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Status of the low energy neutron source at Indiana University

D.V. Baxter *, J.M. Cameron, V.P. Derenchuk, C.M. Lavelle, M.B. Leuschner, M.A. Lone, H.O. Meyer, T. Rinckel, W.M. Snow

Indiana University Cyclotron Facility, 2401 Milo B. Sampson Lane, Bloomington, IN 47408, USA

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Abstract

The National Science Foundation has recently approved funding for LENS (the low energy neutron source) at Indiana University and construction of this facility has begun. LENS represents a new paradigm for economically introducing neutron scattering into a university or industrial setting. In this design, neutrons are produced in a long-pulse (1 ms) mode through (p,n) reactions on a water-cooled Be target and the target is tightly coupled to a cryogenic moderator with a water reflector. This design gives a facility suitable for materials research, the development of new neutron instrumentation, and the education of new neutron scientists.

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1. Introduction

Neutrons are a unique probe of the structure and dynamics for a great variety of systems studied today in many scientific disciplines. With the construction of the spallation neutron source (SNS) at Oak Ridge National Laboratory, which will be the most intense short-pulsed spallation neutron source (SPSS) in the world when completed in 2006, the US hopes to provide the first state-of-the-art facility for neutron research in North America in decades. However, there is also a need for smaller sources at which new ideas may be explored and large amounts of beam time can be devoted to educating new users. In Europe, national-scale research reactor facilities provide a network of centers for these activities, but no similar network exists in North America. This presents a major obstacle to expanding the neutron scattering community in the Americas.

We describe a design for a pulsed neutron facility with an intensity that is sufficient for a

* Corresponding author. Tel.: +1 812 855 0932; fax: +1 812 855 6645.
E-mail address: baxterd@indiana.edu (D.V. Baxter).

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significant program in neutron scattering and yet is at the same time affordable enough for construction at a university or industrial research center. The design is similar to a concept developed in the Chalk River Laboratories in the 1980's [1,2] but goes beyond this original concept in its use of a pulsed beam and cryogenic moderator. Below we describe the source concept along with some of the instrumentation that will accompany its implementation at Indiana.

2. Neutron production

2.1. Overview

The flexibility and low cost of our design for LENS (low energy neutron source) offer significant advantages over existing neutron sources for a number of important research and educational projects. Preparing the next generation of neutron scattering scientists will require education in the use of pulsed sources as the world's flagship neutron facilities will soon be at pulsed sources. Moreover, particularly in areas where neutron scattering is presently emergent (such as biomaterials and chemistry), long-pulsed spallation sources may be the ideal sources for the future [3]. It is therefore important to have a facility available at which instrument components suitable for a long-pulsed source can be tested and where students can participate in the design of such instrumentation. Finally, the relatively small level of radioactivity built up around our source during its operation make LENS an ideal facility for investigating the properties of candidate moderator materials and designs for use in future pulsed sources.

2.2. Accelerator

The LENS facility will initially run using a commercial [4] 7 MeV proton linear accelerator that presently exists at Indiana University. This accelerator consists of a 3 MeV radio frequency quadrupole accelerator (RFQ) directly coupled to a 4 MeV drift tube linac (DTL) [5]. The RF amplifier system used with this accelerator in the past provides a peak power of 600 kW, and it is being upgraded from its original 0.2% duty factor to 1.5%. This existing power system and accelerator will allow us to bring the facility into operation quickly. Although accelerator power in this "phase I" operation will be only on the order of 1 kW, it will be sufficient to conduct research relevant to neutron moderator development, to develop instrument components suitable for long-pulse sources, to provide important new educational opportunities, and to initiate commissioning of some instruments.

The present RFQ will be replaced as part of a facility upgrade to a "phase II" target power on the order of 30 kW and the addition of a second target station. This upgrade will involve replacing the existing low-current RFQ with a new design capable of transmitting at least 50 mA at a duty factor of 5%. To provide this increased beam power, the existing RF amplifiers will be replaced by 425 MHz klystron-based amplifiers. The plan for the facility includes eventually upgrading the accelerator energy to 13 MeV by adding additional DTL tanks onto the present DTL. This choice for the accelerator energy is dictated by our desire to limit activity near the source (and therefore the need to stay below the threshold for production of tritium and ^{7}Be in the target).

2.3. Target moderator reflector (TMR) assembly

The neutron source design for LENS utilizes a water-cooled Be target and solid methane moderator situated in the center of a cylindrical water reflector (50 cm tall and 50 cm in diameter). This reflector is surrounded by a borated polyethylene decoupling layer, a 15 cm thick high-purity lead gamma shield, and a primary neutron shield comprised of polyethylene, epoxy, borax, and lead that extends out to a radius of 1 m from the moderator. We have modeled the neutronics performance of this design using MCNP [6] with the same neutron scattering kernels that were used successfully to compare similar calculations to experimental measurements of the IPNS moderators [7]. The results are shown in Fig. 1 for three different accelerator power levels. Our simulations do not yet contain all the engineering details of the moderator design,

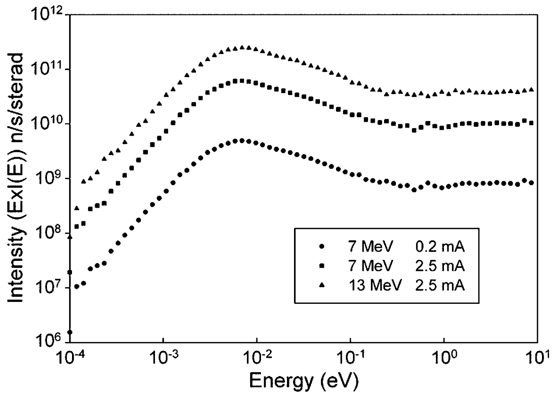

Fig. 1. Monte Carlo simulations of the neutron intensity for the proposed LENS facility operated with a Be target at three different power levels. The lowest power level shown gives the anticipated flux in phase I of the facility, the second the flux after upgrading to 50 mA and 5% duty factor at 7 MeV, and the last at the facility's ultimate power of 13 MeV, 50 mA and 5% duty factor.

and they assume that the moderator material is held at 22 K (whereas we expect to run with the moderator below 10 K). The uncertainty associated with these simulations is therefore on the order of at least 50%, but they nevertheless provide a reasonable indication of the source performance to be expected from LENS.

The LENS moderator design differs slightly from that at other pulsed neutron sources due to the differences between the (p,n) reactions and spallation. The LENS source produces no neutrons above 11 MeV (for a 13 MeV proton energy), essentially no hard X-rays, and its gamma spectrum is completely dominated by capture in the reflector (fewer than 10% of the gammas come from reactions in the target itself). This allows LENS to employ a tightly coupled slab geometry moderator, whose optimal thickness is only 1 cm. In the MCNP model, this moderator is $12 \times 12 \times 1$ cm in size is filled with solid methane at 22 K. The small moderator volume and weaker radiation field at LENS (compared to a typical spallation source) will allow the moderator to be run at lower temperatures (below 10 K) without severely exacerbating the problem of radiation damage in the moderator. With a 13 MeV proton beam of 50 mA peak current energy and an accelerator duty factor of 5%, the neutron yield from the ^{9}Be target is roughly 10^{14} n/s with approximately 0.03% of these entering the neutron beam lines with an energy of 100 meV or less.

The proton delivery system at LENS will include a pair of octupole magnets to produce a relatively uniform rectangular beam (rather than a Gaussian profile) at the target, which intercepts the proton beam at an angle of 45°. For phase II operation, the target will be cooled using the hypervapotron design [8] in order to accommodate the anticipated thermal load of 600 W/cm^2 while maintaining adequate flexibility in the materials placed between the target and the moderator. The power limit for a source design of this type

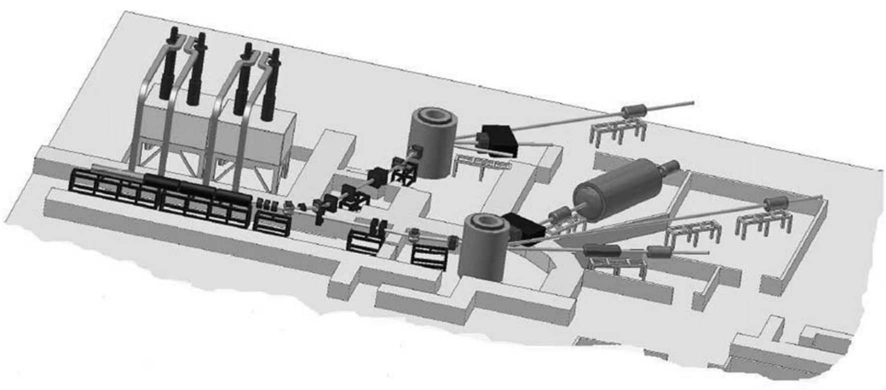

Fig. 2. Schematic layout of the LENS cold neutron facility. Showing the accelerator with its associated RF power systems on the left, one target station for neutron scattering with three instruments (to the right), and a second target station for conducting research into neutron radiation effects (upper left).

appears to be set by the dynamic stresses experienced by the target due to the pulsed nature of the beam and we are presently investigating variations on the basic target design to see how far above 30 kW this concept can be pushed.

The expected layout for the LENS facility in early 2007 is shown in Fig. 2. The first target station (to be used in both phase I and phase II) will support research in the large-scale structure of materials (through small angle neutron scattering (SANS) and radiography) and instrumentation development in addition to educational programs. A Precession Scattering Instrument (Ψ) will be used to prototype instruments for spin-based encoding of momentum transfer on a long-pulsed source and will be used to extend our small angle scattering experiments out to length scales beyond one micron. This technology holds the promise to increase greatly the efficiency of several types of neutron scattering instruments. The second target will be primarily devoted to the study of neutron radiation effects on electronics and materials, but it will also be used for prototyping components of ultra-cold neutron sources and the development of additional instrumentation.

3. Summary

Recent development of high-current low energy proton linear accelerators makes it possible to produce useful neutron fluxes in a facility suitable for a university or industrial setting. By keeping the proton energy below 13 MeV, the activity in the source itself is reduced to the point where it can be reconfigured easily to test new ideas quickly and conveniently. The facility is therefore ideal for investigating new ideas in neutron instrumentation, but it will also be well-suitable for materials research using neutron scattering and for educating students at all levels from a variety of disciplines.

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