Development of a sub-thermal neutron source

Y. Danon, E. Liu, E. Blain, Dominik Fritz

Rensselaer Polytechnic Institute, Troy, NY, 12180

D. Barry, B. Epping, M. Rapp

Naval Nuclear Laboratory, P.O. Box 1072, Schenectady, New York 12301-1072

NCSP Meeting, Amarillo, TX , March 26-27, 2019

Rensselaer NCSP NUCLEAR CRITICALITY SAFETY PROGRAM NAVAL NUCLEAR LABORATORY linac The Gaerttner LINAC Center

RPI Nuclear Data Group

RPI Faculty
Prof. Yaron Danon - LINAC Director
Prof. Li Liu

NNL
Dr. Tim Trumbull
Dr. Devin Barry
Dr. Michael Rapp
Mr. Brian Epping
Dr. Adam Daskalakis

Technical Staff
Dr. Ezekiel Blain
Peter Brand
Michael A. Bretti
Matt Gray
Azeddine Kerdoun
Larry Krusieski

Graduate Students
Amanda Youmans
Adam Ney
Dominik Fritz
Jesse Brown
Kumar Mohindroo
Sukhjinder Singh
Jin Choun

Undergraduate students
Alexandra Laing

BOLD= researcher or graduate students supported by NCSP

Motivation

- The transport equation is a neutron balance equation, it includes a scattering kernel describing both slowing-down and thermal interactions (including up scattering)

$$\frac{1}{v}\frac{\delta\varphi}{\delta t} + \hat{\Omega}\nabla\varphi + \Sigma_t(\vec{r},E)\varphi(\vec{r},E,\hat{\Omega},t) = \int_{4\pi} d\hat{\Omega}' \int_0^\infty dE' \Sigma_s(E' \to E, \hat{\Omega}' \to \hat{\Omega})\varphi(\vec{r},E',\hat{\Omega}',t) + s(\vec{r},E,\hat{\Omega},t)$$

- For thermal systems the scattering kernel is important at low energies.

$$\sigma(E \to E', \Omega) = \frac{\sigma_b}{2kT}\sqrt{\frac{E'}{E}}e^{-\beta/2}S(\alpha,\beta)$$

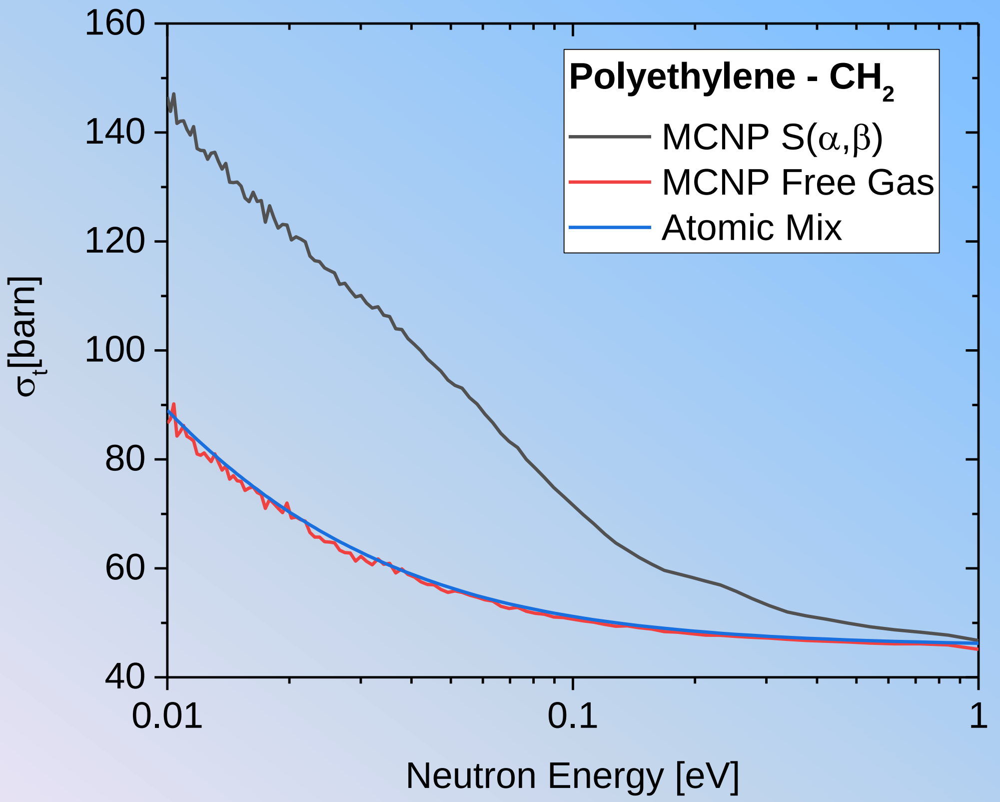
$$\beta = \frac{E'-E}{kT} \qquad \alpha = \frac{E'+E-2\mu\sqrt{EE'}}{AkT}$$

- The integral of the scattering kernel is the total-scattering cross section

$$\sigma_s(E) = \iint \sigma(E \to E', \Omega)\, dE'\, d\,\Omega$$

Rensselaer NCSP NUCLEAR CRITICALITY SAFETY PROGRAM NAVAL NUCLEAR LABORATORY linac The Gaerttner LINAC Center

Motivation – Total scattering cross section



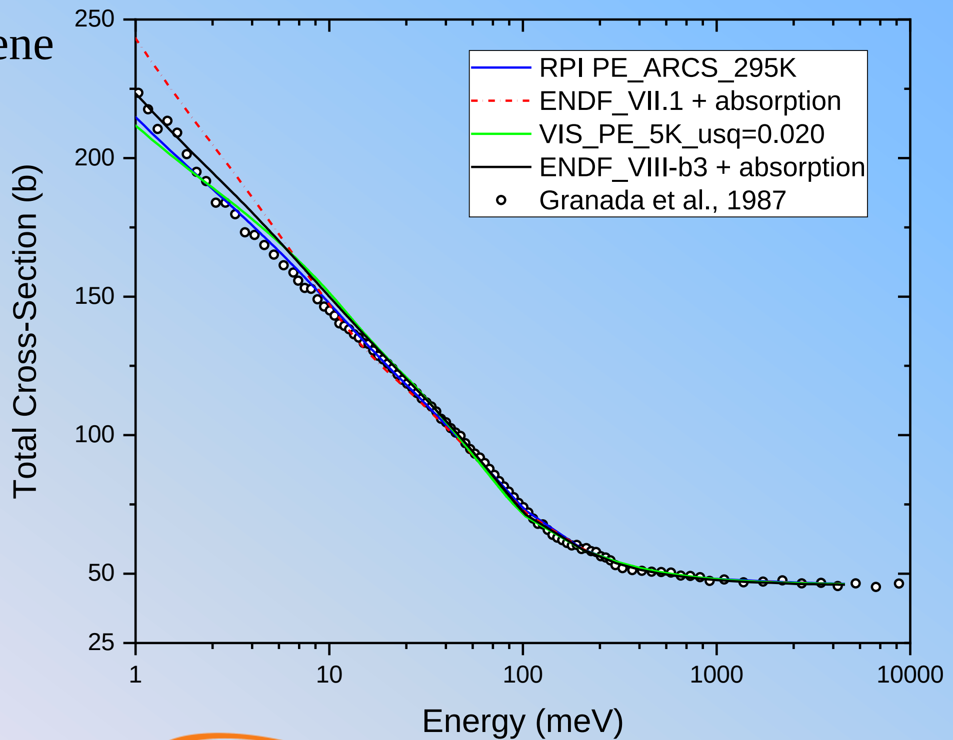
- Accurate scattering cross section is important for determination of criticality.
- The scattering $\sigma_s(E)$ (and thus $\sigma_t(E)$) depend on the model used for treating thermal scattering.
- Atomic mix (or free gas model) is not accurate in the thermal region.
- The difference between free gas and S(α,β) scattering treatment is greater for hydrogenous moderators.
- The total scattering cross section is calculated from theory and validated against experiments.

Rensselaer NCSP NUCLEAR CRITICALITY SAFETY PROGRAM NAVAL NUCLEAR LABORATORY linac The Gaerttner LINAC Center

Thermal total cross section measurements

- It is hard to measure the total scattering cross section, but easier to measure the total cross section. For moderators this is the dominant cross section.
- Need temperature dependent measurements (phase-II).
- Very few measurements exist for materials other than water.

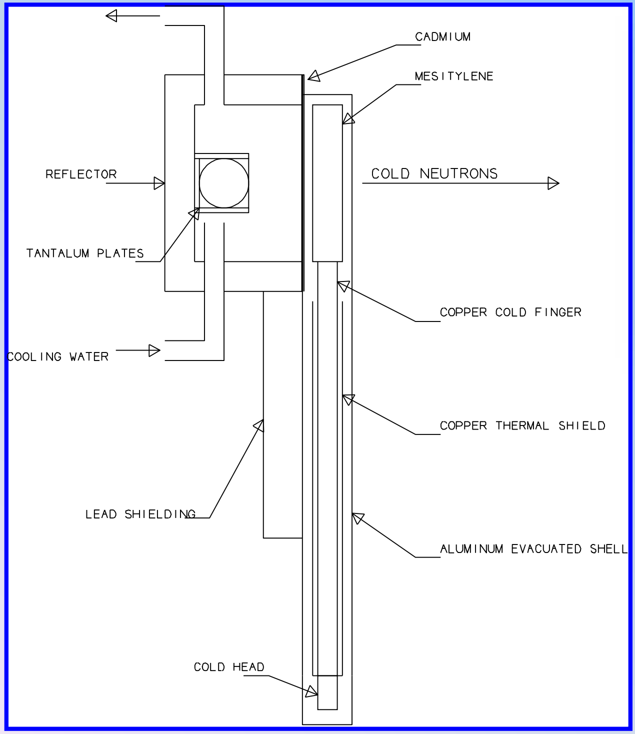
Example: Polyethylene

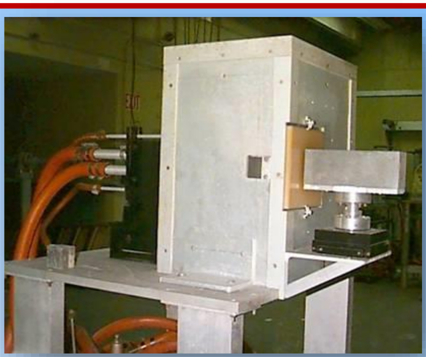


Current and future capabilities

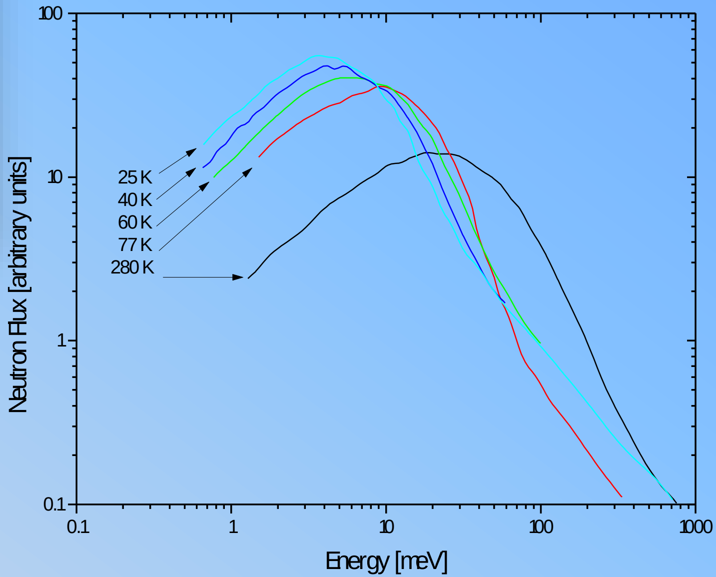
- Current thermal target (without cold moderator) was designed and built in 1993.
  - Was designed to be coupled to a Mesitylane cold moderator
  - Can measure total cross sections accurately down to 5-8 meV.
- Redesign and build the cold moderator

Y. Danon, R. C. Block and R. E. Slovacek, “Design and Construction of a Thermal Neutron Target for the RPI LINAC”, *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 352, no. 3, pp. 596-604, 1995





Measured for Mesitylene (C_9H_{12})



Y. Danon PhD Thesis, RPI, 1993

Rensselaer NCSP NUCLEAR CRITICALITY SAFETY PROGRAM NAVAL NUCLEAR LABORATORY linac The Gaerttner LINAC Center

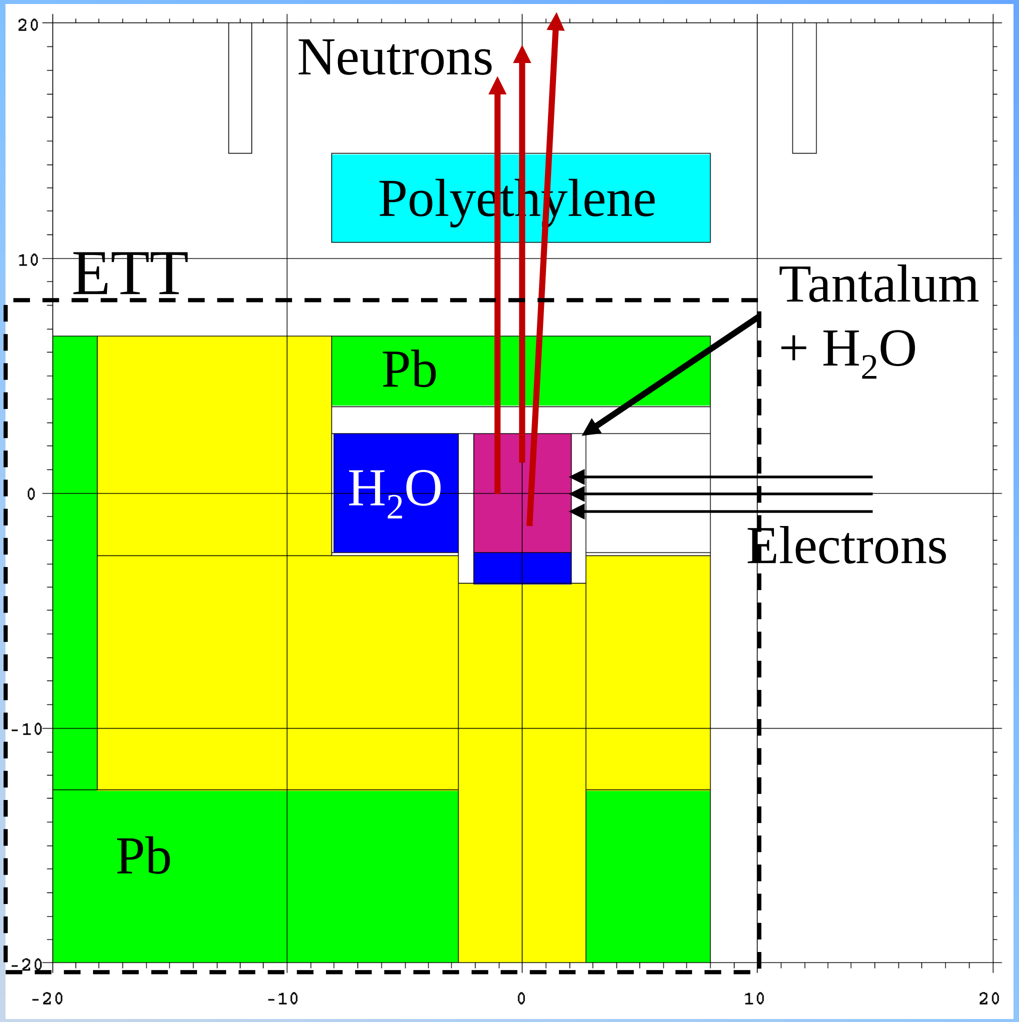
Cold moderator - new design

- The goal is to increase the neutron flux below 5 meV and allow transmission measurements down to about 0.5 meV.
- Best (neutron yield) cold moderator materials include H_2, CH_4, and C_9H_{12}
  - All are hazardous (explosive) materials
- Consider using polyethylene or other plastics.
- Optimize coupling to current thermal target as an add-on moderator:
  - Use current configuration to measure down to ~ 5 meV
  - Use the add-on moderator below 5 meV.
  - Better: use the cold moderator for the whole energy range.

Rensselaer NCSP NUCLEAR CRITICALITY SAFETY PROGRAM NAVAL NUCLEAR LABORATORY linac The Gaerttner LINAC Center

Cold moderator design

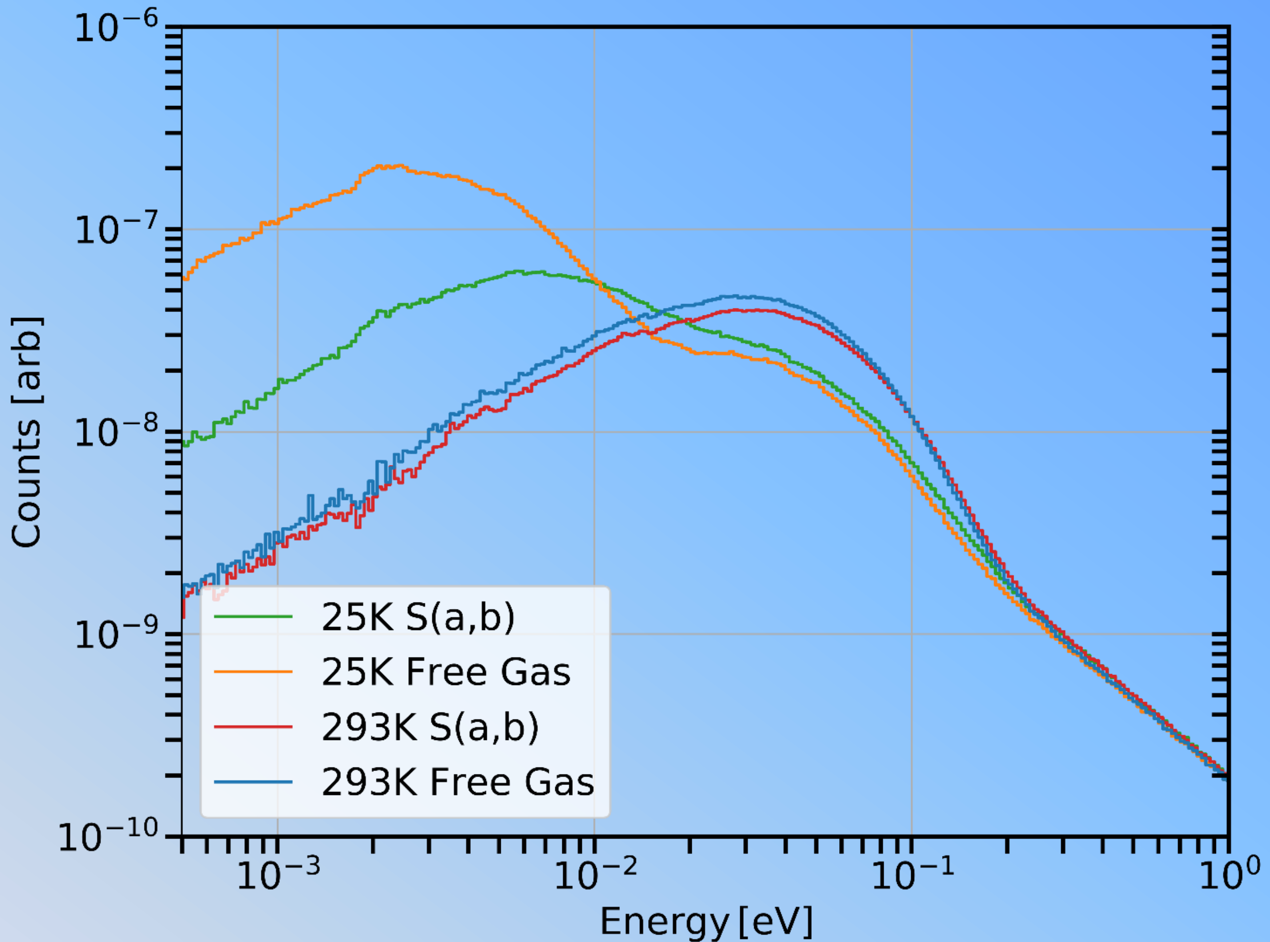
- Use the "Enhanced Thermal Target (ETT)" and add a cold moderator
- Add a polyethylene moderator that can be cooled to 25K
- Use MCNP to find the moderator optimal thickness and the flux gain between 1-5 meV



Rensselaer NCSP NUCLEAR CRITICALITY SAFETY PROGRAM NAVAL NUCLEAR LABORATORY linac The Gaerttner LINAC Center

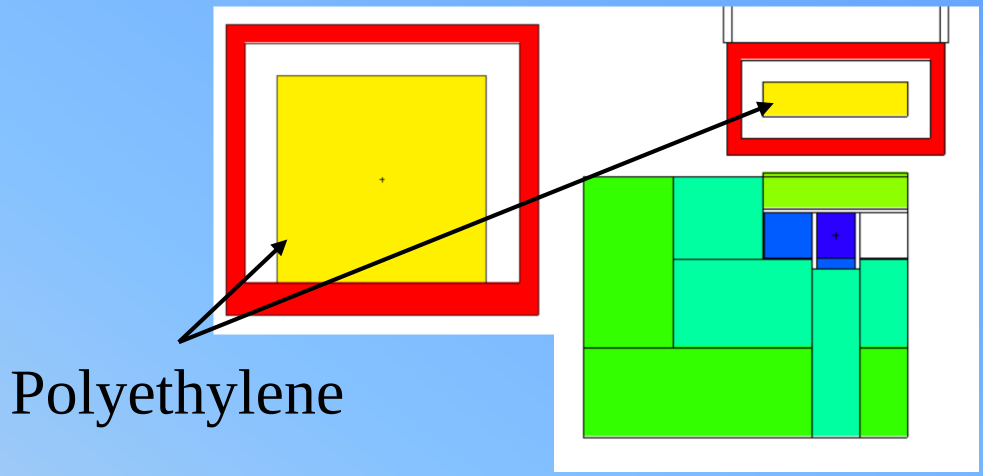
Emitted neutron spectrum

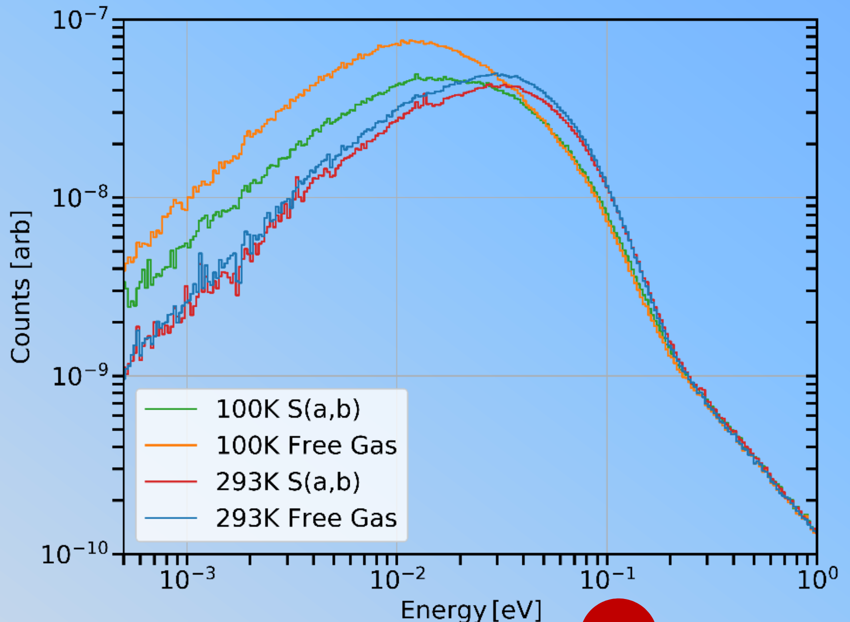
- Cooling provides a flux gain below 5 meV
- Using free gas or S(α,β) for the poly moderator gives very different results
- At 1 meV free gas gain is ~50 while using S(α,β) gives ~7.2
- The S(α,β) should be more accurate but could not find experimental data to validate



Simple experiment

- Qualify the neutronic design calculations
- Cool an thermally isolated polyethylene plate using liquid nitrogen to 100K
- Compare the measured spectra with simulation





Conclusions

- Use current Enhanced Thermal Target (ETT) with the addition of a cold polyethylene moderator.

- Gain calculations with S(α,β) show a gain of x7.2 near 1 meV, free-gas gives a factor x50
  - Experimental data are not available for qualifying the calculations
  - Will measure leakage from room temperature and about 100K polyethylene moderator

- Thermal (heat transfer) design in progress