controlled. A primary source of uncertainty is the spallation background from cosmic ray muons traversing the detector which has led us to propose a dedicated experiment to measure and quantify this process. VSPLAT will provide useful information on these backgrounds for reactor oscillation measurements.

An important sister measurement at a reactor-based experiment is $\sin^2\theta_W$. This is experimentally motivated by the NuTeV anomaly, which indicates that $\sin^2\theta_W$ measured in a neutrino experiment is 3σ from the prediction based on e^+e^- experiments. Reference [3] presents a strategy for measuring $\sin^2\theta_W$ to $\delta(\sin^2\theta_W) = 0.0019$, using elastic scattering ($\bar{\nu}e \to \bar{\nu}e$) events. Several strategies allow the elastic scattering events to be isolated from background. In particular, the measurement is restricted to a narrow energy range of 3 to 5 MeV. This resulting expected error on $\sin^2\theta_W$ is comparable to the NuTeV, SLAC E158, and APV results on $\sin^2\theta_W$, but with substantially different contributions to the systematics. It also probes different combinations of the electroweak variables s and t than the previous experiments [4]. However, this measurement, too, is limited by knowledge of the spallation background, which VSPLAT seeks to address.

The detectors under consideration for these reactor-based measurements are oil-based scintillation detectors [2]. These represent a new generation of detectors for the MeV-energy range, building on what was learned from CHOOZ detector, which ran in the 1990's [5]. The proposed detectors range in size from about 10 to 50 tons fiducial volume. The target is Gd-doped scintillator oil. The target is generally surrounded by a layer of undoped oil, and possibly an intermediate layer of scintillator without Gd-doping.

The background to be addressed by VSPLAT is produced by high energy cosmic rays

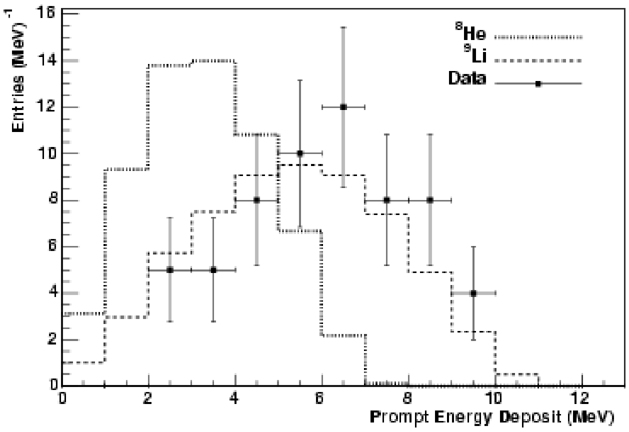


Figure 1: KamLAND measurement of β decays with a correlated neutron. The results favor ^{9}Li over ^{8}He as the source of these events.

interacting in the oil to produce β decaying isotopes. These cosmic ray interactions proceed through spallation, which refers specifically to nuclear disintegration due to interaction with a virtual photon, as well as elastic and inelastic scattering. High energy secondary neutrons and pions can also produce isotopes. For the sake of the discussion, we will refer to all of these processes for producing β-decaying isotopes as "spallation." The isotope decays which produce only a β, with an endpoint above 3 MeV, are a background to the θ_W measurement, while those which produce a correlated neutron, in particular ^{9}Li and ^{8}He, are a background to the θ_{13}.

The ^{9}Li and ^{8}He production rates have been measured together, but not separately. This is a crucial issue to the θ_{13} search because the peak of the ^{8}He decay overlaps the signal region. The best data separating the isotopes comes from KamLAND and is shown in Figure 1 [7]. 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. 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 ^{8}He peaks at the energy of the expected signal.

Rates for isotopes produced by 200 GeV muons have been measured in experiment NA54 [6], to an error which is typically 1%, depending on the isotope. Keeping in mind that the θ_{13} and θ_W measurements both require errors of $\sim$ 1% or less, it is necessary to reduce this systematic. Further measurements using high energy muon beams are unlikely due to lack of an available beamline. Also, 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 measure the rate of production of β-decaying isotopes per incident cosmic muon, at a typical depth for a reactor experiment, in a typical detector, as a full-blown test of the model. That is the primary purpose of VSPLAT.

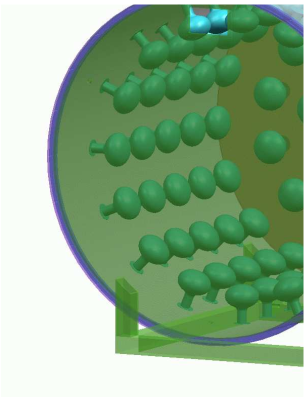


Figure 2: Left: Schematic of the VLAND tank. On the front face (surface without phototubes) the Gd acrylic volume is mounted (not shown) and will provide the majority of the active neutron thermalization/capture region. Right: ...xxxx....missing but coming soon, a photograph of the real VLAND tank.

2 The VLAND Detector

In the age of highly organized and well-financed international terrorism the development of a more sensitive, more versatile, and less expensive method of detecting the presence of illicit radiological materials would constitute a major technical achievement. VLAND is a prototype neutron detector designed for this purpose.

The basic physics community has pioneered very large volume (kiloton) liquid-scintillator detector technology in recent years with the development of detectors for neutrino physics. Smaller scale versions of these detectors offer significant advantages over conventional detector technology for both stand-alone radiation monitoring and for use in active interrogation systems. The concept as applied to counter-terrorism problems is called the Very Large Area Neutron Detector (VLAND). The objective is to build a 6 ton prototype VLAND detector using technology and expertise developed for the LSND experiment at LAMPF and the MiniBooNE experiment at Fermilab, and to demonstrate its application to the detection of neutrons and gamma rays from illicit radiological materials.

Specifically, VLAND is a 2m diameter, by 2m long cylinder, instrumented with 50 Hammamatsu 8-inch (Hamamatsu R1408 and R5912) phototubes, which give 13% photocathode coverage. Precision time and charge readout electronics will be from a 128 channel spare LSND/MiniBooNE crate, with accompanying trigger and DAQ hardware and software. An array of 6 LED flashers spread throughout the tank will provide charge and timing calibrations. The tank will be filled with Marcol 7 oil, doped with 1% concentration of Butyl PBD scintillator. Inside the main tank, a 70 cm diameter by 12 cm length acrylic cylinder volume will be filled with 0.5% Gd doped scintillator oil purchased from Bicron.

Figure 2 shows an engineering diagram of the main tank. The Gd acrylic volume will be attached attached to the front surface (without phototubes), which faces the direction of passing cars/trucks to be interrogated. The Gd volume will provide the neutron thermalization and capture region. The main tank will detect photons from the neutron thermalization, or Compton scattering photons from the 8 MeV capture γ-rays. The detector will also be sensitive to prompt γ's from the fission decays of radiological materials.

Thus, a detection signal will consist of a coincidence (within 10 μsec) of either a neutron thermalization with a subsequent neutron capture γ, or a prompt fission γ with a neutron capture γ.

VLAND has been fully reviewed and funded. At present (Aug 5/04) the main tank has been procured, the phototube support structure completed, and phototubes are being affixed to the structure. The detector will be completed by early fall, and commissioning will commence. By early 2005, tests with a low activity triggered ^{252}Cf source will begin. This will provide the experimental evidence that this technology is capable of detecting small quantities of unshielded radiological material. These measurements will guide future designs for field deployable detectors.

3 Upgrading the VLAND Detector

In the upgrade to VSPLAT, the phototube coverage would be doubled, a muon tracker/veto system would be added and the Gd-doped target for spallation measurement would be installed. As discussed in section 8.3, which presents the schedule, the spallation run for VSPLAT would begin in 2007.

The unused LSND tunnel at LANL would provide an ideal location for construction and initial shakedown of the detector. The location provides xxx mwe of shielding which removes the hadronic component of cosmic rays. There is space, power and an overhead crane. A roll-up door provides access for a flat-bed truck for transport to the experimental location.

We assume that the experiment will run at a remote site. Based on the experience of LSND and MiniBooNE, this is practical because the detector should need little maintenance. The plan would be to use an LSND-style pager system to run remote shifts.

The first upgrade installs 50 more 8-inch phototubes. This increases the detector capability to 26% photocathode coverage, which will provide $< 7\%/\sqrt{E}$ energy resolution. The VLAND phototube support structure can accommodate these tubes. These tubes will use 50 of the 78 unused electronics channels.

The interior of the detector will be modified to contain an acrylic balloon containing xxx liters of Gd-doped scintillator surrounded by a pure-oil buffer. Add some more here xxxx?

A muon tracker system will be installed above and below the tank. 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 remaining readout channels, leaving two open as trigger bits.

Gd doping is needed for the spallation measurement. This reduces the neutron 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 ~ 8 MeV rather than 2.2 MeV. Lastly, since Gd doping is proposed for the reactor experiment, we should use the same oil for this spallation measurement. The Gd-doped scintillator will be contained within an acrylic balloon, with a surrounding un-doped oil buffer.

Our needs for an experimental hall are relatively modest. The space must accommodate the 2m diameter detector and one electronics rack. The acceptable temperature range is from 50 to 75 °F. The upper limit on humidity is 70%. The phototubes will produce a total of 40 W which will dissipate into the ambient air. The power requirements for the all electronics, computing, etc. is less than 10 kW. Electrical supply for 110 V is needed. A power filter will be needed if the room contains turbines. We will need phone and ethernet communications. We will also need fire protection.

The site of VSPLAT has not yet been chosen. A site with flat overburden and a depth that matches the planned reactor experiments [2] is best. However, other configurations still allow a valuable test of the spallation simulation. The sites under consideration, listed in alphabetical order are:

- Levinworth Dam: This has an existing low background counting laboratory. However, it is located under about 100 mwe equivalent, and therefore is not ideal.

- Los Alamos locations: Two tunnel locations are under investigation. This has the advantage that the detector will be easy to maintain. However, the overburden will not be flat, adding complication to the analysis.

- Hoover Dam: This location has been used for double β decay experiments in the past. It offers 323 mwe of overburden. However, it has not been determined if there is room available.

- SNO mine tunnel: The advantage of using a tunnel is that measurements could be taken at both small (100 mwe) and large (300 to 450 mwe) overburdens. We are in the process of discussing this option with the mining company. SNO lab itself is so deep that the cosmic ray rates are too low for VSPLAT.

- Quarry in Illinios: A room in a pillar aggregate mine with about 300 mwe overburden is located in North Aurora. It has been used by Fermilab to house equipment to measure ground vibration, however, since then, mine management has changed. Therefore, we need to re-open negotiations in order to use this space.

- Soudan mine: The Soudan lab is at 710 mwe and thus too deep for VSPLAT. However, the State Parks Facility has a pump stations with lights and power at the 12th level, or 315 mwe. The possibility of using this space is under discussion with the Soudan lab management. In this case, there is an issue of how to bring the detector, which is 2m diameter, into the mine.

4 Expectations for the Spallation Measurement

In calculating the expectations for VSPLAT, we will assume that the detector is located at 300 mwe. 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.

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 to acquire spallation events

	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	$(6.6\pm0.7) \times 10^{-2}$
^{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.

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

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 θ_{13} shape analysis.

Four years of running would mean that results would be available in 2011. 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 that 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 data point on spallation production at depths of xxx mwe – much deeper than the region where the new reactor experiment will run.

5 Associated Research and Development

VSPLAT represents an opportunity to do valuable R&D on Gd-doped scintillator detectors as well as construct useful infrastructure for the future.

5.1 Testing the Concept of a Muon Neutron Veto

Typically in spallation events, neutrons are produced along with the radioactive isotopes. Thus, at the reactor experiment, a muon-neutron veto can be introduced to remove some of the background. The idea of this veto is to search for neutrons produced in coincidence with the cosmic ray, 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.

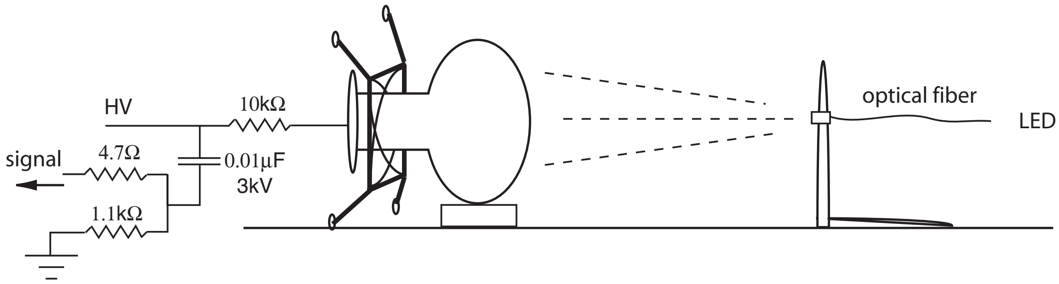


Figure 3: Schematic of the planned setup for testing phototubes.

A measurement giving information on the performance of such a muon-neutron veto would be useful.

Add more here...xxx 0.25 page max

5.2 Testing Stability and Cleanliness of Gd-doped Scintillator

Most reactor experiments propose to use Gd-doped scintillator. This has been used by the CHOOZ reactor experiment in the past, however, the scintillator suffered from deterioration over a period of xxx years [5]. Since that time, R&D efforts have led to doping methods which are expected to be much more stable [8]. Nevertheless, an in-situ test in a realistic detector would be prudent prior to use in a large reactor experiment.

For the θ_W measurement, cleanliness of the materials in the detector is a major issue. The aim is 10^{-17} g/g of U and Th, which has been achieved in past scintillator-based experiments that did not use Gd-doping [14, 9]. However, purification of Gd has not been studied. If the Gd has a substantial Th contamination, this would compromise the measurement. Therefore, we request funding for equipment to purify Gd prior to doping of the oil.

xxx I need to talk with Dick Hahn to see what sort of equipment is needed.

5.3 Assembling a Phototube Testing Complex

Information extracted from testing the phototubes for VSPLAT will be valuable to any oil-based experiment, including proposed reactor experiments. We discuss some of the information we plan to study here, as well as in section 7.2, which describes work already in progress. At the same time, the test stand which will be constructed for VSPLAT can be used in the future for testing phototubes for a reactor experiment. To test the phototubes, we will construct a forty-six bin testing system in a darkroom, similar to the testing "wine rack" used for MiniBooNE [15]. The PMTs will be propped on their sides facing an optical fiber which will illuminate the photocathodes. A side view of one wine rack bin is shown in Fig. 3.

The testing procedure will measure dark rates and waveforms, and will be automated using a VXI readout system with a built-in oscilloscope (5 Gsamples/sec) having a maximum capture rate of 10000 waveforms/90 seconds. Waveforms will be recorded in coincidence with light bursts from the LED pulser. The high voltage settings will be automated using a serial I/O interface, which is capable of testing 22 phototubes in a single run, making the time to test 50 tubes an impressively short 3 hours. While this may seem like a quite ambitious design for VSPLAT, which only has 100 total tubes, it represents valuable preparation for future involvement in a reactor experiment.

We will be studying the following figures-of-merit for each phototube: measure gain, charge resolution, timing resolution and double-pulsing rate. From these, we will calculate an operating voltage for each tube, and knowing this, we can also find the dark rate. Using these figures of merit, we will categorize the phototubes. Each tube which goes in the detector must first pass a threshold cut, and then be rated according to charge and time resolution.

For calibration purposes, we will include a rover and a permanent phototube in the test rack. The permanent tube will remain through all the tests, and we expect a constant result from it. The rover tube will be moved to various positions to ensure a reliable result throughout the setup.

6 Other Physics Goals Under Development

While our main goal is the spallation measurement, we are also in the process of developing ideas for other physics studies which can be done with this detector. One such possibility is the study of orthopositronium to search for new physics. This idea is being developed by Heather Ray (LANL).

Positronium has been an ideal system for precision test of QED because the only known interaction is self-annihilation through the electromagnetic interaction. The singlet state, 1^1S_0 ($\uparrow\downarrow$), called parapositronium ("*p-Ps*"), decays to two photons. Orthopositronium ("*o-Ps*"), which is the positronium triplet state 1^3S_1 ($\uparrow\uparrow$), decays predominantly into three photons. As a result of phase space suppression, *o-Ps* has a relatively long lifetime (142 ns) and therefore has enhanced sensitivity to non-Standard Model interactions such as extra-dimensions [18, 19], fractionally charged particles[20], or a new light vector gauge boson[17]. This new physics would be manifested in an enhanced decay of *o-Ps* into invisible particles. The first experiment to search for invisible decay channels of *o-Ps* was performed in 1989 [21]. The best present limit for the branching ratio is Br($o\text{-}Ps \rightarrow$ invisible) $< 2.8 \times 10^{-6}$ [22].

The VLAND detector is attractive for this search because it is hermetic and will have good energy resolution if 50 additional phototubes are installed. A possible source of positrons is $^{22}\mathrm{Na} \rightarrow {}^{22}\mathrm{Ne} + \beta^+ + \nu_e + \gamma(1.27\mathrm{MeV})$. A 50kBq source would be located in the center of the detector, possibly implanted in a material which transmits photons such as aerogel (the technique used by reference [22]). The 1.27 MeV γ serves as a trigger to open a 3μsec window. A positron with a broad energy range of up to 540 keV will be emitted and will either annihilate in the aerogel during decay in flight or capture to form positronium. In the latter case, the subsequent annihilation leads to zero, two or three photons which exit the aerogel and Compton Scatter in the surrounding scintillator oil. The occurrence of the *o-Ps* invisible decay would appear as an excess of events with zero–energy deposition above the Monte Carlo prediction.

Clearly this is a very difficult experiment. Zero energy can occur for many reasons other than new physics. In 10% of the cases the 1.27 MeV photon from the source is emitted due to the electron capture (EC), without positron emission. Two other physics-sources are: single photon or photonless decays of o–Ps ions ($o - Ps^- \rightarrow e^- + \gamma$, $o - Ps^{--} \rightarrow e^- + e^-$) and photonuclear absorption of annihilation photons accompanied either by photoneutrons or by excitation of long lived nuclear states. Reference [23] argues that the above sources of background will not compromise the sensitivity. There are also experimental sources of background. Dead material may block the acceptance of the photons. Therefore, in the design process, this must be held to a minimum and in the construction, positions of material must be well understood. Also, sources of β decaying elements such as spallation or contamination may induce a spurious trigger.

We are in the process of studying spurious triggers from β decays, but initial indications are that these are a difficult but surmountable problem. Background produced by β decay of spallation induced isotopes peaks in this energy region (see simulation, section 7.1 and associated Fig. 4 (left)). However, this can minimized by the analysis requirement that the 1.27 MeV photon be emitted from the central region, vetoing on incoming muons based on large charge deposited in the detector, and running at depth. For example, at 300 mwe, we expect only 3 events in the relevant energy range per day before any position cuts or muon veto. VSPLAT, will provide a cross check of this background. Contamination from ^{40}K also peaks in this range, but if we achieve KamLAND levels of purity [14], this background will be about two orders of magnitude lower than the spallation background. It should be noted that the detector the small size of the detector reduces the contamination problem considerably compared to large detectors like KamLAND and Borexino

At this point, it is not clear if this detector can substantially improve on past limits. However, because the physics is exciting, it is our plan to continue developing this idea. We have left contingency in the VSPLAT schedule between the installation of the additional phototubes and the installation of the rest of the upgrades to permit a positronium run, should this idea prove feasible.

7 Educational Opportunities for Young Physicists

VSPLAT provides excellent educational opportunities for young physicists. In demonstration, below are two summaries of Monte Carlo development from summer, 2004. The first is written by St. Charles Illinois High School Hannah Newfield-Plunkett (rising-senior) and the second is written by Columbia University Laura Gladstone (rising-sophomore). Aside from demonstrating the interesting projects available to students, this also shows the planned level of detail of the VSPLAT simulation. We expect to have one high school student and at least one undergraduate working on VSPLAT each summer. Laura plans to write an undergraduate thesis on VSPLAT.

7.1 Energy Spectra from β-decaying Backgrounds

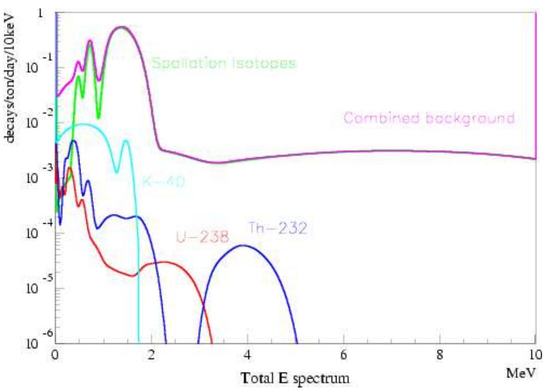
(Contributed by Hannah Newfield-Plunkett)

For input to the Monte Carlo, the energy spectra of β decays were modeled using Fermi's theory of β decay [11],

$$N(T_e) = C\sqrt{T_e^2 + 2T_e m_e}[(Q - T_e)^2(T_e + m_e)] \tag{1}$$

where C is a constant, T_e is the kinetic energy of the electron, Q is the total energy of the reaction, and m_e is the mass of the electron. It was necessary to make several corrections to the spectra produced by this formula, however.

First, many of the pertinent β decays occur to a nuclear excited state, not to the ground state. Information on the different excited states the isotopes decayed into and the branching fractions for each decay were found in reference [12]. Each of these decays was



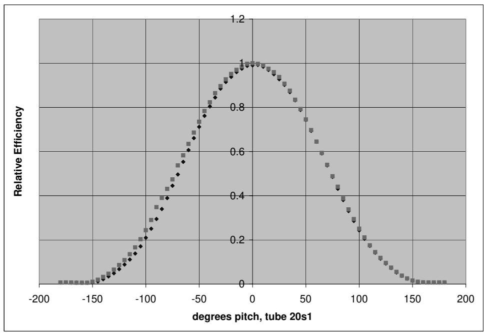


Figure 4: Results from summer, 2004, research by undergraduate Laura Gladstone and high school student Hannah Newfield-Plunkett. Left: energy spectrum of spallation (green) and contamination (cyan, blue and red) events in VSPLAT; Right: response of phototubes in oil, as a function of angle.

modeled separately, normalized with its branching fraction. In the cases of β decay into an excited state, both the spectrum of the β decay, with its corresponding energy from the parent ground state to the daughter excited state, and the prompt gamma decay energy are visible.

Second, some of the decays that occurred were also electron capture, not true beta decay. In this case, only the prompt gamma energy released if the electron capture occurred to an excited state was modeled.

Third, each β decay also had a Fermi correction, which accounts for Coulomb interactions between the β and the parent nucleus and finite radius of the nucleus, applied to it. This correction, found in reference [13], generally increased the number of visible low energy decays.

Finally, a Gaussian smear was applied to the model to account for the resolution of the detector. A spectrum was made for each isotope combining all of its modes of decay, and the spectra were then added to create the final spallation spectrum shown. Each isotope's spectrum was normalized to its relative cross-section, as found in reference [6]. (In this model, it was assumed that half of the ^{8}He and ^{9}Li produced, which were measured together, was ^{8}He, and that half was ^{9}Li. The correlated decays were disregarded.)

Similar calculations were made to model the decay chains of ^{238}U and ^{232}Th. In addition to β decay, these chains included models of alpha decays. Code to model Birks' law quenching of alphas was implemented. (In the model of ^{238}U, a special correction, documented in [6], had to be made to the spectrum of ^{210}Bi.) Less well-understood isotopes such as ^{40}K, ^{85}Kr, and ^{39}Ar are also being modeled.

Shown in Fig. 4 (left) are the spallation isotopes' energy spectra at 450 mwe, in red, the energy spectra for ^{238}U decay, at the KamLAND [14] measured concentration of 3.5×10^{-18} g/g, the spectra for ^{232}Th decay, at the KamLAND concentration of 5.2×10^{-17} g/g, and the spectra for ^{40}K, measured at the KAMLAND measured upper limit, 2.7×10^{-16} g/g.

7.2 Angular Response of Phototubes in Oil

(Contributed by Laura Gladstone)

In the detector, the light which impinges on the phototubes that are immersed in the oil can arrive at any angle with respect to the photocathode. Therefore, it is important to measure the angular dependence of the phototube response. This response is then parameterized and incorporated into the detector simulation. Two types of tubes (Hammamatsu R1408, R5912) are used in the experiment and are tested here. These results are also useful to MiniBooNE, and, possibly in the future, an oil-based SNS experiment[16], and any future experiment using a similar detector.

The setup used to measure the angular response was adapted from MiniBooNE. The procedure called for shining a low-intensity LED, through an optical fiber, about 3 meters towards a 10.25" window in the small oil tank containing the phototube on rotating tables. This setup mimicked light from a β decay striking a phototube, which occurs far from the tube surface and illuminates the entire face. The tank was magnetically shielded in a mu-metal box to isolate the response from any influence from the earth's magnetic field.

Using rapid, short pulses of the LED, measurements were taken of the relative quantum efficiency of the tube at a given position. This was obtained by taking the ratio of the number of responses which coincided with LED pulses to the total number of pulses, with about 10^7 pulses per datum. For each tube, this ratio was measured at five degree increments, mapping out the entire 360 degrees of response. This measurement was taken on 4 old (Hammamatsu R1408) tubes and 4 new (Hamamatsu R5912) tubes. The result was a roughly sinusoidal dependence on angle, as would be expected from ovoid tubes. An example of the results is shown in Fig. 4 (right).

Specialty tests were also performed. The operating voltage was varied by 50V above and below the nominal voltages. It was found that while the amplitude of the response varied, the shape stayed almost exactly the same everywhere except the last few positions, where the response was nearly zero in every case. The position of the light source was varied by 10 inches. It was also lowered and raised 5 inches.

The next step is to integrate these results into the Monte Carlo. Once this is accomplished, it is our plan to publish these results in Nuclear Instruments and Methods, because the information is valuable to any oil-based experiment using Hammamatsu R5912 phototubes.

8 Project Management Issues

VSPLAT is being organized by Prof. Janet Conrad (Columbia) and Dr. Richard Van de Water (LANL). The coordinator for refurbishing the detector is Dr. Heather Ray (LANL).

8.1 Participants

The VSPLAT group is a subset of members of the VLAND collaboration and the Midwest Reactor collaboration. The members of this group are supported on separate grants, outside of this proposal. Those involved in the project are:

- Columbia University: Profs. Janet Conrad, Michael Shaevitz; Drs. Zelimir Djurjic, Jonathon Link, Geralyn ("Sam") Zeller; Graduate Student Kendall McConnel, Undergraduate Laura Gladstone; High School Student Hannah Newfield-Plunkett.

Item	Estimated Cost/item	Total
50 additional phototubes + 5 spare	$800	$44,000
Phototube test stand		$10,000
Acrylic balloon	N/A	$5,000 *(McGregor)
Muon tracker system	N/A	$50,000
Gd purification equipment	N/A	??? *(Hahn)
Gd doped scintillator	100/gallon	$100,000 *(Hahn)
Clean power filter	N/A	$10,000 *(FESS)
Communications	N/A	$10,000 *(FESS)
SubTotal		$229,000 *(not including pur. sys yet!)
Contingency		$100,000
Total		$329,000 *(not including pur. sys yet!)

Table 2: Costs Associated with Upgrading VLAND. xxxxx...*(name) means needs to be double checked by person identified.

Item	Estimated Cost/item	Total
Tank	N/A	$10,000
50 phototubes	$800	$40,000
Readout electronics	$500/channel	$50,000
DAQ system	N/A	$5,000
Total		$105,000

Table 3: Estimated value of In-kind Contribution of VLAND Equipment

- Los Alamos National Laboratory: Drs. William Louis, Gordon McGregor, Heather Ray, Richard Van De Water
- someone else who would like to join?
- someone else who would like to join too?

8.2 Costs and Contributions

The cost for the equipment upgrades to VLAND is expected to be about $329,000. 50% contingency has been included in this cost. We plan to purchase 55 phototubes in order to have 5 spare tubes. Their cost is based on the price per tube charged to MiniBooNE. The cost for the muon tracker system is estimated based on the veto system for NuTeV and the tracker system for MiniBooNE. This only covers the scintillator and frames. The tubes will be borrowed from Kansas State University (????!!!xxxx have sent email to Tim asking if ok...). The estimated cost for obtaining the Gd doped scintillator is based on the recent purchase of 10 gallons by the VLAND group at $300/gallon. This scintillator has 0.5% Gd doping and our needs are for $\sim$ 0.1% doping. Therefore, the cost will be lower. However, we assign a large contingency to this. The acrylic balloon cost is scaled from the cost of the VLAND acrylic balloon, which is not reusable. Clean power is only needed if the location is particularly noisy, for example near large turbines.

Two sources offset the cost of VLAND. The first is contributed equipment. The total from LANL for VLAND represents $105,000. The muon tracker phototubes from Kansas State University represents xxx. These contributions do not change the bottom line to NSF, but do represent one quarter of the total cost of VSPLAT. The second is matching funds

Phototubes:	
Spring 2005 Summer 2005 Fall 2005	Order phototubes; Construct teststand and test tubes; Install phototubes.
Muon Tracker:	
Summer 2005 Fall 2005 Summer 2006	Order tracker scintillator; Design tracker and construct frames; assemble and test tracker.
Oil:	
Spring 2005 Fall 2005 Spring 2006 Spring 2006 Fall 2006	Gd Purification studies; Oil selection studies; Order oil; Order acrylic balloon; Oil is ready for tank-fill.
Assembly:	
Fall 2006 Spring 2007	Begin final assembly; Complete assembly, begin run.

Table 4: Milestones for VSPLAT.

from xxxx, which totals \$100,000. This does change the total, making our request to NSF come to \$229,000+xxxGd.

8.3 Schedule for Funding and Construction

Tab. 4 provides information on the plans and milestones for converting VLAND to VSPLAT. The construction it expected to proceed largely during the summer, when students are available to be involved in the process. Should the positronium study prove feasible, this could occur from Fall 2005 - Fall 2006, following the installation of the additional phototubes. A more conservative schedule adds six months of contingency and the detector is ready to begin data taking in autumn, 2007. Even with the most conservative schedule, the VSPLAT information will be timely for reactor-based experiments. Most of the current proposals aim to begin data-taking at a reactor in 2008 or 2009 [2] and are planned for three to four years of running. Thus a 4 year run of VSPLAT starting in 2007 will provide information on a timely basis. It should be noted that preliminary results could be available as early as 2009.

Based on the this schedule, our request to NSF is for \$229,000+xxxGd provided in the following manner:

- Spring 2005: \$99,000+xxxGd for phototubes, tracker and Gd purification system.
- Spring 2006: \$100,000 for oil.
- Spring 2007: \$29,000 for communications, computing, electronics filtering

9 Results from Prior NSF Support

xxx We are likely to be short of space, so start by giving each group 10 lines of text or less.

The following groups on VSPLAT have received support from NSF within the last five years:

- Columbia University, *NuTeV, MiniBooNE, Neutrino Factory*: Shaevitz was cospokesperson of NuTeV, which ran at Fermilab from 1993-1998 and is completed. NuTeV has published results on rare processes, structure functions, and θ_W. Conrad is cospokesperson of MiniBooNE, which is running at Fermilab. The primary goal of MiniBooNE is the test of the LSND $\nu_\mu \rightarrow \nu_e$ signal. Papers on neutrino cross sections are expected to be submitted soon. Neutrino factory analysis, which result in several papers over the next two years, focuses mainly on secondary particle production data from the HARP experiment, at CERN.

- Another group goes here xxxxx.

xxx...Guess that at most 0.5 pages is added here.

10 Conclusions

VSPLAT is a project of modest cost which will make a crucial measurement for the proposed reactor-based θ_{13} and θ_W experiments. It is proposed by small group of physicists with substantial experience in building such detectors. It is a highly leveraged project, making use of the VLAND prototype detector and other existing equipment. It is also supplemented by $xxx of matching funds from xxx..where??? Thus, VSPLAT is a good investment for NSF. This proposal requests $229,000+xxxGd for equipment for the VSPLAT project.

References

[1] APS neutrino study reference.

[2] K. Anderson *et al.*, "White paper report on using nuclear reactors to search for a value of theta(13)," arXiv:hep-ex/0402041.

[3] J. M. Conrad, J. M. Link and M. H. Shaevitz, arXiv:hep-ex/0403048, submitted to PRD.

[4] J. L. Rosner, arXiv:hep-ph/0404264, accepted to PRD.

[5] M. Apollonio *et al.*, Eur. Phys. J. C **27**, 331 (2003)

[6] T. Hagner, R. von Hentig, B. Heisinger, L. Oberauer, S. Schonert, F. von Feilitzsch and E. Nolte, Astropart. Phys. **14**, 33 (2000).

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

[8] xxx... reference on Gd stability

[9] xxx...CTF ref for contamination

[10] J.M. Moss, *et al.*, "Applications of Antineutrino Detector Technology to Counterterrorism," Physics Div. Research Review, LA-14112-PR.

[11] see, for example, K.S. Krane. Introductory Nuclear Physics.

[12] http://atom.kaeri.re.kr/ton/

[13] G. Keefer and A. Piepke. "Beta Spectra for 39Ar, 85Kr, and 210Bi," University of Alabama, 2004.

[14] xxx...Kamland ref for contamination

[15] B. Fleming and D. Smith, "MiniBooNE Photomultipier Tube Testing," MiniBooNE Tech Note 30, 2000.

[16]

[17] A.Rich, *Rew. Mod. Phys.*__53__, 127 (1981) S.N. Gninenko, N.V. Krasnikov, A. Rubbia *Modern Phys.Lett.A* **17** , 1713 (2002).

[18] S.N. Gninenko, N.V. Krasnikov, A. Rubbia *Phys.Rev.* **D67**, 075012 (2003).

[19] S.L. Dubovsky, V.A. Rubakov, P.G. Tinyakov, *Phys. Rev.* **D 62** (105011); hep-th/0006046.

[20] B. Holdom,*Phys. Lett.* **B 166** 196 (1986).

[21] G.S. Ayotan, S.N. Gninenko, V.I. Ratzin and Yu.V.. Rubakov *Phys.Lett.* **B220**, (1989).

[22] T.Mitsui, R.Fujimoto, Y.Jshisaki, Y.Ueda, Y.Yamazaki, S.Asai and S.Orito,*Phys. Rev. Lett.* **70** 2265 (1993).

[23] Badertscher, P. Crivelli, W. Fetscher, S. N. Gninenko, J. P. Peigneux, A. Rubbia and D. Sillou, arXiv:hep-ex/0404037.