Early Development of the Underground SNO Laboratory in Canada

by G.T. Ewan and W.F. Davidson

Fundamental physics measurements can be made by many different techniques. In particle physics they usually involve expensive high-energy particle accelerators. In the late seventies interest grew in non-accelerator particle physics which makes use of very low background laboratories built deep underground. Some experiments had already been started deep underground - studies of high energy cosmic rays, solar neutrino measurements, and searches for rare processes such as proton decay and ββ-decay. In 1982, Los Alamos National Laboratory hosted a workshop on Science Underground, which reviewed experiments being done underground and examined the possibility of building a National Underground Science Facility (NUSF) in the USA [1]. In late 1982 Norman Ramsay (Harvard University) and in early 1983 Ken Lande (University of Pennsylvania) gave colloquia at NRC, Ottawa and discussed the future trends in particle physics. Following these visits a small group led by George Ewan (Queen's University), Walter Davidson (NRC) and Pierre Depommier (Université de Montréal) started to explore the possibility of developing a deep underground laboratory in Canada for fundamental physics research. A study of possible sites and a consideration of potential experiments led to a proposal for a proton decay experiment in Inco's Creighton mine in Lively, near Sudbury. Other sites were considered but this was selected as the best available and Inco management was very cooperative. In collaboration with Ken Lande, a preliminary proposal was made to develop an experiment to search for nucleon decay using a liquid scintillator detector system. The project involved the construction of a large modular, extremely pure liquid scintillation detector with a special high transparency mineral-oil-based scintillator. This was to be located at the 4800 ft. level in Creighton mine.

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We visited Sudbury with Ken Lande in early May 1983 to explore the potential of Creighton Mine and to discuss with Inco management the possibility of doing an experiment in their mine. They already had a small research activity growing plants underground in association with Laurentian University. We had set up the visit with Inco beforehand and Inco staff was generous with their time. They took us down to the 6600 ft. level, the 7000 ft. level (to inspect the crusher station), and the 4800 ft. level where they suggested a site that might be suitable for the proton-decay experiment and would not interfere with the operation of the mine. The Inco VP, Wint Newman, our host, had set up a meeting with the Sudbury Regional Council, i.e. all the local mayors, so that we could let them know about our proposed project first hand, and through them, reach the local public. This proved to be a seminal meeting. The mayors also learned that we had been looking in Timmins for an underground site, but realizing the benefits that could accrue to Sudbury, unanimously approved that we should come to Creighton.

This was the first time we met Tom Davies, the regional council chairman, who became an enthusiastic supporter of the project as he was very keen to diversify the interests of the Sudbury region. To increase awareness and understanding of the project we also met Doug Hallman and other faculty at Laurentian University, and David Pearson, the director of the new science center, Science North. Fig. 1 shows the authors of this article at the 7000 ft. level in 1983.

In August 1983 NSERC asked that we present our preliminary proposal to an expert review panel for consideration alongside groups with fully developed proposals involving major collaboration in the OPAL experiment at the LEP collider at CERN and at the HERA experiment at the DESY laboratory in Hamburg. Our goal was to obtain funding in order to continue our feasibility study and develop a detailed proposal. The panel recommended that the two out-of-country proposals be funded, and decided to turn down our request. We were disappointed at this rejection as Canada could have been a major player earlier in the fast developing area of non-accelerator particle physics. We continued to explore the possibilities of non-accelerator experiments in fundamental physics and the role that Canada could play if a world-class laboratory were built deep underground in a site such as that in the Creighton mine. We made several presentations to the scientific community and found great interest in the possibilities. In 1984 Ted Litherland reviewed the field at the CAP annual congress in Sherbrooke. Although not directly involved he was enthusiastic about the type of physics that could be done. At that time there was already one experiment in Canada in an underground laboratory: a small group led by

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John Simpson, University of Guelph, and including Barry Robertson, Queen's University, was searching for evidence of ββ-decay in ^{76}Ge in an experiment located in a salt mine near Windsor, Ontario. This required very low radioactive backgrounds and this group's expertise in determining extremely low levels of radioactive contamination in materials and in evaluating environmental backgrounds was of great value in the selection of materials used in the construction of the SNO detector and in estimating background counting rates in the proposed site.

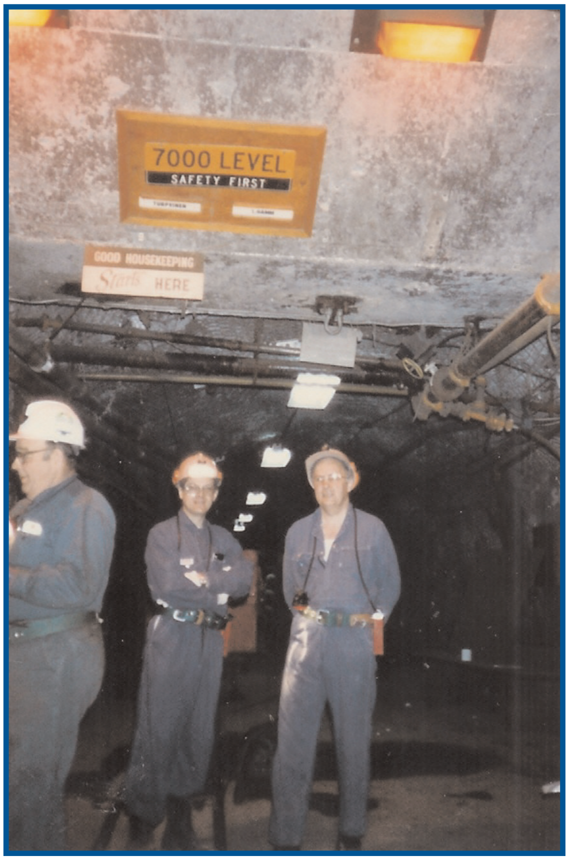

Fig. 1 The authors at the 7000 ft. level in the Creighton mine, May 1983.

In January 1984 we presented our ideas on a Canadian underground laboratory at an International Conference at Park City, Utah [2]. The presentation created great interest in the possibilities of the proposed site, particularly since little progress was being made at that time in the USA to attract funding for a large underground facility [1]. As a result of the Park City conference, many scientists contacted us and several went to Sudbury and were impressed with the possibilities. In March 1984, under the leadership of Al Mann, University of Pennsylvania, a small group deeply involved in the U.S. proposal visited Ottawa and Sudbury. A presentation in Ottawa summarized the great potential of science underground. In Sudbury our visitors were impressed with the potential of the proposed site in Creighton mine. Inco's positive attitude and their enthusiastic readiness to host an experiment were extremely helpful in convincing potential collaborators of the viability of an underground science laboratory in Canada. As a result of the increased interest we were invited to collaborate in preparing proposals for several experiments both in Canada and abroad. One of the visiting scientists was Herb Chen (University of California at Irvine), whose group was working on a 7 kilotonne liquid argon time projection chamber for use in solar neutrino studies and proton decay experiments. Later, as discussed below, he would suggest the heavy water solar neutrino detector, which led to the formation of the SNO collaboration. By this time we were firmly convinced that Canada could develop a world-class deep underground laboratory, which could make a major contribution to the field, and we concentrated our efforts on developing an international program that could be sited in Canada. We felt that this was a unique opportunity that should not be missed. Our work concentrated on solar neutrinos while another suggestion was made by David Hanna to study muon bundles (the DUMBO project) [18].

FORMATION OF THE SNO COLLABORATION

In the summer of 1984 Herb Chen presented a paper at an AIP neutrino conference in Lead, South Dakota, in which he pointed out that a very large heavy water (D_20) detector (several kilotonnes) would be excellent for detecting solar neutrinos [3]. This paper suggested the detection of electron neutrinos by the Charged Current (CC) reaction on deuterium ($\nu_e + d \rightarrow p + p + e$-). Heavy water had been used by other Irvine scientists in experiments at LAMPF and Savannah River, but never in a very large detector. In a later paper, Chen pointed out that all types of neutrinos could also be observed by the Neutral Current (NC) reaction [4]. Detection of the neutral current reaction ($\nu_x + d \rightarrow n + p + \nu_x$) involved the measurement of the neutrons in the SNO detector. Extremely low backgrounds were essential for these experiments. Heavy water had previously been suggested for neutrino detection [5], but availability and cost were a deterrent: a heavy water detector had been used by T.L. Jenkins (Case Western Reserve University) but it was too small and could only put an upper limit on the solar neutrino flux. Chen produced a prototype design similar to that in the light water (H_2O) detector being used at Kamioka, designed originally for proton decay experiments and later used for solar neutrino measurements. This design required several kilotonnes of heavy water and he talked to Cliff Hargrove, with whom he had previously collaborated at LAMPF (Los Alamos), to explore the possibility of using heavy water on loan from Canada's reserve for its CANDU reactor program. Preliminary discussions with Geoff Hanna and Ara Mooradian of AECL indicated that, under appropriate conditions, it might be possible to borrow 1000 tonnes of heavy water (value ~ $300M), provided it was returned in the same condition as when supplied, and for a limited time until it was required for installation in a new nuclear power reactor. The availability of such a large quantity of heavy water was unique to Canada. As a result, we had a meeting at the NRC in Ottawa in September 1984, at which it was decided that, since there was a possibility of obtaining heavy water on loan, we would proceed with a feasibility study to see if there were any physics problems that would make a 1000 tonne heavy water detector unsuitable for solar neutrino measurements. Among the problems discussed were backgrounds from radioactivity in the heavy water, light transmittance in the heavy water, and the size of excavation required deep underground in the Creighton mine. At that meeting, which in retrospect was the first SNO Collaboration meeting, it was decided that Herb Chen would lead the US team and George Ewan would lead the Canadian team. At that time the focus of the US effort was a strong group from the University of California at Irvine and a smaller group from Princeton University. The Canadian team was from Queen's University, Carleton University, the University of Guelph, Laurentian University, NRC and

AECL. In October 1984 we sent a letter of intent to NSERC informing them of our intention to study the feasibility of studying solar neutrinos using a heavy water detector in a deep underground laboratory in Inco's Creighton mine. Right from the start this was an international collaboration with funding to be obtained from the participants' national funding agencies and with the capital costs shared. In 1985 the University of Oxford joined the collaboration, when David Sinclair was on sabbatical leave in Ottawa, thus increasing the international participation.

The feasibility study was funded in Canada by a grant to the universities from NSERC and by support from NRC and Chalk River Nuclear Laboratories (AECL). These two large national laboratories provided many services not available at the universities. The first engineering study of the project was prepared by Ken McFarlane in the design office at CRNL. In the U.S.A. the research was funded through the Department of Energy (DOE). Many facets of the detector had to be explored. As the proposed experiment had counting rates of a few neutrinos per day it was essential to ensure that the background from radioactivity was very low as this could mask the signal. Measurements by Davis Earle at Chalk River found that the level of tritium in the AECL heavy water would produce an unacceptable background. The final stage of enrichment of this heavy water used a system that was also used for upgrading heavy water that had already been in a reactor (tritium is produced during use in the reactor through neutron capture on deuterium). Heavy water from Ontario Hydro, whose enrichment system had never been exposed to heavy water from a nuclear reactor, had acceptably low levels of tritium for our purposes and an exchange was subsequently arranged between AECL and Ontario Hydro. The light transmittance of heavy water was measured at NRC and found to be adequate. The timing and noise characteristics of the proposed 50 cm diameter photomultiplier tubes were measured at Queens's by Hay Boon Mak. The radioactivity from materials was measured at Guelph and other laboratories. Cleanliness of underground facilities was studied at Laurentian University. The photomultiplier glass was found to be a problem and in the final detector the glass envelopes for the photomultiplier tubes were made of special low radioactivity glass provided by the Schott glass company in Germany, who had built a new furnace dedicated to this purpose. As the maximum heavy water available was about 1000 tonnes, the detector had to be redesigned so that all of it would be used to detect neutrinos and none for shielding, as was being done in other water Cerenkov neutrino detectors. A suggestion was made by the Irvine group that we use a transparent acrylic vessel to contain the heavy water with a light water shield outside the acrylic vessel to reduce the effect of radioactivity from the cavern walls. This was incorporated in the preliminary design, which also took into account the levels of radioactivity in the heavy water including tritium, optical transmittance through the water and acrylic, properties of large 50 cm diameter photomultipliers, backgrounds from all sources, and many other aspects. A large cavity, 20 m in diameter and 30 m high, was envisaged. Geotechnical studies by Inco indicated that this might be possible if a suitable location were found away from fault lines and with acceptable stresses in the rock. This would require measurements at the proposed location. Our findings from the feasibility study were summarized in a July 1985 report to NRC and NSERC [6]. As a guide to the sharing of costs we proposed that the construction of the underground laboratory be funded by Canada, and that the construction and cost of components for the SNO detector be equally shared by Canada and the United States.

In October 1985 we submitted a grant request (including an update to the report in Ref. 6) to NSERC for funds to continue our research and to fund an exploration drift to find a suitable site where a very large cavity, 20 m in diameter could be excavated at the 6800 ft. level. This required finding a region in the mine well removed from known shear zones in the rock and from mining operations. Inco engineers had suggested a tentative location. However, before proceeding further a dedicated 200 m drift had to be excavated to this site in order to carry out measurements of the stresses in the rock. Inco agreed to do this at cost.

The grant proposal was reviewed by an international committee appointed by NSERC. The committee was very enthusiastic about the proposal and recommended that funds should be provided for the digging of the access drift ($400K) and funding for the design proposal ($85K). In their conclusions they stated that "*the physics goals of this proposal are of outstanding value*" and that "*the final proposed heavy water detector with very low background would be unique in the world*." The access drift to find a suitable site for the very large cavity was essential if the project was to proceed. Furthermore, the committee concluded "*the access drift will be a wise and valuable future investment for Canadian Science, which can only benefit Canada. Even if the field were to change, this access drift could be used in the future for other important experiments*."

The grant proposal was also reviewed by the NSERC subatomic physics grants committee, which, we understand, gave it lower priority than some experiments at accelerators outside Canada. We were astounded, as were members of the international review committee, to receive notification from NSERC in April 1985 that zero funds were being awarded, but they suggested we could use some funds from existing grants to continue with the feasibility study. These were far too small to allow the construction of the access drift. At an emergency meeting of the collaboration we agreed that the project could die if we did not find a suitable site for the large cavity deep underground. Construction of the drift was essential if the SNO project was to continue in timely fashion. The project had strong support by the scientific community. NRC, Queen's University, University of California, Irvine and the University of Guelph managed to provide support from their limited discretionary funds of ~ $350K. It was highly unusual at that time for funds to be provided to a project that had been rejected by a funding agency. In retrospect the bold decisions by top administrators in these institutions showed confidence in their colleagues and the judgment of the international review committee, and their courage prevented the possible collapse of the SNO project. With this funding Queen's University, on behalf of the collaboration, signed a contract with Inco to excavate the access drift to the proposed site in the "hanging wall" of the mine, where the requisite geotechnical study to characterize the rock *in situ* could be carried out.

The proposed direct counting solar neutrino experiment using heavy water neutrinos created great interest at international scientific meetings such as the meeting in Val d'Aosta, Italy [19], the Seventh Workshop on Grand Unification (ICOBAN '86) [7] in Japan, and the US solar neutrino meeting in Washington. As a result of the many presentations to the scientific community in Canada and abroad there was great support from the scientific community. The major concern expressed was whether or not a sufficiently low background could be achieved in such a large detector in a working mine.

It was important that we inform the general public in the Sudbury region of the proposed experiment deep underground in a local mine. Our initial discussions were with the mine management at the Creighton mine near Sudbury. Before having public meetings, Walter Curlook, Vice President of Inco, in charge of Ontario operations, arranged for a presentation to the Inco Board of Directors in Toronto so that they could be fully informed about the project and assure themselves that it would not affect the operation of the mine. Once INCO were informed about the project and its status we had meetings in the Sudbury region. Bill McLatchie made the presentation to the INCO board in August 1986 and then to the Council in Lively, where the Creighton mine was located, and to the Sudbury Regional Council on successive days in September 1986. He made many other presentations to university groups and politicians. There was great media coverage in the Sudbury region including TV coverage on Global television. The Sudbury Star interviewed Bill McLatchie and George Ewan and had a full page article on the possibility of an international laboratory located near Sudbury. It was also covered in As It Happens, and Ontario Morning. In the national press a story on the underground project appeared in the Globe and Mail. Tom Davies, Sudbury Regional Chairman, was a great supporter of the project and emphasized the importance of keeping the public well informed about our plans. He arranged meetings for us with politicians and the local union at Inco (United Steelworkers of America), and with its Canadian President (Leo Gérard). It was important to let the workers know what was proposed as early as possible. Throughout the project we have continued this policy of informing the public. It was also important to provide both Federal and Provincial politicians of this unique opportunity for Canada to have a world-class research laboratory deep underground for fundamental physics research. Meetings were held with the Minister of Science, William Winegard, and local Members of Parliament. We also met with all three caucuses in Ontario and in the Premier's Office.

The scientific work continued with the objective of preparing a detailed proposal for the SNO laboratory. This had to include both the design of the detector and the underground laboratory. Measurements of backgrounds of materials and backgrounds down the mine showed that it should be possible to obtain a sufficiently low background for the experiment. Light transmittance measurements in heavy water, normal water and acrylic were made and found to be sufficiently good. Simulations of the detector response to neutrinos showed that the position of events could also be established as well as the energy. The exploratory drift to find a suitable site was underway with the expectation from geological data that this should be possible. A preliminary design of the underground laboratory was used to discuss with INCO electrical and other services, such as air and water supplies that would be required. During this phase Hugh Evans had frequent meetings with INCO engineers in Sudbury to establish the feasibility of the preliminary design.

We submitted another grant request to NSERC for funding of the university groups to continue the research and to prepare a detailed proposal. This went to the NSERC subatomic physics grants committee. This year it was impressed by the great scientific progress made since the previous request and by the expansion in the size of the collaboration to include new members from the Canadian institutions. Several members were added when the Queen's University nuclear physics group decided to phase out the research program at the Van de Graaff accelerator and join the SNO collaboration. The committee recommended that funds should be allocated to continue research and to prepare a detailed proposal and funding was received in April 1987. The proposed SNO experiment continued to receive wide support from the scientific community worldwide. For example, it received enthusiastic endorsement in a letter (reproduced recently in an article by S.M. Bilenky [17]) from Bruno Pontecorvo, who was a pioneer in the field of solar neutrino detection and neutrino oscillations. The International Conference on Neutrino Physics and Astrophysics in 1988 sent a message to the President of NRC stating: "*This program will make Canada a leader in the field of fundamental particle physics*."

The detailed proposal for the construction of the Sudbury Neutrino Observatory was submitted in October 1987 [8]. This was supported by a large volume ("Red Book") giving details of measurements that had been made in the development of the proposal. At the time of submission the site of the laboratory at the 6800 ft. level in the mine had not yet been definitively established. This proposal was the basic document on which the construction of the SNO laboratory and experimental program were based. Research continued and several changes were subsequently made, such as the decision to use a spherical acrylic vessel.

At that stage the collaboration consisted of the 6 Canadian and 2 US institutions referred to earlier with the addition of the University of Oxford. The detailed proposal was widely circulated in the scientific community for comments and expressions of interest. In December 1987, a group from the University of Pennsylvania, led by Gene Beier, joined the collaboration. This group had extensive experience in underground science at the Kamioka mine in Japan. One of their important responsibilities was the design of the electronics system. The Oxford and Princeton groups added several new members.

A SNO Scientific and Technical Review Committee was set up jointly by NSERC and NRC to comment on the proposal and make recommendations to the funding agencies. This committee, chaired by radioastronomer Philip Kronberg, University of Toronto, was composed of world leaders in the field, both experimentalists and theorists. The SNO collaboration gave a series of presentations to this committee at NRC in June 1988. In their summary comments the committee's report states "*in conclusion, despite the existence of a number of difficulties associated with the experiment, such as its realization in a hostile mine environment, and the question of unambiguously identifying the neutral current signal the committee is convinced of the exceptional scientific merit of this proposal and the strong justification for its timely funding*."

Fig. 2 shows members of the SNO collaboration after the presentation to the committee at the NRC laboratories in June 1988.

The findings and recommendations of the international Scientific and Technical Review Committee were made public in late August 1988. NRC and NSERC Councils subsequently fully endorsed these recommendations, each provisionally proposing a contribution of some $10M towards the capital cost of the project. In the US, the SNO project was reviewed by the Nuclear Science Committee (NSAC) of DOE and received the highest rating, higher than several US-based projects. The estimated capital cost of the project was ~ $ 40M in 1987 dollars, but with no allowance for inflation. Operating costs were to come from the individual granting agencies in the countries involved. Many discussions took place on funding the project with federal and provincial sources in Canada and with DOE in the U.S and granting agencies in the U.K. The total funding package was approved in January 1990 and construction started soon thereafter.

After the publication of the report we made many presentations of our ideas both to scientists and the general public. Descriptions of the Sudbury Neutrino Observatory project appeared in the national newspapers and interviews took place on television. We informed our federal MPs and provincial MLAs of the project and the unique opportunity that Canada had to become a world leader in this emerging and exciting field. More details are given in the accompanying article [9].

In November 1987 the collaboration had suffered a great loss with the passing of Herb Chen, who had initiated the project and as the US spokesman provided leadership and many scientific ideas. Art McDonald, Princeton University, took over as US spokesperson and was joined by Gene Beier, University of Pennsylvania, as co-spokesperson in 1988. Fred Reines, University of California at Irvine, acted as the interim UC Irvine Principal Investigator, even though he had many other commitments.

In November 1988 a large group from Los Alamos National Laboratory (LANL), led by Hamish Robertson, which had extensive experience in neutrino physics, joined the collaboration. This group suggested using ^{3}He counters for observing neutrons from the NC reaction. Some members of the Los Alamos group moved to the University of Washington, Seattle in 1994, but continued to work on the ^{3}He detectors. In the fall of 1988, a Canadian group from the University of British Columbia (UBC), led by Chris Waltham also joined. The close connection of the UBC group to TRIUMF proved to be of great value for technical assistance and advice. We were sorry that the other members of the Herb Chen's original group left Irvine and went to other positions. Fortunately Peter Doe, a leader in the work on the acrylic vessel, became a member of the LANL group. In March 1989 a group from Lawrence Berkeley Laboratory (LBL), led by Rick Norman, joined the collaboration. Kevin Lesko of this group took major responsibility for the photomultiplier tube support structure. In the period 1987-1989 the teams at the Canadian institutions also expanded and the university research groups were supported by NSERC grants. By the end of 1989 the collaboration had grown to a sizable team of about 70 scientists from 12 institutions. Funding for the construction of the SNO laboratory was approved in January 1990 by the Government of Canada. It was estimated that construction would take around 4 years. We expect that the fascinating story of the construction of the detector and the many problems that were overcome in its successful completion will be the subject of a report in the future.

Fig. 2 The SNO collaboration after the presentation to the International Review Committee June 1988.

Another major change occurred in the administration of the project. During the design stage we were a loosely knit team with George Ewan and Herb Chen as the first spokespersons for the collaboration. The collaboration was always run as a team effort with frequent meetings to discuss progress. The Canadian leader of the project, George Ewan, who had guided the development of the project in Canada from its inception and through the formation and expansion of the collaboration was due to retire in 1992. Major funding of a large experiment required a much more formal organization. It was agreed that an Institute would be set up by Queen's University to administer the SNO project. This Institute was set up under the authority of Queen's Senate. Art McDonald, who had been the SNO Principal Investigator at Princeton, spent a sabbatical year at Queen's and in 1989 accepted an appointment as Professor of Physics at Queen's. He was appointed as the first Director of the Sudbury Neutrino Observatory Institute when it was formed and has guided the project through the construction phase and data-taking phase. George Ewan continued his work on the project and was the Chairman of the SNO Management Committee.

DEVELOPMENT OF DESIGN OF SNO DETECTOR

Herb Chen's initial concept of a heavy water solar neutrino detector is shown in Fig. 3. This design required a very large amount of heavy water (D_2O) in order to obtain an appreciable fiducial volume where the external background from the surroundings would be sufficiently low. This was the type of design used by the group at Kamioka in their water Cerenkov detector, which used 3000 tonnes of normal water (H_2O) with a fiducial volume of 1000 tonnes for neutrino detection. Using this design, and the fact that the maximum amount of heavy water that could be made available to us was 1000 tonnes would have led to a fiducial volume, available for the measurement of solar neutrinos, that was too small for significant results.

This was recognized early in the feasibility study and the decision was made to enclose the heavy water in a transparent container in a bath of ultra pure light water, which would provide shielding from the external background. Various suggestions were made such as a polythene bag or an acrylic vessel. The suggestion of the acrylic vessel came from Herb Chen after a visit with his daughter to Sea World in San Diego where there was a large aquarium window with a sign stating it was made by Reynolds and Taylor (later Reynolds Polymer Technology) by bonding pieces of acrylic together. This firm fortunately was located only two miles from the Irvine campus and he immediately contacted them and began discussions of an acrylic vessel for SNO. Acrylic for use in the heavy water detector required good transmittance in the ultraviolet region and very low Th and U content was required. The strength of the acrylic vessel with walls that did not absorb too much light was a major concern Consultations were held with an expert, G. Stachiw, who had designed acrylic submersibles being used for manned underwater exploration. Although we required a much large vessel, 12 m in diameter, he advised us that it could be practicable if confirmed by detailed calculations. The design of the detector in the SNO proposal is shown in Fig. 4. Detailed calculations after the initial proposal showed that a spherical vessel would be better for optimizing the strength for a given thickness of acrylic and the final design of the detector is shown in Fig. 5. The design had to be approved by AECL as a suitable container of 1000 tonnes of heavy water worth about $300M.

The properties of the acrylic used for the vessel were critical to the success of the experiment. In addition to the structural strength of the vessel, the acrylic had to have as good light transmittance as possible in the ultra-violet region and to be very low in radioactivity, especially in Th and U. The work on the structural strength was concentrated at Irvine with Peter Doe as the leader, the optical transmittance measurements mostly done at NRC, and the radioactivity measurements at Chalk River and Guelph. Quality control of the acrylic supplied by the manufacturer was essential and Davis Earle was the leader of this effort. Cleanliness of the laboratory was essential and Doug Hallman of Laurentian was the leader of that effort. The overall success of the SNO experiment depended on reaching very low background levels.

Because it had to be assembled underground at the 6800 ft. level it was manufactured in 130 separate sections of a size that could be fitted in the underground transport cage 12 ft. by 6ft. and 10 ft. high The vessel was dry assembled above ground to check that all sections fitted and then the sections moved underground and bonded together. The manufacturer of the acrylic vessel was Reynolds Polymer Technology,

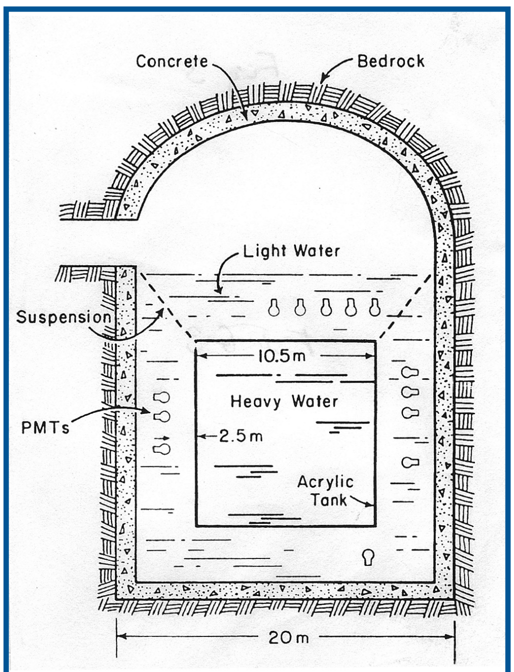

Fig. 3 **Initial concept of the SNO detector from feasibility report of July 1985.**

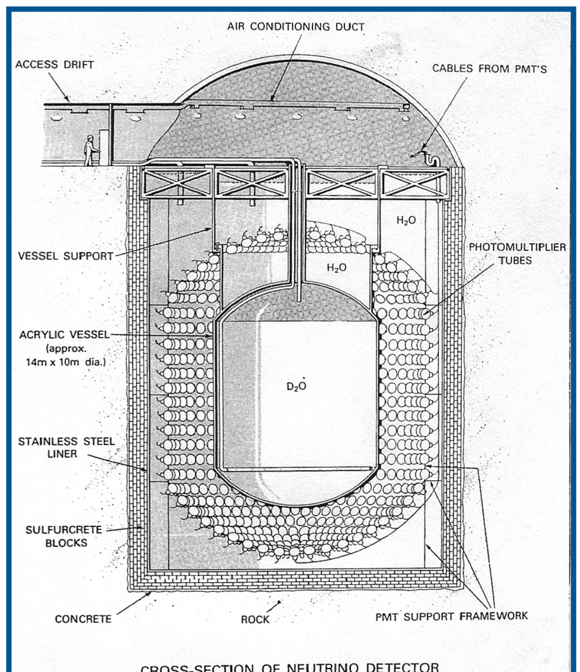

Fig. 4 **The SNO detector design in the SNO proposal of October 1987.**

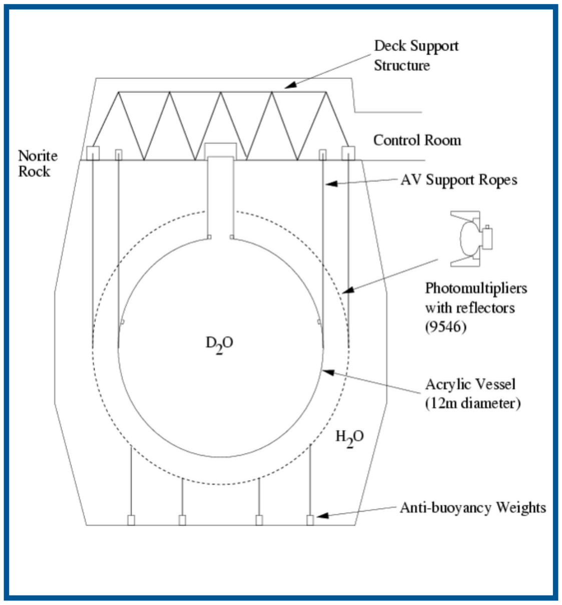

Fig. 5 Design of the detector with spherical acrylic vessel used in SNO experiment.

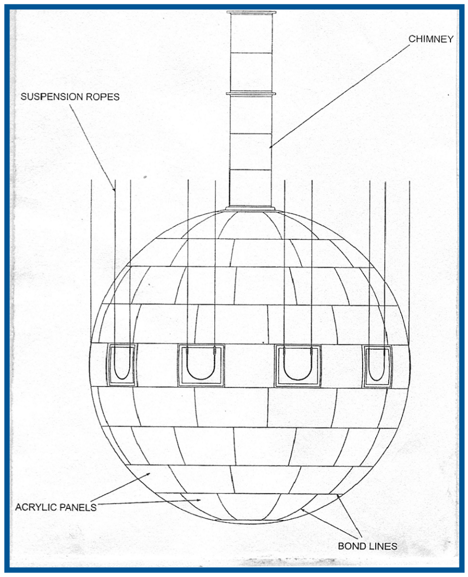

Fig. 6 Schematic diagram of acrylic vessel.

which was responsible for the assembly underground. Fig. 6 shows a schematic figure of the acrylic vessel. All components of the detector had to be transported underground. The assembly was complicated and very time consuming. It involved many of the SNO scientists and innovative solutions to the problems that occurred. The oversight of the construction underground was carried out by Ken McFarlane, Duncan Hepburn, and Bob Brewer. Fig. 7 shows the completed detector before it was filled with heavy water.

The signals from the neutrino reactions are photons of Cerenkov light detected by photomultiplier tubes surrounding the heavy water. Initially, in the reference design we planned to use the same 50 cm diameter Hamamatsu tubes used in the Kamioka detector. The timing and noise properties of these tubes were measured at Queen's. Timing resolution was important as we planned to locate the position of events as accurately as possible by measuring the transit times to the photomultipliers and reconstructing the position. The timing resolution of 20 cm photomultipliers being developed by several manufacturers was considerably better, allowing better event reconstruction accuracy.
In the final design we used 20 cm Hamamatsu tubes with light concentrators added to improve the light collection onto the photocathode. The geometry and material properties of these concentrators had been researched by the Oxford and UBC groups.

Since the glass envelope of the phototubes was a source of background, visits by Hamish Robertson and Hamish Leslie to the Schott glass company led to a glass with lower U and Th content. By careful control of the elements used in their manufacture they were able to make glass envelopes with reduced radioactivity. These were supplied to Hamamatsu who used them in the production of their photomultipliers.

The measurement of the radioactivity in all components of the detector was crucial to the success of the experiment. Key components were the heavy water, the acrylic vessel, the water surrounding the vessel, the photomultiplier tubes and backgrounds from the cavity walls. The cavity walls were lined with Urylon to reduce the level of radon from that source. The phototubes used the special low radioactivity glass and were placed 2 m from the heavy water to enable the light water to provided some γ-ray shielding. The water handling and purification systems were designed to achieve extremely pure water with extremely low levels of U and Th. High-energy γ-rays from radioactivity in the rock walls of the cavity were also a source of background events. The surface of the acrylic vessel was ~ 5m. from the cavity walls and the light water shield acted as an absorber which greatly reduced this problem.

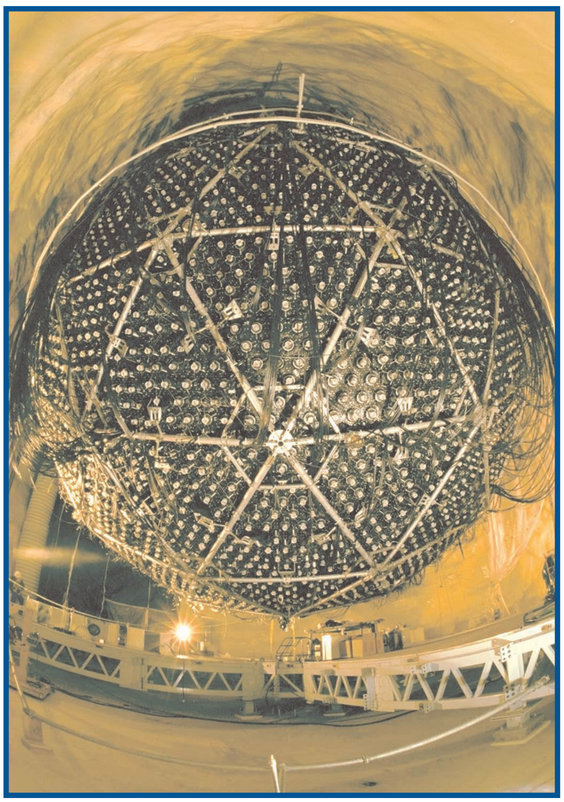

Fig. 7 Photograph of the assembled SNO detector.

An important feature of the SNO detector is the ability to measure both the flux of electron neutrinos by the charged current (CC) reaction and the total flux of neutrinos by the neutral current (NC) reaction. The neutrons from the NC reaction when captured on the deuteron produce γ-rays of 6 MeV, which in turn produce Cerenkov light observed by the photomultipliers. In the SNO proposal it was suggested that we add NaCl to the heavy water to enhance this signal as the cross section was larger and the total energy release following neutron capture greater. An alternative suggestion was made by Cliff Hargrove to use an array of Gd tubes in the detector and another proposal by the Los Alamos group to use an array of ^{3}He counters. It was decided in 1991 to proceed with both the addition of salt and the ^{3}He suggestion. The suggested running scenario was first to do a pure heavy water run, followed by the addition of salt and the ^{3}He counters. These two methods would have different possible systematic errors. The concept of the ^{3}He detectors is shown in Fig. 8. The ^{3}He detectors were funded by DOE in the U.S. and their development was led by the University of Washington and Los Alamos groups.

A detailed description of the final detector design is published in Nuclear Instruments and Methods [11]. Many papers have been given at conferences and descriptions of the detector at various stages appeared in Physics in Canada [10].

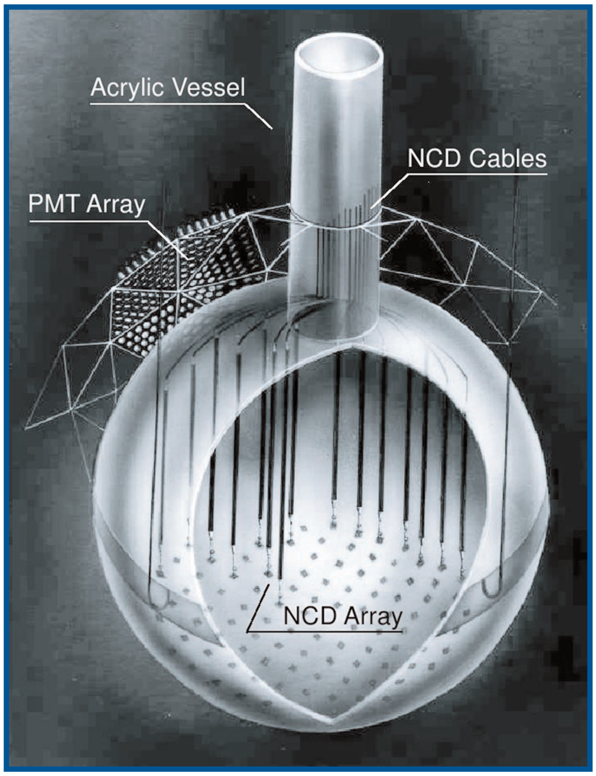

Fig. 8 Concept for ^{3}He tubes (NCD Array) in SNO detector.

SUMMARY

The SNO detector received commitments of funding from sources in Canada, US and UK in 1989. A detailed review of the proposed budget by a joint Canadian-US committee headed by Ed Temple took place in November 1989. The funding of the SNO project was announced in Ottawa on January 4, 1990 by the Minister of Science, William Winegard, who had been a strong supporter of the project.

This brief review has only covered some events before actual construction started in 1990. During this period there were ~ 4 full collaboration meetings per year, in which progress was reviewed and many suggestions for changes to the detector considered. It should be emphasized that the final design was the result of a team effort with all groups contributing. Throughout this period the excellent cooperation of Inco, who helped in the location of a suitable site and in many other ways, was invaluable. The fascinating story of the construction of this complex detector and the problems faced and solved should be the subject of another article.

The results obtained with the SNO detector have made major contributions to the understanding of neutrinos and the limitations of the standard model. These results, which have been published [12-16], provide definitive evidence for the first time that electron neutrinos oscillate between different types in their passage from the center of the sun where they are produced to earth. The total solar neutrino flux observed by SNO agrees with the predictions of solar models, thereby solving a three-decade old problem, often referred to as the Solar Neutrino Problem. Previous experiments measured only electron neutrinos and had zero or low sensitivity to other types. Only ~ 34% of electron neutrinos produced in the sun from ^{8}B arrive at Earth: the rest have changed into other types. Neutrino oscillations show that neutrinos have a finite rest mass and this requires that modifications must now be included in fundamental theories.

REFERENCES

1. M.M. Nieto *et al*., Editors, "Science Underground" Conference at Los Alamos, *AIP Conf. Proc.* **96** (1983).
2. W.F. Davidson, P. Depommier, G.T. Ewan, and H.-B. Mak, "A National Underground Physics Laboratory in Canada", *Proc. International Conf. Baryon Non-Conservation (ICOBAN '84)*, Park City, Utah, 1984, pp. 273-277.
3. H.H. Chen, Solar Neutrinos and Neutrino Astronomy (Homestake, 1984), *AIP Conf. Proc.* **126** (1985) p. 249.
4. H.H. Chen, "Direct Approach to Resolve the Solar Neutrino Problem", *Phys. Rev. Lett.* **55** (1985) 1534.
5. F. Reines, "The Search for the Solar Neutrino", *Proc. Roy. Soc. A* **304** (1967) 159.
6. G.T. Ewan *et al*., *Sudbury Neutrino Observatory - Feasibility Study for a Neutrino Observatory Based on a Large Heavy Water Detector Deep Underground* (SNO-85-3 "Blue Book"), July 1985.
7. G.T. Ewan, "The Canadian Underground Project--Sudbury Neutrino Observatory", J. Arafune, Editor, *Proc. 7th Workshop on Grand Unification, ICOBAN '86*, Toyama (1986) 95.
8. G.T. Ewan *et al*., *Sudbury Neutrino Observatory Proposal* (SNO-87-12 "White Book"), October 1987.
9. W.F. Davidson and G.T. Ewan, *Physics in Canada* (accompanying article).
10. E.D. Earle, W.F. Davidson and G.T Ewan, "Observing the sun from two kilometres underground: The Sudbury Neutrino Observatory", *Physics in Canada* **44** (1988) 49; see also theme issue on the building of the Sudbury Neutrino Observatory in *Physics in Canada* **48** (2002); "Sudbury Neutrino Observatory - Construction Enters Final Stage", E.D. Hallman and A.B. McDonald, *Physics in Canada* **50** (1994)186.
11. J. Boger *et al*., The SNO Collaboration, "The Sudbury Neutrino Observatory", *Nucl. Instrum. Methods Phys. Res.*, **A** 449 (2000) 2909.
12. Q.R. Ahmad et al.,"Measurement of the Rate of $\nu_e + d \rightarrow p + p + e^-$ Interactions Produced by 8B Solar Neutrinos at the Sudbury Neutrino Observatory", *Phys. Rev. Lett.* **87** (2001) 071301.
13. Q.R. Ahmad *et al*.,"Direct Evidence for Neutrino Flavor Transformation from Neutral-Current Interactions in the Sudbury Neutrino Observatory", *Phys. Rev. Lett.* **89** (2002) 011301.
14. Q.R. Ahmad *et al*., "Measurement of Day and Night Neutrino Energy Spectra at SNO and Constraints on Neutrino Mixing Parameters", *Phys. Rev. Lett.* **89** (2002) 011302.
15. S.N. Ahmed *et al*.,"Constraints on Nucleon Decay via "Invisible" Modes from the Sudbury Neutrino Observatory", S.N. Ahmed *et al*., *Phys. Rev. Lett.* **92** (2004) 102004.
16. S.N. Ahmed *et al*.,"Measurement of the Total Active ^{8}B Solar Neutrino Flux at the Sudbury Neutrino Observatory with Enhanced Neutral Current Sensitivity", *Phys. Rev. Lett.* **92** (2004) 181301.
17. S.M. Bilenky, "The History of Neutrino Oscillations", Proc. Nobel Symposium on Neutrino Physics, Enkoping, Sweden, August 2004, in press: preprint arXiv: hep-ph/0410090.
18. D. Hanna, "A Cosmic-Ray Astrophysics Facility in Canada", *Il Nuovo Cimento*, **9C** (1986) 333.
19. D. Sinclair *et al*., "Proposal to Build a Neutrino Observatory in Sudbury, Canada", *Il Nuovo Cimento*, **9C** (1986) 308.

The Funding Campaign for the Sudbury Neutrino Observatory

by W.F. Davidson and G.T. Ewan

This article, a companion to the previous article on the early development of the underground laboratory in Sudbury, focuses on the events in the period from September 1988 to January 1990 when a concerted effort was made to secure capital funding for the construction of the Sudbury Neutrino Observatory (SNO). The search for funding of a large-scale scientific project is never simple, but more so in the Canadian context as there is no framework or appropriate mechanisms laid down to evaluate such a request.

The search for funding of a large-scale scientific project is never simple, but more so in the Canadian context as there is no framework or appropriate mechanisms laid down to evaluate such a request.

The findings and recommendations of the international Scientific and Technical Review Committee were made public in late August 1988. NRC and NSERC Councils subsequently fully endorsed these recommendations, each provisionally proposing a contribution of some $10 million towards the project. The SNO collaboration asked us to devote efforts to secure Canadian funding by giving briefings about the proposed project to key decision makers, including politicians, government officials, civic bodies, and to opinion leaders in the media. We were entering new territory, given that the capital funding required from Canadian sources was at least $35 million, a sum beyond the capability of one single agency of the federal government. The total cost from all sources, both for capital and operating during a predicted 4-year construction period, was $53 million. There was also no precedent in recent memory on which our campaign could be modeled. The campaign was more drawn out than we had anticipated and took, in the end, 16 months, i.e. until the end of December 1989.

Our US collaborators (Irvine, Princeton, Pennsylvania and Los Alamos) made an application in parallel to the US Department of Energy for funding. Their submission was for about US$12 million. After SNO had placed at the top of a Nuclear Science Advisory Committee review, the DOE had attached high priority to supporting the SNO proposal and it was ultimately relatively straightforward to secure the US contribution, contingent on a commitment by the Government of Canada to fund the project. Later a contribution of close to $1 million (Canadian) was proposed by the UK funding body for a fraction of the capital cost and support for the University of Oxford scientists in the project.

THE CAMPAIGN

In the fall of 1988, the only opportunity on the federal scene to fill the funding gap was to apply to the then new Federal Networks of Centres of Excellence program of the granting councils. The collaboration spent two months preparing and submitting the case (the "Brown Book"), but NSERC eventually decided that the SNO proposal did not really align with the criteria (in particular the industrial elements) of this program. After discussion with the federal funding agencies, we decided that it would help the overall case if we could secure a significant fraction of the funding from the Province of Ontario. Therefore, $7.6 million was requested from the province. The argument was that with the site in Sudbury significant benefits would accrue to the province, hence it was legitimate to ask for such a contribution. Again, this was out of the ordinary as this was the first time a province had been asked to provide support for what essentially was a basic science driven initiative.

Over the next few months a number of events were organized and influential people were briefed about the SNO project. The late Tom Davies, Regional Chair of the Municipality of Sudbury, with whom we had had a very fruitful association since we first visited Creighton Mine and Sudbury in May 1983, organized many of the key meetings. Tom Davies introduced us to his network of highly placed contacts. He insisted on accompanying us, opening doors in Sudbury, Toronto, Ottawa, Sault Ste Marie, and elsewhere, to ensure that a broad set of influential people understood the positive implications of having such a high visibility scientific project in the North of Ontario, while we restricted ourselves to presenting the science and the technical issues.

Science North, the hands-on science museum in Sudbury, which became an outstanding example of public communication in Science, was a very willing partner with the SNO collaboration and we benefited extensively from their communications expertise. In fact, a memorable early meeting of Canadian and US scientists interested in exploring underground physics at Creighton Mine, which had just been visited, took place on March 1, 1984 in an area, still under construction, that was going to be the Science North restaurant overlooking Lake Ramsey. Science North arranged for and

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hosted very well attended public lectures on SNO in May 1987 and September 1989. Science North put up exhibits on SNO at that time, and indeed, all during construction and up to the present day Science North has been outstanding in its commitment to bring the essential science of SNO to a wide public.

During this period, members of the SNO Collaboration gave presentations at international conferences and gave lectures to universities from coast to coast, in the US and in Europe, with a view to increasing wider interest in the significance of this opportunity for Canada.

The campaign involved briefings to significant players. These included the deputy speaker of the Senate of Canada, the Solicitor General of Canada, the Minister of Science, the Ambassador of the United States, the caucuses of all three parties of the Legislature at Queen's Park, Members of Parliament, and Members of the Provincial Legislature. Influential groups such as Chair of the Board of Inco Limited and other Inco senior executives, the Council of the Regional Municipality of Sudbury, the United Steelworkers of America Local 6500 (we met with President Leo Gérard) who form the miner's union, the Sudbury Chamber of Commerce, the Sudbury Regional Development Council, and Walden County Council (where Creighton Mine is located) received presentations from us.

An illustrative 6-page brochure in full colour entitled "Sudbury Neutrino Observatory - A Unique Canadian Opportunity" was produced to support these activities. At its head, under the subtitle "Opening a new window on the universe…" stood a quotation by Gerhard Herzberg: "The Sudbury Neutrino Observatory offers incalculable potential for the advancement of science in this country." This attractive brochure, very much geared to a public audience, was distributed liberally at our meetings and served to promote an appreciation of the importance of what we were trying to achieve.

Interestingly, as a result of these activities, questions and statements about the importance of the SNO project were made in the House of Commons by Diane Marleau (MP for Sudbury), John Manley (then Opposition S&T Critic and MP for Ottawa South), and John Rodriguez (MP for Nickel Belt). This was highly unusual since it was extremely rare for a Minister for Science to receive any question during Question Period.

The request we had made to the Government of Ontario for a contribution of $7.6 million became the subject of lively parliamentary repartee about neutrinos during Question Period at Queen's Park throughout 1989, especially the interventions launched by Floyd Laughren (NDP) (later an Ontario Finance Minister) who questioned then Premier Peterson on several occasions, and also by Mike Harris (PC) (a future Premier of Ontario). One particularly outlandish interchange during the 1989 Ontario budget debate was captured in Hansard of May 18, 1989 (see excerpt in Sidebar 1). Such exchanges created a lot of interest and welcome media 'buzz'.

SIDEBAR 1

Hon. R.F. Nixon*: How about neutrinos?*

Mr. Laughren*: As a matter of fact, it is funny the Treasurer would talk about neutrinos. I thought that when the Premier's technology fund was established, it was to accomplish and put in place projects such as the Sudbury neutrino observatory. Because the Treasurer cannot see neutrinos, cannot feel neutrinos, cannot smell neutrinos, he thinks there is no such thing.*

Mr. Wildman: *He is a tactile person.*

Mr. Laughren: *Yes. There is a gap in the Treasurer's education, because there is such a thing as pure research. For the Treasurer not to recognize that pure research is legitimate, I think, does not comment well on his ability to look into the future or at least to try to think ahead as to the society we are going to have. It is bothersome to hear the Treasurer forever sneer at the concept of a neutrino.*

Hon. R.F. Nixon*: Scoff.*

Mr. Laughren*: The Treasurer does. Every time we raise it, he sneers at the idea. That is simply not appropriate. The United States is putting money into it; Great Britain is putting money into it. Ottawa has put money into already through the National Research Council. This province has done diddly-squat, absolutely nothing, for the neutrino observatory.*

Mr. D.S. Cooke*: They only want $7 million, do they not?*

Mr. Laughren*: They want $7.2 million over four years. It is a good project. It is a world-class project. That in itself should attract the Treasurer.*

Hon. R.F. Nixon*: Yes, but is it proactive?*

Mr. Laughren*: Yes, it is.*

Hon. R.F. Nixon*: How much do you need from us?*

Mr. Laughren*: We need $7.2 million over four years. Other jurisdictions are way ahead of this government and it really is sad.*

Hon. R.F. Nixon*: Is there money up there in Sudbury?*

Mr.Laughren*: Yes.*

Hon. R.F. Nixon*: And it's just sitting in the bank.*

Mr. Laughren*: I see what you mean. No, they have committed their money to the observatory and the province has committed nothing. I think the Treasurer should reconsider.*

Hon. R.F. Nixon*: Neutrinos?*

Mr. Laughren*: The Sudbury neutrino observatory. It is an important project; SNO, as it is known for short.*

I would like to talk about post-secondary education and emphasize…….

Another key step in the process of validation of the SNO proposal was the technical and costing review carried out in Ottawa over three days in the autumn of 1989 by a joint Canada-US (NSERC-NRC-DOE) external committee chaired by Dr. Ed Temple, an experienced DOE project manager. Again, the proposed project and the quality of the team of scientists received a robust endorsement.

Among the highly significant benefits we stressed in our presentations that the SNO project would bring to Canada and the Sudbury region were:

· Leading edge fundamental research providing a showcase for Canadian science and assuring international leadership on a major scientific frontier,
· An exceptional opportunity for postgraduate training and source of inspiration for young Canadians to enter scientific and technical careers,
· Stretching of technologies in many areas, e.g., ultra-pure materials, mining techniques and advanced shielding materials,
· Exceptional cost effectiveness: the main capital item (heavy water) was available on loan,
· Development of a high-technology world-class laboratory in the Sudbury Region,
· Project had unique Canadian components, being led by Canadian scientists using Canadian heavy water and being located in a Canadian mine.

SIDEBAR 2

THE SUNDAY STAR,
SEPTEMBER 24, 1989/B3

A scientific bargain

More than two kilometres deep, in a mine shaft near Sudbury, a high-powered international group of scientists wants to build a research observatory to detect neutrinos – the smallest form of matter in the universe.

Most of the bargain-basement $55.7 million required to bring this unique project to fruition has already been promised by Canadian, American and British universities and institutions.

What's still needed, though, is $7.6 million from the Ontario government. If that doesn't come through, some international money might not come either.

Ontario cabinet ministers and officials apparently have two concerns. One is to determine whose ministry's budget the money should come from. The other is to ensure that if Ontario contributes, Ottawa – which has primary responsibility for basic scientific research – won't renege.

What petty considerations for such an exciting project that has already begun to bring some Canadian scientists back home while enticing foreign scientists to Canada.

Observing that "the new wealth of nations is found between our ears," Premier Peterson recently said we must "keep our best minds in Canada."

A good place to start doing that is for the Ontario government to help build the Sudbury Neutrino Observatory.

The importance of attracting favourable media coverage for the SNO project was never overlooked. A constant steam of interviews, in English and occasionally in French, both national and local, by the print media, radio, and television during the campaign brought the aims of the SNO project to wider public attention. A very useful article in support of SNO attracting international attention and entitled "Getting to know the neutrino" appeared in the September 26, 1987 issue of "The Economist". We appeared on the CBC's "The National" in September 1988. Jack Miller, then science writer for the "Toronto Star" wrote some beautiful well-considered articles on SNO, including a compelling editorial piece in September 1989 (See Sidebar 2), just at the time the Ontario Cabinet was deciding to commit to the project.

By the summer of 1989, despite actively pushing the case, we still had not been able to obtain the $7.6 million from Ontario. Events were not made easy, in fact they became rather awkward, when a letter from the NSERC president to the Ontario government enquired if Ontario might be able to double the amount to $15 million. It was in September 1989 that Ontario took a decision to commit the $7.6 million to the project, just after an editorial piece (Sidebar 2) in the "Toronto Star" and after a chance persuasive intervention in Washington with Premier David Peterson on the outstanding opportunity that the SNO project offered by White House Science Advisor D. Allan Bromley. The Ontario contribution was announced shortly after on October 2, 1989 in Sudbury, with a press release quoting Premier Peterson "The Neutrino Observatory will certainly place Sudbury - and indeed all of Ontario and Canada - on centre-stage in the field of sub-atomic research."

With this Ontario contribution in hand, we then returned, in the late autumn of 1989, to persuade the federal government, specifically Industry, Science and Technology Canada, of the need for the final $15 million of funding required to give the project the green light. The US DOE had by this time come up with their commitment, contingent on Canada committing to the project and giving a deadline initially of November 15, 1989. At this critical stage, Tom Davies not only wrote a dramatic letter (including our brochure) in October 1989 to Prime Minister Mulroney about his government urgently needing to commit to SNO, but also he sent close to 4000 copies across Canada -- to every MP, Senator, Ontario MPP, all CAP members, all universities and colleges, and others on his extensive contact list. This alone was an enormous logistical feat, indicative of the desire Sudbury had to land "their project." Over the next several weeks we understand some 500 letters were sent to the Prime Minister in support of SNO.

The mid-November US deadline (linked to the US budget cycle) came and went as we tried frantically to secure the gap in funding. It was only in early December 1989 that two key interventions took place. The first one was a Saturday morning breakfast meeting in Sudbury attended by the federal Cabinet member responsible for Northern Ontario, Doug Lewis, then Transport minister, at which local officials described the SNO project up as the "number one economic priority" and cited the alarming potential of loss of votes for the government if the project did not go forward. The second was a diplomatic intervention involving the Canadian Ambassador in Washington and the Science Advisor in the White House, which, from our view on the sidelines, miraculously seemed to unblock the funding logjam in Ottawa. A Department of External Affairs telegram to the Canadian Embassy in Washington on December 1, 1989 stated about the SNO proposal that: "*Elle est fortement appuyée de toute part et tout indique qu'elle sera acceptée par le Comité du Cabinet.*" This was interesting testimony to the sequel of this intervention, letting us know for the first time that the green light was coming! The whole funding package was put in place and then went to the federal cabinet for approval just before Christmas 1989, where, we understand, SNO was viewed once more as an economic opportunity rather than a scientific one. There was a sigh of relief by all of us, when Minister of Science, William Winegard, made the official announcement at a government press conference held in Ottawa on January 4, 1990 that the Government of Canada had committed to the SNO project.

RETROSPECTIVE AND ANALYSIS

It may be worthwhile to make a few comments about the development of the SNO project and the manner by which it ultimately received funding to go forward. We think there are lessons to be learned from our experience. The whole process of identifying the problem, carry out the feasibility study, then the R&D and proposal preparation, the reviews, and the search for funding took 6 years, i.e. from 1984 to 1990, considerably longer than we had estimated. If one includes the first visits to Creighton Mine in 1983, then it took 7 years.

The process in Canada to identify the funding was difficult, drawn out, irregular, sometimes bizarre, and ultimately political. The funding system in Canada just had no way of handling a request of this magnitude. One of the unexpected turns, for instance, were the discussions in 1988 with the federal government agencies that indicated it would be important to have a financial contribution to the project from the Government of Ontario. This form of sharing costs, sometimes now known as 'matching costs' in the spirit of the Canada Foundation for Innovation, is regarded now as a normal way of doing business. However, back in 1988, this approach was novel. So in a sense we had to pioneer this activity, giving briefings to MPPs, various caucuses, and senior Ontario officials. We were invited to go three times to Queen's Park to brief various parliamentary caucuses. There was considerable reluctance on the part of the Ontario government at first, but as noted above, our persistence eventually won out.

Another essential element was simply sheer good luck. Several well-placed individuals became strong supporters of our cause, pitching in to organize meetings with decision makers and helping us with our briefings. First there were the presidents of NRC and NSERC, at that time Larkin Kerwin and Arthur May, respectively. The committed support of INCO staff, at all levels, was greatly appreciated. Then there was Rhéal Bélisle, Deputy Speaker of the Senate of Canada: he represented the north of Ontario and was a valuable interlocutor in keeping us abreast of the latest developments 'on the Hill'. Significantly he had impeccable access and used it to get us in front of people such as the US ambassador. The fact of having Tom Davies in his position as Chair of the Regional Municipality of Sudbury was a great boon, as he worked tirelessly with us to ensure our case for SNO was heard at the highest levels.

It is worthwhile stressing that we only went along the lobbying route once the very positive report of the international peer review committee had been handed down, that is, in the early fall of 1988. Going earlier down this path would have been premature and inappropriate.

The SNO project was the first large project of its kind since the decision to build the NRU reactor at Chalk River in 1953, and the TRIUMF laboratory in 1969. While the first two projects were funded essentially 'top-town', the SNO proposal was really very much built up from grass roots ('bottom up'). The fact that we simply sought out our own collaborators at the working level contrasts with the now much more prevalent 'dirigiste' approach in Canada to building R&D collaborations. The SNO proposal arrived on the scene when there was a policy vacuum how to deal with a request of this magnitude, in fact, in a wider sense, there was (and still is) no centrally stated science policy for Canada. In the Canadian context, SNO was viewed as a Big Science project with a price tag beyond the capacity of any single federal institution to build and operate.

It is only now in 2005 that a comprehensive framework is under development at NRC, NSERC and the recently created Office of the National Science Advisor to the Prime Minister, for addressing the issue of Canada's involvement in Big Science projects within the overall context of Canadian science and technology. It is envisaged that this framework will deal with the key issues such as proposal development, evaluation, prioritization, decision-making, funding process, management, governance, and the importance of consideration of full lifecycle costs. It will attempt to address how Canada's investments in large-scale scientific projects can be optimized by the implementation of a coherent policy. It is intended that this framework document, after consultations with the scientific community, be brought forward to government for implementation by Dr. Arthur Carty, the National Science Advisor.