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## Indiana University's Low Energy Neutron Source (LENS)

The Low Energy Neutron Source (LENS) is a novel, university-based pulsed neutron source under construction at the Indiana University Cyclotron Facility. The source utilizes a low energy p-n reaction in beryllium coupled with a high-current, variable-pulse-width proton accelerator to produce either short or long neutron pulses. Highly optimized moderators produce cold and very cold neutrons for use by a suite of neutron scattering instruments and development facilities.

LENS will be a regional university facility for research, innovation, education and outreach with a national impact. The emphasis on cold and very cold neutrons makes it suitable for the study of nanoscale structures which are a research focus of many universities in the region. The flexible scheduling and technical resources available at IUCF make it ideal for developing innovative new neutron scattering techniques and instrumentation that will provide national benefits. At the same time, LENS's location in a university environment supports educational development at a local, regional and national level.

## LENS construction timeline

- Sept. 2004** The proton beamline looking from the target station (TMR)
- Sept. 2004** The location of the TMR and the first three neutron beamlines are established
- Nov. 2004** Construction of the target station (TMR) begins



**Dec. 2004** The TMR is fully assembled and ready for beam (no cryogenic moderator yet)

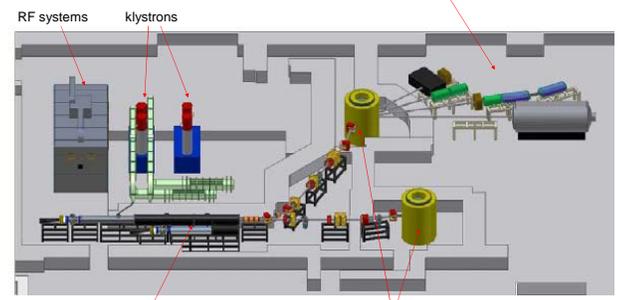


**Dec. 15, 2004** First neutron beam at LENS. The three oscilloscope traces are RFQ and DTL field pick-ups (top traces), and the beam pulse (bottom trace).

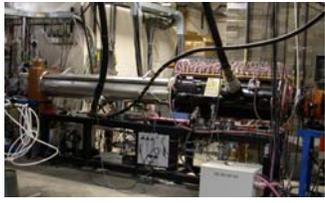


## Neutron Instrumentation

- SANS (Small Angle Neutron Scattering)** instrument will utilize pinhole collimation and cover a Q-range of 0.005 – 0.5 Å<sup>-1</sup> with an expected integrated flux of ~ 3.6x10<sup>4</sup> n/cm<sup>2</sup>/sec at the sample position.
- SESAME (Spin Echo Scattering Angle Measurement)** Spin echo development test-bed for neutron polarizers, analyzers, neutron spin flippers, and neutron spin precession devices.
- Neutron Optics** a beam line for exploring new instrumentation concepts and carrying out experiments with polarized neutrons.
- Radiography, Moderator studies** An important aspect of the moderator development program is the ability to measure emission time distributions and spectra for moderator prototypes and new moderator materials.



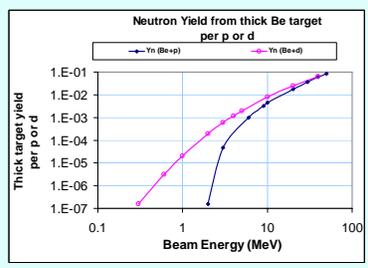
LENS is presently powered by a 7 MeV linear accelerator consisting of a 3 MeV RFQ and a 4 MeV DTL. The picture below is the accelerator shortly after installation in August 2004



There are two target stations at LENS: The first became operational in December 2005, and the second is currently under construction and will be finished in the fall of 2007. One target station is dedicated to neutron radiation effects research and the second will have extracted neutron beamlines for condensed matter research.

- A series of upgrades to the LENS accelerator systems including the addition of klystrons, a new ion source, and an addition DTL will boost the neutron production rates by a factor of ~500 over the current rate. The sequence of upgrades is listed below
- Phase I (Early '05: 7MeV, 7mA, 0.3% DF; 2x10<sup>11</sup> n/s)
  - Phase II (Fall '06: 7MeV, 20mA, 2% DF; 4x10<sup>12</sup> n/s)
  - Phase III (Summer '07: 13 MeV, 1x10<sup>13</sup>n/s)
  - Eventual power (13MeV, 50mA, 5% DF; 10<sup>14</sup> n/s)

## Producing neutrons with low energy nuclear reactions



The yield for protons and deuterons incident on a thick beryllium target is shown in the figure on the left. In both cases the yield increases monotonically. LENS utilizes a proton beam even though the yield is slightly less than that for deuterons because the reaction threshold for deuterons is lower. As a result, the mean energy of deuteron-produced neutrons is higher and is therefore more difficult to moderate.

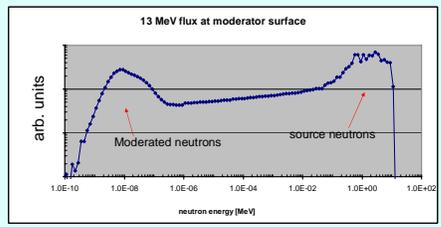
The table to the right lists the lowest energy proton-induced reactions on beryllium, ordered according to the reaction threshold.

The rows shaded in green represent reactions that produce a neutron in the final state.

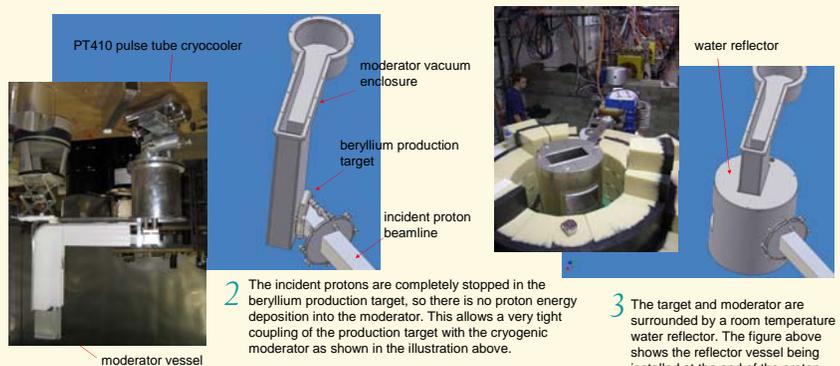
The row shaded in red represents the lowest energy reaction that produces radioactive daughter nuclei. The ultimate proton energy of LENS – 13 MeV – was selected to fall below this reaction threshold.

The gamma yield of the LENS source is expected to be less than 10% of the neutron yield.

initial state	final state	threshold (MeV)	subsequent decays	net reaction products
$p+Be \rightarrow$	$^9Be + \gamma$	-7.3		$^9Be$
$^7Li + \alpha$		-2.4		$^7Li, n$
$^9Be + d + \alpha$		-0.7		$d, 2n$
$^9Be + d$		-0.6	$^9Be \rightarrow 2\alpha$	$d, 2n$
$^9Be + \alpha + p + n$		1.8		$n, p, 2n$
$^9Be + p + n$		1.9	$^9Be \rightarrow 2\alpha$	$n, p, 2n$
$^9Be + n$		2.1	$^9Be \rightarrow 2\alpha$	$n, p, 2n$
$^9Be + \alpha + p$		2.7	$^9Be \rightarrow 2\alpha$	$n, p, 2n$
$^7Li + \alpha + n$		3.9		$n, p, 2n$
$^7He + ^7Li$		4.9		$n, p, 2n$
$^7He + ^7Li$		12.5		$^7He, ^7Li$
$^7H + ^7Be$		13.43	$^7H \rightarrow ^7He + e^+ + \bar{\nu}_e$ (12.3 Y) $^7Be + e^- \rightarrow ^7Li + \nu_e$ (53.8 D)	$^7He, ^7Li$



The predicted neutron spectrum from the LENS moderator consists of two peaks – an unmoderated peak from the beryllium production target, and a (cold) moderated peak from the cryogenic CH4 moderator. The two peaks contain roughly the same number of neutrons.

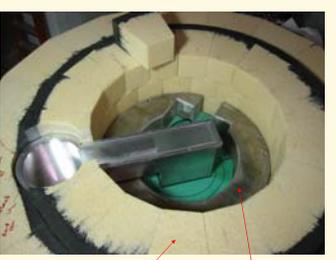


**1** The LENS moderator is solid methane cooled to temperatures of less than 4K with a commercial pulse tube refrigerator. The moderator is 12 cm x 12 cm in cross-sectional area and is currently 1 cm thick. Due to the low moderator heat load at LENS expectations are that the moderator can run at less than 10K even when the facility reaches full power (30 kW proton on target).

**2** The incident protons are completely stopped in the beryllium production target, so there is no proton energy deposition into the moderator. This allows a very tight coupling of the production target with the cryogenic moderator as shown in the illustration above.

**3** The target and moderator are surrounded by a room temperature water reflector. The figure above shows the reflector vessel being installed at the end of the proton beamline. The cavity at the top of the reflector is where the moderator vacuum is inserted. The port on the side of the reflector is where the cold neutrons are extracted for transport to the neutron scattering instruments.

**4** Below is a close-up view of the TMR almost fully assembled. The reflector is surrounded by alternating layers of lead and polyethylene shielding. The entire TMR assembly is 2 meters in diameter.



"caramel corn" thermal neutron shielding  
cast lead shielding