Initial Operation of SNO

The Sudbury Neutrino Observatory

Introduction:
- Detector specifics
- Physics goals
- Backgrounds
- Calibrations

The First 3 months (May 99 - present)

The Future

A.A. Hamian for the SNO collaboration
SUDBURY NEUTRINO OBSERVATORY COLLABORATION

A Collaboration of 11 institutions, ~80 physicists.

Canada:
- Queen’s University
- Guelph University
- Laurentian University
- University of British Columbia
- Center for Research in Particle Physics

USA:
- Lawrence Berkeley National Lab.
- University of Washington
- University of Pennsylvania
- Los Alamos National Lab.
- Brookhaven National Lab.

UK:
- University of Oxford
The Sudbury Neutrino Observatory: A Heavy Water Cerenkov Detector for Neutrinos

• Use deuterium (D$_2$O) as neutrino target.
• Sensitive to $\nu_e$, $\nu_\mu$, $\nu_\tau$.

Features:

• High cross section; 1kT D$_2$O = 10 kT H$_2$O equiv.
• Detect $\nu_e$ flux, $\Phi(\nu_e)$,

and $\nu_e + \nu_\mu + \nu_\tau$ flux, $\Phi(\nu_{\text{Tot}})$.
• Find ratio $R = \Phi(\nu_e)/\Phi(\nu_{\text{Tot}})$ → “smoking gun”?
• Plus other interesting physics...
Detecting Neutrinos with Deuterium

1) Charged Current (CC) \( \nu_e + d \rightarrow p + p + e^- \)

- Spectral shape (~20% resolution).
- Spectral distortion \( \rightarrow \) MSW effect.
- Angular distribution:
  \[ W(\theta_e) = 1 - \frac{1}{3} \cos \theta_e. \]

2) Neutral Current (NC) \( \nu_x + d \rightarrow p + n \)

- Sensitive to all \( \nu \) above 2.2 MeV.
- Total \( {}^8\text{B} \) solar \( \nu \) flux.
- \( \nu \) oscillations from CC/NC ratio.

3) Elastic Scattering (ES) \( \nu_x + e^- \rightarrow \nu_x + e^- \)

- Directional sensitivity.
SNO Physics Goals

Search for $\nu$ flavor change ($\nu$ oscillations):
ratio of CC to NC events.

Distortion of energy spectrum ($\nu$ oscillations; MSW):
CC $^8$B energy spectrum.

$^8$B total flux (test of solar models):
NC $^8$B measurement.

Time dependent solar $\nu$ flux:
regeneration in Earth (MSW);
7% orbital eccentricity;
solar magnetic field effects.

Search for Supernova $\nu$’s:
$\nu_x$.

Good signature for antineutrinos:
$^2$H + $\overline{\nu}_e$ → n + n + e$^+$
SNO: Detector Specifics

INCO’s Creighton Shaft #9 (Lively, ON)

- CN Tower (1015ft)
  (Space Needle: 605ft)

12m diameter acrylic vessel

9450 PMTs and reflectors

25m diam. cavity filled with H₂O

Urylon liner
Neutral Current Detection in SNO

Neutral current interaction: \( \nu_x + d \rightarrow p + n + \nu_x \)

Detect neutron either directly or by capture on deuterium or \(^{35}\text{Cl}\).

Detection Methods:

1) Capture on deuterium: \( n + d \rightarrow t + \gamma (6.26 \text{ MeV}) \)
   • Low cross section, 24% capture efficiency.

2) Capture on \(^{35}\text{Cl}\): \( n + ^{35}\text{Cl} \rightarrow ^{36}\text{Cl} + \gamma \text{ cascade (8.58 MeV)} \)
   • Add 2.5 Tonnes MgCl\(_2\) to D\(_2\)O.
   • 83% capture efficiency.
   • Subtract “no salt” signal from “salt” signal.

3) Add Neutral Current Detectors (T. Steiger’s talk follows)
   • \(^3\text{He}\) proportional counters: \( n + ^3\text{He} \rightarrow p + ^3\text{H} + 0.76 \text{ MeV} \)
   • Neutral current detector materials must be ultra-clean.
   • Distinct event-by-event neutron signature.
   • Always ready for supernovae.
SNO Anticipated Event Rates

Assuming flux-reduced Standard Solar Model: 1/3 SSM(BP98)

- **Charged current:** ~ 9 events/day
- **Neutral current:** ~ 3 events/day
- **Elastic scattering:** ~ 1 event/day

Typical solar ν event has only ~50 detected photons.

Reduction of backgrounds drives the design of the detector.
Suppression of Physics Backgrounds

**Cosmic Rays:** high energy events & spallation products.
   → Detector is located 2km (~6km w.e.) underground.

**Cavity wall radioactivity:** neutrons and high energy $\gamma$’s.
   → Light water shields active volume.

**Phototube radioactivity:**
   → Custom made Schott glass has 5 times lower Radioactivity than standard phototube glass.
   → Light water shield extends 2.5m between $\text{D}_2\text{O}$ and phototubes.

**$\text{D}_2\text{O}$ vessel:**
   → 12m diameter vessel constructed from very low radioactivity acrylic and glue.

**$\text{D}_2\text{O}$ and $\text{H}_2\text{O}:**
   → Uranium and Thorium are the greatest danger, and are found in mine dust.
   → Operate entire underground laboratory as full clean room.
   → Continually purify water with hyperfiltration and reverse osmosis techniques.
Rejection of Backgrounds

Energy:
→ Radioactive backgrounds are below energy regime where neutrinos interact.

Charge:
→ Phototube charge measurements allow identification of anomalous events.
   → In general, expect only 1 photon/PMT.

Reconstruction: Event position and direction.
→ Requires high precision phototube timing measurements.
   → Charge-dependent timing correction requires high precision charge measurements (<< 1 pe)
   → Elastic scattering reaction produces forward-scattered electron.
   → Charged current reaction produces angular distribution that falls as $1 - 1/3\cos\theta$. 
Detector Calibrations

- **Optical Calibration:** determine reflectivity and absorption of detector components.
  - Laser source: photons of 337-700 nm, 0-45 Hz, variable intensity, variable geometry, into $4\pi$..
  - LEDs: photons, 480 nm, 0-1 kHz, variable intensity, fixed & known geometry, into 30 deg. cone.
  - Sonoluminescence: fast photon source.

- **Energy Calibration:** determine energy scale (tubes/MeV) and resolution.
  - $^{16}\text{N}$: $\beta$, 6.1 MeV $\gamma$, energy near threshold, efficiency (triggered source), gain, angular response.
  - $^{3}\text{H}(p,\gamma)^{4}\text{He}$: 19.8 MeV $\gamma$, high energy effects (multiphotoelectron, charge response).

- **Reconstruction:** determine position and angular resolution, efficiency.
  - Laser.
  - $^{16}\text{N}$.

- **Neutron Detection Efficiency:** neutral current measurement.
  - $^{252}\text{Cf}$ fission neutron source.
  - $^{17}\text{N}$ triggered neutron source.
16N Ring
Laser Source, summed events.
SNO Turn-On

The past year has seen the detector brought up and water fill completed.

• April 98 - September 98: Air fill data
  → Ran calibration sources: laser, sono, $^{16}$N.
  → Tube timing looks good.
  → Saw ‘acrylic’ muons.
  → Saw flashing PMTs.

• September 98 - April 99: Partial fill data
  → Saw muons.
  → Radon studies.
  → $\gamma$’s & neutrons from rock.
  → Laser, sono runs.
  → High voltage breakdown (wet end).

• April 30, 99: Water fill complete

• May 1, 99: Detector turned on!
Contained Muon. # of hit tubes >> expected ν signal.
Through-going Muon.
First “Detector Full’ Experience
(May 99 - present)

- **HV breakdown**: only one connector seen to exhibit significant breakdown, plus a handful of breakdown events from other connectors.

- **Livetime**: has been ~65% for this period, dominated by 1 week shutdown for installation of radon barrier. Working towards 100% live within a month or so.

- **Optics/Timing**: first calibration runs with laser done.

- **Energy**: first energy calibration runs done using $^{16}\text{N}$. 
Detector Performance: The First 3 Months

Current channel thresholds < 0.5 pe;
Tube rates < 800Hz.
Overall trigger rate (all trigger types) ~ 10 - 15 Hz.

Very quiet!

Trigger rates by type:

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Threshold</th>
<th>Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulsed trigger</td>
<td>zero bias</td>
<td>5</td>
</tr>
<tr>
<td>100 ns coincidence</td>
<td>17 PMTs</td>
<td>3-5</td>
</tr>
<tr>
<td>20 ns coincidence</td>
<td>17 PMTs</td>
<td>3-5</td>
</tr>
<tr>
<td>Energy sum</td>
<td>~300 pe</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Prescaled (1:10000)</td>
<td>11 PMTs</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

With current thresholds, could run at sustained rate 25 times higher than current rate.

- >98% of all channels fully operational and taking data.
- Water already looks clean:
  - H₂O levels within factor of 10 of goal including Radon levels.
  - D₂O levels within factor of 10 of final goal.
- Rate of “flasher” PMTs dropped by ~ factor of 5 compared to air fill data.
The Future

• Two week mine shutdown started this week; detector is on, will give us longest uninterrupted data set so far.

• Production calibration data taking started (timing, optics, energy), continue after shutdown.

• New sources coming online over next few months.

• Work towards 100% livetime ASAP.

• Production physics data taking to start when radon levels are below final goal and detector is stable (thresholds optimized etc).

• Assess background levels, decide on neutral current detection method(s).
Summary and Conclusion

• Initial operation of the SNO detector has been very promising; quieter at turn-on than had been anticipated. SNO is in good shape!

• Poised to start physics programme in a month or so.

• SNO will soon provide:
  → Measurement of solar $\nu_e$ flux.
  → First high-resolution measurement of solar $\nu_e$ $^8$B spectrum.
  → First measurement of fraction of non-electron type neutrinos from the Sun.

  ... stay tuned!