



Union of Compact Accelerator-driven Neutron Sources I-II

Moderators at LENS: Performance and Development
Research

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Abstract

The Target/Moderator/Reflector (TMR) system at the Low Energy Neutron Source has a flexible design in order to accommodate research into the performance of neutron moderators in general and small-scale accelerator-driven neutron sources in particular. Since producing its first cold neutron beam in April of 2005, the LENS TMR has undergone a number of design changes, and has been used to investigate a number of novel moderator ideas. In this paper we summarize the impact of some of these design changes on moderator performance as well as some recent results from a novel inhomogeneous moderator design that combines traditional moderating material (polyethylene) with single crystals of silicon.

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1. Introduction

The Low Energy Neutron Source (LENS) was constructed as a prototype for a small-scale Accelerator-Driven Neutron Source, and an important element of the research program envisaged for this facility was the development of improved neutron moderators [1-2]. Important design features for this research program are the flexible operating parameters of the source (incident proton energy of 7 or 13 MeV, pulse widths ranging from about 10 to 800 μ sec, and operating frequencies ranging from 45 Hz to 10 Hz or even lower), and the care taken in selecting construction materials near the source in order to minimize exposure to workers involved in modifying the source. We have formed a collaborative research effort to exploit these features of the LENS source in an on-going program of moderator research that involves several institutions and a number of novel moderator concepts.

The LENS facility design has undergone significant changes as we have gained operating experience and installed upgrades. In this paper we document the changes in source performance associated with some of these changes, demonstrate some recent improvements in our experimental capabilities, and describe some recent results to come out of our experimental program on moderator development.

2. Evolution of the LENS Source Characteristics

Initially the LENS source was operated at a proton energy of 7 MeV, since that was the energy of the legacy accelerator upon which the facility was constructed [1]. The cold source was designed using the kernels extant in 2004 for solid methane (phase I at 22K) [2,3], and on that basis it was decided that the optimal thickness of the methane was 1 cm, given the soft spectrum feeding the moderator (from the water reflector). However, this cryogenic moderator was placed inside a vacuum vessel that was large enough to accommodate moderators up to 10 cm in thickness in anticipation of the needs of the future moderator research program even though this over-sized vacuum space reduced the effective coupling of the moderator. Initial measurements and simulations showed spectra exhibiting departures from the usual $1/E$ behavior in the slowing-down portion of the spectrum (a non-zero leakage exponent), suggesting that the neutrons were being under moderated [2,4]. Additionally, subsequent simulations with a methane kernel suitable for methane II at 4.2 K suggest that the optimal thickness for methane at this temperature is between 1 and 2 cm [5,6]. On this basis, it was decided to add several polyethylene elements inside the vacuum can in order to increase the reflector volume near the moderator. At this time, two 5mm-thick sheets of polyethylene were attached to the thermal radiation shield (typically held below 70 K) behind the moderator to mimic a thicker methane moderator (while not increasing the thermal load on the moderator itself nor increasing the methane inventory). After these changes, the moderator spectrum does exhibit the expected $1/E$ behavior, and can now be modeled with a three-Maxwellian form as demonstrated in figure 1. In this fit, the coldest Maxwellian has a temperature of 19 K and we make use of a switch function in which the non-Maxwellian portion of the spectrum is fitted to $E\phi(E) = (E/E_0)^\alpha (a+1)/(a+ \exp(E_c/E)^{1/2})$. The fit is quite satisfactory except in the region near 100-200 meV, where the emission time delay varies (complicating the conversion from measured time-of-flight to energy [2]), and the switch function is known to provide an incomplete description of the physics [7].

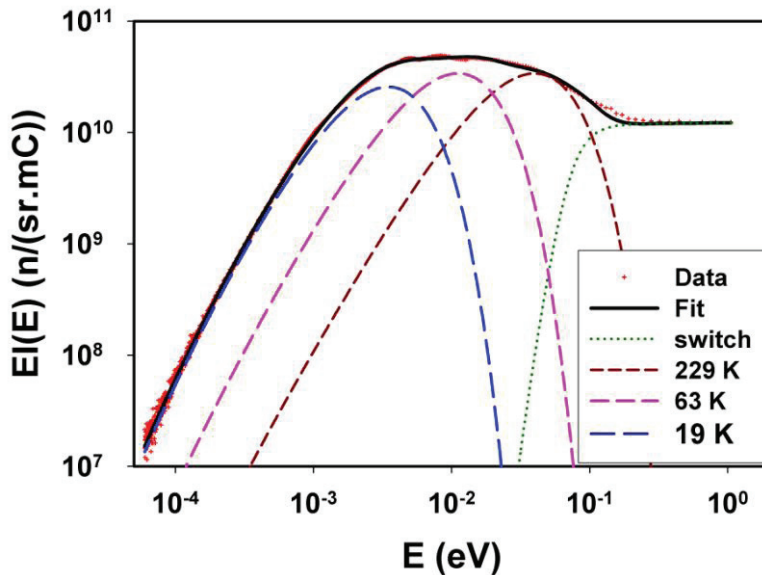


Fig. 1 Lethargy plot of the spectrum from the 1 cm LENS methane moderator (at 6K) after the inclusion of extra polyethylene to increase the coupling to the moderator (thereby eliminating leakage that had previously been evident in the slowing-down regime near 1eV and above).

In addition to the change from 7 to 13 MeV, the LENS target underwent a significant change in order to overcome problems with the accumulation of hydrogen gas near the Bragg peak at roughly 1.3 mm depth from the surface of the beryllium target [8]. The change involved using a 1.2mm thick target with a perpendicular beam, rather than the original 4mm thick target viewed at 45 degrees to the beam (in this new design, the majority of the protons range out in the water rather than the target itself). This moved the target considerably further away from the moderator and increased the amount of water (in the reflector) that was positioned in between these two elements as well. This change also moved the target out from the line of sight of the SANS instrument. These modifications to the target position resulted in a slight increase (roughly 25%) in the cold flux at the LENS instruments as demonstrated in figure 2. Figure 2 shows the spectrum at the SANS instrument, as measured by the instrument's beam monitor with an 8-cm thick beryllium filter in place (which leads to the sharp drop in the spectrum above 5 meV). Note that in addition to the increase below 5 meV, the change in the target configuration decreased the flux above 50 meV (neutrons in this range contribute to the instrument's background).

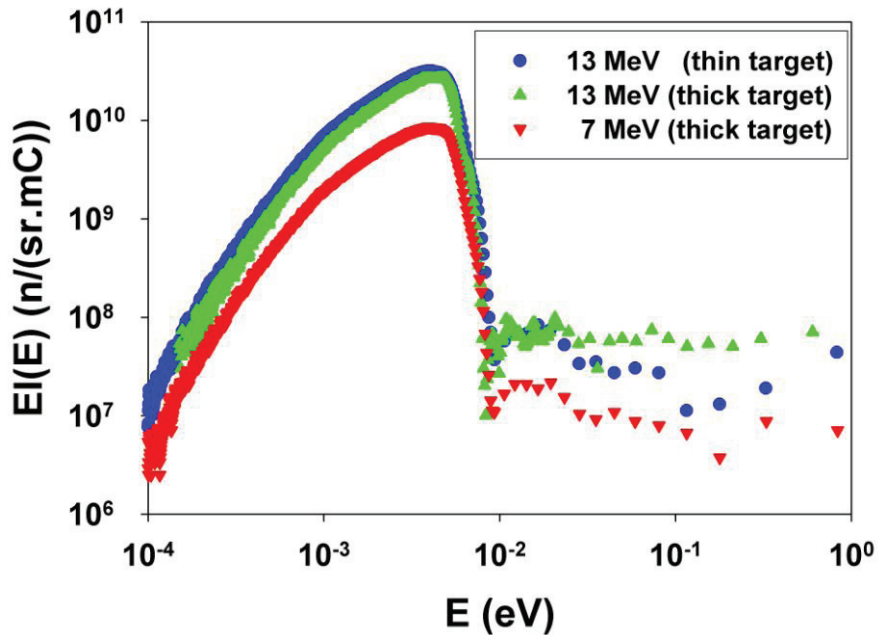


Fig. 2. Evolution of the incident spectrum on the LENS SANS instrument over two changes to the primary neutron source (from 7 to 13 MeV operating energy, and from a thick to thin target, as discussed in the text). An increase in flux of roughly a factor of 3 is seen upon increasing the incident proton energy from 7 to 13 MeV. This change is independent of wavelength (as expected) and is comparable to the change of the primary source strength. We also note that a roughly 25% increase in flux was seen upon changing to the new target design.

3. Moderator Research Program

We have recently commissioned a new apparatus for measuring emission time distributions from moderators. Figure 3 demonstrates the quality of data that may be obtained in roughly 8 hours from the methane moderator when running with a 12- μ sec pulse width at 40 Hz. This instrument uses reflections from the (111) planes in a germanium crystal that was held at 9 K. The crystal had been pressed at high temperature to increase its mosaicity and the neutrons were detected with a GS-20 scintillation plate attached to a photo-multiplier tube. The moderator, crystal, and detector were arranged to form a time-focused spectrometer [9]. The fits shown in the figure are to the Ikeda-Carpenter form [10], and these demonstrate the change from slowing-down behavior to storage behavior as the neutron energy falls below 100 meV. With this apparatus, we were able to identify peaks up to 10th order (roughly 560 meV) in this measurement, although longer counting times would be needed to measure accurately the width of peaks at energies higher than 360meV.

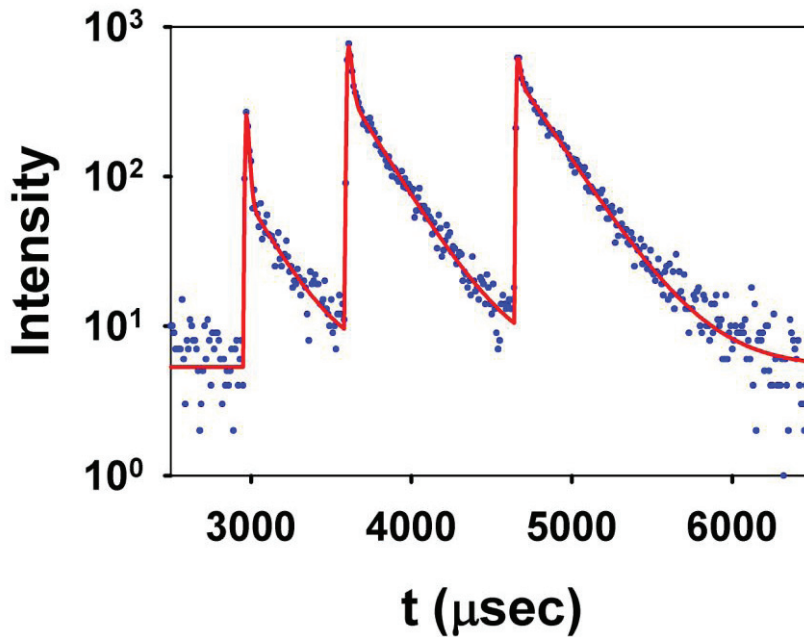


Fig. 3. Emission-time distributions from the LENS methane moderator measured with the (111) reflections of a mosaic germanium crystal and a lithium glass scintillation detector held in a time-focused geometry (the peaks shown correspond to 50, 90 and 140 meV). In the fits to the Ikeda-Carpenter form, all three peaks show $\alpha = 0.12 \pm 0.03 \mu\text{sec}^{-1}$ and $\beta = 3.9 \times 10^{-3} \pm 3 \times 10^{-4} \mu\text{sec}^{-1}$ and the storage term contribution to the peak decreases monotonically with increasing energy (R falls from 0.90 at 50 meV to 0.68 at 140 meV).

In the past, moderator experiments at LENS have included investigations of alternative poison plate designs for use in the moderators at the SNS [11] and preliminary investigations of liquid hydrogen moderators. Recently, we have begun to investigate an idea, first put forward by Stuart Ansell [12], in which moderating material (in this study, polyethylene, or PE) is interleaved with single crystals of silicon (Si, which provide an escape route from deep within the moderator for neutrons with wavelengths longer than the silicon Bragg cutoff). This is an extension of the traditional grooved moderator idea, in that it provides greater flexibility and reduces the moderator volume lost (due to the absence of a need for construction materials to define the groove). Here we will report on our initial attempts to explore the temperature and angular dependence of the flux from such a moderator, as well as preliminary measurements of the emission time distribution. The spectral measurements are summarized in figure 4, where we show lethargy spectra for the PE/Si vanned moderator, viewed at two different angles along with a similar plot for a comparable monolithic polyethylene moderator. In each case, the moderator was 8 cm thick, 12 cm wide and 12 cm tall. For the composite case, the PE layers were 2.4 mm thick and the Si wafers were 0.7mm thick with the $\langle 111 \rangle$ orientation perpendicular to the plane of the wafer. The viewed

face of the moderator was covered at its top and bottom by two layers of borated aluminum (leaving only the central 38 mm of the moderator under study to be viewed by the instrument) in order to increase our angular resolution, and the SANS collimation views a 10-cm circle centered on the moderator face.

For these measurements the moderators were mounted on a stage that could be tilted about a horizontal axis through an angular range of roughly 6 degrees (with a resolution of approximately 0.1 deg), and the temperature of the moderator was monitored with thermometers attached to aluminum plates at the top and bottom of the moderator as well as a third thermometer attached to the side of the moderator. In the case of the monolithic PE moderator this third thermometer took many hours to reach steady state (and indeed, in the time available for the experiment, we were unable to cool to temperatures below 120 K). The PE/Si moderator exhibited much more rapid thermal relaxation. Measurements were made for both moderators at 120 K, 180 K, and 300 K, and the PE/Si moderator was also measured at 50 K. These measurements were performed at a source frequency of 15 Hz, and a pulse width of 12 μ sec (FWHM) to provide adequate time resolution for emission time measurements while maintaining access to wavelengths beyond 2.0 nm in the spectral measurements.

The results shown in figure 4 were obtained for a moderator temperature of 120K using the SANS beamline incident beam monitor (a 4.6×10^{-4} A⁻¹ efficiency ³He pancake-style detector), and in the case of the PE/Si moderator, measurements from several short runs at slightly different angles were combined in order to provide adequate statistics (each curve shown in the figure represents an average of 4 data sets collected over a 1.2 deg range). For this moderator geometry, this detector has an angular resolution of roughly 0.5°. The two things of greatest interest from these measurements are that the vaned moderator provides greater flux than the monolithic moderator over an extensive range of energies (from 1 eV or more down at least to 1 meV), and the spectrum from the vaned moderator varies with (vertical) viewing angle. Interestingly, by changing the viewing angle for the vaned moderator, one can increase the cold flux while simultaneously reducing the epithermal flux (or vice versa if so preferred). At 120 K, these data show a gain of roughly 45% for the vaned moderator over the monolithic within the energy range from 1 through 100 meV and a (vertical) viewing angle of roughly 3 degrees. The angular dependence of the spectrum is something that might be exploited at major facilities to provide spectra tailored for different energy ranges to different instruments viewing the same moderator. The temperature and angular dependence of the spectrum from such a vaned moderator will be discussed at greater length in a future publication.

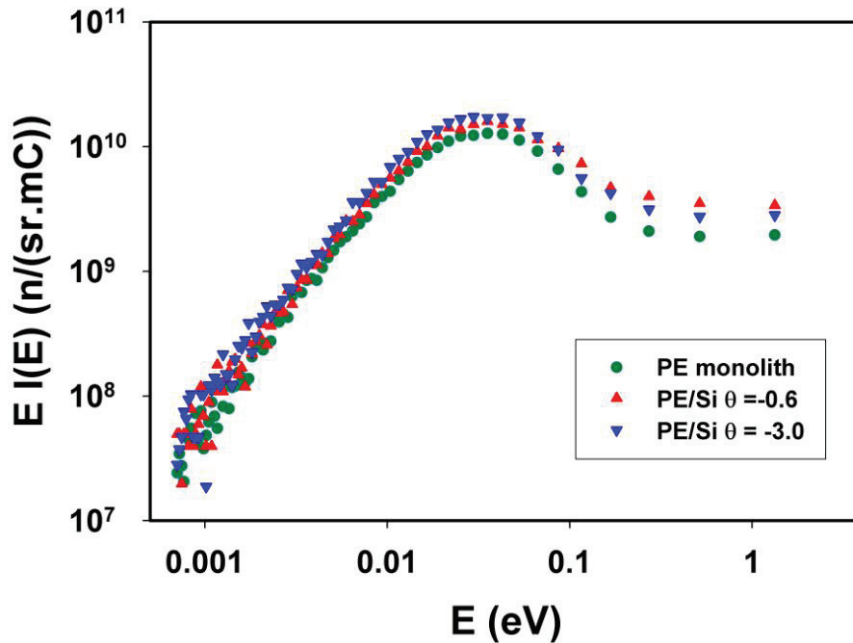


Fig. 4. Lethargy flux measurements from a monolithic PE moderator compared to that from a PE/Si vaned moderator viewed at two different angles and a temperature of 120K. We note that the vaned moderator exhibits greater intensity than the monolithic case across a wide range of energies, and that the shape of the spectrum from the vaned moderator depends on the angle at which it is being viewed.

4. Conclusions

We have shown that the performance of the LENS source has improved since the initial operation of the source due to a combination of changes in accelerator energy and TMR design. The system has been used for several years in experiments of moderator performance, and the original design goal for facilitating such an experimental program without the need for remote handling of components has been validated. On numerous occasions, experiments on three or four different moderators have been performed at LENS within a span of two weeks with minimal exposure to the researchers and support staff. Our preliminary investigation of the angular and temperature dependence of PE/Si vaned moderators have demonstrated that such a design provides a greater flux without a significant degradation of the pulse shape compared to a monolithic PE moderator. The PE/Si vaned design also introduces a spectrum that depends sensitively on the angle (with respect to the orientation of the vanes themselves) at which an instrument views the moderator.

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