ICANS-XVIII
18th Meeting of the International Collaboration on Advanced Neutron Sources
April 26 – 29, 2007
Dongguan, Guangdong, P R China

The Present Status of the Low Energy Neutron Source

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Abstract

The Low Energy Neutron Source (LENS) at Indiana University produced its first neutrons in late 2004, and has been engaged in a series of facility upgrades since that time. Among the important developments over the past two years have been the commissioning of klystron-based RF systems, the demonstration of beam peak proton beam currents of more than 20mA, and the low-power operation of a methane moderator at temperatures below 10K. In this talk we will review the present status of the facility and review some of these recent results along with a few of the milestones anticipated for the construction phase over the next 10 months.

1. Introduction

The Low Energy Neutron Source (LENS) is being constructed with money from the National Science Foundation, the State of Indiana's 21st Century Science and Technology Fund, the Department of Defense, and IU. LENS will run in a long-pulse mode, and will have a number of features that will allow it to fill a unique role in the world of neutron scattering. The facility has a three-fold mission for educating students and other researchers in the techniques of neutron scattering, conducting materials research with neutrons, and developing new technologies for neutron scattering. Initially, we will follow a collaborative access model to allocate beam time on the instruments. LENS will work closely with, and play a role that is complementary to, the Spallation Neutron Source (SNS) and other major facilities in a manner analogous to the role played by smaller reactor sources in Europe.

LENS makes use of low-energy (<13MeV) (p,Xn) reactions in a thick water-cooled Be target to produce neutrons with only limited build up of activity near the source. This approach is much less efficient in primary neutron production than the spallation process used at most existing accelerator-driven neutron sources **[1,2].** However, by making use of a high-current linear accelerator, operating in a long-pulse mode, and using a cryogenic moderator that is tightly coupled to the target, the facility can deliver a significant time-averaged cold neutron flux to its instruments. The limited activity built up near the source provides opportunities for conducting research into new materials and designs for neutron moderation, and its long-pulse mode of operation and low moderator temperature are attractive for exploring instrument designs suitable for future long-pulse and/or very cold neutron sources. The facility has two target stations, one of which is devoted to neutron scattering, and a second one devoted to the study of neutron radiation effects in electronics **[3].** Only one of these stations can be used at any one time. The facility has been designed for operation at up to 30 kW, however budget short falls will restrict initial operation (starting in Jan. 2008) of the neutron scattering program to power levels below about 5kW. We show below that the major goals for the LENS construction project (the commissioning of a SANS instrument capable of performing materials research, and the initial construction of an instrument to measure scattering angles with spin-echo encoding) will nevertheless be achieved even at this lower power level.

Initially, the two principle instruments on the neutron scattering target station will be a Small Angle Neutron Scattering (SANS) instrument, and an instrument devoted to the measurement of scattering angles through spin-echo encoding (SESAME **[4]**). Two other beam lines are available for future instrumentation developments, one (referred to as the neutron optics beam line below) will be devoted initially to neutron transmission measurements and development of neutron optical elements. Eventual expansion to include a reflectometer is anticipated, although funding for such an instrument has not yet been obtained.

The neutron radiation effects station has been set up to allow investigation of neutron-induced single-event-effects (SEE) in electronics. Such effects are expected to play and increasingly important role in determining the reliability of electronics. As device sizes continue to shrink, many circuits have displayed an increasing sensitivity to cosmic-ray-induced atmospheric neutrons. Several outside groups have already made use of this capability at LENS for preliminary studies at low dose rates. This included one measurement of SEE with sub-1MeV neutrons made available by operating only the 3-MeV RFQ section of the accelerator.

2. Description of the LENS source

LENS is presently making use of an AccSys Technology, Inc. PL-7 linear accelerator that had previously acted as the pre-injector for an electron-cooled proton storage ring at IUCF **[5].** This accelerator, which is composed of a 3 MeV RFQ coupled to a 4 MeV DTL, originally was limited by its conventional RF amplifier systems to delivering less than 10 mA at pulse widths below 150 μsec. Over the last year we have installed and commissioned a klystron-based RF power system to overcome these limitations. We have very recently demonstrated delivery to the target a peak current of 25 mA and a pulse width of up to 300 μsec. It is anticipated that normal operation will be 20 mA peak current. We expect to achieve more than 2% duty factor with this accelerator as well, but to date we have not run above 0.5% due to limitations imposed by the present high voltage (HV) power supply feeding the klystrons. Reaching 2% will require some development of the cooling systems on the DTL and the RF drive loops for the system as well as the installation of an additional HV DC power supply for the klystrons. All of these upgrades are scheduled to take place over the next six months. A second 6 MeV DTL will be added to the accelerator in the Fall of 2007 to bring the proton energy up to 13 MeV, and the power level up to roughly 5 kW. An eventual upgrade to the final design power of 50 mA peak current and 5% duty factor will require additional funding to install a new RFQ, develop a higher current (and higher injection voltage) ion source and add an additional klystron. We also note that the introduction of the klystron systems has also allowed us to produce proton pulse widths as small as 10 μsec, an ability that will be exploited in the future for experimental studies of emission times in prototype moderators of various designs.

The present moderator/reflector design employs a thin (1.0cm thick) solid methane moderator surrounded by a 50 cm diameter cylindrical water reflector **[6,7].** The moderator is held at temperatures as low as 3.6 K by a closed-cycle pulsed tube refrigerator to which the moderator vessel is connected by a high-purity (99.999%) Al bar. Under normal circumstances we anticipate running at a temperature near 4.5 K with He at a pressure slightly greater than 1bar above the methane. Simulations with MCNP using the smeth22K kernel indicated that there was little difference between 1 and 2 cm thickness for this configuration and the thinner end of the range was chosen to obviate the need for metallic foam to help extract heat from the moderator medium during full-power operation **[8].** Even at 30kW proton power, our MCNP simulations indicate that the total thermal load on the moderator and its vessel will be under 1.0W (with an additional 700 mW deposited into the first stage of the refrigerator due to heating of the radiation shield and polyethylene shielding attached to it). We have recently developed a scattering kernel for low-temperature methane **[9],** and simulations using this kernel suggest that a 2.0cm thick moderator should yield a lower temperature spectrum, so we will be exploring this avenue to improve the performance of the instruments over the next several months. Given our short-term limit on proton power at 5 kW, this we expect to be able to run at temperature well below 10K even in the absence of additional measures (such as Al foam or sapphire plates **[10]** embedded in the moderator) to cool the methane with the thicker moderator volume. Composite moderators with polyethylene at temperatures below 40K and methane at below 10K will also be explored in the short term. This limited thermal load and the reduction in radiation damage experienced by our moderator as a result of the limited gamma and fast neutron fields near the source **[7]** make LENS an ideal facility for exploring moderator technologies for future very cold neutron sources, and lowering the spectral temperature of the LENS source will be a major development goal for the facility over the next three years.

Moderator coupling to the primary source is enhanced through the use of both a slab geometry and a water reflector that also acts as a premoderator for the methane cold source. The enhanced fast neutron flux in the instrument beam lines resulting from the slab geometry is mitigated by a variety of techniques. The SANS instrument views the moderator at an angle such that at 5kW operation the illuminated portion of the target may be kept completely out of this instrument's line of sight. This instrument also views the target from a direction that produces the softest fast-neutron spectrum of all four beamlines. The SANS instrument has room to install a Be filter to provide additional reduction in fast neutron flux, but initially we hope to run this instrument with no filter. The neutron optics beamline views the moderator at almost normal incidence and this line will have a Be filter installed permanently. The SESAME instrument views the moderator in a direction that gives the hardest fast neutron spectrum, but this instrument will employ a polarizing bender **[11]** with m=2,3 supermirror guides to put the instrument itself out of line-of-sight from the target. In future meetings we will report on the effectiveness of these various mitigation techniques.

3. Moderator spectra and Instrument Performance

Over the past two years we have conducted several measurements of the moderator spectra, developed collimation and detector systems on a prototype SANS instrument, and performed some preliminary studies of neutron radiation effects. Figure 2 shows the spectrum obtained at the sample position of this preliminary SANS instrument (for 7MeV, 7mA, 150μsec pulse width and 15 Hz) with the moderator vessel empty. Under these conditions, the measurement reflects the spectrum from the water reflector, and we see remarkably good agreement between the measurement and the simulated spectrum obtained from MCNP **[12].** There is a modest (30%) disagreement between the simulation and measurement for the 1-eV coupling in this configuration, but this is most likely due to slight deficiencies in the model's representation of the details in the target water cooling systems. Over most of the thermal range, the agreement is well within our uncertainty (of approximately 15%, which is dominated by uncertainties in the absolute measurements of the proton current, the calibration of the thin He^3 detector, and the background present in the preliminary instrument used). We also wish to point out, that even with the 150μsec pulse width used in these tests, it is necessary to include an energy-dependent correction for the emission time distribution from the moderator to obtain the level of agreement seen in figure 2. For this measurement, the correction can take the simple form of an effective delay from the proton pulse arrival to the average emission of neutrons of a given energy from the moderator face. We account for the delay using MCNP simulation as the quality of the instruments and flux levels available to date have not allowed us to measure the emission time distribution for the moderators at energies much above 3meV. We have been able to verify the validity of the MCNP predictions for the emission times of 2.74 meV nuetrons as demonstrated in figure 3. The simulations suggest that for a proton pulse width of 150 μsec, the effective delay varies from 150 to 430 μsec over the range from 200 meV to 20 meV, and on a short instrument (the detector was only 5.70m from the moderator in these studies) this can lead to significant distortion of the collected spectrum if the correction is not taken into account in this energy range.

Somewhat poorer agreement is found in the comparison between measured cold neutron spectra and the MCNP simulations, as demonstrated in fig. 4. This may reflect, to some extent the inadequacies of the available kernel for solid methane, but it should also be noted that for these tests we prepared the moderator by cooling relatively rapidly from the condensation point and there are reports that this can lead to a cracked solid with a non-equilibrium spin configuration (both of which can reduce the effectiveness of the moderator) **[13].** At a moderator temperature of 3.6K the spectrum may be described as a combination of two Maxwellians (one at 29+/-4 K and the other at approximately 200 K) joined with a slowing down term. MCNP simulations suggest that these parameters (particularly the leakage exponent) are somewhat sensitive to details such as the moderator thickness, the thickness of water between the target and cold source, and the size of the vacuum gaps around the cold source. In our present design we have employed a rather large vacuum vessel to accommodate changes to the moderator with relative ease. Over the next several months we will introduce polyethylene spacers effectively to provide reflector material within what has previously been vacuum in order to increase the cold flux. In some cases the polyethylene can be mounted on the thermal shield and there fore this should also reduce the spectral temperature of the cold Maxwellian. Simulations have suggested that cold flux gains of more than 20% could be achieved through such modifications.

Integrating the spectrum shown in figure 4 for a moderator temperature of 3.6K over the wavelength range from 0.2 to 2.0nm we obtain an intensity of 1.3×10^{10} n/sR.mC. For our SANS instrument, with a sample position at 8.0m from the moderator this suggests a sample flux of 2.0×10^{4} n/cm^{2}.mC at 7MeV and 6.7×10^{4} n/cm^{2}.mC at 13MeV, before we consider any increases obtained from the above-mentioned improvements to the neutronic design. These numbers will be cut by a factor of two or so if we need to employ a Be filter to reduce fast-neutron-induced backgrounds (primarily through the loss of the neutrons in the range from 0.2 to 0.4 nm). As indicated in figure 1, the secondary flight path of this instrument can be varied from 1.0 to 4.5m, but we anticipate that for most purposes this will be set at 2.5m to give a reasonable compromise among the available Q_{min}, Q_{max} and sample flux. For a sample of 1.5cm diameter in this standard configuration, the instrument can reach Q_{min}=0.06 nm^{-1} by employing 2.0nm neutrons, and we expect to be able to collect data on a sample with $\Sigma(Q=0.06\text{nm}^{-1})=2\text{cm}^{-1}$ within a period of a few hours. Smaller Q_{min} values can be achieved by reducing the aperture near the moderator, with a corresponding reduction in the flux available at the sample. The data collection time will be determined primarily by counting statistics in the lowest Q bin, and hence our efforts to reduce the source's spectral temperature will have a direct impact on the performance of this instrument.

4. Conclusions

Over the past two years the performance of the LENS source has been evaluated through the study of moderator characteristics at very low beam powers. Reasonable agreement has been found between these measurements and the source characteristics predicted by MCNP simulation. Major goals for the next two years at the facility are to bring online the new accelerator and power systems that will allow us to achieve 5kW beam power, and the reduction of the neutron spectral temperature to values near 10K. The facility has started its program of neutron scattering, education, and instrumentation development and preliminary experiments have been performed on neutron transmission of methane, SEE effects with neutrons, in addition to the primary activities involving source characterization.

Acknowledgements

The LENS project is supported by the National Science Foundation (under grants DMR-0220560 and DMR-0320627), the 21st Century Science and Technology fund of Indiana, Indiana University, and the U.S. Department of Defense.

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Figures

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Figure 1 Overall schematic layout for LENS facility, showing both the Neutron Radiation Effects Program (NREP) target station in the foreground, and the new neutron scattering target station in the background. This representation shows the accelerator in its present (7 MeV) configuration and the two primary instruments (SANS on beamline 1 and SESAME on beamline 4). Beamline shielding components are not shown for clarity. To the left side of the figure you can see the klystron RF systems that are now powering the accelerator. Not shown in the figure is a 1200 ft^2 chemistry lab that has been constructed right next to the scattering floor for sample preparation and characterization.

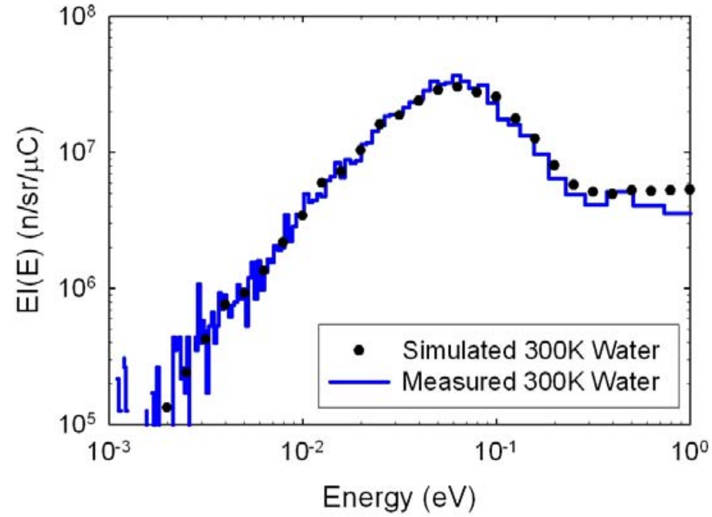

Figure 2 Comparison of the neutron spectrum measured at LENS when operating with an empty moderator vessel and 7MeV (blue curve) proton beam with that predicted from MCNP calculations (black dots). These measurements are dominated by the thermal neutrons emitted by the water reflector (which feed the solid methane moderator under normal operations). We note that there is remarkably good agreement between the two curves, with the exception of a 30% discrepancy in the 1-eV coupling..

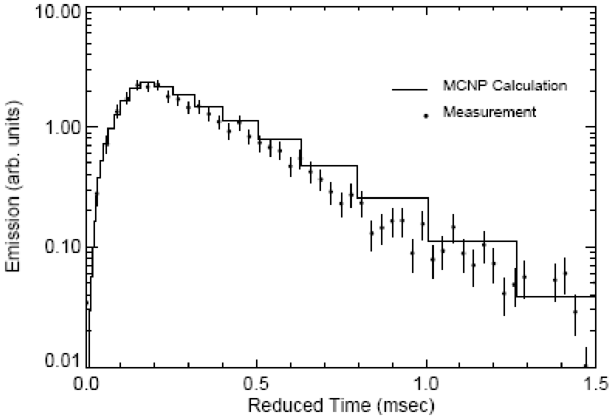

Figure 3 Emission time distribution for neutrons with energy 2.74meV measured for a moderator temperature of 4K, compared to MCNP simulations using the smeth22K kernel.

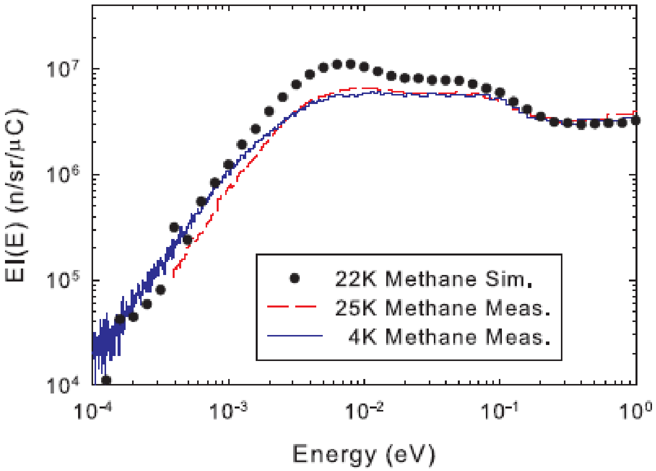

Figure 4 Neutron spectra collected after the installation of the cryogenic methane moderator for two different moderator temperature and a predicted spectrum from MCNP using the smeth22K kernel. The measured spectra appear significantly below the prediction for energies below 100meV, but we note that a significant gain in neutron flux is seen below 2meV when the moderator is cooled to 4K. These spectra were collected with a proton beam power of 110 W.