Indiana University Cyclotron Facility Low Energy Neutron Source: Simulation and Measurement of Neutronic Performance

Abstract

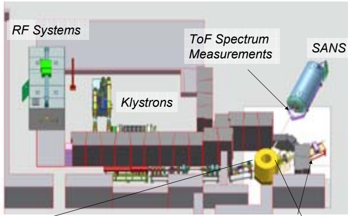
The IUCF LENS Facility is a long pulse accelerator based neutron source in development. The project goal is to produce a high brilliance of long (>10 Å) wavelength neutrons in support of basic research, instrument development, and education in the neutron sciences.

MCNP simulations have been successfully and positively benchmarked against neutron flux measurements, spectrum measurements, and emission time distribution measurements.

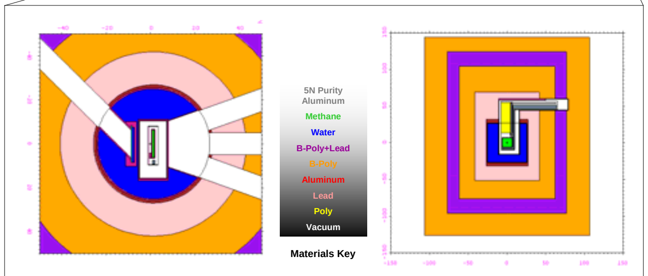
It is found that detailed information on the emission time distribution is required to properly deconvolve the long pulse influence on ToF neutron spectroscopy measurements.

Large gains in long wavelength flux have been achieved by cooling the methane to ~4K.

Schematic of the LENS Facility



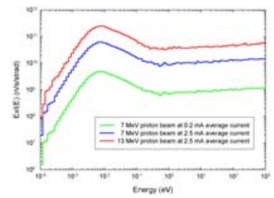
MCNP LENS model of the constructed configuration



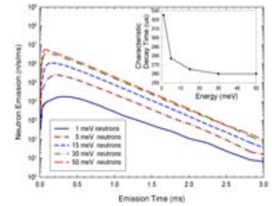
Features:
- Variable Long Pulse mode of operation
  - (from 0.05 to 1 ms proton pulse width)
- Production based on $^9Be(p,xn)$ reactions
  - Presently 7 MeV, 20 μA average current
  - 7 MeV, 400 μA by summer 2007
  - 13 MeV, 2.5 mA planned for the future

- Primary thermalization in 25 cm light water reflector
- 1 cm thick cryogenic methane tightly coupled to reflector
  - Cold Neutron Production by thermal neutrons only
  - 4K Methane standard operating temperature
  - 4 Beam lines will view moderator in final configuration
  - SANS, Radiography, Spin Echo, Moderator Studies planned

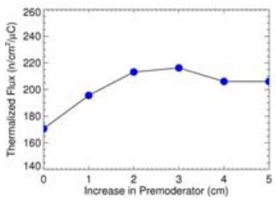
Simulation Results



Simulated Optimal Neutron Spectrum from 22K Methane Moderator at different stages of accelerator development

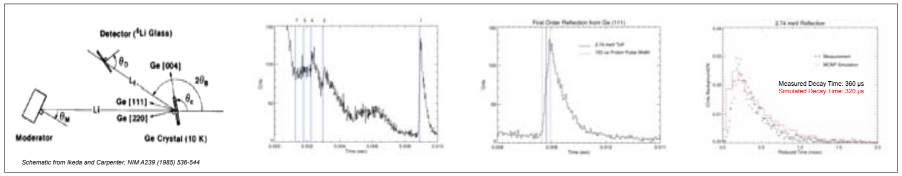


Simulated Emission Time Distribution from 22K Methane Moderator. For E > 5 meV pulse shape is dominated by the H_2O reflector



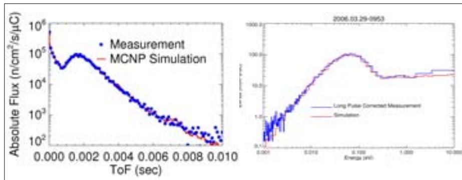
Simulation of improvements in premoderator in constructed geometry. A 3-4 cm thick layer of hydrogenous premoderator material placed in the vacuum gap between the target and moderator should enhance the thermalized flux coupling to the cold source by 25%.

Emission Time Distribution Measurement



- Use of time focused crystal spectrometer [NIM 85 (1970) 163-171, NIM A239 (1985) 536-544]
- The emission time distribution is measured via reflections from the (111) plane in mosaic crystal germanium
- Moderator is 4K solid methane and proton pulse width is 150 μs
- Orders 1,3, & 4 are observed
- 1st order reflection compares favorably to 22K Methane simulation of emission time convolved with 150 μs square pulse

Neutronics Benchmarks – Reflector Thermal Flux Leakage & Foil Activation

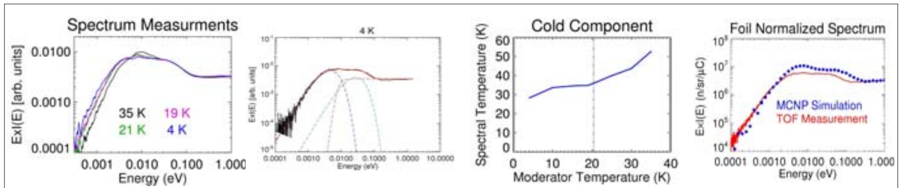


Location	Measurement Method	Flux (n/cm²/uC)	*As Built* Geometry Sim	$\left(\frac{Meas}{Sim}\right)$
10 cm in TMR	Gold Foil Poly Moderator	$3.01 \pm .78 \times 10^6$	3.79×10^6	0.79
10 cm in TMR	Gold Foil Empty Moderator	$2.65 \pm .75 \times 10^6$	3.58×10^6	0.74
140 cm	Indium Foil Poly Moderator	$3.36 \pm .35 \times 10^3$	4.37×10^3	0.77

- Measurement of thermal neutron leakage with calibrated detector
- Measurement at 20 degrees to moderator normal, 570 cm from moderator surface
- Empty moderator Vessel (water moderated neutrons)
- Spectrum accurately reproduced in MCNP calculation
- Successful benchmark of primary target-reflector neutronic modeling

Activation Foil measurements:
- In core TMR Flux for ambient temperature moderators
- Measured on high Resolution Ge(Li) Detector

Moderator Spectra vs. Moderator Temperature

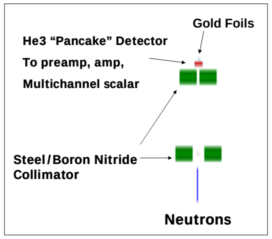


4K moderator, without long pulse correction

- Fit by non-linear least squares to 2 Maxwellians, a warm and cold component, and a joining function reflecting 1/E behavior at high energy
- Gives cold component spectral temperature

$$E\phi(E) = N_{cold}\left(\frac{E}{E_{cold}}\right)^2 e^{-\frac{E}{E_{cold}}} + N_{warm}\left(\frac{E}{E_{warm}}\right)^2 e^{-\frac{E}{E_{warm}}} + \frac{E^{-\alpha}}{1+e^{\frac{a}{\sqrt{E+b}}}}$$

The Long Pulse Correction for TOF Neutron Spectroscopy (simulated results)



In a ToF Spectroscopy experiment, one typically presumes one-to-one correspondence of energy and time.

However, in a long pulse coupled moderator, all neutrons do **not** have approximately the same starting time, which leads to a correction when converting ToF to energy.

$$E_{tof}(t) = \frac{1}{2}m\left(\frac{L}{t}\right)^2 \rightarrow$$

$$< E_{tof}(t) >= \frac{1}{2}m\left(\frac{L}{t - t_{offset}(E)}\right)^2$$

Where E_{tof} is apparent neutron energy from ToF, t is the ToF, and $t_{offset}(E)$ is the energy dependent mean offset in the ToF due to long emission times

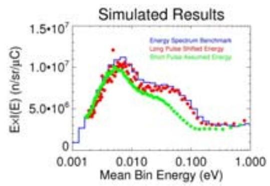
We **simulate** the ToF spectroscopy experiment at 5.7 m, 20 degrees to the moderator normal in MCNP for a 22K methane moderator.

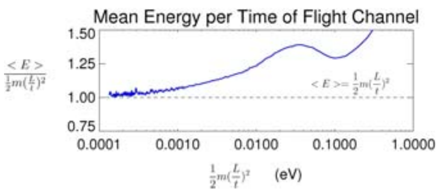
The **energy distribution** at the detector (**blue line, figure top right**) is determined as the baseline. A simulated ToF spectrum in a ^3He detector is also generated.

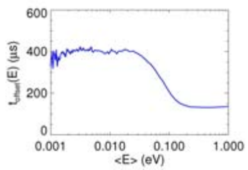
For short neutron pulse relative to the ToF, one can assume <E> ~ $\frac{1}{2}m\left(\frac{L}{t}\right)^2$, which gives the "**short pulse**" energy distribution (**green dots, figure top right**). However, Monte Carlo calculation of <E> shows that this assumption breaks down for a coupled moderator. (**see figure, center right**).

There is an **energy dependent timing offset** (**see figure, bottom right**) due to the use of long proton pulse and coupled moderator. The offset is ~100 us for epithermal neutrons due to the broadening from the long proton pulse and ~400 us for thermal and long wavelength neutrons produced in the reflector and coupled moderator.

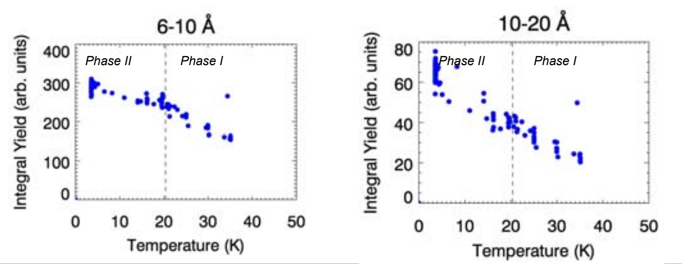
Using the mean energy per ToF bin calculated in Monte Carlo shifts the energy and mean detector efficiency, giving the **Long Pulse Shifted Energy result** (**Red dots, figure top right**), which is in agreement with the expected energy distribution.







Increase in long wavelength flux with low T moderator



Cooling the moderator increases the long wavelength neutron flux considerably. However, the phase I-II transition in methane (indicated by dashed line) appears to be influencing the 6-10 Angstrom behavior.

Future experiments will focus on probing the influence of the low energy rotational modes and the influence of the methane spin state by means of dopants.

~10% Argon dopants can suppress the phase I-II transition, and ~2% oxygen can increase the rate of spin relaxation in the methane

Conclusions

- An accurate model of the constructed configuration for future design work has been benchmarked by foil activation, emission time, and ToF Spectroscopy.
- Large increase in long wavelength flux is possible by cooling the methane as low as possible.
- ToF Spectroscopy results require the use of mean energy per ToF bin to accurately translate to energy dependent flux.

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