Advantages of the Braidwood Experiment

Goal: Implement a multi-detector, reactor neutrino experiment with sensitivity below the $\sin^2 2\theta_{13} = 0.007$ level with cross checks and redundancy. The purpose is to assure a convincing 3 to 5 σ signal if $\sin^2 2\theta_{13}$ is above 0.02. This sensitivity is achieved by searching for a signal using both relative rate and relative energy shape measurements in a set of detectors about 200 m and 1500 m from a nuclear reactor.

We believe the most cost and time-effective approach to address the next steps in the neutrino program is to develop a convincing reactor experiment that has discovery (3 to 5 σ) potential to $\sin^2 2\theta_{13} = 0.02$, and limit sensitivity below the $\sin^2 2\theta_{13} = 0.007$ level. The Braidwood Experiment provides this opportunity, with two modes of signal detection (rate and energy spectrum), multiple measurements of major backgrounds, and multiple constraints on the other significant systematic errors. The use of identical detectors at near and far locations from the reactor eliminates detector and flux systematic uncertainties to first order. Braidwood is an experiment that can be mounted in a timely fashion, has a strong collaboration, and is supported strongly by the Exelon Corporation, the owners of the Braidwood Nuclear Power Station.

Braidwood Experiment Design:

The following design will permit the definitive search described above:

- Near and far detector stations under identical 450 mwe flat overburden shielding
- Two near and two far 65 ton fiducial mass spherical detectors using Gd-loaded liquid scintillator.
- Simultaneous filling of scintillator in near and far detectors to ensure identical composition
- Active muon veto system for background tagging and event identification
- Two-region detector design for maximal fiducial volume and ease of calibration
- Movable detectors that can be cross calibrated at the near location
- A multiple source calibration system

Advantages of Braidwood:

- The Braidwood experimental design allows the measurement of an oscillation signal at the 5 σ level for $\sin^2 2\theta_{13} = 0.02$ at $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2 and, for a very small or null oscillation scenario, allows placing a limit at the 90% CL level of $\sin^2 2\theta_{13} < 0.007$ for all of the currently allowed Δm^2 region.
- Multiple identical near and far detectors
  - Increased fiducial target mass and event statistics
  - Reduction of detector systematic uncertainties through direct comparisons
  - Pairs of near/far detectors will be co-filled with identical scintillator and mineral oil which will eliminate composition differences.
- The geology and overburden has been determined by drilling bore holes at the planned locations of the two shafts on the Braidwood reactor site.
  - Results showed that the rock and water characteristics were as expected, and that the overburden at the two locations is identical to better than 2%.
  - This information has eliminated much of the uncertainty associated with the civil construction project and adds credibility to the "bottoms up" cost/schedule estimate from Hilton Engineering.
- Flat overburden
  - Better shielding for large angle cosmic-ray muons
  - Relative differences in acceptances of spallation-related cuts are minimized by the uniform overburden
  - Capability to put near and far detector at the same depth
  - Capability to have a deep near detector with significant shielding
  - Allows simple method for transporting modules between near and far sites for cross calibration
- Near and far detector at the same depth
  - Allows the use of ^{12}B to perform a relative efficiency and energy calibration between the near and far detectors
  - Measurement of near detector background in the far site.
- Both near and far detectors on the symmetry axis with respect to the reactors
  - Relative reactor power variations cancel exactly since each detector is the same distance from the two reactors.

- Deep near detector
  - Cosmic-ray rates at a level that allows muon tagging of the ^{12}B for near/far cross calibration
  - Neutrino-electron elastic scattering events can be isolated in the near detector allowing a measurement of the neutrino weak neutral current couplings in a purely leptonic process.
- Large (7 m diameter) spherical detectors
  - Increased fiducial volume giving increased data samples and reduced sensitivity to uncertainty in reconstruction cuts
  - Minimal surface area to volume ratio reducing edge effects (e.g., energy tails resulting from lost particles)
  - Ability to see changes in background versus radius and explore observed signal rates as a function of radius
  - Insensitivity to neutrino wind effects compared to cylindrical detectors
- Two zone detectors with Gd-loaded scintillator inner region surrounded by pure oil buffer region.
  - A third zone is not needed for large detectors with good energy calibrations.
  - Increased fiducial volume for a given detector radius
  - Minimal surfaces that need to be understood for light transmission
  - Easier calibration using sources than three zone systems
- The use of Gd-loaded scintillator with long attenuation length, good light output, and chemical stability
  - The BNL nuclear chemistry department has developed prototype scintillators based on pseudocumene and dodecane that appear to meet these requirements, although more R&D effort will be carried out to establish the long-term stability of mixture and to investigate the interaction with the containment vessel.
- Active veto system for reducing and measuring spallation backgrounds
  - Most spallation backgrounds from neutrons and radioactive isotopes are tagged for study and removed from event sample
  - Muon shower veto can identify muons that undergo deep-inelastic interactions. Most of the backgrounds are from these types of muon interactions which happen at low rates and can, therefore, be vetoed.
- Direct cross calibration of detectors at the high rate near site by judicious moving of detectors during the experimental running period.

- The Exelon reactor company is enthusiastic about the project and willing to work with the collaboration in developing, deploying, and running the experiment.
  - Exelon says that there are no security issues with the detector locations being proposed.
  - The use of outside subcontractors for construction and operations is allowed and encouraged. This was tested during the recent bore hole construction project that we set up and carried through using several subcontracting firms.

Cross Checks to Establish a Convincing Measurement:

Multiple cross checks on the backgrounds and relative acceptances for the detectors are necessary to establish a convincing measurement, should a signal be observed, or to place a stringent and robust limit if no signal is seen. The list of cross checks built into the Braidwood Design includes:

1. Multiple methods to determine the relative fiducial volume and efficiency of the detectors
   - Direct measurements of the detector mass and composition during common filling of the detectors
   - Direct measurements of spallation isotope production by muons in the detectors
   - Cross calibration of far and near detectors by movement to the high rate near site
2. Multiple measurements of the backgrounds using muon tagging and event isolation
3. Multiple detectors at each location
   - Direct cross check of rates at a given site
   - Stationary detectors during moving provide a direct monitor of units that are moved
   - Very high statistics samples to compare reactor neutrino response with other calibration methods
4. Large radius spherical detectors allow investigations of the behavior of signal and background events versus radius as a cross check of cuts and systematic uncertainties.