A Low-Background Test Facility in the Morton Salt Mine

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1 Introduction

A discrepancy between the solar neutrino capture rate predicted by standard solar model calculations and the ^{37}Ar rate measured by the chlorine experiment in the Homestake Gold Mine has persisted for eighteen years. A recently calculated value of the flux is 7.9 ± 2.6 (3σ) SNU (1 solar neutrino unit= 10^{-36} captures/target atom/sec) in the Bahcall-Ulrich "Standard Solar Model" (SSM) [1]. This is to be compared with the measured value in the chlorine experiment [2], averaged over the last eighteen years, which is 2.3 ± 0.3 SNU. The deficit has now been corroborated by the Kamiokande II water Čerenkov experiment [3], which observes only $0.46 \pm 0.05 \pm 0.06$ of the flux predicted by the Bahcall-Ulrich SSM. The explanation for this discrepancy may lie in the realm of astrophysics or it may reflect new properties of neutrinos themselves.

The Sudbury Neutrino Observatory [4] is now under construction in the INCO nickel mine near Sudbury, Ontario. It will be the first solar neutrino detector capable of registering and distinguishing both the flux of electron neutrinos and the total flux of all left-handed neutrinos from the Sun. As such, it can make an unambiguous statement that neutrino oscillations are occurring, if the total flux is found to be larger than the ν_e flux. The conclusions will be essentially independent of solar models. In all likelihood, when SNO begins operation in 1995, the celebrated "solar neutrino problem" that has endured for 20 years will finally be laid to rest, with clear evidence for either new neutrino properties or new astrophysical processes. Given that the Standard Model of the elementary particles and fields is incompatible with neutrino mass and oscillations, the former conclusion would be especially revolutionary, and would point toward generally new properties of Nature. Evidence from solar neutrino experiments now in operation strongly favors this exciting possibility.

The sensitive medium of the SNO laboratory is 1000 tonnes of ultra-pure D_2O. The charged-current interaction of electron neutrinos on deuterium produces a fast electron that emits Čerenkov radiation in the water. An array of 9500 photomultipliers records the amount of light and, therefore, the energy of the electron.

Neutral-current interactions of all flavors of neutrino disintegrate the deuteron into a proton and a neutron, and the rate of these interactions can be determined from the rate of neutron production. Detection of free neutrons in the SNO heavy water can be achieved by dissolving NaCl in the water. Neutrons capture on ^{35}Cl with the emission of gamma quanta that shower, producing Čerenkov light. By comparing the Čerenkov rates and spectra with and without salt in the water, the relative rates of neutral-current and charged-current interactions can be deduced.

While this strategy is conservative and secure in its implementation, it has some disadvantages. It requires the subtraction of two data sets taken at different times, with penalties in statistical and systematic precision. Should a supernova occur in our galaxy while SNO is running, the observation of neutral-current interactions would depend on the salt being in the heavy water at the time. Neutral-current interactions of supernova neutrinos are of special significance, as they are perhaps the only feasible way to determine the masses of ν_μ and ν_τ, if the masses lie in the range 20-100 eV, as would be required to explain the dark matter in the Universe.

The SNO collaboration has devoted much effort to searching for a more versatile method of neutral-current detection. Neutrons can be detected with high efficiency in ^{3}He-filled proportional counters without interfering significantly with the Čerenkov light from charged-current processes. We propose to install in SNO an array of such counters, with a total length of 900 meters, and constructed of highly purified materials.

^{3}He proportional counters offer fundamental advantages:

- Neutral-current and charged-current events are *recorded separately and distinguished event by event.*
- The effective CC rates are *doubled* and the NC rates *quadrupled* in comparison with the dissolved-salt method.
- The secular variation in the NC rate due to the Earth's orbital eccentricity *would become observable* at the 95% confidence level.
- Time variations in the neutrino flux could be followed simultaneously in the NC and CC channels *on the time scale of milliseconds to years.*
- All signals and backgrounds *can be determined at the same time*, and there is no need to compare and subtract data taken at different times and under different conditions.
- The date by which a definitive NC measurement has been made could be brought forward *by as much as a year.*
- The method is fully compatible with the dissolved-salt approach, allowing, by two different techniques, *a valuable systematic check* of important physics results.
- The duty factor for full-efficiency NC detection rises *from 50 to 100%*, and the possibility of missing NC data from a supernova or other interesting event is correspondingly diminished. Even if salt is present in the water, the conversion of NC events to Čerenkov light makes inferences about which events are CC and which NC indirect.
- Event-by-event NC detection offers the prospect of *determining a* ν_μ *or* ν_τ *mass* (especially in the cosmologically interesting range of 20-100 eV) if a supernova should occur.

We consider these advantages to be so compelling both qualitatively in the kinds of physics that would be accessible to SNO, and quantitatively in reducing the statistical and systematic uncertainties that we have submitted a proposal [5] to the Department of Energy for Equipment funds to build an array of detectors for SNO. We are optimistic that it will be funded.

2 Demonstration Criteria

The use of ^3He proportional counters for neutron detection is an old and well-established art. The special concerns for SNO are associated with the radiopurity of the construction materials and the possibility of spurious electronic induced signals associated with the required high voltage operation of the detectors. Because of the low rate of production of neutrons, about 10 per day in 1000 tonnes of D_2O, extremely low detector backgrounds are required. These issues require radical departures from standard construction materials and practices.

Before the counters are deployed in SNO, absolute assurance that the intended goals can be reached is required. To this end, the SNO collaboration has identified a set of criteria that must be satisfied in advance:

1. Demonstrate alpha background less than 2 m^{-2} d^{-1}.

2. Demonstrate photodisintegration background less than 10% of SSM signal (about 6 pg/g Th total, determined by mass spectrometry or neutron activation of sample construction materials).

3. Demonstrate spurious-pulse background less than the alpha background.

4. Demonstrate underwater operation of 20 2-m counters for 6 months at 20 C with respect to water ingress, He loss, outgassing, leach rates, gain changes, instability.

The demonstration will require construction of a separate underground laboratory in which the prototype detectors can be tested. After careful consideration of a number of options, we have concluded that the Morton Fairport Mine offers the best combination of factors for success:

1. Adequate depth. The muon flux at the 1800-foot depth is approximately 6 x 10^2 $m^{-2}d^{-1}$. Electronic discrimination can distinguish throughgoing muons from the highly-ionizing α particles to be measured, even though the α rate is about 1000 times smaller.

2. Low radioactivity surroundings. Salt is relatively free of U and Th (in comparison to hard-rock mines like the one at Sudbury). Thus gamma and neutron backgrounds are about as low as can be obtained in any underground location before shielding. If the salt contains 100 ppb of Th, then a flux of 1.5 x 10^6 $m^{-2}d^{-1}$ of 2.6-MeV gammas emerges from the walls of the mine. Neutron rates are also low in a salt mine, about 21 n/d/kg/ppm of U.

3. A long and admirable tradition of cooperation between the Morton Company and Science in making the Fairport mine available.

4. Location in the United States. Costs and logistics are greatly simplified if the Test Facility can be located in the USA.

For these reasons, we hope the Morton Company will be sympathetic to our request for this relatively small-scale use of their mine.

3 Proportional Counters

Each counter is a sealed cylinder up to 2 meters long with a 5-cm outer diameter, and is filled with a gas mixture consisting of 3 atm of ^{3}He - ^{4}He mixture, 1.0 atm of CF_4, and 0.2 atm of CH_4. The body is made of Ni tubing having a 0.25-mm wall thickness. A thin Ni wire runs down the axis and is biased to a potential of about 1500 V to obtain avalanche multiplication of ionization deposited in the detector.

Generally speaking, the choices of construction materials are dictated by the very limited subset that can be purified of Th and U to the necessary pg/g level.

4 Test Facility

In a location where salt surrounds the working area on both sides and top and bottom, two "Sears huts" will be placed on metal-plate pads. One hut is 21 feet by 12 by 9 high, the other 12 feet by 8 by 7 high. The larger hut contains the detectors in a tank of water 2'x3'x14', a water recirculation pump and sterilizer, a rack of electronics, a storage cabinet, a table and chair, and a tool chest. The smaller hut contains a data-acquisition computer and furniture. The objectives of this arrangement are reduction of electromagnetic interferance radiated by computers and isolation of the detectors from traffic during routine data-taking.

Each hut will require a window-mount air conditioner, power for the A/C, and 20 Amps of 110-VAC power. Insulation of the huts to reduce A/C loads is under consideration. A telephone line, especially with data transmission capability, would be an enormous advantage. Security and fire protection will be in accord with Morton Company policy.

Frequent access by up to 6 people to the site will be needed in the setup phase, but thereafter we anticipate that visits to the site will decrease to once a week by one person. Mechanized equipment to bring materials and water from the hoist to the site will be needed.

A surface staging and storage area is highly desirable.

The anticipated duration of work is to the middle of 1996, after which time LANL will remove all equipment and structures it has introduced, except for concrete pads (if used).

Los Alamos National Laboratory employees are covered by health and third-party insurance while working for LANL in another location. Employees who expect to be significantly involved in the work at Fairport will be expected to pass the Morton Company's required training program for unsupervised work underground.

References

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[5] *Neutral Current Detection in the Sudbury Neutrino Observatory (SNO)*, T. J. Bowles et al., Los Alamos National Laboratory FIN-94-ER-E324 Appendix, January 1992 (unpublished).