SNO-STR-91-17

Calibration - Aims and Implementation

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8-Dec-1990 revised 20-Feb-1991

1 Introduction

The purpose of this note is to review the work which is in progress on detector calibration, and to record recommendations of the calibration workshop held at Queen's on Feb 14, 1991.

The goal of the calibration system is to establish the relationship between energy deposited in the detector and the signal produced. An additional requirement is the monitoring of the performance of the detector as the experiment progresses using electronic pulse injection, optical pulsers and sources of high energy electrons. The optical pulser will be used to test the PMTs after installation and to measure the timing properties of the PMTs to allow measurements of time delays produced by PMT positioning uncertainty and to variations in the electronic channels. As the data from the calibration will be used to normalise simulations of detector performance one of the important decisions to be made is where the sources are to be placed within the detector so that the calculations can be checked. The complexity of the design of the source insertion methods will be greatly increased if it is decided that it is necessary to move the calibration sources to all points within the detector. The light water volume near to the acrylic vessel will also be used as part of the detector and consideration must be given to the placement of sources in this region. The use of optical concentrators on the PMTs gives rise to a cut off in the sensitivity as a function of photon angle relative to PMT axis and thus increases the necessity of measurements which explore the detector sensitivity as a function of source position. The calibration system requirements impinges on the parts of the detector being designed at present in two main ways 1) adequate provision must be made in the deck and acrylic vessel neck design for source insertion equipment and 2) the deck and PMT support structure must be able to accommodate penetrations which will permit the insertion of sources into the light water region.

2 Calibration Aims as Defined at the Workshop.

The evaluation of detector performance requires that checks be carried out on:

I Geometry of the PMT support structure and the acrylic vessel.

II Electronics

III Optical Sensitivity

IV Absolute energy calibration

V Light attenuation by the water

VI Neutron detection efficiency

VII Angular sensitivity

VIII Reconstruction accuracy

3 Optical Sensitivity Checks

The optical sensitivity of the SNO detector and the initial testing of the PMT systems will be carried out with a optical dispersing ball fed with pulses from a laser. At present we have a PRA nitrogen laser and have measured the properties of some fibre optic cables. The optical dispersion of the fibre optic cable (Belden 220001) which we had used for some of our work on PMT testing was found to have an optical dispersion of 7 ns for 30 m lengths of cable. This cable is a step index type and it was found that graded index cable (Belden 227201) had an improvement by a factor of three in dispersion. Tests of the fibres were made difficult by the instability of the high pressure nitrogen discharge source used. We have ordered a dye cell and dyes to shift a nitrogen laser output to 400 nm and will purchase optical fibre with better specs for the PMT test set up. For the optical sensitivity checks we are aiming at a optical pulse time resolution of better than 2 ns (FWHM).

4 Physical Methods

We have considered a number of methods of producing energetic electrons in the SNO detector: an electron LINAC; a circulating solution containing ^{8}Li produced by neutron activation in a site on the top of the detector ; a proton accelerator ($<$ 300 keV) to produce radiative proton capture on ^{11}B; direct α-capture on ^{7}Li and a variety of neutron capture sources. As the last two methods seem easier to implement than the others our work has been to make measurements required to check the feasibility of these and to simulate the source properties and the response of the SNO detector to them.

4.1 Neutron capture sources

It is proposed that a high energy data point be established by using the ^{3}He(n,γ) reaction which will produce γ rays of $>$ 21 MeV by fast neutron capture. The ^{3}He is black to thermal neutrons so only high energy ones contribute and the counting rate for this source will be low. A low energy source can be made by thermalising neutrons in a plastic shield impregnated with a capture element - at the present time we are considering Cl as the target material as it is easily found in a suitable form (in PVC for example) and because it will simulate the neutral current signal even though there is no NaCl in the detector. This signal will of course be that produced in the heavy water plus NaCl stage by inserting either a neutron source or a γ-ray source of $E_\gamma > 2.23$ MeV. Other elements such as Ni can of course be substituted for the Cl.

4.2 Direct α capture sources

A source of γ rays of 10.3 MeV can be made by allowing α particles from a radioactive source to impinge on ^7Li. A major background from this source will be neutrons produced by (α,n) reactions which will give rise to spurious high energy γ rays. This source might be straightforward to build for use in the light water part of the detector.

4.3 Detector response simulations

The neutron capture γ rays form a cascade which sum to fixed energy but the γ rays can interact with the physical structure of the source itself so that the output is in general multiple γ rays which in some cases do not add up to the full nuclear decay energy. For use in the heavy water region of the detector it will be necessary to prevent the neutrons from escaping from the source and thus require bulky shielding. This shield will produce a source which is physically large compared to the absorption length of the γ rays produced so that there is a high probability that some of the Cherencov light produced will scatter from or be absorbed by the source. In the case of the ^3He capture source there will be a significant number of γ rays from capture in other materials in the source and detector if the neutrons escape into the D_2O . These can randomly sum to the source energy and thus obscure the peak which the source was intended to produce. We are at present carrying out simulations of the detector response to the sources in order to evolve optimal designs.

5 Calibration Tactics

The response of the SNO detector to electron energy deposition must be initially established and then monitored throughout the course of the experiment. Parameters of importance are the number of photoelectrons (p.e.'s) produced in the Photomultiplier Tubes (PMT's) when electrons and gamma-rays deposit energy in the detector and the relative times at which electronic signals are produced in response to this energy deposition. The absolute relationship between number of p.e.'s and energy deposited will be measured by inserting sources which give rise to gamma rays of known energy and the performance of the detector will be routinely monitored using a light source and the electronic system checked with pulse inputs and by continuosly evaluating the detector output. Our philosophy is,when possible, to test the detector in a way which does not disable the data taking.

5.1 Electronics

Each channel will have a test input so that a charge pulse can be injected into any channel. This will be used for initial set up and to check if a fault in a malfunctioning channel is PMT or electronics related. ADC pedestals and TAC performance will be measured on a round robin basis by triggering all discriminator outputs on each board and the greater than N logic signal. All 128 boards in the system will be triggered in turn and test data sent to the normal data stream with negligible dead time fraction. This test data will be identified by a logic bit and will not interfere with normal data taking. To monitor the performance of individual PMT's we will scale their individual discriminator outputs to test noise rates. This is a much more sensitive test of PMT condition than the real data stream as the real probability of a tube being in any event exceeds the random probability by a factor of at least ten under normal operating conditions. The individual PMT rate in the real data stream will be measured and the spectra also accumulated and checked for constancy of PMT performance.

5.2 Optical pulser - relative calibration

Light diffusing systems fed by optical fibres from a pulsed laser will be used to check the sensitivity of the detector. It is probable that the system will contain significant radioactivity so that the diffusers will be lowered into the detector prior to use and an identifier bit set in the data stream to indicate this status. It is thus possible that the detection of solar neutrinos will be suspended during optical calibration but that neutrino burst events could still be observed. These tests could be performed once a week with inputs to give average numbers of p.e's per PMT in the range of <1 to 100 to check gain, detector threshhold efficiency and single p.e. response. These checks would take approximately one hour at 10 Hz pulsing, occupy one third of a 6250 bpi tape and produce negligible dead time for neutrino burst events but if performed once per week would reduce our counting time for solar neutrinos by 0.6%.

5.3 Absolute calibration

As the muon rate will be so slow at the depth of the SNO detector, it will not be possible to use stopped muon decay as a calibration point although we will use the few hundred per year expected to monitor the detector performance. Weak neutron sources will be used to produce high energy gamma rays from chlorine (8.6MeV)and deuterium (6.25MeV) - during the light water fill and pure heavy water phase of the experiment a chlorine (or other) compound will be contained in a hydrocarbon moderator shield with the neutron source placed at the centre. When the detector is NaCl loaded the shield will not be necessary. A second distinct calibration point will be established with a ^{3}He fast neutron capture source at E_γ of 22 MeV. It is anticipated that the 22 MeV measurement will be done once during the light water fill and once during the heavy water fill. During these times the Threshold for the detector will be so high that the detector will be dead for all events below 10MeV, in particular neutral current events. The ^{35}Cl(n,γ) and D(n,γ) sources will be easier to insert so that they could be used at more frequent intervals although in this case the detector would be dead for most neutrino induced events unless they occurred at a rate or energy high compared with the calibration events. It has been calculated that a ^{3}He source can be designed to give several thousand high energy gamma rays per day, while the other absolute calibration rates can easily be chosen to be 10-100 per second.

6 Work in Progress

The following work is in progress at Queen's:

I The measurement of the $^3He(n,\gamma)$ cross section.

II Simulations of the SNO detector response to calibration sources has been initiated.

III Optimal designs of the neutron capture sources to be carried out using the information from 1) and 2) and the neutron capture codes previously used in a preliminary simulation of the sources.

IV A study of optical diffusers, optical fibres and dye laser system for PMT testing and for future optical sensitivity checks of SNO.

V A conceptual design for mechanisms to lower and locate sources in the detector has been carried out and a study of a manipulator to move sources in the sensitive region of the detector is underway.

7 Discussion points and recommendations from the Workshop

The matters were considered at the workshop and it is important that feedback be received from the rest of the collaboration .

7.1 Deck and clean room design.

At a meeting with MONENCO design engineers it was proposed that the clean room/glove box be in the form of a cross the arms of which have radial monorails to carry winches for source insertion and places for parking sources when not in use. The arms would have glove box windows and air lock feed throughs to permit insertion and removal (to storage) of radioactive sources. The top of the room would be removeable to allow the fitting of systems for neutral current detector placement and for extra headroom for a remote manipulator.

7.2 Access to the light water region

It is proposed that two deck/PMT support structure penetrations be provided to allow the dropping of small optical and radioactive sources into the light water region. This should be arranged so that the sources could move on a vertical tangent to the outer surface of the vessel and sample the full range of radial displacements. More than one penetration of the deck was required because of the lack of spherical symmetry in recent vessel support proposals. Two penetrations will be required in the room above the deck - each will have to be provided with a sealed box and lowering mechanism. After the installation of PMT's and before the water filing measurements of the optical sensitivity of the reflector PMT combinations will be made by placing light sources in the region between the vessel and the PMT's.

7.3 Geometrical monitoring

In order to ensure accurate reconstruction of events and to ensure knowledge of the appropriate fiducial volume it is important that we know the position of the PMTs and the vessel. It is suggested that this be done using ultrasound so that motion of the structures be known as the detector changes from the empty to fill condition.

7.4 Transmission of calibration status to the data taking system

It will be requested that the data taking system record the status of the calibration system with the data. The request will be made on the form provided.