Low energy neutron spectrometer (LENS) for OMEGA and the NIF

One of the findings and recommendations from OLUG 2010 was to acquire a high-resolution neutron spectrometer to measure neutrons with energies in the range 2-3 MeV on OMEGA. Such an instrument could be developed and tested on OMEGA, and later implemented on other ICF facilities, such as NIF and Z. Fruitful discussions during OLUG 2011 resulted in an expanded target energy range of 0.1-5 MeV, and identification of a number of scientific goals that could be met with such a low energy neutron spectrometer (LENS) system:

1. ***Measurements of the DD neutron spectrum.*** A main purpose of a high-resolution low energy neutron spectrometer is detailed measurements of the neutron spectrum from D2 capsule implosions (including DD yield, T_{ion} and DSR). Existing neutron detector systems measure yield and T_{ion}. T_{ion} is currently measured by the nTOF systems to high precision, but with a large and unknown systematic error[i]. An independent high-resolution measurement could be used to cross-calibrate the nTOF T_{ion} measurements to reduce the systematic errors. In some scenarios, DD DSR can be inferred from charged particle spectrometry of ranged-down D^3He protons. This measurement, however, has an intrinsic upper ρR limit of applicability due to the proton stopping power. In principle, nTOF systems could measure the downscattered neutron spectrum from D2 capsule implosions to infer ρR, but this measurement has so far proven impossible in practice due to the complicated response of the nTOF systems at these low energies. A high-resolution neutron spectrometer with the ability to resolve e.g. the elastic carbon peak from CH capsules (at ~1.8 MeV) would provide a useful complement to existing measurements, allowing for DSR/ρR measurements in scenarios where no such diagnostic capability is currently available.

2. ***Non-thermal effects.*** A high-resolution low energy neutron spectrometer would also be used to look for non-thermal effects in the neutron spectrum, appearing as a broadening of the thermal DD neutron peak at 2.45 MeV. Non-thermal beam-target reactions constitute a large fraction of the DD reactions at Z[ii]. There is also no reason to believe that the fuel ion populations in e.g. a DD exploding pusher implosion at OMEGA are Maxwellian[iii], meaning that non-thermal effects should appear also in this scenario. A LENS type system could be used to verify existence of, explore and quantify such effects.

3. ***Basic science.*** A LENS detector would also contribute to advancing basic science. Two examples of LENS relevant basic science applications are:
   (i) Measurements of the TT neutron spectrum from ICF implosions in the region below 4 MeV, not observable with the currently available MRS[iv]. The TT neutron spectrum cannot at this time be accurately modeled by theorists and the development of a theoretical framework would greatly benefit from the availability of measurements also in this neutron energy region[v].
   (ii) Planned NIF measurements of the (n,γ) cross sections relevant to the weak s-process [[vi]]. In this experiment, γ rays from neutron capture reactions in heavy nuclei loaded in the ICF capsules

will be measured to determine the branching ratios. The cross sections for this type of (n,γ) reactions peak around 90 keV. The success of the experiment requires accurate measurement of the source neutron spectrum at these low energies. This could be accomplished by LENS.

MIT is currently investigating what type of spectrometer system would best accomplish the listed tasks. A detector combining the proton or deuteron recoil telescope[vii] and lithium sandwich[viii],[ix] concepts is emerging as a promising candidate (FIG 1). In this setup, the lithium sandwich detector would cover the lower (below 1 MeV) energy range not feasibly diagnosed with a thin-foil based system due to the finite range of low energy recoil particles. Detailed optimization of the particle recoil system remains to be done, but it is clear that an efficiency of order 10^{-9} with a resolution of about 130 keV at 2.45 MeV can be easily achieved.

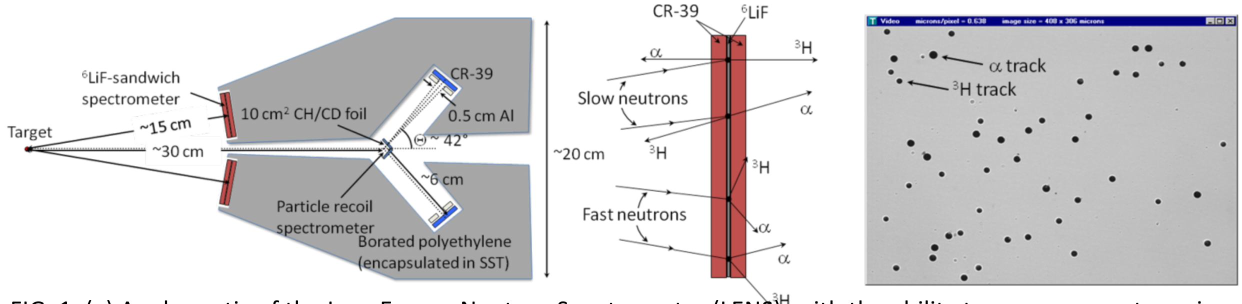

FIG. 1. (a) A schematic of the Low-Energy Neutron Spectrometer (LENS), with the ability to measure neutrons in the energy range 0.1-5.0 MeV. This spectrometer will be used for diagnosing ρR, Y_n, T_i, and possible non-thermal features in an implosion, and for conducting basic science experiments, as discussed in the text. The spectrometer is a compact system that is based on the ^{6}LiF-sandwich technique and particle-recoil technique (deuterons or protons). The advantage of such a system is that these two techniques can be used independently of each other. In the particle-recoil technique, the energy of the neutron is determined from the recoil-particle energy, which in turn is determined from the particle-track size in the CR-39. (b) The ^{6}LiF-sandwich spectrometer. (c) A scan image of CR-39 triton and alpha tracks, from which the energy of these particles and the neutron that produced them can be determined.

The time scale for implementation of this type of detector system is realistically medium term, about 2 years, due to the R&D needed. Implementation should not impact other operations at the OMEGA facility. The first goal of this work is to develop, test, and implement a prototype LENS for OMEGA. The tests will be done primarily on the MIT accelerator. After the spectrometer has been successfully implemented on OMEGA, the experience gained from this effort will be used to design, test, and implement a LENS system optimized for the NIF. This system will serve the same functions as the OMEGA prototype, but with further improved performance thanks to substantially higher yields on the NIF.

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[i] V. Glebov, private communication
[ii] D.R. Welch et al., PRL 103(2009)255002; D.R. Welch et al., PoP 17 (2010) 072702
[iii] P.B. Radha, private communication
[iv] D.T. Casey et al, Evidence for stratification of deuterium-tritium fuel in inertial confinement fusion implosions, provisionally accepted for publication in PRL, and D.T. Casey et al, Measurements of the TT neutron spectrum and

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[v] D. McNabb, private communication

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[ix] H. Bluhm and D. Stegemann, Theoretical and Experimental Investigations for an Improved Application of the ^{6}Li-Semiconductor sandwich spectrometer, Nuclear Instruments and Methods 70, 141-150 (1969)