Additional Physics Opportunities from the Near Accelerator: The Previous ORLaND Study

Frank Avignone
University of South Carolina and ORNL

Yuri Efremenko
University of Tennessee and ORNL

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Outline

- The Spallation-Neutron Source (SNS) at the Oak Ridge National Laboratory
- Neutrino Production at the SNS
- What would ORLaND have been?
- Neutrino Physics at the Cyclotron Facility Discussed at this Meeting
- Conclusions
Special section on:
Neutrino Physics at Spallation Neutron Sources
November 2003, Volume 29, Number 11

2497  Neutrino physics at spallation neutron sources
      F T Avignone III, L Chatterjee, Y V Efremenko and M Strayer

PAPERS

2499  Neutrino physics at meson factories and spallation neutron sources
      R L Burman and W C Louis

2513  Supernova neutrino–nucleus astrophysics
      A B Balantekin and G M Fuller

2523  Supernova science at spallation neutron sources
      W Raphael Hix, A Mezzacappa, O E Bronson Messer and S W Bruenn

2543  Science from detection of neutrinos from supernovae
      R N Boyd, G C McLaughlin, A St J Murphy and P F Smith

2569  Neutrino–nucleus reactions and nuclear structure
      E Kolbe, K Langanke, G Martínez-Pinedo and P Vogel

2597  Solar neutrinos, SNO and neutrino–deuteron reactions
      V Gudkov and K Kubodera

2615  Neutrino–nucleus cross-section measurements at intense, pulsed spallation sources
      F T Avignone III and Y V Efremenko

2629  Neutrino–electron scattering theory
      W J Marciano and Z Parsa

2647  Measurements of neutrino electron scattering
      R Inlay and G J VanDalen

2665  Searches for neutrino oscillations at intense spallation sources
      F T Avignone III and Yu Efremenko

Bibliographic codes
Spallation Neutron Source

- World’s most advanced accelerator-based pulsed-neutron source
- Neutron beams with more than 10 times the intensity of any existing pulsed neutron source
- 1-GeV, 1.4-MW proton LINAC with accumulator ring
- 60 Hz pulses with FWHM less than 400 nsec
- $1.5 \times 10^{14}$ protons per pulse delivered to the mercury target
SNS after completion
Neutrino Production at SNS

Neutrino production involves the reaction of a proton (\(p\)) with mercury (\(\text{Hg}\)) to produce positrons (\(e^+\)), electrons (\(e^-\)), and other particles. The reactions are as follows:

- Neutron capture by \(\text{Hg}\) with a probability of 99.6% results in the formation of a \(\text{e}^-\) and a positron (\(e^+\)).
- Neutron capture by \(\text{Hg}\) with a probability of 94% results in the formation of a \(\text{e}^-\) and a positron (\(e^+\)).

The diagram illustrates the various outcomes of these reactions, with probabilities 0.068 and 0.042, respectively.
Just the Hg target test facility was a total project of its own requiring several years to develop!
MEDICAL ISOTOPE PRODUCTION BY NEUTRONS AT THE APT

A study conducted in 1997 and 1998 surveyed the medical isotopes that could be produced by spallation neutrons at the (APT) Accelerator Production of Tritium Accelerator.

- P-32
- Sc-47
- Co-60
- Sr-89
- Y-90
- Mo-99
- Pd-103
- Rh-105
- Sn-117m
- I-125
- I-131
- Sm-153
- Re-186
- Re-188
- Ir-192
- Au-198
- Bi-213

R.W. Benjamin et al., WSRC-MS-97-0573 (WSRC)
Westinghouse Savannah River Company.
Positive Pion Production

MIT Proposal

K-production at 1.5 GeV

SNS
BEAM _ POWER = 1.4 MW
PROTON _ ENERGY = 1.0 _ GeV
PROTON _ CURRENT = 1.4 mA

PROTONS / PULSE on TARGET = 1.5 × 10^{14}
REP _ RATE = 60 Hz
PULSE _ DURATION ≈ 400 ns

\[ \pi^+ / PROTON = 0.068 \]

\[ R(\nu_e) = R(\bar{\nu}_\mu) = R(\nu_\mu) = 6.14 \times 10^{14} / \text{sec} \]

DISTANCE = 50 m, \Phi(\nu_e) = \Phi(\bar{\nu}_\mu) = 1.95 \times 10^6 \text{ cm}^{-2} \text{ s}^{-1}
SNS is a Unique Neutrino Source

- The SNS will produce $6.1 \times 10^{14}$ electron- and muon-neutrinos/sec.
- That makes it the most intense, pulsed, intermediate energy neutrino source in the world!
- The pulsed source would drastically reduce backgrounds from cosmic rays.
- It would also allow separation of $\mu_m$ from $\mu_m$ and $\mu_e$.
- Spectra of $\mu_m$, $\mu_m$ and $\mu_e$ well known.
- Intensity of $\mu_e$ severely suppressed: $\frac{\mu_e}{\mu_m} \approx 3.7 \times 10^{-4}$. 

![Muon flux graph](image)
NEUTRINO FLUX AND ENERGY SPECTRA

Normalized spectra

\[ N(\nu_e) = \frac{12}{W^4} E^2 (W - E) \]
\[ N(\nu_x) = \frac{6}{W^4} E^2 (W - \frac{2}{3} E) \]

\( W = 52.83 \text{ MeV} \)

\( \nu_x \) is monoenergetic at \(~30\) MeV

Neutrinos from SNS are in the same energy range as neutrinos from Supernovae!
Simulated Energy and Time Spectra of Neutrinos from SNS

Energy

Time

OAK RIDGE NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY
Neutrino Production at the SNS

Neutrinos result from decay of pions and muons produced in p+Hg collisions in the SNS target. Large, high Z target (10x40x65cm): essentially all $\pi, \mu$ stop before decay.

$\bar{\nu}_e$ production is strongly suppressed by capture of negative $\pi, \mu$ before decay.

$\text{Beam pulse width 600 ns}$
$\text{Rep rate 60 s}^{-1}$
Proposed neutrino bunker location is at the 90 degrees relative to the proton beam, at the north side of the target hall.
ORLaND Dream Bunker

- Large enough to accommodate one large 2 kt detector and 5-6 ~100 t detectors
- Designed to be located in a closest proximity to the SNS target
- Has 30 meters of water equivalent of overburden to reduce cosmic rays flux
- Has independent access tunnel
Reaction Cross sections for DAR neutrinos

\[
\begin{align*}
&\, e^- + e^- \rightarrow e^- + e^- & 0.0297 \times 10^{-41} \text{ cm}^2 \\
&\, e^- + e^- \rightarrow e^- + e^- \rightarrow e^- & 0.0050 \times 10^{-41} \text{ cm}^2 \\
&\, e^- + e^- \rightarrow e^- + e^- \rightarrow e^- & 0.0048 \times 10^{-41} \text{ cm}^2 \\
&\, e + ^{12}\text{C} \rightarrow ^{12}\text{N}_{gs} + e^- & 0.92 \times 10^{-41} \text{ cm}^2 \\
&\, e + ^{12}\text{C} \rightarrow ^{12}\text{C}^* + e^- & 0.45 \times 10^{-41} \text{ cm}^2 \\
&\, e + ^{12}\text{C} \rightarrow ^{12}\text{C}^* \rightarrow e + ^{12}\text{C}^* & 0.27 \times 10^{-41} \text{ cm}^2 \\
&\, e + ^{12}\text{C} \rightarrow ^{12}\text{C}^* & 0.55 \times 10^{-41} \text{ cm}^2 \\
&\, p + n \rightarrow n + p & 7.2 \times 10^{-41} \text{ cm}^2
\end{align*}
\]

A 2 kt detector at 50 meters from target would have ~ 300 neutrino interactions per day!!!
ORLaND Large Detector
Two options

Dilute Scintillator Detector
- Neutrino Oscillations
- Neutrino-Electron Scattering
- Measurement of electro-weak angle
- Neutrino magnetic moment
- Neutrino-Carbon interactions

Water-Cherenkov Detector
- $^3$-d disintegration (calibration of SNO)
- $^1$-O interaction (SK and SN)
- $^3$-e scattering (calibration of SK)
- Neutrino Oscillations?
- Search for strangeness in nuclei?
Search for neutrino oscillations
for $\nu_e$ appearance mode

If LSND result confirmed – $r$ measurements of mixing parameters, with better separation between $\nu_x \nu_x \nu_x e$ and $\nu_y \nu_y \nu_y e$ mode.

If LSND result is not confirmed, then explore mixing parameters in the regions of interest for Big Bang Nucleosynthesis and Supernovae dynamics.
- e- Scattering

Measurement of $\sin^2 \theta_W$

$$R = \frac{s(\W m e)}{s(\W e e) + s(\W m e)}$$

Integrate over $T$:

$$R = \frac{3/4 - 3 \sin^2 \theta_W + 4 (\sin^2 \theta_W)^2}{1 + 2 \sin^2 \theta_W + 8 (\sin^2 \theta_W)^2}$$

W. Marciano et al.

Neutrino magnetic moment
An accurate measurement of this interference, and another stringent test of the Standard Model
$^{16}\text{O}(e, e^-)^{16}\text{F}$

LARGE CERENKOV DETECTOR
Fiducial vol. 1472 m$^3$ of water $N \sim 4.9 \times 10^{31}^{16}\text{O}$

Event rates
For 30% efficiency $\sim 12300$ events per year

Haxton, PRD 36, 2283 (1987)
$\langle \sigma \rangle = 8.84 \times 10^{-42}$ cm$^2$ DAR spectrum
\[ {^{16}\text{O}}(\gamma, \gamma' n)^{15}\text{O} \]

Use Large Size Cerenkov Detector

\[ N \sim 4.9 \times 10^{31} \text{ of } ^{16}\text{O} \]

Event rates:

For \[ ^{16}\text{O}(\gamma, \gamma' n)^{15}\text{O} \] \( R \sim 4200 \text{ y}^{-1} \)

For \[ ^{16}\text{O}(\gamma, \gamma' (n \text{ or } p))^ {15}\text{X} \] \( R \sim 21500 \text{ y}^{-1} \)

Can some compound of Gd be added to boost neutron detection?


\(<\gamma> = 9.1 \times 10^{-43} \text{ cm}^2 \text{ DAR spectrum}\)
Calibrating the Sun

\[ p + p \rightarrow d + e^+ + {\bar{\nu}}_e \] (99.75% solar energy)

Can be deduced from:

\[ {\bar{\nu}}_e + d \rightarrow p + p + e^- \]

Theory: Kubodera + Nozawa \( s = 52 \times 10^{-42} \text{ cm}^2 \)

Experiment: Lampf E31 \( s = (53 \pm 18) \times 10^{-42} \text{ cm}^2 (34\%) \)

A Measurement to a few % needed

Calibrating the SNO

CC:

\[ {\bar{\nu}}_e + d = p + p + e^- \]

NC:

\[ x + d = p + n \]
SNOINO

30 ton Cerenkov Detector
($D_2O$ is expensive, 30 ton can be borrowed)
30 tons of $D_2O$ is contained in an acrylic cylinder inside a large water Cerenkov detector

Event rate
$R(\text{detected}) \sim 2800 \text{ y}^{-1} 30 \text{ ton}^{-1}$
$<\Delta R> = 5.4 \times 10^{-41} \text{ cm}^2$ DAR spectrum

Neutrino nucleus cross sections at ORLaND

Large detector C, d, O
Smaller detectors: Cl, Fe, I, Pb,..
Concept of segmented detector

Metal or other solid targets

$^{51}\text{V}, ^{27}\text{Al}, ^{9}\text{Be}, ^{11}\text{B}, ^{52}\text{Cr},$  
$^{56}\text{Fe}, ^{59}\text{Co}, ^{209}\text{Bi}, ^{181}\text{Ta}$

Active detector – gas tubes
Energy measurement - by range

Expected resolution for tubes 10mm and 0.5 mm at 30 MeV is $\sim 25\%$
Detector size for 20 t fiducial mass is $- 3.0 \cdot 2.3 \cdot 2.3$
Expected event rate (for iron target) $\sim 16$/day:
Good separation from neutrons
What was the status when it ended?

- Engineering feasibility study was completed
- Science workshops were held; a complete proposal written
- FY 2001 ORNL program development funds $1000k
  - FY2000 ORNL PD funds $400k
  - Prior years- ORAU/universities ~$200k
- Coordination with SNS was established
  - A Site was selected
  - Basic schedule requirements established
- Review committee met in 2000
- Letters to solicit formation of experimental collaborations
- LDC formed - 20+ universities, NSF MRE
- Other collaborations formed
- Pre-CDR engineering continued into 2001
- Is ORLaNd is still Long Range Plan?
The bad news!
The ORLAND facility will probably never be built!
The good news!!
The facility described by Conrad and Shaevitz (arXiv:0912.4079) could probably do all that ORLAND could do and also the proposed CP-violation search
INTEGRATED - BEAM _ POWER = 1.0MW
PROTON _ ENERGY = 2.0 _ GeV
PROTON _ CURRENT / PULSE = 2.5mA
PROTONS / onTARGET / year = 9.8 \times 10^{22}
REP _ RATE = 2000Hz
PULSE _ DURATION \approx 100\mu s
\pi^+ / PROTON = 0.145
R(\nu_e) = R(\bar{\nu}_\mu) = R(\nu_\mu) = 4.521 \times 10^{14} / sec
DISTANCE = 1km, \Phi(\nu_e) = \Phi(\nu_\mu) = \Phi(\bar{\nu}_\mu) = 3.6 \times 10^3 \text{ cm}^{-2} \text{s}^{-1}
CONCLUSIONS

- The SNS could have been used as a unique intermediate energy neutrino source
- The ORLaND collaboration proposed an underground neutrino facility adjacent the SNS target hall (DOE delayed it indefinitely)
- This facility would have been large enough to host one large 2 kt detector and several smaller 50-100 t. detectors
- Such a facility could have provided a unique facility for a broad neutrino research program
- The facility discussed by Conrad and Shaevitz could provide the CP-violation search and everything that was proposed at ORLAND
<table>
<thead>
<tr>
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</tr>
</thead>
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This report has 75 pages of neutrino physics that can be done at such facilities. It was written by FTA and 27 authors following a 4-day workshop at ORNL in 2000.
YOU CAN DOWNLOAD THIS COMPLETE REPORT FROM THE WEB SITE BELOW.

http://www.orau.org/orland/white-paper.pdf