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Status report on the Low Energy Neutron Source — 2014

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Abstract. LENS produced its first neutrons almost 10 years ago and has now entered a steady state of operations with particular focus on the educational and instrumentation innovation aspects of its mission. Key elements in the facility's success over the last decade have been the alignment of its mission with the objectives of a number of major neutron sources and its ability to educate and train students in ways that are difficult to implement at major facilities. In this paper, we summarise some of the recently installed improvements to the facility, describe some recent scientific activities, and look back at some of its significant accomplishments over the last 10 years.

1. Introduction

LENS is a Compact Accelerator-driven Neutron Source (CANS) based on (p,nX)Be reactions involving a 13 MeV proton beam and a 1.1mm thick beryllium target. It normally operates at a beam power of 3 to 4 kW with a 20 Hz repetition rate, but the repetition rate and pulse width can be varied to suit particular experiments [1,2]. The facility operates on the campus of Indiana University and is supported by a portion of the indirect funds generated by research grants associated with the facility. Therefore, it does not serve as a traditional user facility, but rather concentrates on providing unique educational and instrumentation innovation opportunities while also facilitating materials research. The facility has three conventional neutron instruments (SANS, SESAME, and a neutron radiography/tomography station), a developmental beam line used for studies of moderator performance and testing novel detector ideas (the Moderator Imaging Station, or MIS), and a station for irradiating electronics with fast neutrons (Neutron Radiation Effects Facility, or NREF). Over the last decade, 10 students have received their PhD for work associated with LENS (some during construction and some using the neutron beams at the facility) and seven more are currently pursuing their PhD, 10 post-doctoral fellows have worked with LENS, and another 10 undergraduate students have conducted research at the facility.

The facility ran for an average of roughly 1500 hr/yr over the past couple of years. Something under 10% of this time was devoted to operation of the fast-neutron target station. Roughly 25% of the operation time on the cold-neutron target station is devoted to experiments on the performance of novel moderator designs (in collaboration with researchers from SNS, LANL, ESS and ISIS) and the remaining time devoted to normal operations for research with the SANS, SESAME and MIS

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instruments. In the upcoming years, we expect to see an expansion of operations on the fast-neutron target as we will ramp up both our radiation effects and radiography activities.

The floor plan of the facility is shown in figure 1. The facility's two target stations are the circular features at the end of the proton beamlines leading away from the accelerator (which appears at the lower left in figure 1). The upper target station houses a 1-cm thick solid methane moderator operating at 6K and feeds the SANS, SESAME and MIS instruments with cold neutrons [2]. The lower target station in figure 1 feeds the radiography instrument and a station for irradiating electronics with neutrons at a rate of up to $2x10^{10}n/(cm^2{\cdot}s)$ (1 MeV equivalent flux for small samples right next to the target). This second target station has a room-temperature polyethylene moderator that may be covered with Cd (to allow a difference measurement that is sensitive to only thermal neutrons), or removed completely (to study the effects of fast neutrons).

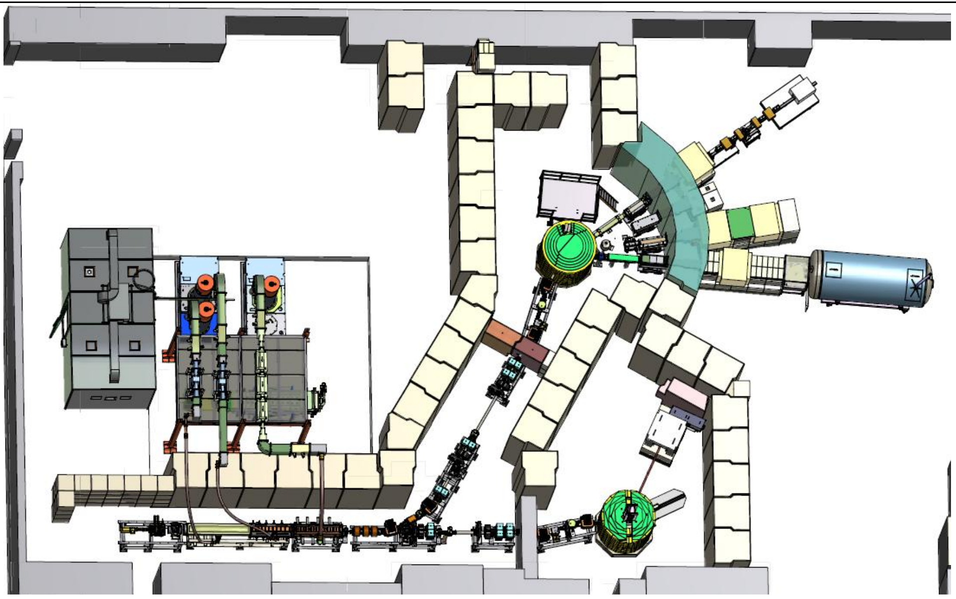

Figure 1. Floor plan of the LENS facility in 2014. Recent additions to the facility include improvements to the DUT assembly, and upgrades to the radiography facility (both on the lower, fast neutron, target station) and the installation of an in-situ polarized ^{3}He analyser and new detector on the SEAME instrument on the (upper) cold neutron target station.

2. Recent facility activities

Over the last two years, we have introduced some improvements to a number of the instruments at LENS. The SESAME (Spin-Echo Scattering Angle Measurement) instrument was fitted with an on-line pumped ^{3}He polarization analyser and an array of 16 linear position sensitive detectors to replace the supermirror analyser and multi-PMT position-sensitive detector that were previously used on this instrument. We have discovered that the complicated correlation between neutron phase space and polarization analysing power of the supermirror analysers causes issues with the interpretation of SESAME data, so installation of the ^{3}He analyser was a major step forward for this instrument [3]. The instrument has also supported the development of several generations of magnetic Wollaston prisms, which are presently used to effect the spin encoding at the heart of the instrument's operation. This included a novel water-cooled triangular prism design with only two layers of Al wire in the beam path for each prism, in order to maximize the transmission of the devices. We also discovered that the polarization loss in these wire-wound devices is very sensitive to the precise geometry of neighbouring sheets (in particular, it was important that the individual wires in the current sheets that define the common hypotenuse of neighbouring triangular coils shown in figure 2 interdigitate rather than lining up directly each other to reduce polarization losses [4]).

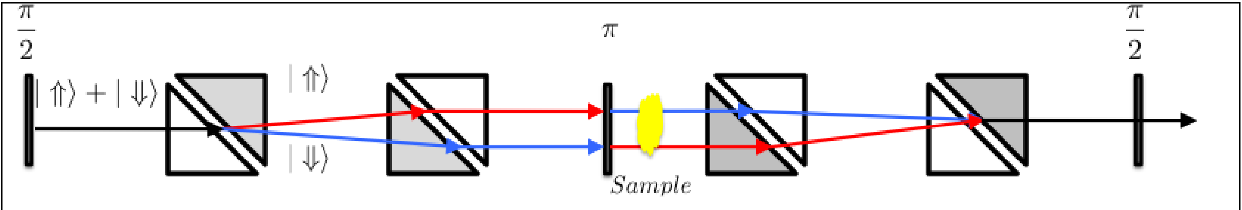

Figure 2. This schematic shows the basic operation of the SESAME instrument in SESANS mode. The triangular regions are magnetic prisms (grey for fields in the positive z direction, and white in the negative z direction). Each pair of triangles forms a magnetic Wollaston prism. The instrument starts with a π/2 flip to place the neutron spin in the x-y plane, and the prisms act as birefringent media for the up and down components of the neutron spin. These components are separated spatially by the first pair of Wollaston prisms (through refraction at the common hypotenuse of each triangle pair), and recombined by the second pair. Any difference in the integrated scattering length density of the sample over the length defined by this separation distance will show up as a change in the neutron polarization when measured at the end of the instrument [3,4,5].

The Neutron Radiation Effects Facility was modified two years ago in order to increase the size of the electronics boards that can be irradiated by providing vertical access to the target area for the Device Under Test (DUT) through a dumb-waiter system. We are presently adding new diagnostics to provide better real-time monitoring of the dose delivered to the parts as well. As a part of this more recent project, we are also upgrading the radiography facility to enhance its fast-neutron imaging capability by providing line-of-sight to the target from the imaging instrument's fluorescent screen. In the coming years, we anticipate an increase in the activity for both the irradiation and radiography stations at LENS through increased interactions with a regional base of users with interests in these areas. We note that the current standards for radiation effects testing specifically mention use of reactors which may no longer available for such testing within a decade or less [6], so this could be another area where small sources such as LENS could have a significant impact.

3. Operational Experience

Over the last several years, the performance of our RF system has improved considerably [7]. Three years ago we completed the transition from legacy switch tubes in our klystron control circuitry to modern Y-847B tubes from CPI. Prior to this change, the RF systems would typically trip several times per week (up to a few times per day). Even after the installation of the new switch tubes, the system continued to trip more often than we would like, but most recently our RF reliability has steadily increased to the point where it is no longer a significant issue (it is now common to go several days or even a week without RF trips interfering with operation). In addition to the installation of the new tubes, key elements of this transition have been the decision to run the high-voltage tanks with heaters to raise the oil temperature to about 35°C, and the slight re-working of some of the connections in those tanks. Collaborations with the RF group at Los Alamos have proved most helpful in addressing these issues.

For reasons that we do not yet understand, target lifetime has become a major operational issue within the last year. When we changed target design to the current 1.2 mm thick circular target from our original 4mm thick rectangular version in 2010 [8], we initially found it necessary to change targets only after the target's O-rings providing the seal between the target cooling system and the vacuum failed due to accumulated radiation damage. This typically resulted in a routine where we would change an intact target at something like 80 to 100 kW-days of accumulated beam. More recently, although the target design itself has not changed, the targets themselves have started to exhibit cracking after accumulate beam of from 1 to 70 kW-days of operation, and in typical operation these cracks have most often been the feature that limits the time between target exchanges. This is a continuing problem, and our present thinking is that it will have to be address by going over to a composite target design similar to that developed for the Riken Accelerator-driven Neutron Source (RANS) [9]. In this design, the Be target material is backed by a layer of Vanadium or Niobium, which acts as a sink for the protons.

4. Research Activities

The majority of the research conducted at LENS over the last few years has been associated with the development of new neutron instrumentation. The relative ease with which the LENS TMR may be reconfigured has led to the development of a program in experimental neutronics that has been active for more than six years. The most recent projects in this area have included several experiments investigating the convoluted moderator concept originally put forward by Stuart Ansell of ISIS [10], and most recently an experiment on a single-crystal reflector/filter. In this same general area, we have measured the neutron total cross section of a number of potential neutronic materials (methane, D_2O etc.), and have demonstrated that our SANS instrument, with suitable small and temporary modifications, can be used to measure neutron transmission in samples from below 0.1meV to above 1eV with a single accelerator setting (typically 10Hz with a 0.15ms pulse width). Our neutronics experiments have been conducted in collaboration with researchers from the SNS, ESS, ISIS and LANSCE neutron facilities, and this activity demonstrates the important role that CANS facilities are able to play in supporting the international scattering facilities. Over the last two years we have also conducted a number of experiments to provide preliminary data on samples to be measured later at one of the major facilities, which is another example of synergistic interactions among these two different types of facilities [11].

Our SANS instrument has recently provided published data on micelle structures [12] and several more SANS studies are in preparation at this time. We see this activity increasing over the next two years. As discussed above, changes to the analyser and detector have been crucial to bringing the SESAME instrument into useful service, and we have now demonstrated measurements at spin-echo lengths up to 1 micron with this instrument [3,4,5]. Even with its earlier detector and analyser, however, the SESAME instrument has provided the polarized neutron optical bench that was crucial to the second major instrumentation development program at our facility. In constructing the SESAME instrument, several refinements have been made to the devices through which the neutron spatial position or momentum can be encoded in the neutron spin state. This started with the development of novel coil winding patterns in conventional magnetic prisms in order to minimize the material seen by neutrons as they pass through the instrument [4], but it has also included increased current capacity (to extend the instrument's range) and the development of novel techniques for alignment of such instruments [5].

Over the last several years, the SESAME instrument has supported the development of a number of devices for manipulating neutron spins using magnetic fields confined to precise geometries using high-Tc superconducting YBCO films deposited on sapphire substrates as Meissner screens [13]. One of the key challenges in developing spin-echo instrumentation is minimizing the impact of Larmor aberrations on the final spin state of the neutrons as they pass through the instrument. The use of symmetry in the design of the instrument can cancel many of these aberrations, but the use of

Meissner screens to precisely define the magnetic field geometry helps to minimize the aberrations associated with each element. Another advantage of these YBCO on sapphire films is that they introduce negligible absorption or small angle scattering, and this maximizes the transmission of the neutron beam through the devices [14]. The high transition temperature of the films allows us to use inexpensive cryocoolers and relatively straight-forward cryogenic engineering in the design of the devices. By using YBCO tapes to produce the magnetic fields, we have been able to construct a simple device for Spherical Neutron Polarimetry. [15]. A number of other similar spin-manipulation devices have also been developed on this instrument, and these are discussed in more detail in other publications [13-17]. We have also found that the design of these components is aided enormously through the use of modern magnetic field simulation codes, provided the code is equipped to handle superconducting components.

5. Conclusions

Over the last ten years, LENS has demonstrated the traditional role of small university-based neutron facilities (education, instrumentation development and materials research) can be fulfilled with an accelerator-based source design. We have demonstrated a number of novel neutronic concepts and established important research programs in neutronics and novel instrumentation. We look forward to continuing these activities into the coming decade.

6. Acknowledgements

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