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Status of the Laser Inertial Fusion Energy (LIFE) Hohlraum Point Design

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Abstract: *Progress on the hohlraum point design for the LIFE engine is described. New features in the original design [Amendt et al., Fus. Sci. Technol.* ***60****, 49 (2011)] are incorporated that address the imperatives of low target cost, high manufacturing throughput, efficient and prompt material recycling, an ability for near-term testing of key target design uncertainties on the National Ignition Facility, and robustness to target chamber environment and injection insults. To this end, the novel use of Pb hohlraums and aerogel-supported liquid DT fuel loading within a high-density-carbon (HDC) ablator is implemented in the hohlraum point design.*

1. Introduction

The National Ignition Facility (NIF) is aiming to demonstrate ignition by 2013 using the central hot spot mode of ignition and propagating thermonuclear burn [1]. A success-based, follow-on strategy is to advance inertial fusion as a carbon-free, virtually limitless source of energy by the mid-21st century that substantially offsets fossil fuel technologies. To this end, an intensive effort is underway to leverage expected success at the NIF and to provide the foundations for a prototype market entry plant, followed by a demonstration power plant operating at 1 GWe. The current design goal for LIFE is to accommodate ~2.2 MJ of laser energy (entering the high-*Z* radiation enclosure or "hohlraum") at a 0.351 μm wavelength operating at a repetition rate of ~16 Hz, and to provide a fusion target yield of 132 MJ [2].

The requirements of a LIFE point target design are challenging in many ways. First, the integrated target (hohlraum + capsule) must survive intact the injection phase (~700 *g*'s of acceleration) to target chamber center. This means that the position of the capsule relative to hohlraum center must be maintained to within 100 μm and the integrity of the cryogenic deuterium-tritium (DT) fuel layer is not appreciably compromised. Second, the materials comprising the integrated target must be low cost, recoverable and recyclable [3], as well as compatible with chamber system operations [4]. Third, the target design must ensure adequate performance margin to assure reliable base load electricity generation. This includes sufficient robustness to hydrodynamic instability growth in the capsule and benign laser backscatter from parametric instabilities generated in the hohlraum, gas-fill and capsule blowoff plasmas. Fourth, the design of the LIFE target must not substantially deviate from the current laser beam geometry on the NIF in order to allow direct testing of ignition thresholds and performance margins. In addition, the target design must allow for LIFE-relevant sensitivity studies on the NIF to define allowed laser pointing and target fabrication errors.

The technique of choice for developing a LIFE target point design are 1- and 2-dimensional radiation hydrodynamics simulations that self-consistently incorporate laser beam transport, x-ray radiation transport, atomic physics, and thermonuclear burn.[2] These simulations form the basis for assessing the susceptibility to hydrodynamic instability growth, target performance margins, laser backscatter induced by plasma density fluctuations within the hohlraum, and the threat spectrum emerging from the igniting capsule, e.g., spectra, fluences and anisotropy of the x rays and ions, for input into the chamber survivability calculations. The simulations follow the guidelines of a "point design" methodology, which formally designates a well-defined milestone in concept development that meets established criteria for experimental testing.

2. Challenges with current point target design

The previously reported LIFE point target design [5] has several features that need to be redressed on the path to establishing inertial fusion energy viability.

2.1 Pb hohlraums

The former point design [5] was based on a NIF ignition point design and used a gold-uranium hohlraum wall for optimal hohlraum efficiency. This material is not compatible with the target fabrication costs and non-proliferation requirements of a LIFE power plant. Consequently, Pb has been proposed as an economical and low activation candidate hohlraum material. Recent experiments on the Omega laser facility have demonstrated comparable performance to pure Au hohlraums. However, a 15-17% decline in hohlraum efficiency with Pb is expected compared with Au-U, based on integrated hohlraum simulations.

2.2 Foam loading of DT fuels

The previous design assumed a solid DT fuel layer within the HDC ablator [5]. Unfortunately, the standard method of β-layering for self-smoothing of the gas/solid DT interface is prohibitively time-consuming (currently ~12 hours) and is projected to lead to an unacceptably high tritium inventory (with accompanying strict and costly nuclear regulatory requirements). A promising solution to this problem is the use of nano-porous, carbon-based, DT-wetted, annular foams [6]. The tradeoff in such a technology is the 14% lower fuel density (and target output energy gain) and contamination of the fuel by carbon for enhanced (radiation) energy losses. The revised target point design uses 20 mg/cc $CH_{1.2}$ (dicyclopentadienyl) nano-porous foams for liquid DT loading of the LIFE capsule.

2.3 Laser energy balance

Another challenge with the former design was the required large imbalance (~3×) in energy (and power) between the inner beams (30° incidence angle relative to the hohlraum symmetry axis) and outer beams (50°) required to achieve acceptable x-ray drive symmetry on the capsule. Such a partitioning of laser energy promotes a high risk of Raman backscatter in the inner cone, due to the larger path length and intensity. In addition, the LIFE power plant design benefits significantly from achieving a more uniform distribution of the (laser) line replaceable units in the target chamber exterior.

3. Revised LIFE target point design

Figure 1 shows the revised hohlraum and laser cone geometry for the current point design. In order to achieve more energy balance between the inner and outer cones, the hohlraum was appreciably shortened, the hohlraum gas fill density was increased to minimize symmetry excursions in time, and the cone angles modified (35°, 55°) to provide greater clearance with the pair of laser entrance holes (LEHs) and P2-shields. By virtue of using Pb hohlraums and the foam-supported DT fuel, an energetics penalty of nearly 600 kJ is expected. However, the use of a shorter hohlraum and higher gain capsule design is found to appreciably offset these two sources of inefficiency.

The 1-D thermonuclear yield is 242 MJ with an input laser energy of ~2.7 MJ. Symmetry tuning of the hohlraum is accomplished by repositioning the laser beams, by varying the power fraction of the two cones of beams in a time-dependent manner, by adjusting the position and height of the P2-shield, or by changing the LEH fraction. Over 95% of the 1-D yield is expected when the hohlraum flux symmetry is satisfactorily tuned. The requirement of nearly equal cone energy fractions is now met with this improved hohlraum geometry. An assessment of backscatter arising from laser-plasma interactions is planned, and sensitivity to laser pointing and hohlraum/capsule fabrication errors will also be assessed. In addition, the overall performance margin of the design will be quantified, as well as the susceptibility to hydrodynamic instability. All of these degradation effects are seen as ultimately testable on the NIF.

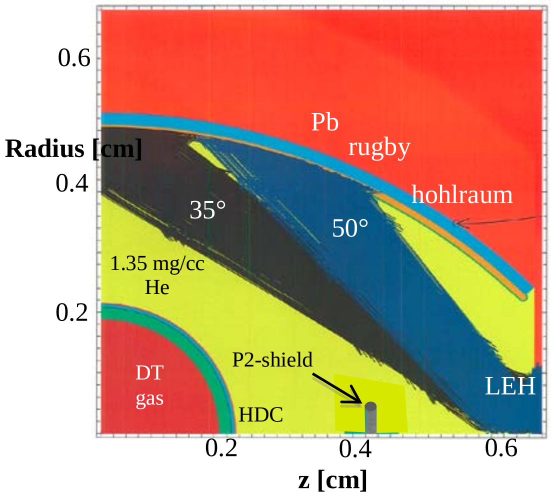

Fig. 1. Schematic of (quarter) rugby-shaped hohlraum showing HDC ablator, P2-shield and incident laser cone angles.

4. Conclusions

Progress in developing an improved LIFE target point design in 2-D radiation-hydrodynanics simulations is described that aims to redress the key issues of target material cost and recovery, simplified fabrication protocol for DT fuel loading of the capsule, and chamber system operation compatibility. Three main improvements to the original LIFE target point design are discussed: (1) use of Pb hohlraums for low material and fabrication costs along with low activation; (2) aerogel-supported DT fuel loading for reduced tritium inventory and simplified fabrication protocol; and (3) balanced inner and outer laser cone energy for LIFE facility optimization.

Acknowledgement

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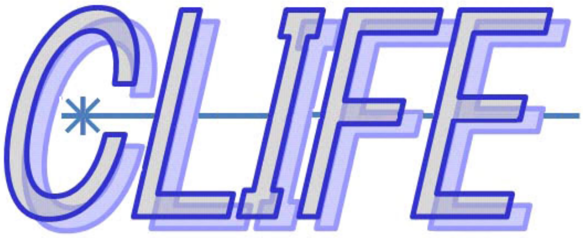

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[1] F. Rotermund, C. J. Yoon, K. Kim, S. Kurimura and K. Kitamura, "Optical parametric chirped pulse amplification of Cr:forsterite laser pulses in periodically poled stoichiometric $LiTaO_3$ at 1 kHz," Appl. Phys. **B 85**, 17-20 (2006).

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[2] K. Kuroda, "*Laser Display* -from basics to applications-", K. Kuroda, K. Yamamoto and S. Kurimura, ed. (Optronics, Tokyo, 2010).

For citation of a book as a whole or book chapter, authors or editors are listed first, followed by the title in italics, and publisher, city, and year in parenthesis. Chapter number may be added if applicable.

[3] S. Kurimura, *Handbook of Multifunctional Ceramics* (NTS, Tokyo, 2011), Chap. 2-2-2.

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