The 1999 NSERC and SNO-ARC Science Review of SNO

Version 1.0

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Executive Summary

A review of the Sudbury Neutrino Observatory was carried out on 8-9 December 1999 by a joint committee from NSERC (GSC-19 site visit) and SNO-ARC (science subcommittee). We are pleased to report that SNO has been commissioned and began taking physics data in October 1999. This is the culmination of many years of hard work and we extend our congratulations to the collaboration. The science potential of SNO continues to be high and the experiment should provide a solution to the solar neutrino problem in the next 2-3 years. The committees recommend that funding both for site operations and for the Canadian university groups be continued and that two year grants would be appropriate at this time.

This year saw much progress at SNO. A working solution to the potentially serious high voltage breakdown problem was found in March, allowing commissioning to proceed. The committees recommend that work continue on establishing a permanent solution, in case the connectors start to fail prematurely. Several calibration runs have been done, indicating that the detector is working very well and that the detector can be operated at the necessary low energy trigger threshold. The required low levels of radioactivity have been attained in most cases and where they have not (e.g. radon), the collaboration is successfully taking steps to continue to reduce them. The analysis of the data is progressing well, with emphasis given to calibrations and the identification of algorithms to eliminate background and/or spurious events. The analysis effort is well organized but suffers from a lack of personnel, which is not unusual for a large project in transition between construction, commissioning and data taking. More scientific effort, however, will have to be diverted to the data analysis in the near future.

The collaboration has produced a long range plan extending over 3-4 years with roughly one year each allocated to running with pure D_2O, D_2O plus $MgCl_2$, and pure D_2O with the ^3He detectors. Running with light water is also planned once the heavy water is returned to AECL. It is crucial that the lease agreement with AECL be extended to 2004, and it is expected that this will be settled by June 2000. The long range plan should be improved by setting clear milestones and criteria for switching between the three running configurations.

The collaboration has reorganized its management structure to address upcoming retirements and the reduction in the onsite presence of senior managers. Deputies and/or assistants have been identified to allow a smooth transition to a new management team.

In summary, the SNO experiment is now on-line and taking data. The remaining problems are typical for an experiment this size, and are being dealt with efficiently. The biggest challenge facing the collaboration is the transition to the analysis phase of the experiment. The committees look forward to seeing physics results from SNO in the not too distant future.

1 Introduction

The NSERC Subatomic Physics Grant Selection Committee (GSC 19) and SNO Agency Review Committee (SNO-ARC) commissioned independent reviews of the Sudbury Neutrino Observatory (SNO) in fall 1999. The NSERC review follows on similar annual reviews that have been arranged by GSC 19 in the context of the project grant renewals for the Canadian SNO collaborators. The SNO-ARC review was performed by a "science subcommittee," which has been recently established to give advice to both SNO-ARC and SNO on the science and management of the project. The memberships of the two committees are listed in Appendices B and C.

These two committees coordinated their reviews so that a common set of presentations by SNO collaborators were made to both committees on 8 December 1999. The committees then split up on December 9 for presentations on funding (GSC committee) and more detailed discussions on specific issues such as calibration and the long range plan (SNO-ARC subcommittee). The agenda for the two-day review is provided in Appendix D. A common set of recommendations on scientific and technical matters was arrived at by the two committees, and so this report documents the findings of the review. In the case of the NSERC review, Appendix A of this report details the committee's funding recommendations to GSC 19.

The committees wish to thank the SNO collaborators and NSERC staff for arranging a productive two-day review. In the opinion of the two committees, the needs of an NSERC GSC review and the SNO-ARC science subcommittee review are so similar that a more efficient process could be established. Since the SNO-ARC science subcommittee is an ongoing one, it is suggested that this committee be augmented by two GSC members to perform the funding review in the future.

This report is organized as follows: Section 2 describes the status of the current science issues that SNO was designed to address. Section 3 gives a brief status report on the various aspects of the experiment. Section 4 addresses issues related to the physics analysis effort, section 5 addresses management issues and section 6 address the schedule and long-range plan. Section 7 summarizes the status of the HV connectors and section 8 comments on the longer term science opportunities of the SNO detector and site. In section 9, we summarize our recommendations.

2 The Science

A series of experiments, covering almost three decades of neutrino observations of the sun, have established an electron neutrino (ν_e) flux from the sun of about half the expected value. The set of available data cannot easily be reconciled with standard solar model (SSM) calculations because they are incompatible with the existence of the so-called ^{7}Be neutrinos. Moreover, the SSM appears robust from the theoretical point of view and has been confirmed by helioseismology studies. Therefore, the assumption has been that the solution to the "solar neutrino problem" resides with the particle physics of the neutrino and not with the astrophysics of the sun. SNO has the potential to reveal the properties of neutrinos responsible for the deficit in flux, with neutrino oscillations providing the best motivated explanation. The prospect that SNO provides the first conclusive evidence for ν_e oscillations has been reinforced by the recent indirect observations of ν_μ oscillations in the atmospheric neutrino flux.

In the last year, the chances that the competing SuperKamiokande experiment will determine that the source of the solar neutrino deficit is due to a specific oscillation scenario has all but faded. Their much larger detector has made impressive observations of the solar neutrino flux, confirming once more, the ν_e deficit. But hints provided by the time and energy dependence of the solar neutrino flux have not converged on a particular solution with sufficient statistical or systematic accuracy. SNO has the next opportunity, over the three-year timeframe described in its current scientific plan, to resolve the solar neutrino problem as being due to neutrino oscillation. It must make good use of this time, because new experiments such as Borexino and KamLAND will turn on in this 3-year period and have the potential to identify certain oscillation scenarios.

Using D_2O as a target, SNO has the unique capability to measure both the flux of electron neutrinos via the charged current (CC) interaction as well as the flux of other neutrino flavours via the neutral current (NC) interaction.[1] SNO can therefore observe the reappearance of the oscillating ν_e as a neutrino with a different flavour.

The SNO collaboration has proposed a four-stage run plan that spans the next 3-4 years to make these measurements. In the first stage, SNO will run with pure D_2O and make a CC measurement. After approximately one year of running, magnesium salt ($MgCl_2$) will be added to the D_2O in order to raise the NC detection efficiency to 83%. The collaboration expects to take data for approximately one year in this configuration. In the third stage of the scientific plan, neutron detectors (NCDs) will be inserted in the SNO detector to replace the magnesium salt, resulting in a lower NC detection efficiency but a potentially better separation of the NC events from events resulting purely from ν_e interactions. The fourth stage would be a run with just light water.

Even before a precise measurement of the NC rate is made in the second and third phases, information about which oscillation models are viable could be obtained with several thousand events recorded in pure D_2O. However, this observation alone is unlikely to be compelling or definitive. It is therefore important to determine how one decides the duration of the pure D_2O data taking with a stable and well-understood detector before moving on to the definitive NC measurements. During this period, SNO will also provide information on the possible "high-energy anomaly" observed by the SuperKamiokande collaboration in the form of an excess of events with neutrino energies (E_{ν_e}) above 12 MeV.

Another path to identifying neutrino oscillation as the source of the solar neutrino puzzle is to measure a distortion in energy spectrum, which is well predicted by the nuclear physics of ^{8}B beta decay. Although the SuperKamiokande collaboration has not observed a statistically significant distortion, it is hampered by the poor neutrino-electron energy correlation in charged current electron scattering. With an neutrino energy threshold of about 2 MeV, SNO has the unique ability to use the CC absorption reaction (with a 1.44 MeV Q-value) to recognize distortion in the neutrino energy spectrum due to vacuum oscillations or certain matter-enhanced solutions. In addition, the 2 MeV threshold provides additional leverage not available to SuperKamiokande (currently triggering at a approximately 4.5 MeV and analyzing data above 5.5 MeV). The SNO

[1] The elastic scattering process (ES) is an important third process that SNO has sensitivity to at a significantly lower level than the CC and NC processes.

experiment should recognize this opportunity and continue with their extensive calbration plan for the lowest possible energy systematic uncertainty. Naturally, they should also achieve the lowest possible analysis threshold.

In the near term, the SNO experiment can readily study the high energy end of the ^8B spectrum, which should be more free of background. By studying events above 13-14 MeV, they can potentially identify an enhanced hep neutrino flux.

SNO has several other science missions that include measuring the properties of atmospheric neutrinos and the detection of galactic supernovae. The scientific importance of observing a supernova with a detector like SNO far outweigh the low probability that such an event will occur during its lifetime. The participation in the SNEWS early warning network clearly enhances SNO's science reach, as it will allow astronomers to make the important early observations that were not possible with SN1987A.

In summary, with its ability to detect neutrinos through their CC and NC interactions, SNO holds the key to solving the solar neutrino problem. It will possibly provide the first direct observations of solar neutrino oscillations. The detector has started data taking with an adequate time window to deliver results before competing detectors will be commissioned.

3 Detector Commissioning Status

3.1 Operations

The SNO collaboration has made very good progress in commissioning the detector over the last seven months since the water fill was complete. This was evidenced in all aspects of the experiment. The team now is focussed on understanding the detector and optimizing its performance. Since the water fill was completed at the end of April 1999, all detector subsystems have been commissioned and brought into routine operation. Significantly, the last major changes to detector configuration were made in the middle of October (the photomultiplier tube (PMT) high voltage was increased by 100 V). Since then, the collaboration has been operating the detector with increasing efficiency, while at the same time calibrating the detector and measuring background rates.

The significant problems with the high-voltage (HV) connectors seem to have been solved (see Section 7). An annoying source of of background light has been traced to sparks arising from charging of the acrylic vessel. These have been largely eliminated and are no longer affecting detector operations.

The electronics and data acquisition (DAQ) systems are operating smoothly, with typical trigger rates in the neighbourhood of 15-20 Hz. The detector is operating with a trigger that requires at least 18 PMT's above pedestal threshold, corresponding to an energy threshold near 2 MeV. The "livetime" of the detector – in this case the fraction of time that the detector was ready to detect supernovae events – was reported to have reached 94% in the month of November, an impressive figure given the complexity of the detector. Livetime for solar neutrino collection was significantly lower due to conflict between certain operations during calibration and normal data taking.

The reviewers recommend that the collaboration determine the livetime for solar neutrino data-taking, accounting for the effects of calibrations and other activities that interrupt normal data-taking. A target livetime should be determined that optimizes the requirement to fully calibrate the detector and collect the maximum amount of solar neutrino data.

The operations team appears to be well-managed and highly competent. The committees are confident that the necessary structure is in place to operate the detector, although overall personnel resources are stretched when one accounts for the large number of parallel tasks that must be underway to support the calibration, operation and analysis activities.

3.2 Calibration

The SNO detector has an arsenal of calibration sources designed to measure the optical response of the detector, its energy resolution and background rates. An understanding of the optical transmission and detection of photons is a fundamental issue, and must be established before a detailed energy calibration can be completed. The optical calibration, performed using a laser source and a diffuser ball suspended in the D_2O, appears to be well understood, although this work is not yet complete. The committees were shown preliminary results, demonstrating that the agreement between observed performance of the detector and the Monte Carlo (MC) predictions was at the few percent level. The non-uniformities of the illumination of the source remain to be completely resolved, though a reasonable plan exists to address this issue.

Three calibration runs using a ^{16}N source (producing a 6.1 MeV γ) have been performed, providing an energy calibration at this energy with an uncertainty better than 6%. The ultimate goal is an understanding of the energy calibration to an uncertainty of 1%, which requires periodic ^{16}N runs and the deployment of additional sources. These calibration sources are:

- U and Th sources to measure the characteristics of the principle backgrounds in the D_2O,
- a $(\mathrm{p}, \mathrm{t}\gamma)$ source that provides a 20 MeV γ calibration point,
- a ^{8}Li source to provide a β source with a continuous spectrum to measure the efficiency of the "data cleaning" operations and test the understanding of the detector's energy response, and
- a number of lower-energy sources for background studies and low-energy calibration points.

The collaboration's highest priorities are the analysis of the existing calibration data and the deployment of the U, Th, $(\mathrm{p}, \mathrm{t}\gamma)$, and ^{8}Li sources in order to meet its initial physics milestones. The reviewers agree with this strategy.

The collaboration noted that personnel resources may limit its ability to implement these additional calibration sources on a schedule consistent with the milestone of June 2000, when the initial optical and energy calibrations of the detector will have been completed. The committees are not convinced that the schedule is credible either, given the limited number of personnel involved in the calibration effort. The reviewers recommend that the collaboration make every effort to identify additional scientific personnel for this task to ensure that these additional calibration sources are deployed and the calibration data are analyzed promptly.

3.3 D_2O, H_2O and Radioactive Backgrounds

The key to the SNO detector is the 1000 tonnes of D_2O suspended in a spherical acrylic vessel at the centre of 7000 tonnes of light water (H_2O) shielding. The light and heavy water both must be maintained ultrapure for optical clarity and low background radiation. The radioactivity in the water is required to be less than one uranium disintegration per day per tonne of water. The heavy water is valued at $300M and therefore has to be accurately accounted for. The heavy water is insured against a catastrophic loss or dilution with light water, but the cost of restoring heavy water that has been downgraded (diluted by light water) or lost through normal operation is considered part of the normal operating and decommissioning costs.

The heavy water itself is on loan from AECL to the end of 2000. Negotiations are underway to extend the loan, first to the end of 2001 and then to the end of 2004. The first date is well in hand and the collaboration is optimistic about achieving the second.

The SNO water handling team has done a highly professional job of designing, building, commissioning and operating the water systems. Moreover, they have met a number of significant challenges including some unsuspected experimental conditions that became apparent once the water was in place. The most difficult task has been controlling radon ingress from the mine air leaking into the gas volume above the light and heavy water surfaces.

The water operations require a specially trained team of six operators, four assistants and three others in charge of maintenance, cleaning and other functions. The team works six twelve-hour day shifts and three twelve-hour night shifts per week. The water system may only be run when there are at least two operators underground at the experiment. The ongoing operations include running the circulation systems for the heavy and light water and making radioactive assays. Recently the water team has moved one technician to the surface to help with the assay chemistry.

The radiation levels in the water have improved and are approaching design. Radon levels are an important indicator of the uranium content of the water, and weekly assays are scheduled. Radon levels in the D_2O have dropped to approximately the design criteria following the stable application of a flowing nitrogen cover gas for the D_2O. This results in a loss of 200 ml of D_2O per day ($60), an acceptable short-term consequence but clearly not optimal. The radon in the light water is nearing design specification, with the largest source of radon appearing to be from air entering from the mine. The water team is working on sealing leaks into the light water cover-gas volume.

Assays for radium contamination in the D_2O are made to estimate the amount of uranium (^{226}Ra) and thorium (^{224}Ra) using MnO_x and seeded ultrafiltration techniques. The uranium assays are at 10^{-15} gram U per gram water, well below the required levels. The thorium assays have only yielded upper limits that are consistent with the required levels. A direct observation confirming the thorium concentration is required, and the collaboration is working on a high flow system with eight parallel columns of MnO_x to solve this problem. A system to detect lead is also being developed.

The water team is also developing the plant that will produce the $MgCl_2$ brine and remove it from the D_2O. This operation is critical for the NC measurement of the second phase of the SNO experiment. The system will be reviewed in the next couple of weeks. The schedule calls for the brine to be produced and underground by September 2000.

The total inventory of heavy water received from Ontario Hydro is 1,106,484 kg. The isotopic purity of the bulk water is checked regularly and has not changed significantly. Approximately 170 kg of heavy water has been lost, mostly by absorption in the acrylic vessel. Further losses from evaporation are expected to be 73 kg per year. The cost of replacement is approximately $300 per kg. Another 2025 kg have been isotopically downgraded as part of the initial setup and due to ongoing assays. There is a further 30 kg that is isotopically pure but contaminated. This water can be cleaned on site.

The downgraded water can be returned to Ontario Hydro for upgrading at a cost of $8 per kg, so that the cost of upgrading the present inventory will be about $20 000. The SNO collaboration would like to start returning degraded water to Ontario Hydro to reduce their stored inventory, but Ontario Hydro has requested a delay while it develops an appropriate facility. Over the longer term, upgrading costs are expected to be roughly $10 000 per year.

3.4 Neutral Current Detectors

Construction of the neutral current detectors (NCDs) is proceeding well, after the collaboration resolved a number of problems affecting the series production of the counters over the last year. Currently, 165 of the required 300 detectors are completed and now underground in the mine. Completion of the remaining counters is scheduled for fall 2000, well in advance of when they would be required for insertion in the D_2O volume.

4 Physics Analysis

The SNO collaboration has put together a comprehensive analysis plan, consisting of a series of "supporting analyses" and a set of "physics analyses." Working groups have been established for each of the supporting analyses, although the personnel effort in many of these groups is limited to only one individual (who in many cases has multiple responsibilities). Convenors have been identified for organizing each working group, and a Gantt chart detailing the analysis effort over the next three years has been developed. Each group has clear goals and is working toward a common schedule and set of milestones.

The organization of this analysis effort is an impressive first step toward getting science out of SNO, and the reviewers applaud the collaboration for the commitment to this structured process. The reviewers endorse the collaboration's commitment to use the SNOMAN framework as the basis for all "final, publishable analyses." The collaboration was able to report significant progress on all major analysis fronts: software and databases, detector support, calibrations, data flow, data cleaning and event characterization. They have set as important milestones the completion of the optical calibration by April 2000, the energy calibrations by July 2000 and a preliminary measurement of the CC and ES flux by February 2001.

However, much remains to be done and personnel resources appear to be a limiting factor in analysis progress. There are approximately 10 full-time personnel working on solar neutrino analyses, an additional 6 physicists working part-time on solar neutrinos, 4 physicists involved in analyses of through-going muons, and 2 physicists working full-time on the supernova watch. Of these analysis efforts, the reviewers were satisfied that sufficient resources were allocated to the latter two topics. However, the reviewers were very concerned that the analysis effort on solar ν's was too dispersed and not sufficiently focussed. The collaboration reported that four independent groups were involved in solar neutrino analyses. Although it is important to have several independent analyses on this topic, given it is where SNO is expected to have the greatest scientific impact, the reviewers believe that four such analyses are simply too many given the limited physicist resources. The reviewers recommend that the solar neutrino physics analysis efforts be more focussed with a smaller number of independent efforts.

5 Management Issues

The SNO collaboration has taken significant steps over the last year to improve its management structure. The Scientific Management Committee and the Senior Executive Committee were replaced by a Scientific Board (SB) that meets at least monthly. The SB includes one representative from each SNO institute, the national spokepersons, the scientific officers (director, two associate directors and the analysis coordinator) and key group leaders. Two members are elected at large by the collaboration, with the intent that they represent the junior members of the collaboration. The scientific board is responsible for setting policy on topics such as the length of data runs in each configuration of SNO, run plans within each configuration, and publication and conference talks. The board's decision must be ratified by the collaboration. This management scheme seems to be working well.

The collaboration has also reorganized the supervision of the operation of the water systems and the detector. David Sinclair was appointed as Associate Director - Science with overall responsibility for running the experiment. Tony Noble replaced Sinclair as Associate Director of underground operations with main responsibility for the water systems. Richard Van de Water is the head of the detector working group and is responsible for the day-to-day operation of the detector systems. Finally, Josh Klein is continuing as analysis coordinator. This team is effective and the committees feel that SNO operations run smoothly.

Last year's GSC site review committee expressed concern over the long term staffing of key management positions related to the fact that several individuals would have to return to teaching duties, or to retirements. The SNO collaboration has responded to this issue by designating replacements and/or deputies for these key individuals, and the situation seems to be in hand.

6 Schedule and Longer Range Science Plan

The SNO Collaboration presented to the review committees a four-stage running plan. In essence, the plan proposes taking data over the next three to four years to attack the solar neutrino problem in four 1-year periods:

1. running with pure D_2O,
2. adding $MgCl_2$ to the D_2O to enhance NC detection,
3. deploying the ^3He Neutral Current Detectors (NCD's) in pure D_2O, and
4. running with pure H_2O.

This plan is consistent with the overall scientific goal of SNO, which is to determine independently the total flux of "active" neutrinos from the neutral current (NC) interactions in D_2O and to compare this with the flux determined only from the charged current (CC) interactions.

The scientific goals for each of the four stages outlined above are clear, and are detailed below.

Running in Pure D_2O

The scientific objectives for running with pure heavy water are:

- to measure the integral ν_e flux with the CC interaction for ν_e with $E_{\nu_e} > 7.5$ MeV,
- to measure the energy spectrum with the CC interaction for ν_e with $E_{\nu_e} > 7.5$ MeV,
- to measure the integral ν_e flux with the ES interaction for neutrinos with $E_{\nu_e} > 7.5$ MeV,
- to make an initial measurement of the ES/CC ratio, and
- to make an initial measurement of the NC/CC ratio.

This last measurement will require a proper understanding of the radioactive backgrounds.

This is a sensible initial programme, which will allow experience to be gained with running the detector over an extended period in stable conditions, and will also test the calibration, data reduction and data analysis techniques. The results from the ES interactions could be compared to the SuperKamiokande data.

A sufficiently precise measurement of the spectral shape could, in principle, yield valuable information on the origins of neutrino oscillations, but this probably requires a longer run than can otherwise be justified given the importance of the NC measurements. There is a risk that a measurement of the ES or NC rate, combined with the CC rate and the SuperKamiokande data, will allow almost anyone to do "quick and dirty" analysis to "resolve" the solar neutrino problem. The collaboration therefore needs to have a clear strategy for deciding what data can be shown publicly, consistent with the imperative to publish important results as quickly as possible.

Adding $MgCl_2$

By adding salt ($MgCl_2$) to the D_2O, the sensitivity to neutral current events is significantly enhanced. Techniques have now been developed that allow the NC/CC ratio to be deduced statistically from the data, making this a robust technique. The operation is relatively quick - it should take about a week to introduce the salt though a brine solution - and reversible - it should talk about a month to remove the salt by reverse osmosis. This should yield the first statistically significant measurement of the NC/CC ratio.

Given that this procedure is relatively quick and could be repeated should problems or inconsistencies arise, it makes sense to perform this test early.

The committees note that some concerns have been raised earlier about the impact of the magnesium salt on the acrylic vessel, but this issue was not addressed during the review. The reviewers therefore recommend that the SNO Collaboration prepare a memo to SNO-ARC that addresses this issue.

Using the ^{3}He Neutral Current Detectors

The NCDs enhance the sensitivity for NC detection by using ^{3}He counters. This allows NC interactions to be recognised on an event-by-event basis, and may help reduce the systematic errors on the measurement of the energy spectrum.

The deployment of the NCDs is a major interruption to the schedule, and is estimated to take about 3 months, during which time the detector will be more exposed to mine air and SNO will not be able to participate in the supernova watch. The deployment is not easily reversible if problems with their operation should arise. However, the NCDs will enhance the science reach of the detector and remain an important element of the SNO experiment.

Running in pure H_2O

The main objectives are to confirm the radioactivity backgrounds and the ES measurements. It is clearly prudent to plan this at some stage, but for practical reasons this should be done last.

6.1 Discussion and Recommendations

The proposed long-range plan defines a coherent programme for achieving the scientific goals of the experiment. However, the Committee was not given sufficient detail to be able to judge whether this ambitious programme was realistic in the timeframe suggested. The committees make the following comments and recommendations:

1. The committees endorse the general strategy for the NC measurements. In particular, the committees believe that it is essential that the $MgCl_2$ run be completed before deployment of the NCD's.

2. The committees are concerned that there is no set of criteria which determines the time at which the change over from pure D_2O to D_2O+$MgCl_2$ takes place. They recommend that these criteria be identified.

3. The committees recommend that a set of milestones be developed against which progress for at least the first two stages of the long-term plan can be measured and monitored. The committees recognise that this is an ambitious programme, and are concerned that without a clear schedule against which to operate, the scientific goals might be compromised.

4. The committees believe that it will take until at least 2004 to complete this programme of work, and that it is therefore important to negotiate by June 2000 an extension of the lease of the D_2O until at least 2004.

7 Photomultiplers, Bases and the HV Connectors

In late 1998, very serious problems were observed associated with "wet-end breakdown" in the HV connectors leading into the photomultipler tube (PMT) bases. Since March 1999, when the regassing with nitrogen of the light water that surrounds the PMTs, the breakdown problem in the connectors has been dramatically reduced. The detector has operated stably with minimal problems from high voltage breakdown or tube loss since that time. The PMT death rate, from all causes, based on about 6 months of operation, is presently 0.4% per year or about 1 per week, well in line with other large water detectors. Wet-end breakdowns still occur so there is no evidence that the HV problems are completely solved but there is no indication at this time that a connector replacement program will be needed.

The SNO collaboration has followed the recommendations of the External Advisory Committee on the High Voltage Connector, which reported to SNO-ARC in April, 1999. The first recommendation was to implement automated tools that would monitor the HV breakdown phenomena. Several on-line and near-line monitoring tools have been implemented to track high voltage effects such as the presence of "sharkfin" pulses and blown terminator resistors in the PMT base to give an early warning of the onset of problems.

Sharkfins are large charge pulses generated in the absence of light, which are assumed to be due to micro-discharges in the connector. They appear as events in the ESUM trigger and can be monitored with the random PULSE_GT trigger. As they are characterized by a large (> 100 mV) pulse in one channel with pick-up in several nearby channels on the same HV distribution card, they can be easily identified and separated from the neutrino interactions during the data cleaning process. The wet-end breakdowns are known to first blow the 75 Ω terminating resistor in the PMT base after tens of discharges and this can be monitored by reflection tests or by checking for gain increases in a channel, since the loss of this resistor causes the gain to double. If the sparking persists, a 100 kΩ series resistor can fail, causing the tube to become inoperable. Another potential problem leading to tube loss is a water leak into the connector or PMT base, which causes a HV short.

The most serious potential source of background to neutrino data are "flashers," which are believed to be light-emitting breakdowns inside the PMT. The light is picked up in several surrounding tubes and in tubes on the opposite side of the detector. These are not related to problems with the HV connector. A significant fraction of the tubes exhibit flasher behaviour, and it has been observed that seismic activity increases the rate of flasher events. A sufficiently large number of tubes are involved when a flasher occurs that the event is likely to satisfy the event trigger and be recorded. The flasher signature has now been well characterized so that these events can be removed during the data cleaning, although the efficiency of doing this has not been determined as yet.

In October 1999, the voltages on all PMTs were increased by 100 V to improve the signal/noise and provide the design sensitivity threshold of 0.25 photoelectrons. During this increase the HV phenomena were closely monitored. Both the sharkfin and flasher rates increased and then settled to acceptable rates; sharkfin rates increased from 1.5 Hz to 2.5 Hz and flasher rates rose from 30 per hour to 50 per hour. The tube loss rate since that time has not noticeably increased. There are presently 160 PMTs not functioning in the detector, with most of these due to failures before the regassing was carried out in March.

The External Advisory Committee on the HV Connectors made two other recommendations: The SNO collaboration was to develop and test a replacement high voltage connector, and to produce an implementation plan showing the cost and time impact if a repair were necessary. A new connector design has been produced but only variations of this connector have been tested to date. A draft report on the SNO Detector Connector Repair was submitted to the SNO collaboration and to the SNO-ARC science subcommittee at this meeting. The main conclusions/recommendations of the draft report, which still needs to be reviewed by the collaboration, are as follows:

- If a connector repair is required, a new wet-end male connector/full cable assembly replacement represents the best understood methodology at this time. (We note that this is solution 1. as recommended by the External Advisory Committee.)
- A dry repair with full cable assembly replacement will cost 5.18 million 1999 Canadian dollars, and will take 12.5 months of detector non-operation.

The committees make the following recommendations:

1. The SNO Collaboration should continue the close monitoring of the detector HV performance.
2. The SNO Collaboration should complete the development and fabrication of the production prototype of the replacement connector and test 10-20 of these, first in an initial long-term test to be completed in 6 months and then in the SNO detector using the Berkeley underwater test sleds.
3. The External Advisory Committee on the High Voltage Connector should continue to receive bi-monthly reports on the HV performance.
4. If a HV connector repair is required, a review of the detector repair plan be performed.

8 Future Science Opportunities

SNO represents a unique scientific resource, due to the low radioactive background levels achieved in the clean-room conditions of the underground laboratory and the low cosmic-ray backgrounds due to its 2-km depth. In addition, the underground laboratory is a well-instrumented and serviced location, and is well-integrated into the SNO surface facility. It therefore provides numerous scientific opportunities for future astrophysics and particle physics experiments. At the same time, one has to keep in mind the significant cost associated with operating the underground laboratory and the fact that it is located in an operating INCO nickel mine.

No formal plans are in place for possible future projects that may be well-suited to the underground laboratory. The committees therefore recommend that SNO-ARC initiate discussions with the various "stake-holders" in order to assess the quality and scope of possible extensions of the current scientific mandate of the SNO underground facility. These discussions should probably include the SNO Collaboration, INCO, the various funding agencies and the scientific community. This is not urgent, but given the long timescales of typical astrophysics and particle physics experiments and the expectation that a long-range planning process will commence in the Canadian subatomic physics community in 2000, it is appropriate to define a process that will allow SNO-ARC to understand the potential future value of the science that can be done in the underground laboratory beyond the current SNO experiment.

9 Summary of Recommendations

The recommendations outlined in the report are summarized here:

1. The collaboration review the personnel requirements for the deployment of the highest priority calibration sources (U, Th, $(p, t\gamma)$, and ^{8}Li) and the associated analysis efforts.
2. The reviewers recommend that the collaboration determine the livetime for solar neutrino data-taking, accounting for the effects of calibrations and other activities that interrupt normal data-taking. A target livetime should be determined that optimizes the requirement to fully calibrate the detector and collect the maximum amount of solar neutrino data.
3. The collaboration focus the solar neutrino analysis efforts to make use of limited personnel resources in as effective a way as possible. The number of independent analyses should be reviewed and reduced.
4. The committees endorse the general strategy for the NC measurements. In particular, the committees believe that it is essential that the $MgCl_2$ run be completed before deployment of the NCD's.
5. The committees recommend that a set of criteria be developed that determines the time at which the change over from pure D_2O to D_2O+$MgCl_2$ takes place.
6. The committees recommend that a set of milestones be adopted against which progress for at least the first two stages of the long- term plan can be measured and monitored. The committees recognise that this is an ambitious programme, and is concerned that without a clear schedule against which to operate, the scientific goals might be compromised.
7. The committees believe that it will take at least until 2004 to complete this programme of work, and that it is therefore important to negotiate by June 2000 an extension for the use of the D_2O until at least 2004.
8. The collaboration prepare a memo to SNO-ARC regarding the effect of the magnesium chloride on the acrylic vessel.
9. The collaboration should continue the close monitoring of the detector HV performance.
10. The collaboration complete the development and fabrication of the production prototype of the replacement connector and test 10-20 of these, first in an initial long-term test to be completed in 6 months and then in the SNO detector using the Berkeley underwater test sleds.
11. The External Advisory Committee on the High Voltage Connector should continue to receive bi-monthly reports on the HV performance.
12. If a HV connector repair is required, a review of the detector repair plan be performed.
13. SNO-ARC initiate a dialogue with the appropriate "stake-holders" in order to assess the quality and scope of possible extensions of the current scientific mandate of the SNO underground facility. The next 12 months would be a suitable timeframe for initiating this discussion.

Appendix A: Funding Recommendations

This section is only made available to members of GSC 19.

Appendix B: Membership of SNO-ARC Science Subcommittee

- Prof. Pekka Sinervo, Department of Physics, University of Toronto (chair)
- Dr. Ewart Blackmore, TRIUMF
- Prof. Francis Halzen, Department of Physics, University of Wisconsin
- Prof. Ed Kearns, Department of Physics, Boston University
- Prof. John Martin, Department of Physics, University of Toronto
- Prof. Ken Peach, Particle Physics Department, Rutherford Appleton Laboratory

Appendix C: Membership of the NSERC SNO Review Committee

- Dr. Michel Vetterli, TRIUMF (chair)
- Prof. Enrico Bellotti, Department of Physics, University of Milano
- Prof. Patricia Kalyniak, Department of Physics, Carleton University
- Prof. Richard Keeler, Department of Physics and Astronomy, University of Victoria
- Prof. Jim Waddington, Department of Physics, McMaster University
- Ms. Kate Wilson, Team Leader for Subatomic Physics and Astronomy, NSERC (observor)

Appendix D: Agenda for Review

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Wednesday, Dec.8th: SNO Project Status
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 9:00 Committees in camera (15)
       - organisation of the two committees

 9:15 Introduction  A.B. McDonald (15)

 9:30 Status of Experiment (35) D. Sinclair
       - overview of commissioning
       - status of outstanding problems from last year
       - what new problems have arisen?
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- prospects for physics results

10:05 Water (35) T. Noble
- rate of loss of D2O
- status of degradation
- assays: time & number
- contamination levels
- status of MnO2 fabrication
- status of MgCl2

10:40 COFFEE

10:55 Detector (30) R. Van de Water
- PMT's (status of HV breakdown)
- electronics & DAQ
- monitoring

11:25 DAQ (15) A. Hamian
- DAQ status
- Future development

11:40 Analysis (45) J. Klein

Organisation

Technical:
- status of software & databases
- status of data reduction
- online analysis

Physics:
- analysis chain & software
- Monte Carlo studies
- prospects for physics results

12:25 LUNCH

1:25 Calibration (30) A. Hallin
- what has been done?
- current development of new sources
- future sources

1:55 3He Detectors, U.S. Status H. Robertson (15)

2:10 Discussion of morning session (20)

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 2:30 Scientific Priorities & Strategy (45) A. McDonald
       - Time required for CC measurement
       - Competition
       - Neutral Current Measurement

 3:15 COFFEE

 3:30 Special Topics
       - Supernova Detection (15) C. Virtue
       - Muons, Atmospheric Neutrinos (15) C. Waltham

 4:00 Discussion of afternoon session (30)

 4:30 Committees in camera (60)

 5:30 Close-out meeting

 5:45 Adjourn

 7:00 Working Dinner

Thurday, Dec.9th
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 9:00 Committees in camera (60)

10:00 COFFEE

The two committees will split at this point.

Schedule for GSC Committee
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Operations Grant:
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10:15 Site Operations Grant (60) McDonald, Sinclair, Hepburn,
Noble
       - Services funded by this grant
       - Staffing requirements
       - Budget
       - Organisation
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Institutional Grants:

11:15 Overview (20) A. McDonald
- Group responsibilities
- # of people to satisfy these responsibilities
- Typical travel costs

This information should be given in tables we can refer to in later presentations. Questions to be reserved for individual groups.

11:35 Queen's (20) A. Hallin

11:55 Carleton (20) D. Sinclair

12:15 LUNCH

1:15 Guelph (20) J. Simpson

1:35 Laurentian (20) D. Hallman

1:55 UBC (20) C. Waltham

2:15 General Discussion

2:45 COFFEE

3:00 GSC Committee in camera (60)

4:00 Close-out meeting

4:15 GSC Committee in camera (60+)

Adjourn when required for travel

Thursday, Dec.9th

Schedule for SNO-ARC Sub-Committee

9:00 Committees in camera (60)

10:00 COFFEE

The two committees will split at this point.

SNO-ARC Science Sub-Committee

10:15 - 11:30 SNO-ARC Committee Meeting in camera

11:30 - 12:15 LUNCH

12:15 - 2:15

Calibration Details (A. Hallin) (20)
- Status of all calibration systems
- Detector tuning

HV Connectors (R. Helmer) (20)
- Status of HV connectors

Run Plan (D. Sinclair) (30)
- Priorities for next year and schedule
- Resources plan (personnel, responsibilities)

Review of Plan for Neutral Current Detection (A. McDonald)(30)
- Update on plan and schedule
- Progress on run sequence

Discussion of Possible Future Projects (A. McDonald) (20)
- What experiments are possible to augment SNO
- New projects running parasitically in mine
- Proposed strategy for review and approval

2:15 General Discussion

2:45 COFFEE

3:00 SNO-ARC Committee Meeting in camera

4:00 Close-out