Project Description

September 3, 2004

1 Introduction

1.1 Status of Neutrino Oscillations and Next Steps

1.2 Reactor Experiment: Contributions and comparisons

1.3 Elastic Scattering Measurements at Reactor Experiments

The availability of a high statistics, high precision reactor neutrino experiment provides an ideal environment to search for new exotic physics. In particular, one can use neutrino-electron scattering to make precision tests of what is predicted by the Standard Model. Neutrino-electron scattering is sensitive to one of the most fundamental parameters in the Standard Model of particle interactions, the weak mixing angle. Deviations from theoretical prediction would be evidence of new physics processes at work.

The differential cross-section for $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$ scattering is given by the following expression [1]:

$$\frac{d\sigma}{dT} = \frac{G_F^2 m_e}{2\pi}[(g_V + g_A)^2 + (g_V - g_A)^2(1 - \frac{T}{E_\nu})^2 + (g_A^2 - g_V^2)\frac{m_e T}{E_\nu^2}] + \frac{\pi\alpha^2\mu_e^2}{m_e^2}\frac{(1 - T/E_\nu)}{T} \tag{1}$$

where E_ν is the incident $\bar{\nu}_e$ energy, T is the electron recoil kinetic energy, and the vector and axial vector coupling constants are given by:

$$g_V = 2\sin^2\theta_W + \frac{1}{2} \qquad g_A = -\frac{1}{2} \tag{2}$$

The electron scattering cross-section allows a direct measurement of the weak mixing angle θ_W. As such a process is purely leptonic, it is void of uncertainties associated with nuclear structure or strong interactions. A high precision future measurement of the weak mixing angle is motivated, in part, by the result report by the NuTeV experiment, who measures a 3σ deviation from Standard Model predictions [2]. Various exotic models to explain the measurement have been put forward, and those which best explain the result require a follow-up experiment which probes the neutral weak couplings specifically using neutrinos. The proposed measurement is also interesting as an additional precision study at $Q^2 = 4 \times 10^6$ GeV^2. The two existing low Q^2 measurements are from atomic parity violation [3], and Moeller scattering [4]. A careful, controlled measurement of neutrino-elastic scattering should provide a measurement of the weak mixing angle at the level of 1%.

The technique of using reactor neutrinos to measure the weak mixing angle measurement has been pioneered by Reines, Gurr, and Sobel [5]. The weak mixing angle measurement comes mainly from tagging electrons that possess an energy greater than 3 MeV. Above this energy threshold, many of the environmental backgrounds are reduced or removed entirely. In order to make a precision measurement, the incoming neutrino flux has to be known to better than 0.5%. Current uncertainties in nuclear fuel burning limit one's knowledge of the neutrino flux and spectrum to no better than 2%. Thus, it is necessary to use inverse beta decay events ($\bar{\nu}_e + p \rightarrow e^+ n$) as a normalization constraint. These events can be tagged by the subsequent neutron capture on Gadolinium. The inverse beta decay cross-section for low energy neutrinos is given by the following expression [6]:

$$\sigma(E_{e+}) = \frac{2\pi^2}{m_e^5 f \tau_n} p_{e+} E_{e+} \tag{3}$$

Here, $E_{e+}(p_{e+})$ is the energy (momentum) of the outgoing positron, f is the free neutron decay-space factor, and t_n is the neutron lifetime. The total uncertainty on the cross-section is 0.2%, making it an ideal process by which to normalize electron scattering events.

To reduce the uncertainties associated with neutrino electron scattering, careful control must be placed on the backgrounds and systematics associated with counting the number of electrons and their subsequent recoil energies. Further details regarding background rejection and error reduction techniques can be found in Reference [?]. A total uncertainty of 1.3% is, in principle, achievable with sufficient flux, adequate overburden, and a careful calibration program. We believe such a measurement will greatly complement a θ_{13} measurement program at reactor experiments.

In addition to being a direct probe to the weak mixing angle, neutrino-electron scattering is also sensitive to other exotic physics. More notably, the differential cross-section $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$ depends also on the neutrino magnetic moment, μ_e. The Standard Model prediction for the neutrino magnetic moment is very small, XXX [8]. Thus, a positive measurement of μ_e beyond this prediction would be an indication of new physics. The current limit on the neutrino magnetic moment is less than XXX at the 90% confidence level [9]. Reactor experiments may be able to probe at this level of sensitivity or greater.

2 Strategy to reach sensitivity of $\sin^2 2\theta_{13} = 0.01$ in reactor experiment

2.1 Overview of Braidwood Experiment

2.2 Backgrounds

The e^+/n coincidence provided by the inverse beta signal reduces all serious sources to a neutron capture on Gd in association with an uncorrelated or a correlated in-time energy deposition from another neutron or a radioactive decay in the detector. The correlated background has long been recognized as the most important. It arises almost entirely from cosmic ray muon spallation that creates the radionuclides Li^9 and He^9 inside the detector, or by spallation events in the experimental enclosure walls or shielding system that produce fast neutrons which then enter the detector. Li^9 and He^9 each produce a neutron in their beta decays that mimics the antineutrino signature closely. Their 100-200 ms half-lives mean that it is not possible to to veto these events by putting them in coincidence with the cosmic muon that produces them without introducing prohibitive dead time. Fast neutrons can enter the signal sample by producing one or more recoil protons that produce scintillation light as they slow down in the detector, mimicking a positron signal that is then followed by the capture of the neutron. Spallation neutrons also dominate the uncorrelated backgrounds, which occur when a neutron capture by chance takes place in coincidence with an energy deposition in the detector initiated by radioactive decay or by an independent spallation event.

These neutron-driven background rates may be theoretically uncertain by as much as $\delta B/B = 50\%$ in some channel;this requires as high a signal-to-background ratio as possible, perhaps S/B˜100, in each Braidwood detector in order to achieve an overall 1% sensitivity on $\sin^2 2\theta_{13}$. Extrapolations from previous experiments and other studies indicate that this should be feasible, provided that the detectors are at sufficient depth, that an effective active and passive shielding scheme is implemented, and that radioactive impurity levels be kept under control. It will also be essential to measure as many of the attrubutes of the background as possible *in situ*. The $\sin^2 \theta_W$ determination, essentially a singles rate measurement, imposes

Quantity	D=300 mwe	D=450 mwe
$\bar{\nu}_e$ interaction rate– near detector	55 day^{-1}ton^{-1}	55 day^{-1}ton^{-1}
$\bar{\nu}_e$ interaction rate– far detector	1.8 day^{-1}ton^{-1}	1.8 day^{-1}ton^{-1}
mean muon energy	61 GeV	83 GeV
muon flux	0.46 m^{-2}s^{-1}	0.16 m^{-2}s^{-1}
6.5 m detector muon rate	15 Hz	5.4 Hz
inclusive neutron production rate	303 day^{-1}ton^{-1}	138 day^{-1}ton^{-1}
6.5 m detector neutron rate	0.39 Hz	0.18 Hz
^{12}B/^{12}N production per day	8.0 day^{-1}ton^{-1}	3.7 day^{-1}ton^{-1}
^{8}He/^{9}Li production per day	0.034-0.15 day^{-1}ton^{-1}	0.016-0.07 day^{-1}ton^{-1}

Table 1: Muon and cosmogenic neutron properties expected at two candidate Braidwood depths. Muon rates and energies are from Ref. 10. Inclusive neutron rates are obtained by convolving these muon rates with production spectra from Ref. 14. The upper numbers for radionuclide rates are obtained by assuming the same excluse/inclusive production ratios at KAMLAND as obtained from Ref. 15. The lower rates are from Horton-Smith's model described in Ref. 16.

more stringent requirements. In this section, non-environmental backgrounds from, e.g., electronic noise will be neglected, although clearly this is an area that demands care in experimental design.

2.2.1 Muon Flux and Neutron Production

All estimations of cosmogenic backgrounds require an accurate characterization of the muon flux at the detector. This mandates development of a good monte carlo generator tuned to external data and to the local geology as determined from bore hole samples (which are currently being obtained at the Braidwood site). Preliminary calculations[10] that employ a muon flux at the surface tuned to data and GEANT4 to propogate the muons through a flat "standard rock" overburden appropriate for Braidwood yield flux and rate values for muons given in Table 1. The values are consistent at the 15% level with computations with the MUSIC[11] package that employ the Gaisser parameterization[12], and with determinations by CHOOZ[13] for similar depths.

Neutrons generated by muons in the important 50-200 GeV energy range arise from several processes of comparable importance, including direct muo-spallation, nuclear photodisintegration, and spallation by secondary pions and neutrons from a muon-nucleus induced hadronic showers. Inclusive production rates are estimated by convoluting cosmic ray muon spectra with neutron muo-production formulae provided by Wang et al[14].

Of particular interest are the long-lived $\mu + {}^{12}C, {}^{13}C$ spallation products ^{9}Li$\big(Q = 13.6$ MeV, $\tau_{1/2} = 178$ ms$\big)$ and ^{8}He$\big(Q = 10.7$ MeV, $\tau_{1/2} = 119$ ms$\big)$, with 49.5% and 16.1% branching fraction $\beta + n$ decay modes, respectively. Production estimates for these are obtained by assuming that the ratio of radiocuclide to inclusive spallation neutron is the same as in KAMLAND[15]. The radionuclides ^{12}B $\big(Q = 13.4$ MeV, $\tau_{1/2} = 20.2$ ms$\big)$ and ^{12}N $\big(Q = 17.3$ MeV, $\tau_{1/2} = 178$ ms$\big)$ production rates are given as well since they provide spallation rate monitors and serve as useful calibration sources; their rates are estimated by the same procedure. Horton-Smith has argued[16] that this technique overestimates radionuclide production rates at shallow sites (in particular, Chooz) by a factor of $4 - 5$ because the bulk of the production at KAMLAND is due to hard secondary neutrons spallating nuclei in the detector; and the production rate for these energetic secondaries decreases more rapidly with energy than the inclusive neutron rate in scaling to the softer cosmic ray spectra of Braidwood or Chooz.

2.2.2 Fast Neutron Shielding

Fast neutron correlated backgrounds can be reduced by combination of active and passive shielding that surrounds the detector. Active shielding in the form of scintillation counters or wire chambers, provides a muon veto. Passive shielding, typically 1 m of water equivalent between the active shield and that detector, that, in combination with the outer buffer layer of scintillator, attenuates the flux of spallation neutrons reaching the detector from the surrounding rock. R&D questions relating to shielding include: What is the required size and coverage of the vetos? Does passive shielding need to provide 4π coverage? Can passive shielding be omitted below the detector? Does the active shilding need to extend beyond the enclosure walls, especially along the top? What is the required veto efficiency of the active shield? What tracking resolution is needed for the active shield? What is the best technology choice? How is the shielding installed and supported– especially the ˜100 tons above the detector and the ˜100 tons that will need to be moved in place between the detector and the shaft once the detector is installed?

2.2.3 Cosmogenic Radionuclides

In-detector spallation backgrounds are harder to suppress. Fortunately, measurements at CHOOZ[13] and KAMLAND[15] indicate that Li^9 and He^8 cross sections are tolerably small; and there are some prospects for improving the precision of these measurements. It would be valuable, however, to obtain further constraints on these and other radionuclide production rates at depths more similar to Braidwood's. Possible extra handles[15] that might be available using the data itself include: (1) an ability to remove events off-line in which the positron-like primary ionization signal is spatially correlated with the track position of a muon passing through the detector within a specified time window before the event of interest, and (2) an ability to remove events offline in which the neutron capture is correlated with a muon-induced shower detected either in the detector or the veto system. Implementing the former procedure requires study of the muon tracking resolution, the neutrino detector vertexing resolution, the optimal time window, and the data acquisition scheme. Implementing the latter requires similar studies plus development of a procedures to identify a muon-induced shower using the veto system either alone or with the neutrino detector.

It is possible in principle to discriminate via pulse shape analysis neutron-generated proton recoils from the ionization/annihilation signal from $\bar{\nu}_e$-induced positrons, although this technique has enjoyed limited use to date. Implementing this scheme in Braidwood requires an R&D program in fast neutron and recoil proton response in the scintillator oil, and a method to monitor and calibrate the technique during actual data taking.

2.2.4 Intrinsic Radioactivity

Beta and gammas from U, Th, and K decay chain products in the PMT glass, scintillator, support structures, and atmosphere can produce ≥ 1 MeV energy depositions in the detector that form an accidental coincidence with a stray neutrons produced by neutron spallation in the external rocks. For the $\sin^2 2\theta_{13}$ measurement, procedures must be developed to limit U/Th levels to ˜10^{-12} $\left(10^{-10}\right)$ g/g concentrations in the scintillator (acrylic); the tolerances for K are two orders of magnitude looser. These levels are well above those achieved by KAMLAND and BOREXINO, although ithese experiments do not use Gd. A procedure must be developed to insure that the Gd does not carry contaminants into the system; this will likely require a method for cleaning the scintillator and Gd separately before making the final mixture. Assuming these levels can be achieved in the scintillator and acryllic, then the singles rate is expected to be dominated by PMT radioactivity, where K(U/Th) levels of 60 ppm(30 ppb) can be achieved using low radioactivity glass. It will of course be crucial to work with the PMT vendor to insure that this glass is used. The critical detector parameter the determing the singles rate from radioactivity is the thickness of the outer mineral oil buffer. This must be established by Monte Carlo study and then verified in a test setup.

Instrinsic radioactive background requirements may need to reach Borexino levels (˜10^{-18} g/g U/Th in the scintillator) for the $\sin^2\theta_W$ measurement.

2.2.5 *In Situ* Measurements

Background rates *must* be measured; and it is therefor imperative to design the triggering and data acquisition system to tag and record as many of the important types of these interactions as possible.. For both types of spallation backgrounds this can be accomplished by developing a trigger for muon tracks in coincidence with a delayed neutron signature. Issues to decide include the required tracking resolution of the veto system and the specific triggering schemes. Extending the area of the active veto even beyond the size of the enclosure roof would permit better implementation of triggers for fast neutron production in the surrounding rock.

Uncorrelated background rates can be measured in the data by examining neutrino candidate events in which the neutron energy signal comes in at many capture time constants after the positron-like signal, or by selecting events using the "swap" technique[17], wherein the postron selection criteria are interchanged with the neutron selection criteria. Special triggers for the 164(0.3) μs time correlated ^{214}Bi-^{214}Po(^{212}Bi-^{212}Po) $\beta\alpha$ decays from the ^{238}U(^{232}Th) chain will allow constraints to be placed contributions from radioactivity in the oil and acryllic.

2.2.6 Special Needs for $\sin^2\theta_W$ Measurement[18]

This singles rate measurement is much more sensitive to uncorrelated radioactive backgrounds. These concerns can be addressed by lowering the U/Th/K contaminations to the levels achieved by KAMLAND and BOREXINO, by restricting the analysis to an energy range in which radioactive contributions from the oil are minimized, and by requiring that the vertex position of the neutrino interactions be well separated from the PMTs and acryllic tank walls. A key R&D task for the first part of this strategy is establishing whether the KAMLAND/BOREXINO cleaning techniques can be extended to Gd-doped scintillator (and what the cost implications of a new procedure would be). The third item part of the program needs careful Monte Carlo studies that can be verified in a test setup (such as the proposed VSPLAT facility) with data.

Important backgrounds also arise from both radionuclide and fast neutron spallation events. The former can be studied using methods described previously. The latter almost certainly require a better understanding of the level and energy dependence of the spallation neutron flux, and of the detector response to proton recoils than the $\sin^2 2\theta_{13}$ measurement.

2.3 Calibration

For a two-detector reactor experiment, we need only understand the differences in acceptance between the two, and not the absolute detection efficiency. The detection efficiency ultimately depends upon what cuts we choose in our final analysis, but we will assume here only cuts on the positron and neutron energies and the coincidence time between the two detectors. The difference in overall detection efficiency between the two detectors then depends primarily on a small number of response parameters:

1. The number of hydrogen targets
2. The Gd loading fraction
3. Scintillator light output, including aging effects
4. Detector optics, including the attenuation lengths of the different media (five for a three-zone detector, three for two-zone), PMT angular and wavelength response, Rayleigh scattering, and diffuse and specular reflection off of all media
5. Number of working PMT's, as well as their individual gains and efficiencies
6. Number of working electronics channels and individual efficiencies

7. The livetime of each of the two detectors

All of these items may change with time, and furthermore can create position dependences within the detector which in turn may depend on time. The parameters can be measured individually and then used in the context of a detector model (such as a Monte Carlo simulation) to predict the relative detector efficiencies, or they can be measured in an integral way by using a source identical or nearly so to the antineutrino signal. In practice, we expect that we will use both approaches, and in so doing not only be able to calibrate the two detector efficiencies relative to one another but determine the systematic uncertainty on the calibration.

The primary goals of the calibration program are therefore:

- To measure differences in the two integral detector responses directly through radioactive source deployments, *in situ* calibrations (spallation products and neutrons from reactor antineutrinos), and possibly detector movement
- To measure the individual response parameters in order to build detector models for use in the efficiency calibration and the determination of the relative systematic uncertainties between the detectors
- To provide an analytic form of the detector response so that each event's measured PMT hits, charges, and times can be re-mapped into event energy [1]

For the first goal, we will need to be able to deploy various radioactive sources at many positions within the volume of both detectors (using the same physical source for each detector). We also need to be able to accurately tag cosmic-ray spallation products, so that they can be used as calibrations and checks which can illuminate the entire active detector volume.

For the second and third goals, we will need to deploy optical sources of various wavelengths both inside and outside the active volume, at as many points as are necessary to measure the bulk optical properties of all the detector media. We will also need to develop a full detector model which includes the light generation (both scintillation and Cerenkov light), propagation (using the measured optical parameters), and detection.

2.4 Proposed Work

Well before the design of the detectors and calibration systems, several basic questions need to be answered: How many positions within the detector volume will sources need to be deployed? How well does the angular and wavelength distribution of optical sources need to be known—and how well can they be known in a low-cost, practical system? How well must the source position be known to calibrate the position-dependence of the response functions? Can there be differences between the detectors which are not seen by *in situ* calibrations like the inverse β-decay neutron capture peaks, and cosmic-ray spallation nuclei? How well matched do radioactive sources need to be to the expected signal and backgrounds, in order to be useful?

Much of the work to answer these questions will necessarily be done by simulation. For such a simulation to be useful, it must be based upon input parameters taken from measurements of the actual detector media. We would therefore like to being a research program whose goal is the measurement of many of these properties, and we list the many of the most important of these below.

2.4.1 Photomultiplier Tubes

Based upon the experience from detectors like the Sudbury Neutrino Observatory, we believe that a large part of the point-to-point variations in response will be due the response of the PMT's to light at different angles. For events occurring near the edge of the active volume, the near-side PMT photocathodes will on average be illuminated by high incidence angle photons. For events nearer the center, the photons tend

[1] We note that with a two-detector experiment, such an explicit reconstruction of event energy is not strictly necessary. The differential response function for the two detectors can be cast to map neutrino energy into observed hits and charges, rather than into observed energy, removing the energy calibration step.

toward normal incidence. The position sampling we will use for source calibrations will therefore depend on how steep the PMT response is with incidence angle, and this response is something we must measure now.

In addition to angular response, to build a complete model we will need to measure the charge and timing spectra (including any late- and pre-pulsing) for the various PMT's we may consider using in a complete experiment. Stability issues—such as the gain variation as a function of high voltage setting or PMT age, the PMT noise rates as function of temperature, light illumination, and age, and possible failure modes all need to be investigated and measured.

2.4.2 Scintillator

The model we use to predict the source response within the detector (which will be used to determine which sources are needed for calibration and what we can learn from them) depends directly upon the distribution of scintillation photons as a function of particle energy and species. We therefore need a measurement of the scintillator photon creation as soon possible.

The attenuation length, scattering length, and index of refraction all need to be measured and optimized for a full detector.

If the scintillator can change either in its optical or light creation properties, the two detectors may evolve separately. We therefore need to begin studies of how much the scintillator does change, in what ways it changes, and how predictable the changes are.

The scintillator timing for various mixtures also needs to be measured and input to the simulation, to determine how well the position of events can be reconstructed.

The neutron capture efficiency as a function of the Gd loading will also be critical for the simulation model, and will help to tell us how well we need to measure the capture efficiency between the detectors and the time dependence (if any) of that efficiency.

In addition, we will need to develop of a directly way of measuring the source strength of our neutron source (either an Americium-Beryllium source and/or a ^{252}Cf source) to much better than 1%, so that the relative capture efficiency between the two detectors can be measured and checked.

2.4.3 Acrylic and Oil

The same optical properties which need to be measured for the scintillator will need to be measured for the remaining media in the detector. For a 3-zone detector, the unloaded scintillator will also have to be measured.

2.5 Cross checks

2.6 Questions and proposed R&D

3 Proposed Engineering for Cost and Schedule Determination

3.1 Proposed engineering for Cost and Schedule Determination

3.1.1 The Braidwood Site

The Braidwood Nuclear Station is located about 90 km southwest of Chicago. The plant is built next to an old coal strip mine which has been converted into a cooling lake. The terrain at Braidwood is very flat with a change in elevation of less than two meters over the region of interest. The plant consists of two reactor each with a rated maximum thermal energy of 3586 MW. Averaged over the last eight years both reactors have operated with a capacity factor of greater than 90% and capacity factor has continually improved throughout this period. The two reactors are separated by about 100 meters running north-south (see Figure 1). The reactors sit in the middle of a rectangular security area. All experimental facilities must be located outside this security fence. Outside the fence, the point of closest approach is on the east side at a distance of about 200 meters from the reactors.

To get the required cosmic ray shielding the detectors will be located at the bottom of two shafts, one at the near site and one at the far site. (Figure 2 shows the proposed layout of the facility.) The shafts will be dug to a depth of 115 to 170 meters (300 to 450 meters water equivalent (mwe)). Geological data collected during the planning and construction of the plant [19] show a rock formation, known as the Galena/Platteville, that begins at a depth of about 85 meters and extends to nearly 200 meters. The Galena/Platteville formation is made up of dolomitic limestone, a rock type that is typically good at supporting tunnel structures. In addition, the radioactivity of limestone is typically low compared to most other rock types. The low intrinsic radioactivity of this specific rock group is confirmed by several gamma surveys performed during the original site characterization studies [19]. It is in this layer that the detector rooms will be constructed. The actual depth will be determined by the results of a core boring study that is currently in progress. The rock cores and bore holes will provide data on rock strength and water flow rates which will be used to determine the feasibility and cost of civil construction and maintenance as a function of depth. From a physics point of view, deeper shafts are preferable since background rates and dead time decrease with depth. On the other had, depth may be a cost driver for the experiment and it may not make sense to go below where background uncertainties are the limiting systematic. Continuing this cost benefit analysis will be a high priority in the coming year.

3.1.2 Baseline Design

In the baseline design the detectors halls are located due east of the reactors on the line that is equidistant from both reactors. The near detector hall is just outside the security fence (∼200 meters) and located 175 meters (450 mwe) below the surface. Therefore the neutrino path length distance is approximately 270 meters. The far detector hall is 1500 meters due east of the reactors and is also down 175 meters which results in a neutrino path length of about 1510 meters. The baseline calls for two detectors at each site, each with an outer diameter of 7 meters. Each detector will be surrounded on 5 sides by a veto system that has

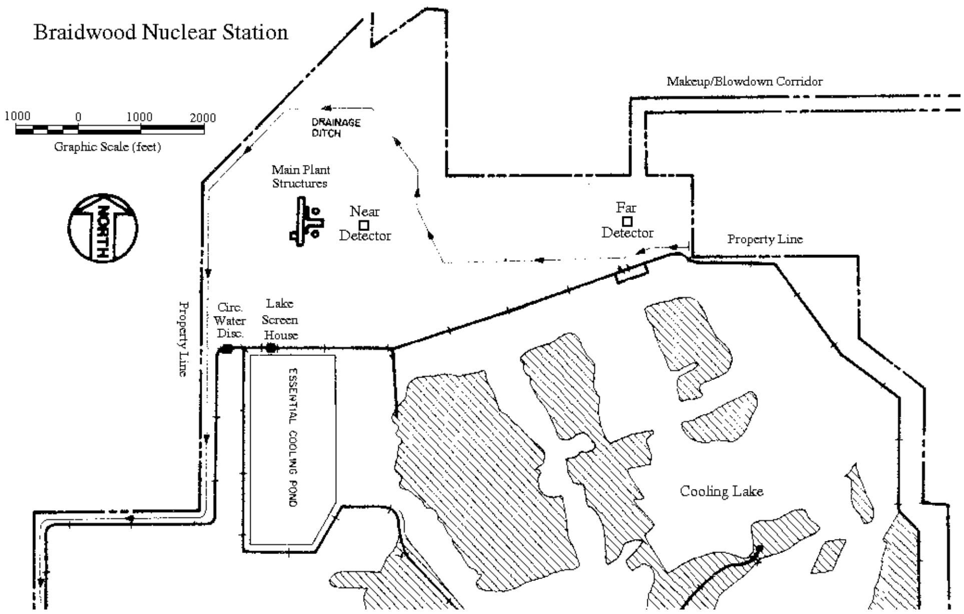

Figure 1: Drawing of the plant and sourounding area showing the approximate locations of the near and far detectors with respect to the plant and cooling lake.

an array of active cosmic ray detectors outside about a meter of passive shielding. Each detector sits inside a veto which is housed in an excavated room of dimensions 12 meters wide, 11 meters high and 32 meters long. Each room holds two complete detector-veto systems.

Ten meter diameter shafts connect the surface to the detector level at both the near and far sites. Each shafts contains two elevators, ventilation ducts, electrical and data cables, as well as pumps and water pipes for removing water from the shaft sump. The detector halls are connected to the shaft by a tunnel stub. At the far end this stub will be approximately 10 meters in length, which is the minimum required for structural integrity. The near tunnel stub will be about 45 meters long, because surface infrastructure at the near site does not allow construction of the shaft directly above the detector hall location.

In March of 2004, the collaboration commissioned a study of the cost and schedule of constructing an underground neutrino facility at the Braidwood site. The study was conducted by the consulting firm of Don Hilton and Associates. The results of the study were presented in such a way that cost of specific tasks could be broken out into manageable units (cost/meter of shaft, of tunnel, etc.) and rearranged to optimize the physics potential per unit cost. Table 2 show the estimated cost of the baseline civil construction as determined using the results of the Hilton study. The 15% scale factor for EDIA (Engineering, Design, Inspection and Administration) is consistent with industry standards for a project conducted under a design and build contract. The 25% contingency number assumes that the rock conditions along the full length of each shaft have been fully characterized, which will be the case when the shaft core borings are completed this October. The Hilton study estimates that each shaft and detector hall will take about 18 to complete,

Description of Work	Quantity	Units	Unit Cost	Subtotal	Total
General Mobilization	1	each	\$3,286,691	\$3,286,691	\$3,286,691
Shaft					
mobilization	1	each	\$512,165	\$512,165	
pregrout overburden	15	meters	\$7,538	\$113,074	
excavate & line soil	15	meters	\$62,891	\$943,360	
excavate & line rock	160	meters	\$42,262	\$6,761,941	
water ring	1	each	\$87,445	\$87,445	
surface facilities	1	each	\$104,532	\$104,532	
equipment	1	each	\$664,844	\$664,844	
sump room	1	each	\$226,295	\$226,295	
decommissioning	1	each	\$412,289	\$412,289	
Shaft Total	2	each	\$9,825,945	\$19,602,870	\$19,602,870
Detector Room (each room houses 2 detectors)					
excavate	32	meters	\$69,156	\$2,212,981	
grout	32	meters	\$5,641	\$180,511	
Detector Room Total	2	each	\$2,393,492	\$4,786,984	\$4,786,984
Tunnel					
excavation	55	meters	\$28,237	\$1,553,035	
grout	55	meters	\$2,247	\$123,585	
Tunnel Total	55	meters	\$30,484	\$1,676,620	\$1,676,620
Subtotal					\$29,353,165
EDIA	15	%			\$4,402,975
Contingency	25	%			\$8,439,035
Total					\$42,195,175

Table 2:
The cost of civil construction for the baseline project estimated using the study of Don Hilton and Associates.

with about 3 months on each end to mobilize and demobilize. The work on the two shafts can either be done serially or in parallel, so the civil construction should take between 2 to 3 1/2 years to complete.

3.1.3 Civil Engineering Needed for a Proposal Design Report

Developing the Scope for a Design and Build Contract Package The current plan for civil construction is to use a design and build contract [20]. In a design and build situation the collaboration specifies the layout, requirements and baseline design and the final design is determined by the contractor. This allows contractors the freedom to select techniques that they are already familiar with or to use equipment that they already own. The contractors know best how to use local labor, methods and means most cost-effectively. This can potentially result in a faster and less expensive overall project. The design and build process requires that the collaboration focus, early on, on developing a well-defined set of requirements that gives bidding contractors the maximum design flexibility. This will be a major activity in the next year as the collaboration prepares a full proposal.

In order to determine the requirements a significant baseline design study is needed. This study will include geotechnical, civil, electrical, and mechanical engineering. It will provide a framework for estimating cost and schedule, and for creating a bid package suitable for completing a design and build contract. The specific elements of this study, and their approximate costs, are discussed in the following paragraphs and they are summarized in Table 3. The cost estimate of this study is done to a precision of $25k where each units of $25K represents 1 senior engineer-month or 2 junior engineer months.

Geological and geotechnical engineering tasks will include the characterization of the ground units (or strata), and the determination of the ground water table and ground permeabilities in the various units. Viable options for excavation methods, rock support systems and water control will be identified. These studies are expected to cost approximately $75k.

Civil and structural engineers will determine the requirements for all surface work platforms and buildings. They will also determine the study all needed utility runs and access roads. Underground they will look at shaft lining and floor requirements. These studies have an anticipated cost of approximately $50k.

Electrical engineering tasks include determining the specifications for power and communications: power distribution, transformers, lighting, grounding, safety systems such as fire detection, phone and internet. The estimated cost of these studies is $25K.

The mechanical engineering studies will determine the requirements for heating, ventilation, and air conditioning (HVAC), fire protection ground water pumping systems, and other utilities. The approximate spatial layout and routing of pipes and ducts will also be determined. The mechanical engineering cost is assumed to be $25k.

Task	Cost ($\times$1000)
Geology/Geo-technical	$75
Civil/Structural	$50
Electrical	$25
Mechanical	$25
Drafting	$75
Cost & Schedule	$25
Other Costs	$50
Management& Administration	$75
Contingency (25%)	$100
Total	$500

Table 3: This cost estimate is made in increments of $25K where one unit of $25K represents 1 senior engineer-month or 2 junior engineer months.

All engineering studies will result in a reviewed outline of the determined specifications, and text for the related sections of the bid and contract documentation. In addition these engineering studies will generate the drawings required to bid the contract. These will include scale-approximate schematics of the layout of the surface buildings, shafts, tunnels, and chambers. Accurate scale drawings will be generated for the existing surface conditions; the spatial envelope of the minimum required excavations; and for the baselines of the electrical, mechanical and structural design. Drafting costs are expected to to be about $75k.

In the course of these studies a methodology will be determined for estimating the cost and schedule. A risk analysis will be made to help in setting the appropriate contingency. These tasks have been allocated $25K. In addition, $50k has been allocated for "other costs." These costs include a land survey, evaluations of environmental safety and health requirements, and permitting.

Finally, $75K is allocated to the project management. These tasks will include inter-agency coordination – with Exelon, the funding agencies and the collaboration – conducting the engineering reviews, and contractor selection and pre-qualification.

Detector Moving Study The experiment baseline specifies movable detectors which allow for an important cross check of the relative normalization of the near and far detectors as discussed in Section **??**. In addition movable detectors allow for detector construction on the surface in a single facility Without this capability, clean rooms and overhead cranes would need to be installed in the detector rooms at both the near and far ends. Also, the manipulation of scintillator and other potentially hazardous materials underground would present a significant environmental and safety issue.

The issue of how best to lift a 150 to 200 ton detector from the bottom of a 175 meter deep shaft, across 1300 meters of flat land and down a second 175 meter shaft again must be addressed in the in the full proposal. The Fermilab Facilities Engineering Services Section (FESS) is currently in discussion with the Belding Walbridge Company about the cost and scope of such a study. Belding Walbridge is a contractor in heavy lifting and rigging which has worked with Fermilab in the past.

This study will divide up into two phases. In the first phase Belding Walbridge will develop a small number of initial schemes including sketches and order of magnitude cost estimates. In the second phase the collaboration will select one of these schemes for further development. This development will include scaled drawings; a detailed cost estimate that separates one-time costs – such as equipment – and reoccurring cost for each move operation; and a move schedule detailing the time required for each detector move.

3.2 Detector R&D

3.2.1 Introduction

The Argonne group in the Braidwood collaboration is performing the detector engineering for A new experiment to be located at the Braidwood nuclear power plant to study electron antineutrino disappearance to measure of limit the important neutrino mixing parameter θ_{13}. The important features of the experiment design are to locate one 25 ton (fiducial volume) detector about 200 m from the average core position, and another two identical 25 ton detectors at a distance of about 1.5 km. Both detector sites need to be under sufficient overburden that muon induced spallation products do not produce a significant amount of correlated background, and are at the bottom of shafts with an overburden of at least 400 MWE.

A baseline design has been completed for the detector. However, detailed work needs to be completed on the detector structure and further R&D is needed on designing structures with acrylic and scintillator. This section outlines a plan for 2005-2006 to address remaining R&D questions/issues about the mechanical design in order to have a detector design that is ready to go out for construction.

3.2.2 Detector Design

Below is a list of tasks and estimated effort required to develop a complete detector design.

- *Design of Acrylic Sphere* Significant work has already been completed on the requirements for designing and constructing large acrylic sphere[21]. However, additional work is needed to investigate the method of bonding, develop a final design for supporting the structure, and perform a detailed structural analysis.
  - Engineer - 2 month FTE
  - EA - .5 month FTE
  - Designer - .5 month FTE
  - $4k M&S to perform bonding tests
- *Design of Outer Steel Sphere* The outer steel sphere is used as a containment vessel and must be constructed in two halves joined by a flange in order to provide access to the PMT's. Work is needed design the basic sphere, design the flange connection, and to identify vendors who can construct such large spheres.
  - Engineer - 2 month FTE
  - Designer - .5 month FTE
- *Calculation of Pressure Variation Inside Detector* During the movement of the detector lateral accelerations will result in variations of the pressure distribution inside each sphere. Calculations are needed to determine this variation in order to see the maximum pressure that the PMTs will be subjected to and if a potential shock wave effect could occur because of very high accelerations. Also, the potential for damage due to a PMT exploding needs to be investigated.
  - Engineer - .5 month FTE
- *Development of Assembly Procedure* A procedure is needed for assembling the detector. This involves designing the fixtures, tools, and procedures for assembling the acrylic sphere inside the outer steel sphere, mounting the PMT tubes, and mounting the steel sphere inside its support structure
  - Engineer - .5 month FTE
- *Design of PMT Mounts* The method for mounting the PMT inside the steel sphere has to be developed.
  - Engineer - .25 month FTE
  - Designer - .25 month FTE
- *Design of Detector Support Structure* The structure that will support the detector and will be used for lowering into the cavern and for movement inside the cavern needs to be designed.
  - Engineer - 2 month FTE
  - Designer - .5 month FTE
- *Scintillator/Acrylic Investigation* The potential of scintillator crazing the acrylic needs to be investigated for the proposed makeup of scintillator.
  - Engineer - .5 month FTE
  - EA - 1 month FTE
- *Scintillator Handling/Storage and Detector Filling Procedure* The inner and outer spheres will be filled at the same time. This will require accurate control of the fluid flow rate. Also, it is required that the liquid in each detector be identical which can only be achieved if the liquid is mixed on site and the detectors filled at the same time. This will require large storage tanks on site and a piping system for mixing and filling.

- Engineer - 1 month FTE
- EA - 1 month FTE

- *Detector Transport System in the Cavern* The detector structure will rest on a set of Hillman rollers. The rail system and method of pushing/pulling the detector needs to be designed for moving the detector after it has been lowered into the cavern.
  - Engineer - 1 month FTE
  - Designer - .5 month FTE
- *Method for Moving Detector Between Far/Near Sites* The detectors will be moved relatively infrequently between the far and near sites. However, given the large size/weight of the detector it may be impractical to move them on by a truck. A dedicated rail line between the sites has to be designed and a simple way of moving the detectors along this rail must be developed.
  - Engineer - 2 month FTE
  - Designer - .5 month FTE
- *Above Ground Facilities at Near/Far Sites* The surface buildings/crane/office space at the near and far detector sites must be designed and costed.
  - EA - 2 month FTE
  - Designer - .5 month FTE

3.2.3 Total Effort

The total Argonne effort for developing a final mechanical design for the Braidwood Reactor experiment that is ready for construction is 11.75 FTEmonths for Engineering at $15,972 per FTEmo, 4.5 FTEmonths of Engineering Assistants at $15,972 per FTEmo, and 4.5 FTEmonths of Design work at $9,416/FTEmo. The total estimated expense, including $4,000 M&S is $353,000 as shown in Table 4

Item	Units	Unit Cost	Cost
Engineer Effort	11.75	$16,000	$188,000
EA Effort	4.5	$16,000	$ 72,000
Drafting	3.25	$9,400	$ 30,550
Materials and Supplies	n/a	n/a	$ 4,000
Contingency		20%	$ 58,900
Total			$353,000

Table 4: Estimate of Detector Engineering Costs for the Braidwood Reactor Neutrino Project

4 Outreach Possibilities

Three subject groups for outreach are considered. The first are people in the local area, the second are students, and the third is the population at large.

4.1 Local Area

A list of talk topics and speakers will be distributed to local organizations (Kiwanis,...) and schools. Some sample topics might be:

- What are the big physics questions today?
- Do we still need basic research?
- Nuclear engineering; Reactor monitoring and safety.
- General energy management
- Particle physics; what are we trying to measure and why?
- History of the neutrino
- Nuclear physics
- Astrophysics

The excitement of new discoveries will be emphasized. The present day discoveries are unifying the understanding of the very large (the universe) and the very small (sub-atomic forces and particles). Some of these things are understood (quarks, basic strong and electroweak forces), and some are not (dark matter and energy). Black holes, wormholes, extra dimensions and other wild, yet possible aspects of the real world will be discussed.

Many of the discoveries which changed the world and established the economic leadership of the USA during the twentieth century came from basic research. Nuclear power, lasers, superconductors, transistors, all came from basic research. The world-wide web came as a spinoff of particle physics basic research. Most of these discoveries were unanticipated in advance, even by the experts in the field. Targeted research would not have found them.

Reactor power will certainly have to be maintained and almost certainly expanded in the near future. Although some public concerns are justified, there is a fear factor for many people that is considerably worse than justified by the facts. Some discussion of the safety record of existing reactors (except in Russia) will be made. The role of this experiment in providing an independent monitor of the reactor flux could be described.

The fascinating phenomenon of neutrino oscillations can be discussed as well as the violation of fundamental symmetries. The role of the measurement of θ_{13} for the future of this line of research will be described as will some of the projected future experiments with superbeams and neutrino factories, utilizing detectors hundreds or thousands of miles away from the accelerators.

The proposers will work with the Exelon Corporation to establish an office of outreach for the θ_{13} experiment. Publicity releases will be sent to local papers, TV and radio stations describing the project and its progress. When justified, the releases will go to national media. Researchers will be made available for interviews. Local people will be utilized for construction where possible, and this, also, will be publicized. We will try to develop an on-site welcome center that provides inquiry-driven experiences in content areas in which materials developed for web-delivery are adapted for live engagements. The welcome center will be tied into tours of the power plant.

4.2 Students

A Summer jobs program for college and possibly high school students will be established. They will help with construction and testing of prototypes and the detector, with PMT testing, and with electronics construction and testing. Cooperation with the American Physical Society and the American Association of Physics Teachers will be established for development of online activities as well as workshops and seminars.

4.3 Population at Large

A web site will be produced which will contain the information described above for talks. θ_{13}-specific activities will be bound into ongoing outreach efforts at universities and national laboratories. The site will be linked to education databases. A 1-2 page brochure on the experiment will be produced concerning physics. technology, and local aspects of the experiment.

5 Summary

References

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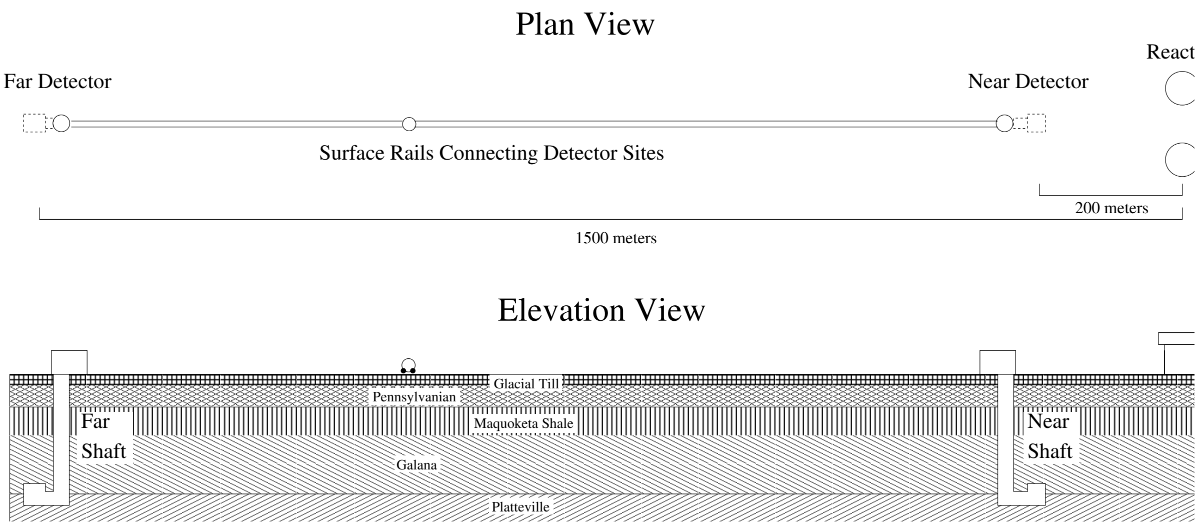

Figure 2: Plan and elevation views of the proposed layout of the experimental facility are shown. The elevation view shows the the major geological strata and their approximate elevation, in meters above sea level. Buildings, shafts and detectors are not drawn to scale.