Boosting the performance of IFE targets with magnetized fuel

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This proposal is in the category of **IFE concepts – target physics**

Executive Summary

Magnetizing the fusion fuel in direct and indirect drive (DD and ID) ICF implosion schemes is a transformational strategy that can boost the performance of any design that is close to ignition and push it potentially into the runaway self-heating regime [1]. Magnetizing fusion fuel shuts off electron thermal conduction loss in the directions orthogonal to the B-field [2] and traps alpha particles generated in deuterium-tritium (DT) fusion events. Consequently, the imploded core temperature increases > 30% leading to a significant yield increase in certain designs. Experiments at the University of Rochester, Rochester NY [3,4,5,6] and Sandia National Laboratory (SNL), Albuquerque NM [7,8,9,10] over the past decade have demonstrated that an axial magnetic field (open field lines) in laser and magnetic direct drive leads to performance improvements in close agreement with simulations. Applying a 40 T field to the high yield (1.35 MJ) NIF shot with no other changes increases the yield by 2x. There are modified designs, relative to this NIF experiment, that use a larger and thicker capsule and can burn more of the fuel giving ≥ 10 MJ yield. Magnetizing these designs shows that the same yield can be achieved at 80 % of the laser energy / power. This can be an advantage to IFE systems where application of a target B-field could reduce the required drive and increase the life-time of laser components. Recent experiments on magnetized gas-capsule ID implosions [11] on NIF show a 35% hot-spot temperature increase and a 3.5 times yield increase. These results are in good agreement with post-shot simulations and show that magnetized cryogenic DT-layered experiments may be able to generate the predicted yield improvements. Magnetized fuel opens up a new design space for implosions which can offer versatile IFE target designs. Exploring techniques to generate closed-field lines in the fuel could add another transformational aspect to magnetizing the fuel, by eliminating direct heat loss and alpha particle loss. It is important for IFE schemes to explore and develop high performing magnetized target designs, explore methods to obtain closed fields in the capsule and test these designs.

Expectations for magnetizing high-performing implosions on NIF

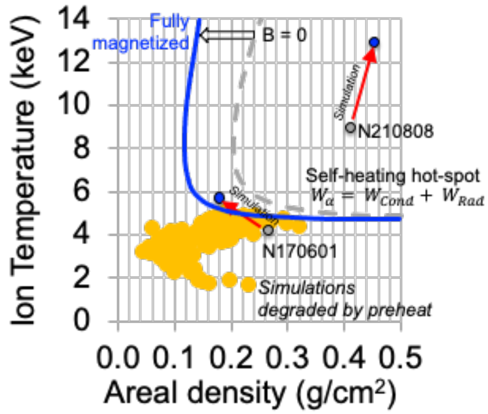

Figure 1 – Plot of T_{ion} vs ρR for NIF implosions from 2010 – 2018 (in yellow) [12] and two specific experiments, N170601 and N210808. The gray dotted line represents the boundary where alpha re-heating of the hot spot equals the losses from thermal conduction and radiation. Adding a 40 T B-field with no other changes doubles the yield for both shots; modified designs can generate much higher yield at reduced drive requirements. The self-heating hot-spot boundary also shifts to the left as shown by the blue line, indicating that implosions with lower ρR and a B-field may achieve run-away self-heating.

Capsule-only simulations [13] of the effect of magnetizing two specific NIF implosions are shown in Fig. 1. The simulations are degraded using preheat to obtain agreement between the unmagnetized simulation and the experimental data. The two shots simulated are N170601, which had 55 kJ of yield and N210808 which had 1.35 MJ of yield. Both experiments use a high-density carbon ablator and a 3-shock laser pulse [14,15]. Applying a 40 T magnetic field to the unmagnetized simulations (and using the same preheat) causes both experiments to double their yield. Magnetization of both NIF experiments show an increase in simulated hot-spot temperature of more than 30%. The areal density for magnetized N170601 decreases, mostly because the hot-spot is higher temperature and the same drive leads to less compression. However, N210808 shows an increase in areal density. The nuclear burn wave in this experiment sweeps up some of the cold fuel into the hot-spot leading to an increase in areal density. The important point is that in simulations, we find that adding a B-field to the implosion can lead to a significant improvement in the performance. In addition, we find that modified designs can offer reproducible high yield while relaxing the requirements on the laser energy, target fabrication and DT ice-layer quality.

Experimental evidence for improved performance of NIF ID implosions

Experimental evidence demonstrating performance improvements with magnetization on NIF was obtained over the last year. Room temperature experiments using D2-filled HDC gas capsules placed in a special high resistivity hohlraum ($AuTa_4$ alloy) showed a 1.1 keV (35%) temperature increase and a 3.5 times yield increase with the application of a 26 T magnetic field. Post-shot simulations using radiation magnetohydrodynamic models show a good agreement with the experimental results. Experimental evidence of a compressed core magnetic field is in the measured secondary (14.1 MeV) to primary (2.45 MeV) neutron ratio. A simple 0D model for this ratio which requires no tuning gives an average core B-field of 4.9 kT [16] based on the measurements. The experimental performance improvements make a good case for continuing the effort toward testing magnetized cryogenic DT ice layered implosions on NIF.

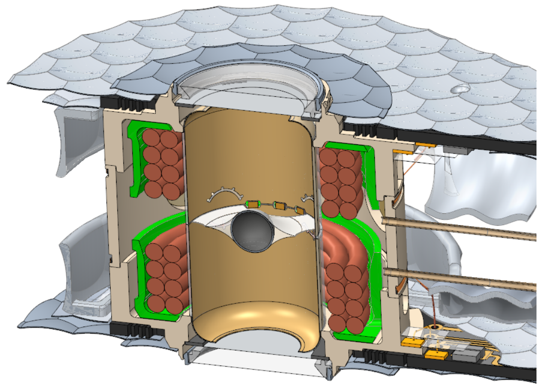

Figure 2 - Sketch of the magnetized cryo DT-layered target. Separate heaters are used to adjust the temperature of the hohlraum as well as the wire coil.

The current NIF facility schedule will allow magnetized layered implosion experiments to start by 8/24 at 30 T. There is an ideal opportunity now to begin exploring the high performing design space afforded by magnetized fuel and identify several designs for testing on NIF. Now is also an important time to explore technologies for creating closed-field geometries for spherical fuel layers [17]. The cryo-pulser is setting the experimental readiness schedule but once the system becomes available the best designs could be tested and improved. Figure 2 shows a sketch of the cryogenic magnetized hohlraum target planned for NIF ICF experiments. However, there could be significantly modified target designs that are better suited to IFE schemes. Any of these designs require development which should be starting now.

Proposal details

This is a proposal to develop new magnetized fuel target designs that are relevant to IFE schemes and show promise of high yield. In addition, there should be an effort to design and explore closed field technologies capable of providing significant advantages to IFE targets. Finally, there should be experimental tests of the designs on NIF to quantify their performance. The experiments require target fabrication and a small team to execute and analyze the experiments. The end goal of these modeling and experimental studies is to identify several magnetized implosion designs with significant yield that can be used directly in the first IFE schemes.

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