# Supplementary Information on the ORLaND Project

## 1. Introduction

This is intended as a supplement to document "Scientific Opportunities at the Oak Ridge Laboratory for Neutrino Detectors (ORLaND)" (refered to hereafter as the ORLaND white paper), which we have distributed to you earlier. It provides some additional technical material for ORLaND, and presents more detailed cost and schedule information.

We will develop ORLaND as a user facility for stopped pion neutrino research. The Oak Ridge National Laboratory Physics Division would construct and equip an underground detector laboratory (bunker) as near as possible to the SNS neutron production target. We are convinced that one large volume (~2000 ton) experiment would be an essential component of the physics at ORLaND. It appears necessary to design the bunker around a tank large enough to contain this experiment. Experiments to be run in the ORLaND Facility, including experiments utilizing the large tank, would be selected by a Program Advisory Committee.

At the time the white paper was written the reference design for the SNS called for a 1.3 GeV 2 MW proton beam for neutron production. The present SNS design is for a 2 MW 1 GeV pulsed proton beam incident on a thick mercury target at a repetition rate of 60 $s^{-1}$ with a pulse width of ~600ns. The reduction in proton energy, while maintaining constant power results in an ~10% reduction in neutrino yield: the SNS produces an approximately isotopic total yield of $\sim 10^{15}\ \nu_x\ s^{-1}$ of each of three neutrino flavors $(\bar{\nu}_\mu, \nu_\mu, \nu_e)$ with the same pulse structure as the incident beam. This corresponds to a flux of $\sim 3\times10^{6}\ \nu_x\ s^{-1}cm^{-2}$ 50 m from the target. The availability of such a neutrino source presents a tremendous opportunity for the nuclear physics community. Not only can we take advantage of a $1.4 B investment by the DOE Office of Basic Energy Sciences (BES); we can have access to the world's most intense source of stopped pion neutrinos without paying the operating costs of the accelerator. There is however, a great sensitivity in DOE BES, as well as the SNS, to the requirements that any use of the SNS that is outside the original mission of the facility must have no impact on the facility cost or schedule. We have taken great care to show that we can meet these requirements.

## 2. Bunker Location

For optimal location of the neutrino bunker several parameters were considered. Options explored were: place the bunker under the target building, putting it at zero degrees or at 90 degrees relative to the proton beam direction. Factors considered in selecting the optimum location were: maximization of the neutrino flux both for the decay at rest (DAR) and (decay in flight) DIF neutrinos, availability to access to the bunker, and potential for the future upgrades.

For the optimization of the DAR neutrino flux, the situation is quite simple. Because of the isotropic nature of DAR neutrinos, the best position is as close to the target as possible. Unfortunately the most favorable position under target building is not available because of the time conflict with the SNS construction, as well as the recent change to use of micro piles under the target building. The closest location at zero degrees is two times further from the target than at 90 degrees because of the geometry of the target building.

The SNS target, optimized for the production of the maximum number of cold neutrons per proton, consists of a large triple wall vessel filled with mercury. The dimensions are 9 cm. high, 23 cm wide and more than a meter long along the beam direction. Mercury is a high-density material with large stopping power, resulting in very short range and thus a small decay in flight probability for all particles produced in the target. Only a few tenths of a percent of the pions, and almost none of the muons have time to decay in flight. Interestingly, the highest flux of DIF neutrinos is under and above the target, where secondaries pass through a relatively thin layer of mercury and then enter low-density neutron moderators where the pion flight path and hence probability of decay, is significantly larger than in other directions. Unfortunately this location as we mentioned before is unavailable because of construction constraints. Some pions and muons are produced as a result of the interaction of the protons in the beam pipe and beam window. A large number of such interactions can produce a significant flux of DIF neutrinos at zero degrees. It has been impossible so far to accurately estimate the flux of such neutrinos because continuous evolution and improvement of the SNS design. Our assumption is that the SNS designers will do their best to keep such interactions to the lowest possible level.

A neutrino bunker located at 90 degrees at the north side of the target building is almost on the direct continuation of the LINAC beam line. Neutrinos produced in the LINAC beam dump in the forward direction will go directly to the neutrino bunker. Unfortunately, this beam dump is located before the accumulator ring and thus does not have the compressed time structure. The only other beam dump with fine time structure is a beam dump after the accumulator ring that faces the south side of the target building. According to the SNS management this area is already subscribed to by a number of long baseline neutron experiments and is not available for the neutrino bunker. One more beam dump suitable for DIF neutrino production may appear later, with the construction of the second target building. So far, there is no definite layout for the location of that dump.

## 3. **Detector Size**

The size of the large detector has been selected based on the following considerations. Experiments at ORLaND can be separated into two groups. The first group provides measurements of various neutrino-nucleus cross sections as a probe of nuclear structure and to provide information for astrophysics. The second group is concerned with the search for neutrino oscillations. A high level of accuracy for the cross section measurements requires good knowledge of the absolute neutrino flux. We will measure the flux using neutrino-electron elastic scattering, which is well understood. For an accurate measurement of the flux it is necessary not only to accumulate good statistics, but to have a good knowledge of the fiducial mass of detector. All homogeneous detectors have limited vertex reconstruction accuracy, which gives some uncertainty in the determination of fiducial volume. For the larger detectors with more favorable volume to surface ratio this uncertainty is less than for small ones.

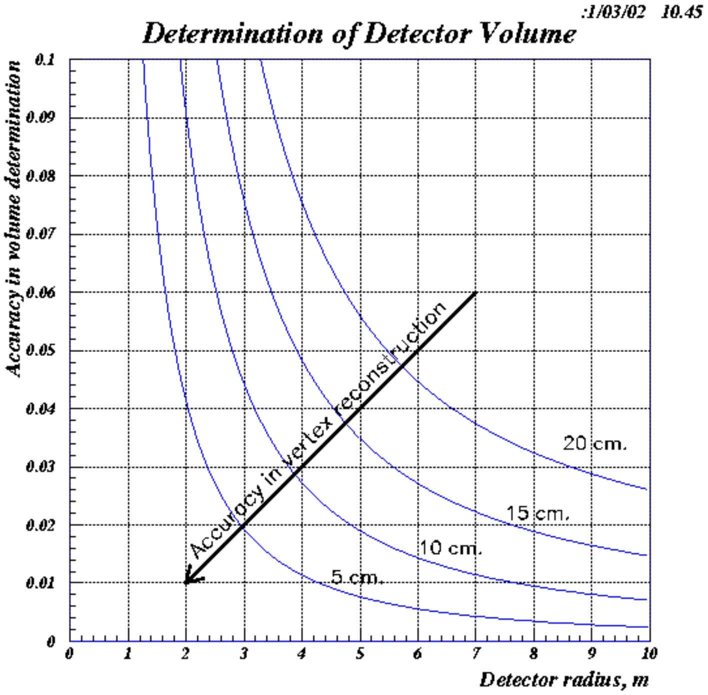

Fig. 1. presents the accuracy in determination of a fiducial volume versus detector size for various accuracies of vertex reconstruction. The detector is assumed to be cylindrical with diameter and height equal. For the large detector with photocathode coverage of 50%, the expected vertex resolution is about 15 cm. As a result, to obtain 3% accuracy in absolute flux normalization, the detector radius should be more than 5.5 meters, which corresponds to a fiducial mass of more than 1 kton. Another argument in favor of a detector with fiducial mass of greater than 1 kton, is a sensitivity to small mixing angles for neutrino oscillations. Strong suppression of electron antineutrinos in the SNS target provides the possibility to explore the region of neutrino mixing parameters important for big bang nuclear synthesis and production of heavy elements during supernovae explosions. Those regions correspond to a large $\delta m^2$ and very small mixing angles.

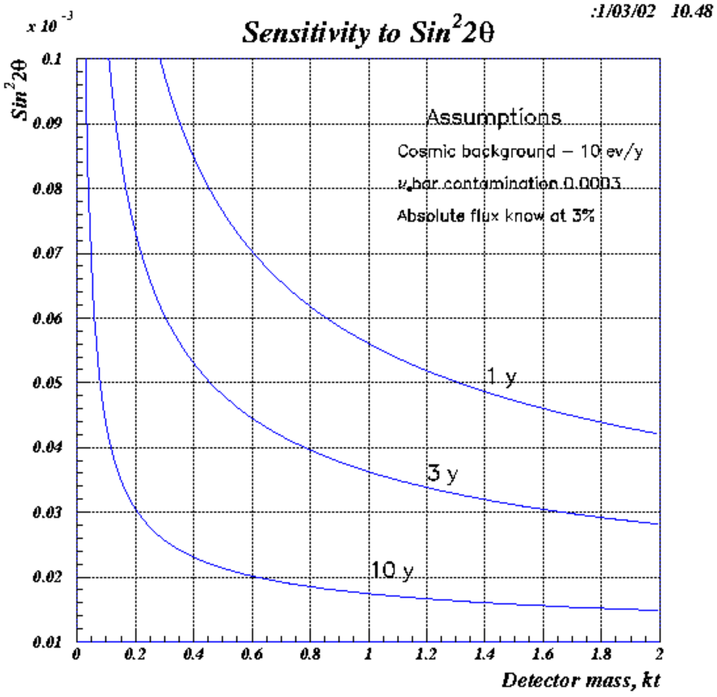

Fig.2 presents sensitivity to the small mixing angles for $\delta m^2$ around 1 eV. Assumptions are: absolute flux is known with 3% uncertainty, intrinsic antineutrino contamination is 0.0003 relative to other neutrino flavors, and the number of background events is 10 per year. One can see, for example, that for a three-year experiment, sensitivity quickly improves with increasing detector mass up to 1 kt. However above that size improvement is quite slow.

## 4. Cost and schedule

A discussion of the ORLaND cost and a possible implementation schedule is included in section 5 (pages 67-69) of the white paper "Scientific Opportunities at the Oak Ridge Laboratory for Neutrino Detectors (ORLaND)". The tables below contain an updated version of the information contained in Table 8 of the white paper. The total project cost (TPC) is broken down in two ways. The first is a division into "facility" and "experiment" costs. The experiment costs include full implementation of three experiments (one 2000 ton and two ~100 ton) including commissioning costs. It should be noted that the cost of the 14m x14m tank for the large experiment is included in the facility costs. The second breakdown of the TPC is an identification of those aspects of the facility construction that are time critical with respect to the SNS construction schedule.

Table 1. ORLaND Cost Breakdown: Facility and Experiments,( $M)

| | **Facility Construction*** | **Experiments (3)** | **Total** |
|---|---|---|---|
| Engineering, design & mgt. | 5.7 | 4.7 | 10.4 |
| Construction | 8.8 | 0.5 | 9.3 |
| Special facilities & equip | 4.2 | 11.0 | 15.2 |
| ES&H | 0.5 | 0.0 | 0.5 |
| Other costs | 0.2 | 0.1 | 0.3 |
| Contract burdens | 1.3 | 1.1 | 2.4 |
| Total direct cost | 20.7 | 17.4 | 38.1 |
| Contingency | 4.3 | 5.5 | 9.8 |
| Total | 25.0 | 22.9 | 47.9 |
| CDR and Planning | 1.1 | 1.0 | 2.1 |
| Commissioning & Pre-ops | 1.5 | 7.3 | 8.8 |
| Escalation | 2.4 | 2.6 | 5.0 |
| **Total Project** | **30.0** | **33.8** | **63.8** |

Table 2. ORLaND Costs: Time Critical Construction and Non-Time-Critical costs ($M)

| | **Construction Phase 1 ( time-critical)** | **Construction Phase 2** | **Total** |
|---|---|---|---|
| Engineering, design & mgt. | 1.3 | 4.4 | 5.7 |
| Construction | 2.6 | 6.2 | 8.8 |
| Special facilities & equip | 0.0 | 4.2 | 4.2 |
| ES&H | 0.5 | 0.0 | 0.5 |
| Other costs | 0.1 | 0.1 | 0.2 |
| Contract burdens | 0.3 | 1.0 | 1.3 |
| Total direct cost | 4.8 | 15.9 | 20.7 |
| Contingency | 1.4 | 2.9 | 4.3 |
| Total | 6.3 | 18.7 | 25.0 |
| CDR and Planning | 1.1 | 0.0 | 1.1 |
| Commissioning & Pre-ops | 0.0 | 1.5 | 1.5 |
| Escalation | 0.3 | 2.1 | 2.4 |
| **Grand Total Construction** | **7.7** | **22.3** | **30.0** |

According to the present (3/2001) SNS construction schedule, the window for heavy civil construction at the ORLaND site closes in FY2006. The time required to complete the time-critical pieces of the ORLaND construction is estimated to be ~11 months. The bulk of corresponding funds (~$4.0M) would therefore be required no later than FY2005 and FY2006, with about 75% of that ($3.1M) needed in FY2005. The remainder of the construction, and the implementation of experiments are not so critically tied to the SNS schedule, but maximum cost effectiveness is achieved with continuous construction. Our estimated funding profile for the remaining "non-time-critical" aspects of the facility ($55.1 M total, Construction phase 2 from Table 2 and Experiments from table1) spreads over approximately 4 years with a peak annual funding of about $16M.