Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Calibration of the SNO+ experiment

To cite this article: J Maneira *et al* 2017 *J. Phys.: Conf. Ser.* **888** 012247

Calibration of the SNO+ experiment

J Maneira[1], E Falk[2], E Leming[2], S Peeters[2], on behalf of the SNO+ collaboration.

[1] Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa and Universidade de Lisboa, Faculdade de Ciências, Departamento de Física, Portugal
[2] University of Sussex, Brighton, United Kingdom

E-mail: maneira@lip.pt

Abstract. The main goal of the SNO+ experiment is to perform a low-background and high-isotope-mass search for neutrinoless double-beta decay, employing 780 tonnes of liquid scintillator loaded with tellurium, in its initial phase at 0.5% by mass for a total mass of 1330 kg of ^{130}Te. The SNO+ physics program includes also measurements of geo- and reactor neutrinos, supernova and solar neutrinos. Calibrations are an essential component of the SNO+ data-taking and analysis plan. The achievement of the physics goals requires both an extensive and regular calibration. This serves several goals: the measurement of several detector parameters, the validation of the simulation model and the constraint of systematic uncertainties on the reconstruction and particle identification algorithms.

SNO+ faces stringent radiopurity requirements which, in turn, largely determine the materials selection, sealing and overall design of both the sources and deployment systems. In fact, to avoid frequent access to the inner volume of the detector, several permanent optical calibration systems have been developed and installed outside that volume. At the same time, the calibration source internal deployment system was re-designed as a fully sealed system, with more stringent material selection, but following the same working principle as the system used in SNO. This poster described the overall SNO+ calibration strategy, discussed the several new and innovative sources, both optical and radioactive, and covered the developments on source deployment systems.

1. Introduction

1.1. From SNO to SNO+

The transformation of SNO [1] into SNO+ [2], from a water Cherenkov to a liquid scintillator experiment, is what allows for several new physics goals – the search for ^{130}Te neutrinoless double-beta decay, measurements of geo- and reactor neutrinos, supernova and low energy solar neutrinos. To achieve this, a set of detector changes are required, driven by the properties of the scintillator, linear alkyl-benzene (LAB) with 2 g/l of 2, 5 diphenyloxazole (PPO).

The central volume of 780 tonnes of liquid scintillator is enclosed in a 5 cm thick, 12 m diameter acrylic vessel (AV), immersed in a large cavity filled with ultra-pure water. The AV is surrounded by a geodesic structure supporting 9300 8-inch Hammamatsu photomultipliers coupled to light reflectors that increase the geometric coverage to about 54%. A new process and purification plant was built underground at SNOLAB in order to purify the scintillator at fill time, with capability for online purification as well. ^{130}Te will be loaded into the scintillator by means of a Te-butanediol complex [3]. A new purification system for the Tellurium itself will be constructed underground, in order to avoid build-up of cosmogenic activity. Due to the

LAB density of 0.86, the AV has positive buoyancy and has to be held-down by a new rope net [4] that is anchored to the detector cavity floor. A repair campaign was undertaken in order to recover several hundred PMTs that had failed during the lifetime of SNO. The high light yield from scintillation relative to Cherenkov radiation also drove several changes in the detector electronics [5], with new readout and trigger cards being able to handle higher currents and data rates. A new DAQ system, based on ORCA, was also developed for SNO+

1.2. Calibration requirements
The goal of the calibration is to provide multiple handles on each parameter used in describing and simulating the detector response. In particular, we need to understand performance of the detector for reconstruction of the energy, position, particle type and its uncertainties.

The three phases of the SNO+ experiment will give increased and complementary understanding. In the first phase, with the detector full of water, the response of the photomultiplier with the light reflectors and the electronics can be fully characterised. In the second phase, with the detector full of pure scintillator, the scintillator response can be characterised: optical absorption, re-emission and scattering. In the third phase, with the Te-loaded scintillator, the modified optical parameters and detector response will be characterised.

2. Calibration tools
2.1. External sources
A light-injection system based upon LEDs, lasers and optical fibres was designed in order to calibrate and monitor the photomultiplier array and the scintillator liquid. Permanently installed optical fibres, mounted in the PMT support structure, are used to inject light pulses in the range 375-510 nm from the externally located light sources, thus minimising the risk of ingress of radioactive contaminants. The system consists of three parts: One is dedicated to the calibration of the PMT timing and gains; this system relies on 92 sets of fibres providing wide-angle beams covering the entire set of PMTs [6]. The second part uses four pencil beams from a multi-wavelength laser source in order to measure scattering properties of the scintillator liquid [7]. The third and final system uses narrow beams from LEDs of two wavelengths at four injection points, in order to monitor optical attenuation.

2.2. Deployed sources
SNO+ uses a mixture of optical, gamma and neutron sources for calibration. Beta and alpha sources have been considered, but due to the restrictions on the encapsulations, the contamination risk is too great, and the information can be obtained using internal radioactive sources (see Section 2.4). The list of planned deployed calibration sources is shown in Table 1.

Table 1. Deployed calibration sources in SNO+.

Source	Tagged source?	Information
Laserball	Yes	Optical (quasi uniform diffuser)
Supernova source	Yes	Optical (fast pulsed generator for laserball)
Cherenkov	Yes	Optical (^{8}Li betas on acrylic)
^{16}N	Yes	Gamma (6.1 MeV)
^{60}Co	Yes	Gamma (1.1,1.3 MeV)
^{24}Na	Yes	Gamma (2.7, 1.3 MeV)
AmBe	Yes[1]	Neutrons, gamma (2.2, 4.4 MeV)
^{57}Co	No	Gamma (122 keV)
^{48}Sc	No	Gamma (1.0, 1.1, 1.3 MeV)

1: Using the coincidence between neutrons and gammas in the majority of the decays.

2.3. Deployment systems

Sources are introduced inside the AV through its top part, a 1.5 m wide chimney. They are moved inside it by means of ropes that pass through a set of pulleys in the source itself, that have one end attached close to the AV equator, and the other controlled from outside the detector. Another rope is secured directly on the source and takes up its weight. Finally, sources are connected to an umbilical cable that can bring optical fibers for the "laserball" source, tubes for the radioactive gas sources, and electrical wires for a small PMT, in the case of tagged sources.

The calibration source deployments systems consist of a glove box located on top of the AV, on top of which the mechanisms employed in moving and storing the ropes and umbilical – the side rope boxes, and the umbilical retrieval mechanism – can be mounted. In order to prevent the ingress of Radon in the detector, and the buildup of its daughters in the scintillator, all these systems have been constructed with very tight material quality and gas sealing requirements. For example, double o-rings are employed, and all motors in the mechanisms are sealed. In addition, when not in use, the sources themselves are stored in another sealed glove box.

2.4. Internal radioactive sources

Despite employing low radioactivity materials in the construction of the SNO+ detector, as well as significant efforts to purify the scintillator material and minimise its cosmogenic activation, a minimal level of radioactive contamination is unavoidable. A significant fraction of the irreducible radioactive contamination will derive from the ^{238}U and ^{232}Th chains, both naturally occurring radioisotopes present in the liquid scintillator. In the Tellurium-loaded phase we expect 7.6×10^5 and 2.8×10^4 decays/year for the ^{238}U and ^{232}Th respectively.

It is possible to use these background signals to aid in the calibration of the detector. In the first instance, a full spectrum fit can be applied to the recorded energy spectrum using the known pdfs of the daughter isotopes and floating the energy scale and offset. Such a technique can be used to calibrate the floated energy parameters for both alpha and beta decays. Additionally, some key, time-correlated, decays from these chains can be tagged for observation outside of the full data spectrum [2]. Such decays can be fitted for energy scale, offset and resolution independently of the full spectrum.

3. Outlook

A calibration program that is thorough, but does not compromise the radioactivity budget, is essential to keep the analysis systematics under control, and to deliver the physics goals. We expect that a large fraction of the upcoming commissioning phases of SNO+, in water and pure scintillator, to be dedicated to calibrations.

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