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ABSTRACT

UTILITY OF THE U.S. NATIONAL IGNITION FACILITY FOR DEVELOPMENT OF INERTIAL FUSION ENERGY

This paper assesses the potential contributions of the U. S. National Ignition Facility (NIF) to the development of Inertial Fusion Energy (IFE). We find the NIF can provide important data in areas of target physics and fabrication technology useful to a variety of IFE driver and target options, in generic IFE target chamber phenomena and materials responses to target emissions, and in many IFE fusion power technology areas.

1. INTRODUCTION

The demonstration of inertial fusion ignition and gain in the proposed U. S. National Ignition Facility (NIF) [1], along with the parallel demonstration of the feasibility of an efficient, high-repetition-rate driver, would provide the basis for a follow-on Engineering Test Facility (ETF) [2], a facility for integrated testing of the technologies needed for inertial fusion energy (IFE) power plants. The NIF target chamber is shown in Fig. 1. A workshop was convened at the University of California, Berkeley on February 22 - 24, 1994, attended by 61 participants from 17 U.S. organizations, to identify possible NIF experiments relevant to IFE. We considered experiments in four IFE areas: target physics, target chamber dynamics, fusion power ethnology, and target systems, as defined in the following sections.

2. IFE TARGET PHYSICS EXPERIMENTS

The NIF ignition target physics program with indirect drive targets as the baseline plan will explore a range of target yields and gains, studying capsule implosion characteristics and symmetry requirements, and fusion ignition and burn physics. A total of 192 beamlets generating 1.8 MJ, 500 TW at 0.35 μm, can each amplify independent light input pulses, allowing significant flexibility to produce variable pulse shapes up to 20 ns and in different illumination geometries, including both direct and indirect drive capabilities. Table I lists IFE target physics issues for generic ion and laser drivers, and for direct and indirect drive illumination geometries. "X's" marked in Table I indicate those issues that could be largely resolved using NIF capabilities. The table shows that the NIF can resolve most IFE target physics issues. NIF, along with Omega Upgrade, PBFA II, and other ICF facilities around the world will be able to address all of the issues. The completion of these experiments will provide the target physics basis to proceed with an ETF.

Figure 2(a) shows an indirect drive target design for a heavy-ion fusion (HIF) target based on the work of Ho and Tabak [3], 2(b) the laser-driven NIF target for ignition tests, and 2(c) a conceptual NIF-HIF model target to simulate capsule and x-ray transport physics relevant to 2(a). Many fuel capsule requirements for 2(a) are less demanding than those for 2(b), as indicated. Recent success in volume-heating dense gas targets on the NOVA laser facility at LLNL supports future study of the use of gas radiators as in 2(c) to simulate the foam radiators of 2(a) [3].

3. TARGET CHAMBER DYNAMICS EXPERIMENTS

IFE target chamber dynamics issues addressable on NIF are: characterization of IFE target soft x-ray and debris emissions, response of first wall materials and protective-wall fluids to target emissions, and subsequent gas dynamics of the vapor blow-off, vapor condensation, and vacuum recovery. A typical NIF target output at a full target yield of 20 MJ will put ~ 50 J/cm2 of soft x-rays and target debris plasma on surfaces ~ 1 meter away from the target, similar to the deposition from ~ 350 MJ yields on walls ~ 4 m away in an IFE power plant target chamber. Thus, NIF can provide a reduced-scale test chamber environment representative of an IFE power plant. There are several 1-D and 2-D hydrodynamics and radiation-hydrodynamics codes that need to calibration with NIF chamber-dynamics data, including CONRAD [4], HYADES [5], SRIPUFF8 [6], L2D [7], PHD-4 [7], and TSUNAMI [8]. NIF chamber dynamics experiments will need new diagnostics to measure ion velocities, energies, species, and flux originating from targets, and improvements of existing instruments to measure gas dynamics and condensation phenomena (e.g., fast response pressure transducers).

Figure 3 shows a possible NIF experiment designed to test the predictions of a chamber dynamics code such as TSUNAMI. The test assembly consists of a conical chamber in which a candidate material at the back surface is ablated by x-rays that are admitted through a hole in the larger front plate. The conical shape provides decreasing pressures along the row of transducers to test the 2-D modeling capability of codes. Condensation rates can be determined from pressure decay, and the amount and distribution of condensed material from post-shot analysis of the cone's inner and back surfaces.

4. FUSION POWER TECHNOLOGY EXPERIMENTS

Basic operation as well as specific experiments on NIF can contribute data on IFE fusion power technology in the following areas: fusion ignition; design, construction, and operation of NIF (integrating many prototypical IFE subsystems); response of first-wall protection schemes; dose rate effects on radiation damage in materials; data on tritium burnup fractions in the target, some important tritium inventory and flow rate parameters, and data on achievable tritium breeding rate in samples; and neutronics data on radioactivity, nuclear heating and radiation shielding.

With uniquely-high neutron dose rates of 10 to 1000 dpa/s, NIF can be useful for basic physics of radiation effects in materials, even for single shot exposure of samples. Examples include: cascades (morphology, size, fraction of free and clustered defects, impurities); microstructural evaluation; electrical properties; optical properties (fiber optics, coatings); and molecular cross linking. NIF can provide data testing Molecular Dynamic Simulation [MDS] codes [9], to improve predictions of microscopic bulk material responses to neutron damage. Figure 4 indicates how MDS calculations predicting overlap of damage clusters (a dose rate effect) can be validated with samples exposed to a single NIF shot.

5. IFE TARGET SYSTEMS TESTS

The NIF can provide important performance and sensitivity tests of candidate IFE target fabrication and transport parameters. In Table 2, we assessed both the potential NIF usefulness and uniqueness to resolve IFE target fabrication and transport issues. By stagger-firing four sections of the NIF laser chains ~ 200 ms apart, NIF may test a series of non-ignited model targets injected in a 5 Hz burst, to test the repeatability of beam-target engagement accuracy, in a multi-shot chamber environment. Most remaining IFE target systems developments can pursued separate from the NIF.

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TABLE I. IFE TARGET PHYSICS ISSUES FOR ION AND LASER DRIVERS, DIRECT AND INDIRECT DRIVE. AN 'X' INDICATES ISSUES THAT CAN BE LARGELY RESOLVED WITH THE NIF CAPABILITIES.

	ION DRIVERS		LASER DRIVERS	
	Indirect	Direct	Indirect	Direct
Usability of a variety of pulse shapes	X	X	X	X
Radiation flow, illumination geometry and internal pulse shaping	X		X	X
Sensitivity of capsules to radiation asymmetry	X		X	X
Materials issues (capsule, hohlraum, ablator)	X	X	X	X
Fabrication surface finish and precision	X	X	X	X
Capsule mounting and injection	X		X	X
Power vs. energy tradeoffs	X		X	X
Output spectra and shielding	X	X	X	X
Reduced tritium	X	X	X	X
Advanced targets	X	X	X	X

TABLE II. ROLE OF NIF IN IFE TARGET FABRICATION AND TRANSPORT ISSUES

IFE TARGET FABRICATION ISSUES	NIF Usefulness*	NIF Uniqueness**
Low-cost mass-production techniques for capsules and their effect on quality, materials choice and gain	2	3
Low cost mass production of laser driver hohlraums	2	3
The effect of cryogenic layer quality on gain	2	3
Automated cryogenic assembly techniques	3	3
Fast fill techniques for low tritium inventory	2	3
High-throughput quality inspection techniques	2	3
IFE TARGET TRANSPORT ISSUES		
Injection techniques for high rep-rate cryogenic targets	0	1
Time and space accuracy and sensing	0	1
Integration	2	1 - 2
Target survival under acceleration	2	3
Thermal protection and temperature control	2	2
Chamber environment effects on trajectory	1 - 2	3
Demonstration of high rep rate operation	2	3

* Usefulness: 3 = Complete resolution, 2 = Partial resolution, 1 = Useful information, 0 = No use

** Uniqueness: 3 = NIF unique and required, 2 = NIF not unique but could be used, 1 = Issue addressed better or cheaper in new facility, 0 = Issues addressed better or cheaper in existing facility.

FIGURE CAPTIONS

FIG. 1. The target chamber of the U.S. National Ignition Facility. The 192 beams shown distributed around two pairs of cones for vertically-oriented indirect-drive targets, can also be configured for direct-drive experiments. The equatorial plane allows good access for remote insertion of targets, test samples, and diagnostics.

FIG. 2. Schematic views of a heavy-ion-driven HIF target design for an IFE power plant 2(a); the laser-driven NIF target for ignition tests 2(b), and a conceptual NIF-HIF model target 2(c) to simulate the capsule and x-ray transport physics of 2(a).

FIG. 3. An experiment on NIF to calibrate gas dynamic codes.

FIG. 4. A Molecular Dynamic Simulation experiment on NIF. Samples placed within 20 cm of a NIF yield capsule will receive a significant exposure to 14 MeV neutrons. The Ta shield will stop most x-rays. Electron microscope images of damage sites will be compared to MDS code predictions, as shown on the right.

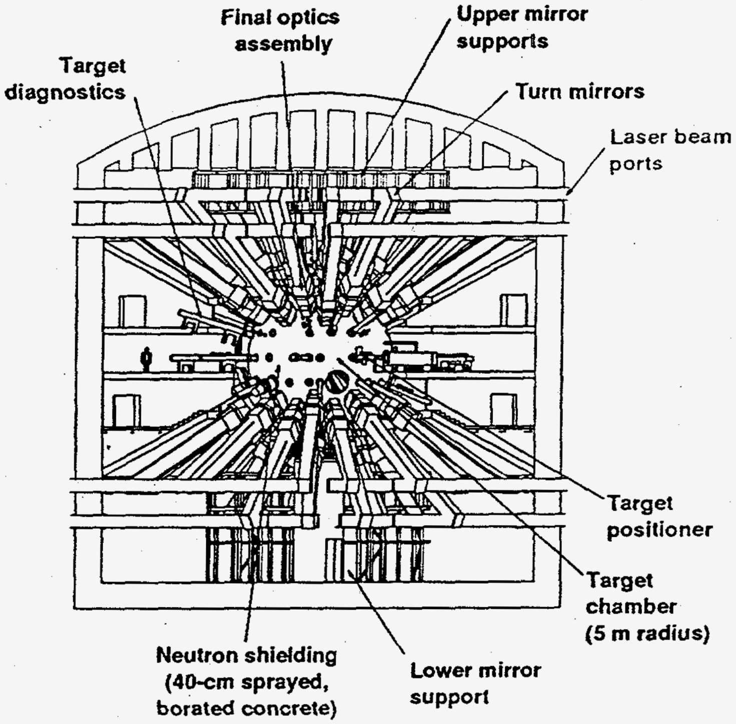

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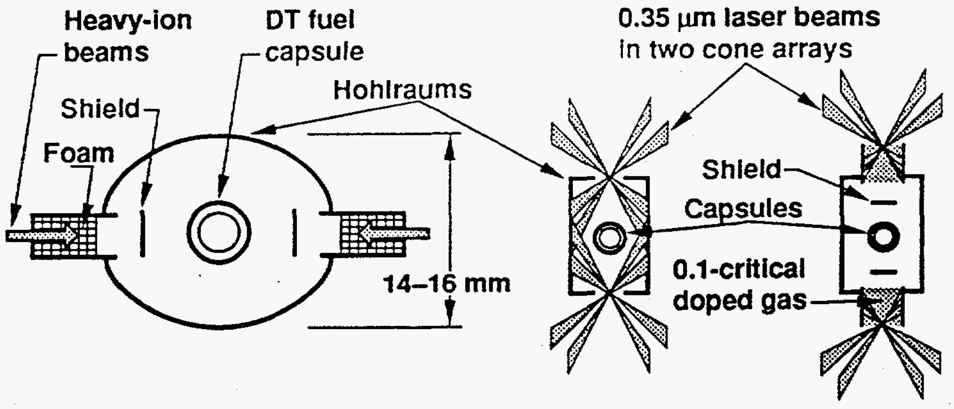
Fig. 1



	(a) HIF target	(b) NIF target	(c) NIF-HIF model
Driver energy (MJ)	4 to 6	1.8	
Yield (MJ)	300 to 450	15	
Convergence ratio	27	36	
In-flight aspect ratio	40	45	
Imploded speed (cm/µs	32	41	
Max density ρ (kg/m^3)	6.5×10^5	1.2×10^6	
Max hohlraum temp (eV)	260	300	

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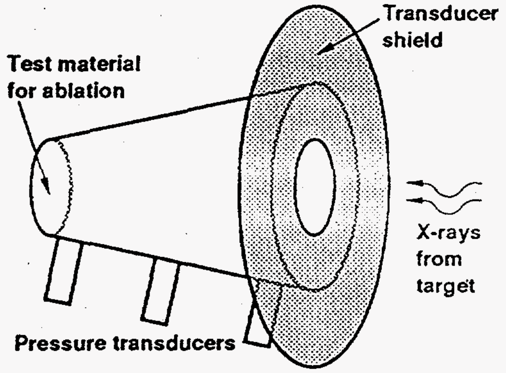

Pressure transducers	Peak values, condensation effects, reflection strength
SEM/AFM	Post-shot material removal depth from near surface
XRF	Trace surface analysis for condensed material distribution

		IFE first wall		
	NIF expt	OSIRIS	HYLIFE	CASCADE
X-ray fluence @ radius	200J/cm^2 0.4 m	60J/cm^2 3.5 m	2000J/cm^2 0.5 m	60J/cm^2 3.1 m
Ablation depth	20 μm	20 μm	200 μm	3 μm
Time scale	40 μsec	100 μsec	50 μsec	90 μsec

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Fig. 3

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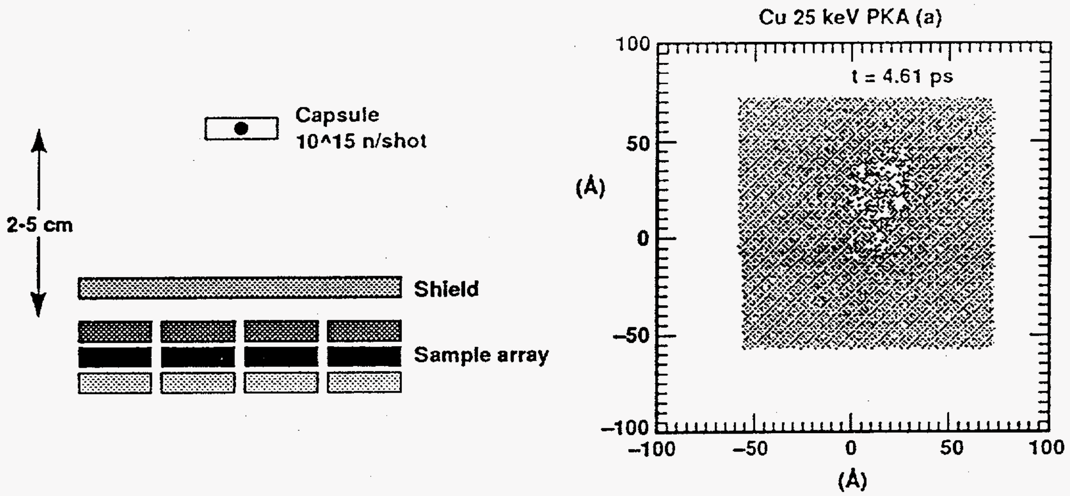

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Fig 4

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