Laser and Particle Beams (2005), *23*, 475–482. Printed in the USA.
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DOI: 10.1017/S0263034605050664

Laser targets compensate for limitations in inertial confinement fusion drivers

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(Received 20 January 2005; Accepted 5 June 2005)

Abstract

Success in inertial confinement fusion (ICF) requires sophisticated, characterized targets. The increasing fidelity of three-dimensional (3D), radiation hydrodynamic computer codes has made it possible to design targets for ICF which can compensate for limitations in the existing single shot laser and Z pinch ICF drivers. Developments in ICF target fabrication technology allow more esoteric target designs to be fabricated. At present, requirements require new deterministic nano-material fabrication on micro scale.

Keywords: Inertial confinement; Inertial fusion; Targets

INTRODUCTION

Inertial fusion energy (IFE) is widely regarded as the energy source of the future (Hora, 2004), and intense laser and particle beams are discussed as potential drivers. Especially the fast ignition concept is currently at the focus of research efforts (Mulser & Bauer, 2004; Deutsch, 2003; Koshkarev *et al*., 2002). The current status is still dominated by intense basic research of inter action phenomena of intense laser and particle beams with ionized matter (Deutsch, 2004; Malka *et al*., 2002; Hoffmann *et al*., 1990). The availability of suitable targets was identified as a key issue for inertial fusion basic research with lasers and heavy ion beams as well (Callahan *et al*., 2002; Borisenko *et al*., 2003; Koresheva *et al*., 2005).

Over the last decade and for the next few years, the U.S.A. is making major investments in laser and Z pinch drivers for inertial confinement fusion (ICF). Three major facilities, the national ignition facility (NIF) at the Lawrence Livermore National Laboratory, OMEGA-EP at Laboratory for Laser Energetics (LLE), and ZR at Sandia National Laboratories (SNL) are being built or refurbished, with ignition as one of the major strategic objectives of the American ICF program. The goal of achieving ignition by inertial confinement is pursued by the X-ray (indirect)-drive and direct-drive ignition programs in America (McCrory, 2003). Ignition in the laboratory has very demanding conditions of the facility in heating and compressing the deuterium-tritium (DT) filled targets, because radial convergences on the order of >30 in radius, i.e., $\gtrsim 30^3$ in volume, are required to achieve ignition with laboratory scale drivers. These high convergences imply a drive symmetry $<1/30$ which cannot be achieved for X-ray drive in cylindrical hohlraums without engineering the hohlraums to help with summarizing the drive (Kauffman *et al*., 1998; Delamater *et al*., 2000), or engineering the capsule to minimize the effect of hydrodynamic instabilities (Kilkenny *et al*., 1994). These are examples of where the advent of accurate multi-dimensional codes and increasing sophistication in making and characterizing targets allows innovations in target fabrication to compensate for drive limitations in qualities such as symmetry drive energy and pulse shape.

Moreover, other limitations in the facility such as complications in cryogenic target manipulator can be compensated for by advanced target manufacture. Advances in target fabrication are being achieved to reduce the risk associated with achieving ignition and to compensate for cost and schedule issues or lack of flexibility of the drivers.

For single shot ICF as is being sought on NIF, these and other advances in nano-scale fabrication are required. However there is a large difference in the shot rate requirement for IFE. Ignition on the NIF will be achieved with one

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of-a-kind targets, with high target costs, and shot rates measured in units of ignition shots per week at best. To go from one of-a-kind ICF targets to power plant target shooting at 5 times/s, is an extrapolation of about five orders of magnitude in target production rate or target costs, as well as requiring target injection. We are working on demonstrating a credible pathway to a reliable, consistent, and economical target supply, as a major part of establishing that IFE is a viable energy source.

2. INNOVATION IN TARGET FABRICATION COMPENSATE FOR ICF LIMITATIONS

To achieve ignition in the laboratory with hot spot ignition, requires a radial convergence of 30 to 40 placing stringent criteria on the growth rate of hydrodynamic instabilities, and symmetry of drive on the spherical capsule. Hydrodynamic instabilities cause growth of both the initial target roughness and also perturbations in the target caused by non-uniformity of target and drive (Kilkenny *et al.*, 1994). Asymmetric drive results from several sources and can be approximated as resulting from implicit asymmetry resulting from the irradiation geometry in hohlraums drive (Kauffman *et al.*, 1998; Delamater *et al.*, 2000), and random asymmetries resulting from real world lasers with individual beam energies not exactly balanced, or targets not being perfectly balanced or round. Here an artificial distinction is being made between roughness, which is high Legendry order perturbations and asymmetric drive which is non-uniformity, low order mode perturbations. In terms of Legendry modes, the difference between target asymmetries and target roughness is a question of mode number. Asymmetry is low modes up to normally $l = 8$, whereas target imperfection cover all modes from low mode (out or roundness) to high order (up to $l = 100$'s normally referred to as target roughness). As a combined result, the best convergence that was achieved to date in ignition scaled implosions on OMEGA is ~20 (McCrory, 2003).

Advanced targets can and do compensate for limitations of the facilities. A well known requirement in target fabrication (Kauffman *et al.*, 1998; Delamater *et al.*, 2000) is to reduce the initial imperfections, simplistically characterized by an initial perturbation of amplitude a_0 so that after growth by a factor G by the hydrodynamic instabilities the size of the perturbation G, a_0 is a small fraction of the radius of the compressed fuel, resulting in acceptably low mixing of cold material into an igniting hot spot. The initial roughness of the target is both in the ablator and the initial deuterium-tritium cryogenic ice roughness.

In addition, we here review other aspects of advanced targets which can compensate for limitations in drivers and facilities. Limitations in drive energy can be reduced by "cocktail" hohlraum wall material and radiation shims both reducing the X-ray energy loss through the hohlraum wall and the laser entrance hole, respectively. Symmetry swings in the X-ray drive in a hohlraum are reduced by gas filled hohlraums. Graded doped ablators reduce the hydrodynamic instability growth rate and allow fill tubes and results in a simpler cryogenic target handling system.

2.1. Mixtures of high Z materials for radiation enclosures (cocktails)

The energy balance in a typical NIF hohlraum ignition point design is dominated by the energy loss into the wall. For example, from 1.3 MJ of laser energy absorbed into a hohlraums, the wall loss is about 0.6 MJ if the wall is gold. In single high Z materials, the energy loss into the wall is enhanced in spectral regions where the absorption coefficient is lowered. For radiation temperatures of ~300 eV, the energy losses below the M edges of the high Z wall material which is usually gold become significant. Mixtures of high Z materials which have peaks in absorption of one of the constituent material overlapping with minima in absorption of the other material can reduce the energy loss. Orzechowski *et al.* (1997) showed a delayed burn through the radiation wave in a mixture of Au and Gd. Olson *et al.* (2003) showed a delay in the radiation burn through mixtures of Au:Dy:Nd with an effective opacity of the cocktail material, inferred to be increased by a factor of 1.5 of Au. However attempts to measure an increase in the reemission of the surface of the cocktail material in the same experiments (i.e., the albedo) had less success.

A recent hypothesis (M. Rosen, private communication and J. Kaae, private communication) in the construction of mixtures of high Z metals, there is a high level of oxygen contamination as U and Dy are excellent getters for oxygen. The additional specific heat of oxygen at material temperatures ~200 eV would absorb energy in the radiation wave, slowing radiative burn through but does not cause a greater reemission. The construction process so far has used an aluminum mandrel for coating either thin multi-layers or mixtures, and then mandrel removal by an aqueous solution. During the construction process, the getters of oxygen would become oxidized. Measurements of the level of oxygen contamination have qualitatively shown a high level, although this was not quantified. In the future, additional process steps could reduce the oxygen contamination. A permeation barrier could be coated over the mandrel and over the cocktail to prevent oxygen uptake after the manufacture off cocktail material, and an acrylic mandrel without an aqueous, each should reduce oxygen contamination. Future fabrication and experiments with well characterized hohlraums will hopefully verify this hypothesis.

2.2. Laser entrance hole shine shields

A normal cylindrical hohlraum with two laser entrance holes (LEH) has substantial radiation energy loss out of the LEHs. On Nova (Amendt *et al.*, 1996) the concept of LEH shields was explored and found to be beneficial for both reducing energy loss by up to 40% through the LEH and reducing low order asymmetry.

On Nova the angle of the laser cones was relatively steep—50 degrees to the axis of the hohlraum. On NIF and OMEGA some of the beams enter at a lower cone angle (25 degrees) and the LEH shine shield has to be correspondingly smaller. This makes the material of construction, to minimize the stimulated Brillouin and Raman scattering in the plasma that forms as the LEH blows up into the path of the laser beam, and the mounting of LEH on an ultra-thin foil is a challenge. LEH shields will be retested on OMEGA in NIF-like cone geometry.

2.3. Symmetry swing reduction by gas fills

In the early 1990s, the ignition designs for X-ray drive used vacuum hohlraums. Advances in computational capability and experiments on Nova led to an understanding that during the several nano-second laser pulses, there was sufficient motion of the X-ray emitting spot that low l mode drive asymmetry could not be controlled sufficiently (Kauffman *et al.*, 1998; Delamater *et al.*, 2000). As a result, target fabrication advances in the strength of thin polyimide windows (Orzechowski *et al.*, 1997) allowed gas filled hohlraums to be used where the gas fill inhibits motion of the X-ray emitting spot sufficiently to overcome limitations in the number of rings of laser beams.

2.4. Ablators' choice for ignition designs

For X-ray drive ICF, a low Z ablator surrounds the cryogenic fuel. Currently ablator materials being considered are doped plastics such as Ge-doped CH, or doped beryllium such as Cu-doped beryllium where the dopants limit the penetration of the harder part of the X-ray drive spectrum. It was known for some time (Wilson *et al.*, 1998) that capsules with beryllium ablators offer improved target performance because of beryllium's low opacity, and high initial density. However beryllium has several problems as an ablator namely: (1) it cannot be diffusion filled, (2) its optical opacity precludes optical characterization of the cryogenic DT ice, and (3) the beta layering which drives the smoothing of the cryogenic ice, cannot be augmented by infra-red heating (Wilson *et al.*, 1998). For this reason, the point design for the NIF ignition targets has, until very recently been doped plastic which can be diffusion filled, optically characterized, and have augmented beta layering, although smoother cryogenic ice surface finishes are required. A remarkable achievement of the American target fabrication community (McCrory, 2003; Nikroo *et al.*, 2004*b*) is the achievement of adequately smooth surface finishes in plastic, as shown in Figure 1 and Section 3.

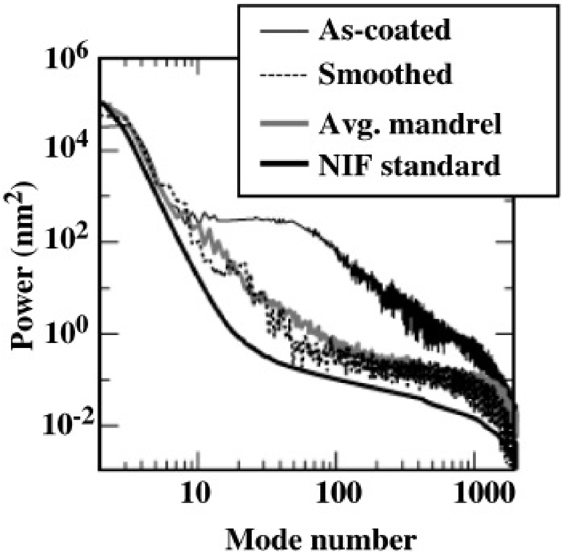


Fig. 1. The surface finish power spectrum of plastic mandrels compared to NIF specification.

Plastic targets have a sufficiently high porosity that can be diffusion filled at temperature with deuterium (D) or tritium (T). A fill, cool, layer, transport, insert, align, and shoot sequence is possible as shown in Figure 2, is followed on OMEGA at LLE (Besenbruch *et al.*, 1999). Such a capability was needed for the OMEGA program in direct drive and was of value in developing critical community experience for the more difficult and expensive NIF cryogenic target handling system (NCTS). As illustrated in Figure 2, there are nine operations for "cold transport."

(1) A fragile target shell is filled at room temperature to about 1100 atm of DT gas.
(2) The target is cooled to cryogenic temperatures (about 20°C above absolute 0 or −253°C) to the freezing point of DT ice.
(3) The target is transported to the NIF or OMEGA.
(4) A small amount of infrared (IR) heating is then applied to the target to form a uniform DT ice layer with a very smooth inside ice surface.

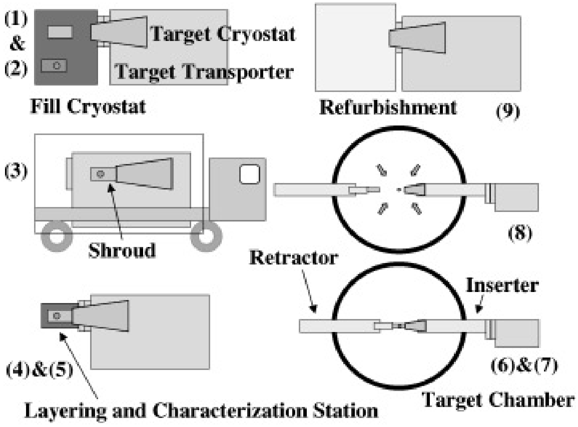


Fig. 2. The separate operations of a cold transport cryogenic target handling system such as on OMEGA. A warm transport system could eliminate at least three sub-systems.

(5) The target must be characterized continuously to verify that the ice is formed with a smooth enough surface.
(6) The target is transported to the target chamber while keeping the target cryogenic with the IR heating applied to the ice to keep it smooth.
(7) The target, contained in a thermal shroud, is inserted into the target chamber, and aligned.
(8) Just before the laser shot, the target is exposed by rapidly retracting the shroud (1/10 s) without disturbing the target alignment. This complex set of operations has a high cost.

In the early stages of the NIF facility, it is now proposed to use a warm transport system delaying the need for three of the subsystems of Figure 2. In one incarnation, a warm transport target has a small (~6 μm) fill tube as shown schematically in Figure 3. The capsule is mounted centrally in a hohlraum and placed, warm at the centre of the target chamber. It is filled in situ by cryo-condensation, layered and then shot. Several subsystems of Figure 2 are not required for warm transport, at a large cost saving, but at the expense of designing and fabricating a target which can with stand the hydrodynamic and cryogenic perturbation of a fill tube (Hoffer & Foreman, 1988; Martin *et al.*, 1988). Another incarnation of a warm transport system is a beryllium shell strong enough to with stand the bursting pressure of the DT fill at non-cryogenic temperatures (Besenbruch *et al.*, 1999).

This concept was made possible by the new target design in Figure 4 (Dittrich *et al.*, 1998), which has a graded layer of Cu doping in the beryllium ablator to reduce the hydrodynamic growth rate sufficiently low to with stand the initial perturbation of the fill tube. At this stage, a few beryllium shells with graded dopants were made but research on surface finish and characterization of the dopant levels is ongoing. The target fabrication issue is that the morphology of coated material is non-uniform on the sub-microns scale. This leads to issues with the surface finish of the coated material as well as issues with the bulk material such as its strength, its thermal conductivity for cryogenic uniformity, and its ability to transmit in a known manner shock. Recently it was shown (M. Hoppe, private communication) that the primary issue of surface roughness can be ameliorated by polishing achieving specifications close to NIF ignition requirements. Fabrication of the fill tube and its joint to the shell to precision specifications is also challenging, but monolithic nano-technology techniques look promising

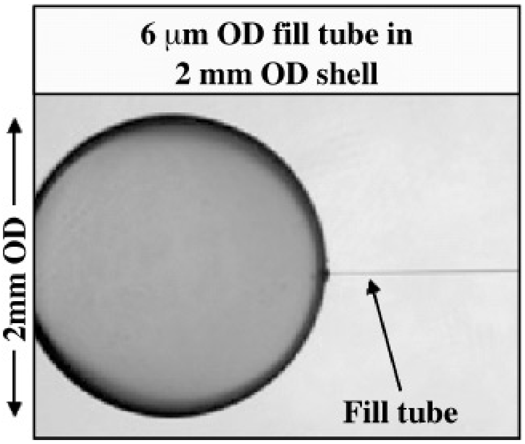


Fig. 3. A 2 mm NIF scale ignition target with a 6 μm fill tube.

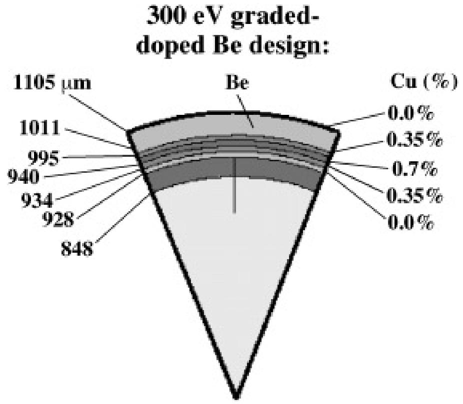


Fig. 4. Laser fusion baseline high-gain target and expected target specifications.

The issue of the best ablator for ignition is complex because of the trade offs necessary between the best ablators in theory and the real world of material science which affects the quality of the real target.

These issues are summarized in the Table 1. All aspects of the progression of concepts here are driven by target fabrication capability. At present most of the concepts were shown to be credible but much of the development work remains to be performed. Other examples are polar direct drive, shims to control symmetry in X-ray drive and double shell targets to reduce pulse shaping and cryogenic requirements.

3. SYNERGY WITH TARGET FABRICATION TECHNOLOGY DEVELOPMENT BETWEEN ICF AND IFE

The starting point for the fabrication of plastic and one type of beryllium X-ray drive capsule is a spherical mandrel onto which the ablator is coated. The sphericity of this mandrel largely determines the sphericity of the final capsule, especially at low to intermediate modes (Nikroo *et al.*, 2004*a*). A major advance in target fabrication was the development of micro-encapsulation techniques for ICF to produce a large number of high quality mandrels in batch mode. In addition, the development of the decomposable mandrel route, in which the initially formed shells are over-coated with a thermally more stable layer, and the mandrel is then de-polymerized, has markedly increased our flexibility. We can overcoat these thermally stable mandrels with plasma polymer, vapor deposited polyimide, or sputtered beryllium with unparalleled wall thickness and composition control. For plasma polymer and beryllium a dopant of Ge or Cu,

Table 1. *Different ablators*

Ablator	Pros	Issues	Mitigation
Be	best ablator-in theory (hi r, low t)	surface finish	post polish
		bulk homogeneity	processing, first shock
		fill-impermeable	drill, fill, plug
		strength-hi P warm transport	research topic, fill tube
		no deuterium implosions	
		no enhanced I.R. ice smoothing	unnecessary?
		characterization of layering	phase contrast imaging
Doped CH	Target fab issues solved	diffusion fill cryo system	
	fabrication	fill tube CH marginal for ID?	
	fill by diffusion		
	optical characterization		
	infra red enhanced layering		
	deuterium implosions		
Diamond	good ablator-in theory (higher r, mid t)	fabrication	research area
		mandrel removal, surface	research area
		smoothness	research area

respectively, can be added with excellent control, providing either uniform or radically banded dopant regions. Plastic and polyimide shells can be diffusion filled (operation 1 of Fig. 2) with DT. A cryogenic layer of DT ice can be formed on the inner surface, which can be optically characterized.

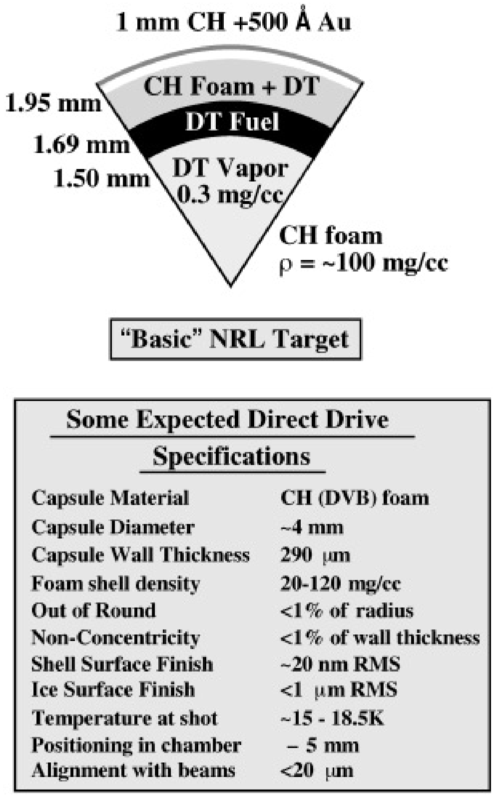
For direct drive, the ablator is the cryogenic fuel with the thin plastic non-cryogenic part of the capsule providing a skeleton to form the fuel. The high aspect ratio plastic shells needed for all DT direct drive design can now be made to the ignition specifications (McCrory, 2003; Nikroo *et al.*, 2004*a*). Alternate designs use cryogenically-wetted low Z foam. Low Z foams have now been made for ignition scaled cryogenic and non-cryogenic experiments on OMEGA at the laboratory for laser energetic (LLE) (Nikroo *et al.*, 2004*a*). A full density gas tight permeation seal was successfully deposited for retention of the fill gas at room temperature or the ice at cryogenic temperatures. Room temperature gas filled foam shells as well as cryogenic foam shells were shot with good results on OMEGA.

All of the above activities and more are developing the techniques for target fabrication for IFE. However the processes are in batch mode, often by hand. For a production line, feeding a laser or Z pinch driver at shots/s, the boutique techniques of Section 3 must be redesigned to work in a production line mode.

4. REQUIREMENT OF 500,000 TARGETS A DAY FOR AN IFE POWER PLANT

The shot rate of the existing ICF facilities described in Section 2 is measured in shots per day. For example, the design specification for the NCTS is one shot/every eight hours. In contrast the many hundreds of MW (e) output required for an economic inertial fusion power facility require a target shot rate of many per second. The "target fabrication facility" of an IFE power plant must then supply more than 500,000 targets per day, including manufacturing the spherical target capsule and other materials, filling the capsules with the DT fusion fuel, redistributing the frozen DT uniformly around the inside of the capsule (layering), and possibly assembling the capsule in a hohlraum (for indirect drive) or with transmission lines for Z pinch fusion energy. The feasibility of developing successful fabrication and injection methodologies at the low cost required for energy production (about $0.25/target for direct laser drive) is a critical issue for inertial fusion (Woodworth & Meier, 1995; Rickman & Goodin, 2003). This change of order a million in the capability or cost of the targets from the current situation is very high in the list of difficult technology advances required for economic IFE. Demonstrating a credible pathway to a reliable, consistent, and economical target supply is a major part of establishing IFE is a viable energy source, for laser-driven, heavy-ion driven or Z pinch driven concepts. IFE target fabrication research has concentrated on investigating and developing various materials needed by the target designs and on fabrication techniques that could eventually scale to low cost and high production rate.

A major strategic objective of the on-going ICF program in America is demonstrating ignition using existing facilities with X-ray drive and then direct drive. The basic target design for an IFE high gain direct drive target is shown in Figure 5. Regardless of drive, a demonstration of ignition will unequivocally establish the credibility of physics and computer codes involved in ICF. Features include hot spot ignition and burn, adiabatic shaping, and drive uniformity. In parallel there is a program in the U.S. to address the feasibility of economic power generation developing the technology required for IFE such as repetitively pulsed-lasers, final-optics, chambers, targets, and target injection. Progress on the targets and injectors is described below albeit only for laser direct drive because of space restrictions.



Some Expected Direct Drive Specifications

Capsule Material	CH (DVB) foam
Capsule Diameter	~4 mm
Capsule Wall Thickness	290 μm
Foam shell density	20-120 mg/cc
Out of Round	<1% of radius
Non-Concentricity	<1% of wall thickness
Shell Surface Finish	~20 nm RMS
Ice Surface Finish	<1 μm RMS
Temperature at shot	~15 - 18.5K
Positioning in chamber	– 5 mm
Alignment with beams	<20 μm

Fig. 5. Baseline NRL high gain direct drive target.

The basic direct drive high gain target uses a divinylbenzene foam shell (Streit & Schroen, 2003) to contain the cryogenic DT fuel. Density matched micro-encapsulation was used in the laboratory to produce these shells. This fabrication step is relatively well-understood and demonstrated for ICF, although work remains to scale the process to larger batches and to increase product yields for IFE capsules (Goodin *et al*., 2004). The principal technical issues are meeting non-concentricity and out-of-round requirements when fabricating the CH capsules at large diameter and with thick walls. Filling of polymer capsules with hydrogen isotopes by permeation through the wall, removal of the excess DT after cooling to cryogenic temperatures (to reduce the capsule internal pressure and prevent rupture), and transport under cryogenic conditions were demonstrated in the laboratory.

Layering is the process of redistributing the cryogenic DT fuel into a smooth uniform layer inside the ablator. Layering requires establishing an extremely precise (~250°K), uniformly spherical temperature distribution at the surface of the capsule. A cryogenic fluidized bed experiment was designed to demonstrate this process with hydrogen isotopes in a batch-mode. This concept is for the fluidized bed to rapidly randomize the targets yielding a very uniform time-averaged surface temperature. Layering in a fluidized bed is followed by a very rapid (a few seconds or less) removal of the layered capsule from the bed, and assembly into a sabot for injection. The sabot protects the cryogenic target during injection, and springs apart and is deflected from the capsule trajectory prior to its entering the target chamber. The target in the back half of the sabot is supported by a thin membrane which distributes the load and prevents point-contact loading of the fragile capsule during the ~1000 g acceleration.

A potential option for the laser fusion target that helps protect it from thermal radiation during its injection is a "foam-insulated" target which uses a relatively thin layer of foam to reduce the heat load to the cryogenic DT (Norimatsu *et al*., 2001). The degree of heating the target during injection is determined by the radiation heating from the chamber first wall and by heating from the gas in the chamber.

The cost of the target is also a key issue in the IFE target supply. Laser fusion targets were the subject of the most extensive and well-documented analyses for future target manufacture of all the IFE concepts considered. We prepared preliminary equipment layouts (Petzold & Jonestrask, 2005), and determined floor space and facility requirements for nth-of-a-kind production of high-gain laser-driven IFE targets. The results for a 1000 MW(e) baseline plant indicate that the installed capital cost is about $100 M and the annual operating costs will be about $19 M (labor $9 M; materials/utilities $4 M; maintenance $6 M), for a cost per target of slightly less than $0.17 each.

To arrive at this cost, a number of process assumptions were made, based on (1) preliminary requirements for the NRL high gain direct drive targets, (2) discussions with researchers in each of the enumerated process steps to reflect their latest findings, and (3) interactions with vendors of process equipment that is adaptable to this service—such as critical point driers. The plant conceptual design includes a process flow diagram, mass and energy balances, equipment sizing and sketches, storage tanks, and facility views (plan, elevation, and perspective). The cost estimating process uses established cost-estimating methods and factors for the chemical process industry. Recycle and beneficial reuse of process effluents is designed into the facility. A detailed material and energy balance was prepared to provide information on flow rates and quantities of raw materials, finished products, and byproducts for the entire plant. All of the cost calculations for chemical, utilities, and waste disposal use mass quantities calculated in the material and energy balances.

The feasibility of fabricating specific foam capsules needed for high gain IFE targets were shown. Further work is underway to improve capsule quality, reproducibility, and large-scale production. The work with DT over foam has shown that the system can be cooled down well below the DT triple point, so the target can with stand the acceleration during injection, and has more margins for heating during its transit across a high temperature chamber.

Proof-of-principle layering experiments were performed with multiple targets in a fluidized bed using a surrogate fuel material at room temperature to simulate DT ice. These experiments provide a demonstration that fluidized bed technology could be used to form DT ice layers in production mode.

Existing ICF facilities have the luxury of a solid support to position the targets to the required accuracy of ~1% of the initial capsule radius, set by the ~40-fold convergence of the target. Introducing a target so rapidly on a solid support would be very difficult and so the system approach adopted for laser driven IFE is to accelerate the fragile cryogenic target outside of the chamber in a protective sabot fast enough (~400 m/s) that it enters the chamber (without the sabot), cleared of the debris from the previous shot. Background gas in the target chamber makes shooting the capsule accurately enough for passive laser beam, focus is more difficult than the concept presently adopted for shooting the target close (~5 mm) to the center of the chamber, tracking its exact trajectory, and steering and timing the implosion laser beams onto the target once its anticipated position is tracked to within about 20 μm within the 5 mm focusing box.

At General Atomics, a new and versatile facility for studying target injection was constructed as shown in Figure 6. The accelerator is a full scale simulator of an IFE reactor target chamber and its target injector, with the goal of eventual repetitive cryogenic injection of targets into a chamber held at reactor chamber temperatures. The phase I version is limited to single shot, room-temperature target injection using a gas gun initially, to be replaced with an electric accelerator. The facility was operational for 1 year, successfully demonstrating sabot separation needed for handling of direct drive targets. We must predict target position to within ±14 mm at a distance of at least 16 m from the gun barrel and 9 m from the nearest detector used for the prediction as neutron shielding requires that the detectors must stand back from the target injection path more than about 0.5 m. Future work will convert the system for use with cryogenic targets injected into a high-temperature chamber at 5–10 Hz. Elements of the facility include mass production (in batch mode) of cryogenic targets, injection into the chamber (under simulated background gas and wall temperature conditions), and steering of a low-energy pulsed laser onto the target in flight.

5. CONCLUSIONS

One of the most critical aspects of IFE remains the credibility of the capability to make at cost a million precise targets per day and place them with precision at the center of a reactor target chamber. Target fabrication technologies for today's single shot ICF facilities are demonstrating that target features compensate for limitations in ICF driver's capabilities such as energy, symmetry or pulse shaping. Some of these same target fabrication technologies are being extended to mass production demonstrations for IFE requirements. A full scale pellet injector is now in operation to demonstrate target tracking capability to establish credibility of placing a targets in an IFE reactor chamber. Although much work remains to be done, our initial results are promising and suggest that a credible pathway to a reliable, consistent, and economical target supply is within reach.

ACKNOWLEDGMENTS

Work supported by U.S. DOE under NRL Contract N00173-01-C-6004, DE-AC03-01SF22260, DE-FC02-04ER54698, W-7405-ENG-36, W-7405-ENG-48, DE-FG03-00ER54595.

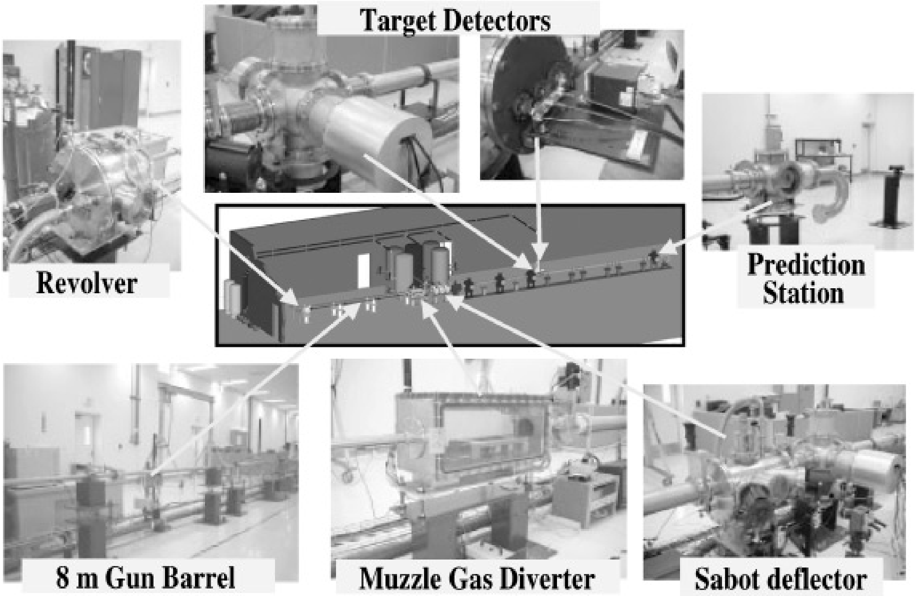


Fig. 6. Components of experimental system to develop and demonstrate target injection and tracking methodologies.

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