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Relevance of the U.S. National Ignition Facility for Driver and Target Options to Next-Step Inertial Fusion Test Facilities *

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Achievement of inertial fusion ignition and energy gain in the proposed U.S. National Ignition Facility [1] (NIF- Figure 1) is a prerequisite for decisions to build next-step U.S. inertial fusion facilities for either high yield (> 200 MJ) or high pulse-rate (> 5 Hz) [2,3]. There are a variety of target and driver options for such next-step inertial fusion test facilities, and this paper discusses possible ways that the NIF, using a 1.8 MJ glass laser in both direct and indirect-drive configurations, can provide target physics data relevant to several next-step facility options. Figure 2 illustrates several possible next-step facility options for the U.S., and how the NIF contributes to the target and driver decisions for those options. Next step facility options illustrated in Fig. 2 include the Engineering Test Facility (ETF) [4], which needs several-Hz pulse-rates for testing relevant to Inertial Fusion Energy (IFE) development. An option for high yield, called the Laboratory Microfusion Facility [5] (LMF), does not require such high pulse-rates, but may still benefit from driver technologies capable of much higher shot rates than possible with glass lasers. A high-pulse-rate driver could also be used for a combined ETF/LMF facility, driving multiple target chambers with a common driver [6]. Driver technologies that could support high-pulse rates for next-step options include heavy-ion (HI) and light-ion (LI) accelerators, diode-pumped solid-state lasers (DPSSL), and krypton-flouride (KrF) gas lasers.

A U.S. workshop [7, 8] last year found that the NIF can contribute data important to IFE in fundamental target physics relevant to both ion and laser drivers, and in direct as well as indirect drive configurations. The NIF could be used to provide important data for IFE in generic areas of target chamber damage and materials responses, neutron activation and heating, tritium recovery and safety management, and in performance tests of prototypical IFE targets and injection systems. In the study of ignition in both direct and indirect-drive, the NIF would explore generic ICF fuel capsule implosion physics common to all driver and target options for next-step facilities. In the following, we point out specific ways in which the NIF could be used to study target physics specifically relevant to the above-mentioned driver options for such next-step facilities, as well as how the NIF laser system itself could be relevant to the DPSSL option.

Figure 3 shows how the 192 NIF laser beams can be configured for both indirect drive (a) and direct drive (b) geometries. The direct drive configuration is achieved by moving 24 of the 48 final optics assemblies (each assembly containing a 2x2 array of beams) into ports closer to the equater of the NIF target chamber. The indirect-drive configuration (a) provides illumination of two ends of hohlraums in a vertical axis orientation from beams arranged around two pairs of cones on the top and bottom of the target chamber. This configuration will be used to test ignition in indirect-drive laser targets, where the beams enter the hohlraum through holes or thin windows (the upper target shown next to Fig. 3a). This configuration can also be used to test

IFE-model targets simulating heavy-ion (HI) targets (the lower target shown in Fig. 3a). In this "HI-simulation" target, the laser beams are absorbed in "gas bags" at each end filled with 0.1-critical neopentane. This hydrocarbon gas can be doped with a high-Z gas like xenon to provide similar radiation optical depth as that provided by the Pb dopant used in the beryllium converters of the HIF target. Recent success in volume-heating dense gas-bag targets [9] on the NOVA laser facility at LLNL supports the suggestion that such gas radiators could be used to simulate heavy ion converters. Because of x-ray loss out the ends of the gas-bag radiators, the HI-simulation target shown in Fig.3a would have lower hohlraum-to-capsule coupling efficiency than would the actual IFE target of Fig.4a, which has high-Z radiation cases enclosing the ends of the radiators (through which the heavy-ions can pass). Thus, the HI-simulation targets would not be expected to achieve ignition, but would be useful for studying hohlraum drive symmetry relevant to HI-IFE targets. Since the soft x-ray intensity radiating out of the beam converter sources on the poles, viewed from the capsule, would be higher than the x-ray flux from the equator of the hohlraum, "shine shields" such as shown in Fig. 3a (lower target) and Fig. 4a are used to improve HIF capsule x-ray drive symmetry. Recent NOVA experiments with shine-shields inserted into indirect-drive laser targets have shown that such shine shields can be used to control the x-ray drive symmetry on the capsule[10].

Recent studies [11] have found that high-Z plasma blow-off from the HI-target hohlraum walls into the channels between the shine shields and the beryllium converters can significantly impede the transport of soft x-rays through those channels, and thereby affect the capsule implosion symmetry. These type of HIF-model targets can and should be first tested in existing facilities like NOVA at ~1-ns pulse lengths. But such targets could also be tested in NIF at longer pulse lengths up to 10 to 20 ns more relevant to the HIF designs, where wall plasma blow-off can be more important. Such experiments in NIF can test ways mitigate the effects of hohlraum wall blow-off for HIF targets by optimizing the hohlraum and shine shields geometry, and by filling the hohlraum with various densities of helium gas.

The NIF direct-drive beam configuration (Fig.3b) would be used to test both laser direct-drive (the upper target shown next to 3b), and spherical foam-overcoated capsules to simulate indirect-drive light-ion targets (the lower target shown next to 3b). The direct-drive targets would use 48 spherically-symmetric illumination points, each illumination point overlaped with 2x2 beamlets at different wavelengths to provide the bandwidth needed for 2-dimensional SSD beam smoothing. Direct-drive capsule ignition and gain performance could be studied for a range of capsule aspect ratios, surface finishes, and pulse-shapes (various adiabats α) relevant to direct drive with DPSSL and KrF laser options for next-step facilities. By re-aiming the 48 NIF 2x2 beams to 12 spherically-symmetric illumination points on a thick-foam overcoated capsule, the NIF can be used to study target physics issues important to light-ion (LI) targets relevant to the LMF [12]. At some depth into the foam past the outer laser absorption zone, such light-ion simulation targets could be used to study the symmetrization from 12 illumination points by x-ray transport through the foam, as well as simulate internal pulse-shaping in the capsule ablator. Because there would be no outer high-Z radiation case to allow laser beam absorption, such "LI-simulation" targets would have lower coupling efficiency from laser energy to the capsule than in actual light-ion targets (Fig. 4b), which would have an outer radiation case. Thus, as in the "HI-simulation" targets, such "LI-simulation" targets would not be used for ignition, but to study relevant issues of x-ray transport and capsule drive symmetry.

Besides target physics relevant to each driver option for next-step facilities, the NIF target chamber could also be used to provide data relevant to wall protection and chamber recovery. For all next-step facility options, the NIF could provide data on chamber wall and final optic materials damage to soft x-ray and target debris emissions from direct or indirect-drive targets appropriate to each option. For next-step facility target chamber concepts using high-Z gas for attenuation of target x-rays and debris, the NIF chamber [13] might be adapted to allow a gas fill (such as a few torr of Argon or Xenon), to test the degree of protection such gases could provide to final optics and in-chamber structural surfaces. The decay of gas ionization, shock-reverberations, and cool-down times subsequent to each shot in the NIF would be useful to determine the chamber recovery time to ambient conditions, which would be important to the maximum pulse repetition-rates that may be allowed in next-step facilities. Experiments with a series of no-yield targets injected into the NIF chamber (such as several foil disks injected 0.2 second apart), might be used to simulate multi-pulse chamber recovery dynamics in a burst of shots [13]. This type of experiment may be possible since all NIF 192 beams have independent front-end pulse timing, allowing laser chain sections to be stagger-fired.

In addition to providing data relevant to target physics and target chamber clearing and materials damage, operation of the NIF's 192 beam glass laser will itself assist the development of any laser driver in terms of broad considerations such as the following:

1. Deployment of hundreds of beams that must be aligned, synchronized, balanced for uniform delivery of energy, and transported through a switchyard to interface with a target chamber.
2. Arrangement of the beams into cones or other patterns subtending large solid angles upon entrance through the envelope of the target chamber.
3. Transport of UV light, which requires the development of high-damage threshold optics and coatings.
4. Use of the modularity of the laser system in the formation of a suitable pulse shape for a high-gain target.
5. Development of bandwidth (i.e., a band of wavelengths) and the investigation of the effect of bandwidth on target performance.

The NIF laser development and operation can have a special relevance to a DPSSL option for a next-step ICF facility. A major difference is the NIF uses Nd:glass side-pumped with flashlamps, while a DPSSL uses a special crystal, Yb^{3+}-doped $Sr_5(PO_4)_3F$ (called Yb:S-FAP), end-pumped with laser diodes. Apart from using a different solid-state gain medium and method of pumping, a recent DPSSL design[14] shares many features in common with the NIF laser: Both use four-pass regenerative amplifiers operating near 1.05-μm wavelength, with an optical switch composed of a Pockels cell and a polarizer. Both use similar beam transport equipment and both use harmonic conversion to 3ω in KD*P crystals. Both must interface with high-gain targets using hundreds of laser beams configured around a target chamber. The NIF laser operation can verify the functionality of a DPSSL driver in several areas: front-end electronics, four-pass regenerative laser amplifier operation, efficient conversion from 1ω to 3ω, computerized control equipment for aligning, synchronizing and energy-balancing many beams, final-optic interfaces to the target chamber, damage thresholds for optics and coatings, pulse shaping, beam transport in the target chamber with residual gas, focusability of 3ω beams on target, and target physics in both direct and indirect-drive configurations. Individual DPSSL beamlets have less bandwidth than the NIF glass laser, but the NIF will also test beam smoothing with the use of multiple colors in overlaping beams, which a many-beam DPSSL can also be designed to do.

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Figure Captions

Fig. 1 The U.S. National Ignition Facility. The NIF will provide 192 beams of 0.34 micron wavelength light for a variety of inertial fusion ignition and gain experiments, delivering a total energy of 1.8 MJ, at a peak power of 500 Terawatts.

Fig. 2 The role of the NIF in providing key data for a variety of possible options for next-step inertial fusion test facilities in the post 2005 time-frame.

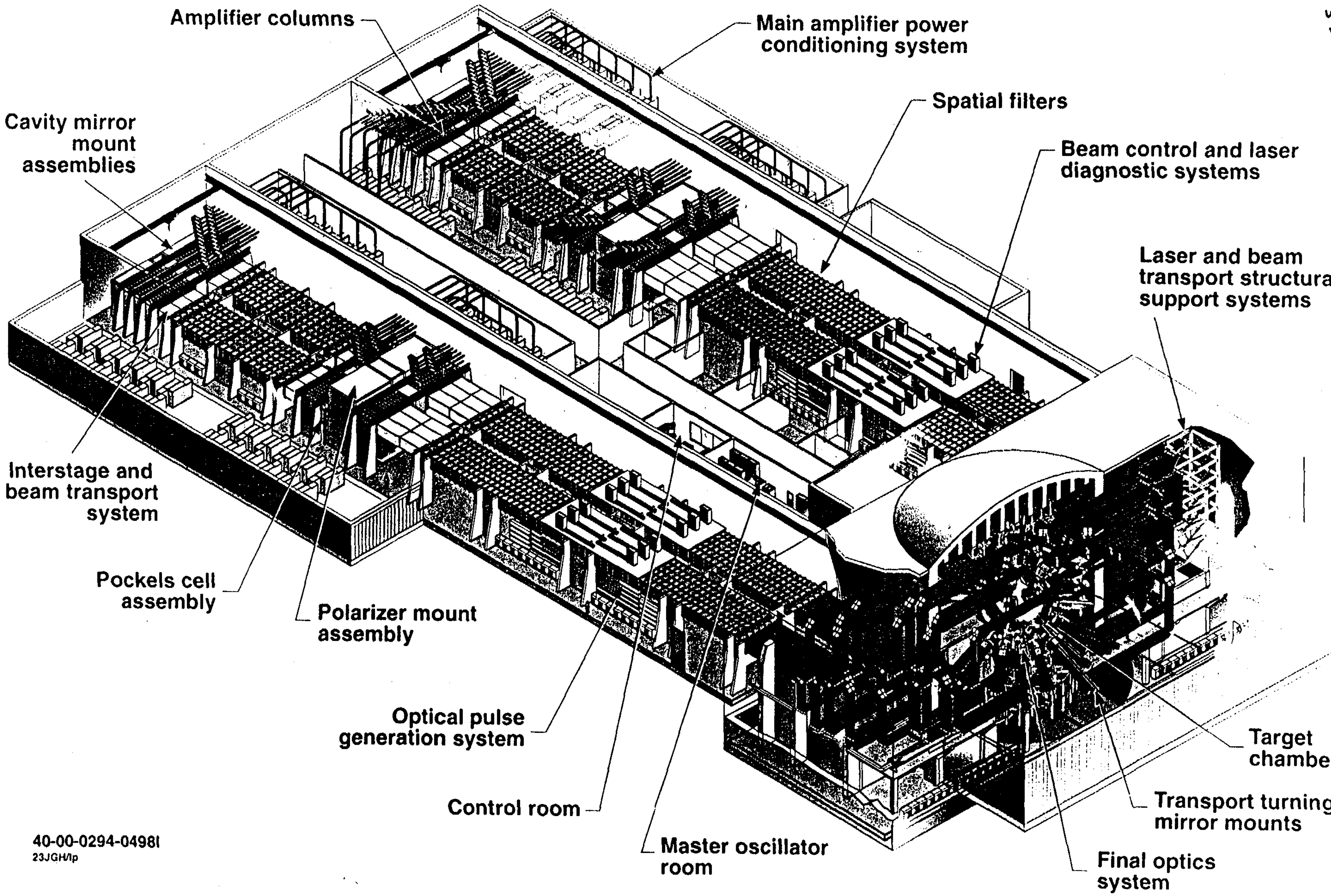
Fig. 3 The NIF target area shown in two beam illumination configurations for (a) indirect drive, and for (b) direct-drive geometries. Sample targets that may be tested in each configuration are shown to the right of each NIF beam configuration. The light-ion simulation target (lower right of 3b) would use the NIF direct-drive beam configuration for 12-point illumination symmetry, but simulates an indirect-drive light-ion target design.

Fig. 4 Schematic target designs for a heavy-ion driver (a) and a light-ion driver (b). In both designs, the ion beams penetrate a thin, high-Z radiation case completely surrounding the capsule.

Fig. 1

~~The National Ignition Facility—192 Beam~~

See Jason Carpenter (he has this figure as a figure without the vignette titles) as done for ICF quarterly



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rotate, shrink to fit in portrait

~~US Inertial Fusion Program Strategy~~

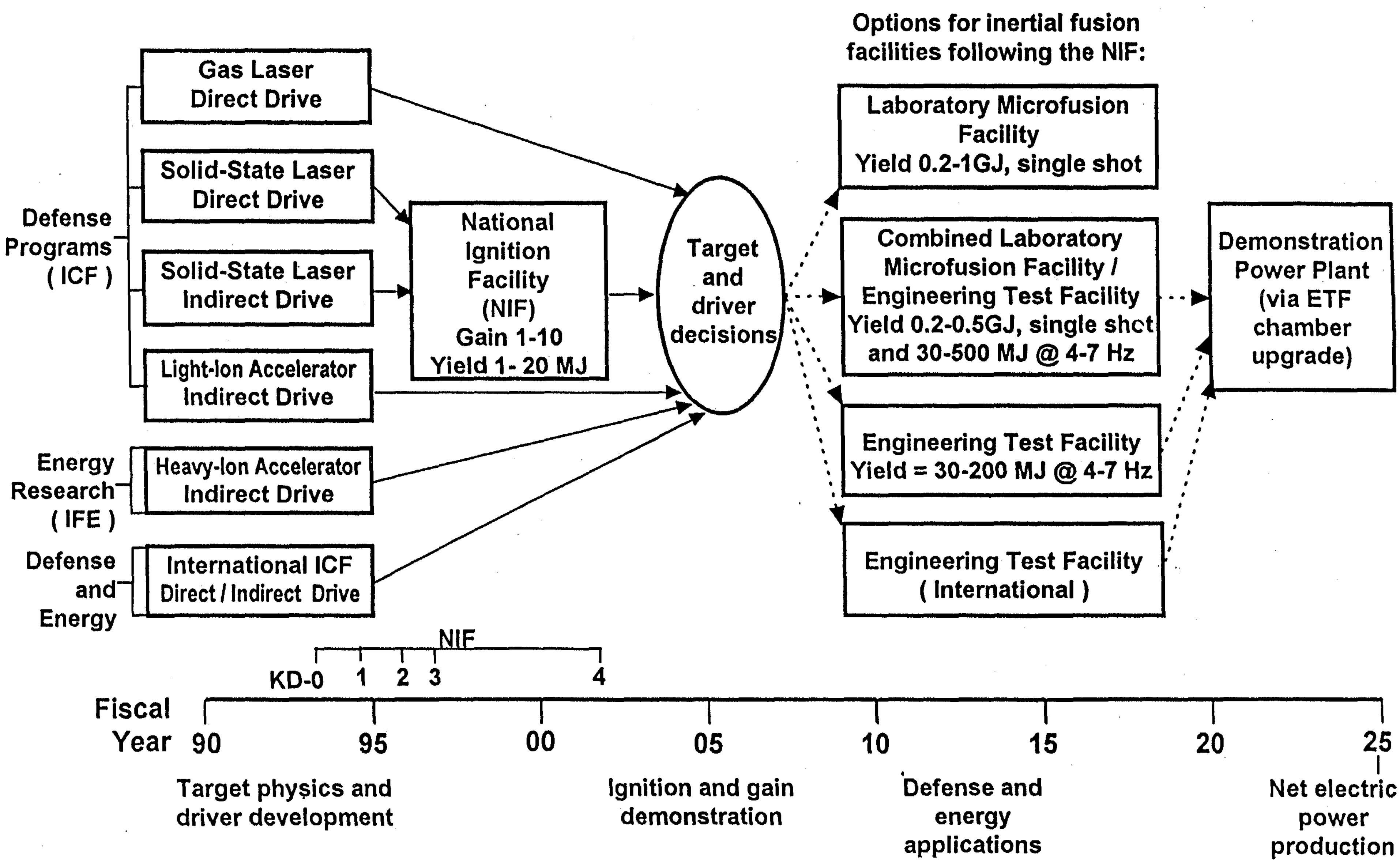
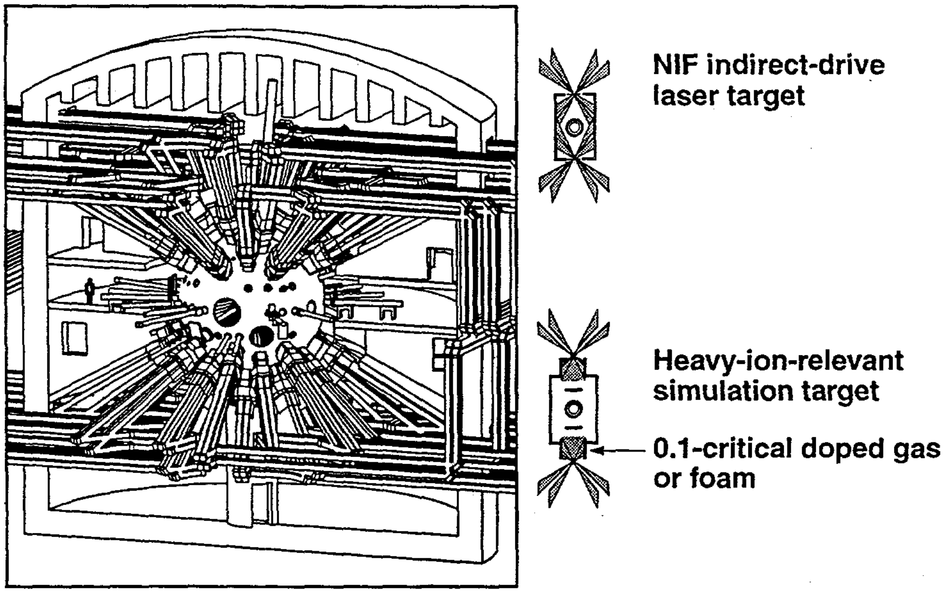
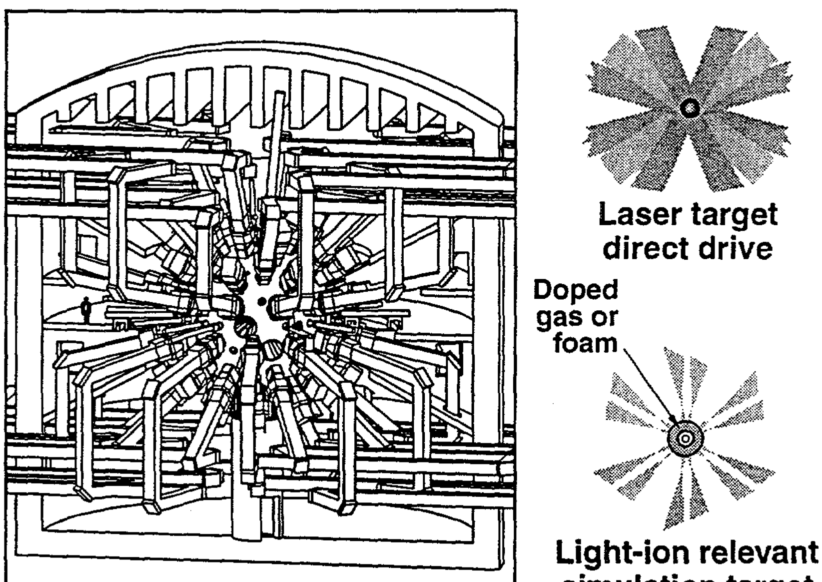


Fig. 2 (See Jason Carpenter – he has this figure done as a figure (without title above) for my ICF quarterl

Indirect drive geometry (a)

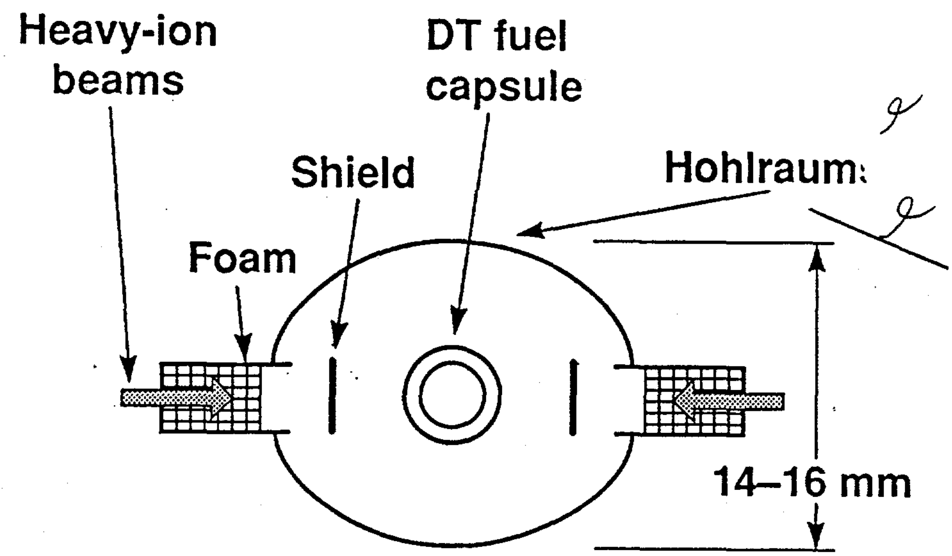


Direct drive geometry (b)

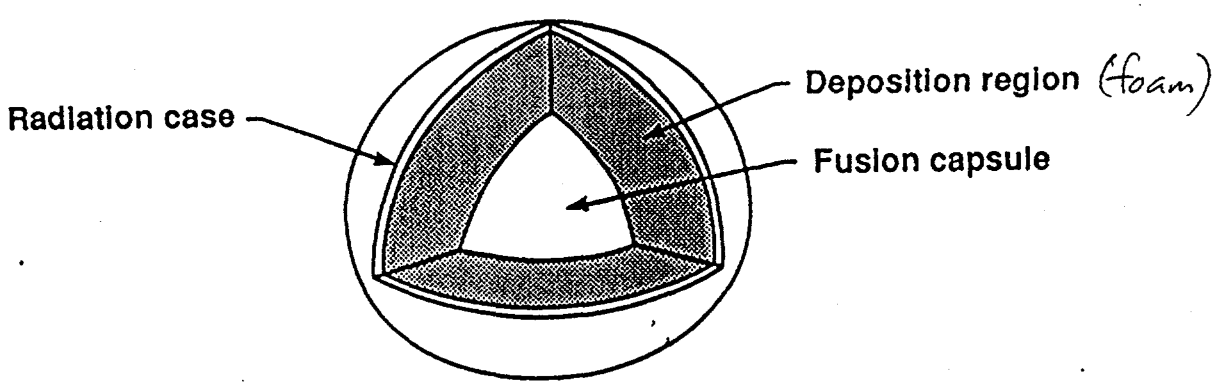


Reposition 24 4-beam clusters

Fig. 3 a, b — see Jason Carpenter (he has this figure in my ICF quarterly done) (or, can use enclosed viewgraphs and redo



(a) Heavy-Ion Target



(b) Light-Ion Target

Fig. 4 a,b (please construct from pieces on enclosed two vugraphs on file modify as indicated.