GA–A23055

A COST EFFECTIVE STEPS TO FUSION POWER: IFE TARGET FABRICATION, INJECTION, AND TRACKING

by
K.R. SCHULTZ

JANUARY 1999

GA–A23055

A COST EFFECTIVE STEPS TO FUSION POWER: IFE TARGET FABRICATION, INJECTION, AND TRACKING

by
K.R. SCHULTZ

This is a preprint of a paper presented at the Workshop on Cost-Effective Steps to Fusion Power, January 25–27, 1999, Marina Del Rey, California, and to be published in *The Proceedings.*

GA PROJECT 4808
JANUARY1999

Cost Effective Steps to Fusion Power:
*IFE Target Fabrication, Injection and Tracking**

K.R. Schultz
General Atomics

This paper was prepared for the Fusion Power Associates workshop on Cost Effective Steps to Fusion Power, January 25–27, 1999, and summarizes the role of IFE target fabrication, injection and tracking must play in pursuing a cost effective development program for inertial fusion energy that will lead to a cost effective fusion power plant.

Introduction

It is generally accepted that inertial fusion energy (IFE) has the potential to lead to a cost effective fusion power plant. Many of the elements of the driver and the target physics of inertial fusion are being developed as part of the Inertial Confinement Fusion Program in support of the US Stockpile Stewardship activities. While IFE has been less studied than magnetic fusion energy (MFE), there have been several detailed design studies of IFE power plants, and these have concluded that plausible design solutions can be developed for the technical challenges of IFE, and that, if successful, this development will lead to power plants offering attractive technical, safety, environmental and economic features.[1, 2] In this sense, IFE is comparable to MFE in offering the potential for an attractive, long term energy source.

Study	Cost of Energy (cents/kW-hr)
MFE - ARIES II/IV	6.8–7.3
IFE - OSIRIS	5.6
- SOMBRERO	6.7
- HYLIFE-II	6.5

Table 1. Design studies predict IFE Cost of Energy comparable to that of MFE

Also similar to MFE, IFE has the potential for future improvements by development of "advanced concepts" that, while somewhat speculative, promise the potential for lower cost compared to the mainline hot-spot ignition approach. The "fast ignition" approach[3] would use one set of driver beams to compress a target to high density without a central hot spot, and then use a second, extremely intense laser beam to ignite this compressed target. If this approach is successful, it could offer better economics by achieving higher gain at a given driver energy, and could offer a cheaper development pathway by allowing ignition and gain at lower driver energy, as shown on Fig. 1.

---

*Work supported by General Atomics Internal Funding.

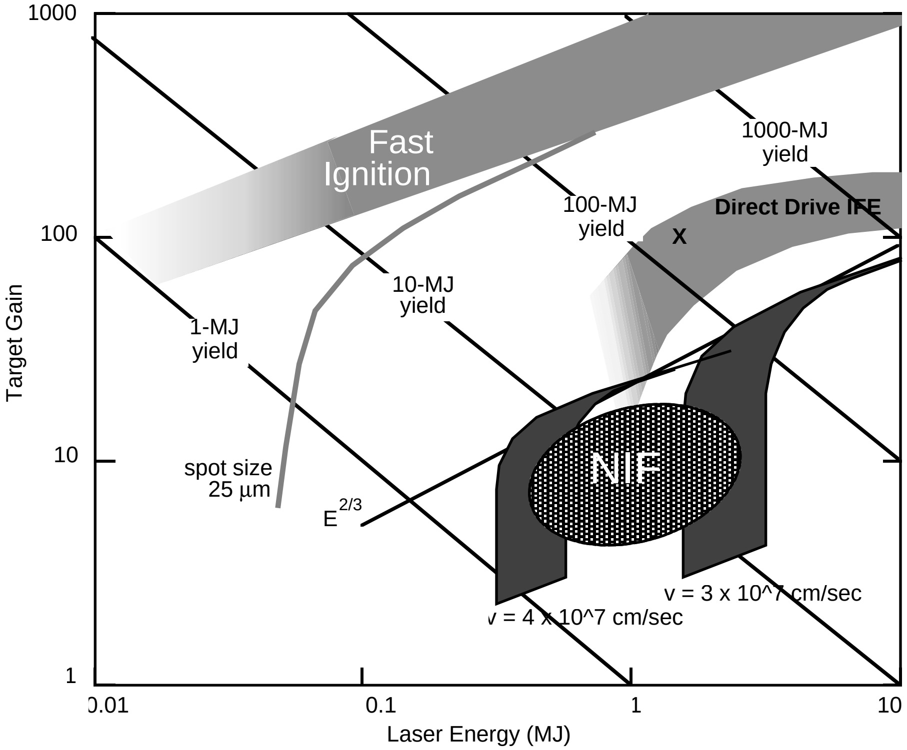


Fig. 1. Fast Ignition offers the possibility of lower cost IFE[3]

In addition to potentially leading to cost effective fusion power, IFE has the potential to offer a cost effective development pathway. The IFE community has adopted a cost effective, phased development strategy shown on Fig. 2.[4] The development process has been divided into a sequence of logical steps. At each step, the options are weighed and down-selection is done. For each step, only the minimum development needed to support the decisions to be made at that step would be done. The first decision point of this development strategy is scheduled for the end of FY 2002, when the decision must be made as to whether to proceed with an IFE Integrated Research Experiment (IRE), and, if so, what technologies will be used for this experiment. The IFE development program is focused on providing the information needed for this IRE decision.

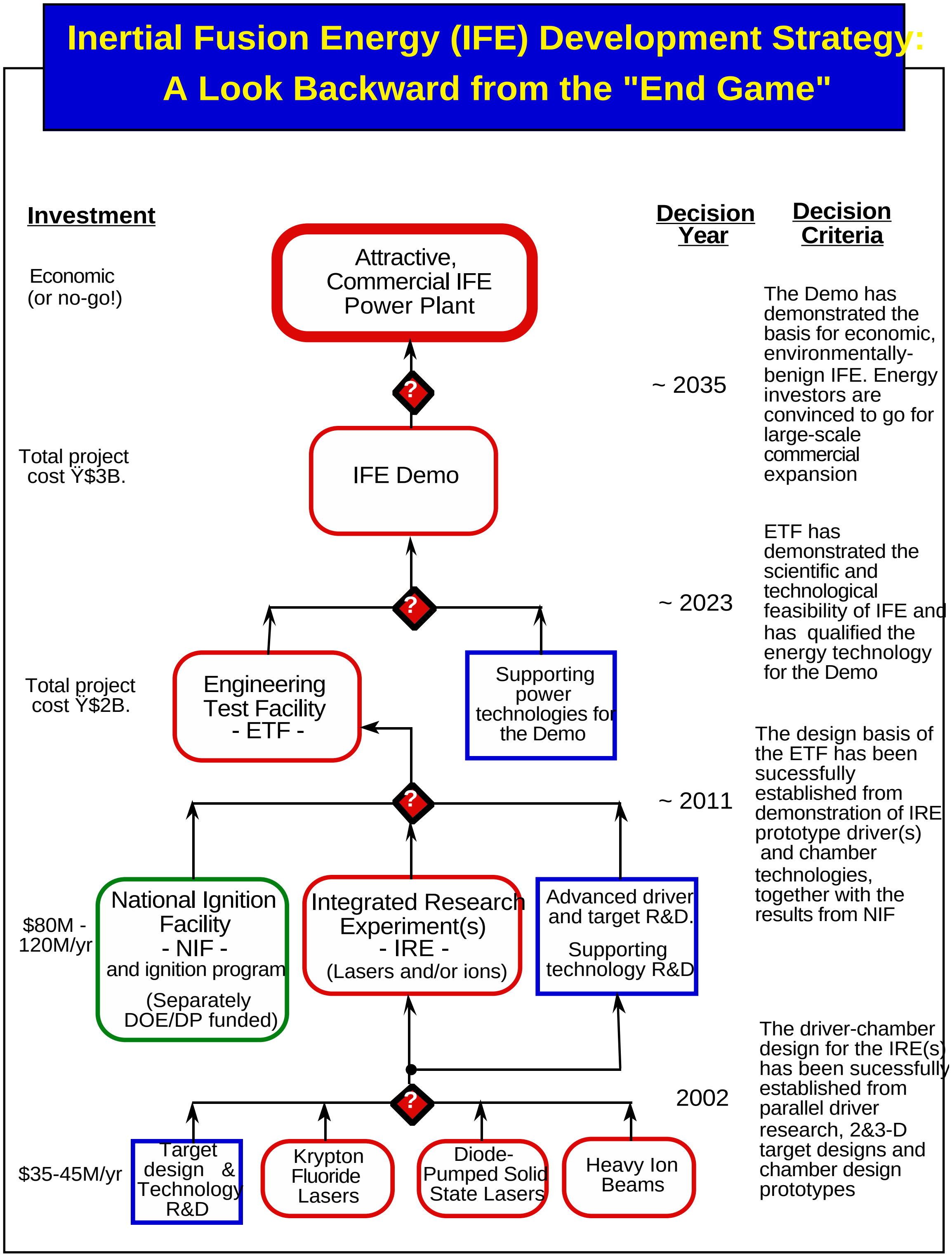


Fig. 2. IFE has a cost effective, phased development strategy.[4]

Background and Issues for IFE Target Fabrication, Injection and Tracking

To some extent target fabrication, injection and tracking have become "credibility" issues for IFE. The IFE design studies[1,2] have shown plausible design solutions to the problems of IFE target fabrication, injection and tracking, but skeptics remain unconvinced. They point to the tight specifications that must be achieved for current ICF experiments and question whether the design approaches proposed for IFE will prove to be technically feasible, whether they can meet the accuracy required, whether the targets will survive injection into the hostile target chamber environment, and whether all this can be done with high reliability and at a total cost per target of only about 25¢.

Simplified Typical ICF Target Specifications	
Capsule out-of-round	≤1%
Ablator thickness uniformity	≤1%
Outer surface smoothness	≤200 Å
Inner surface smoothness	≤1 µm
Capsule centered in hohlraum	≤25 µm
Allowed ΔT after layering	≤0.5K
Location at shot time	≤200 µm
Reliability	≥99%

Table 2. Typical ICF target specifications are stringent. They may be relaxed somewhat for indirect drive IFE, or tightened somewhat for direct drive IFE.

Target fabrication, filling, layering, injection, and tracking at the rate required for IFE is, in fact, a significant technical challenge. About 500,000 targets must be prepared and injected each day at a rate of 5–10 Hz into a target chamber operating at elevated temperatures. These targets must have high precision and be prepared at reasonable cost. Little serious work has been done to date to address these issues. In order to justify proceeding with the IFE IRE, the technical feasibility of IFE target fabrication and injection concepts must be demonstrated, and it must be shown that a credible pathway exists to achieving the accuracy, reliability and economy requirements for IFE.

Before IFE can become a reality, target-manufacturing costs must be reduced by four orders of magnitude from today's "typical" ICF target cost of about $2500. The cost of the current ICF targets is at least partly due to the small number of targets produced of any single design and the extensive characterization required for each target. Large-scale target production will significantly reduce the manufacturing cost and, once targets are being mass-produced by a reproducible process, characterization must be reduced to that required by statistical quality control requirements. Some of the current ICF target manufacturing techniques may have the potential to meet the cost and production requirements of IFE. Indeed, some of the current processing steps, such as microencapsulation of target capsule inner mandrels by a triple-orifice droplet generator, already employ continuous processes that operate at rates consistent with IFE requirements. Nevertheless, significant issues are involved in scaling up these processes from the 1-mm capsules required currently for OMEGA to the 5–7 mm contemplated for IFE while still achieving the precise specifications required. Moreover, the cost of capsules under IFE production conditions has never been seriously studied.

Other processes are available that would need to be scaled-down (in size) to meet the requirements of IFE. Hollow spheres made by commercial processes (e.g. ping pong balls) are too large, too thick walled, and have excessive surface roughness and localized defects. These processes would need to be scaled-down in sphere size, but scaled up in quality and rate to meet IFE requirements. For IFE hohlraum production, there are significant questions as to the viability of the machine-electroplate-leach technique used for ICF hohlraums. But again there have been no recent studies of potential cost reduction through automation of this technique. Processes, such as stamping, die-casting and injection molding, are used commercially for production of parts superficially similar to a hohlraum — these need to be investigated to determine if they are indeed suitable for IFE hohlraum production.

It isn't enough that a target, designed for high-gain energy production, can be produced economically. It must also lend itself towards economic and practical filling and layering, and it must survive injection into the target chamber without degradation. In the case of permeation filling, the strength of the capsule dictates the maximum over-pressure that can be used and thus the time required for filling. The strength of the target may limit the acceleration to which the target may be subjected during injection. The emissivity of the target, at the temperature of the target chamber, will dictate the velocity it must have to avoid excessive heating while traveling to chamber center. Indeed, all the ramifications of the target design on the various systems of the IFE power plant must be evaluated.

The overall goal of this work is to develop a self-consistent scenario demonstrating an economic path towards manufacturing, filling, layering, injecting, and tracking a plausible IFE target. This must not only consider the cost of mass-producing IFE targets, but also the impact of the target design on the total target supply system.

Capsule filling and layering techniques are just now being fielded for ICF targets. Capsules are filled by permeation and layered by augmented beta layering. The time required, at room temperature, to permeation fill a 10-micron wall, 1-mm diameter capsule is 8 hours. Thinner walled or larger diameter capsules would take significantly longer, although filling at higher temperatures could reduce the fill time. Using these ICF processes, the tritium inventory required to sustain the IFE target filling throughput rate could be excessive. Development of alternative, innovative processes for target filling should be investigated for IFE.

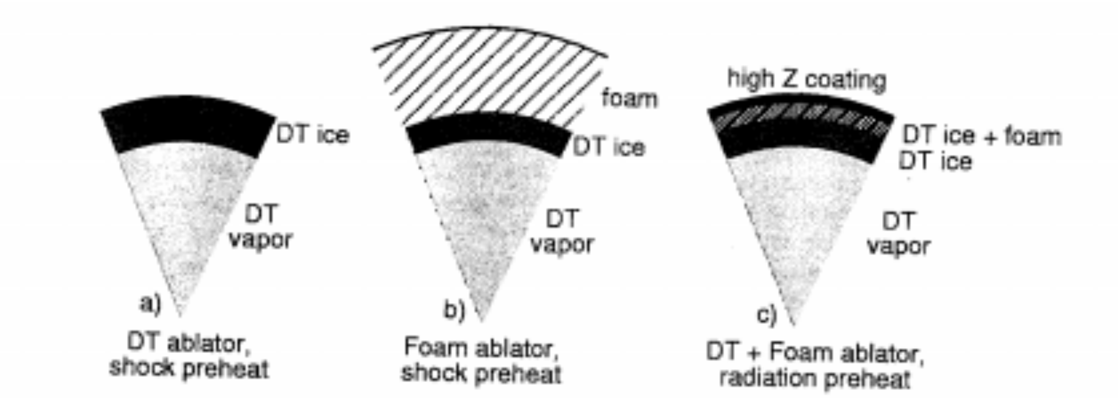
Early IFE studies proposed alternative methods of filling and layering. These techniques must be revisited, and other innovative techniques should be investigated to optimize filling and layering systems for IFE.

The target design can also have serious cost impacts on the target injection and tracking systems. The injector design is based on the required target velocity as it enters the chamber and the acceleration used in achieving that velocity. Target design limits both of these parameters. The velocity must be sufficient to prevent overheating and degradation of the fuel layer by thermal radiation from the chamber walls. The required velocity increases with the emissivity of the target (the ratio of energy adsorbed by the target to the total thermal energy flux) and decreases for increased fuel fill. For uncoated capsules, the emissivity increases with wall thickness. The maximum permissible acceleration decreases for targets with thin walls or weak wall materials. This results in a greater distance for acceleration, greater accelerator length and increased cost for the acceleration portion of the target injector.

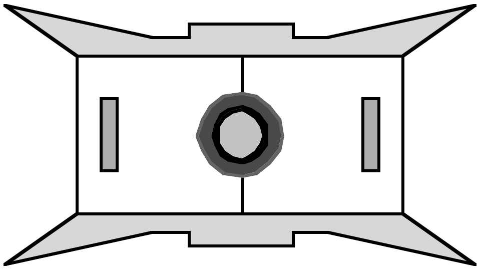
Current Status

Targets currently fabricated for ICF experiments have many of the characteristics that will be needed for IFE, although the size is smaller (capsule diameter ~ 0.5 mm for Nova, ~1 mm for OMEGA and ~2 mm for the NIF vs. ~5 mm for IFE). Several of the IFE target designs also contain various foam materials that are not currently used for ICF targets, as shown on Fig. 3. ICF targets are also made with a variety of diagnostic features that will not be needed for IFE and only a dozen or so of any one target design are needed. The fabrication techniques used for ICF targets were developed to meet exacting product specifications, to have maximum flexibility to accommodate changes in target designs and specifications, and to provide a thorough characterization “pedigree” for each target. The current ICF target fabrication techniques may not be — and were not intended to be — particularly well-suited to economical mass production of IFE targets. The cost of current ICF targets certainly is not well suited to IFE power plant operation. Because of constant development required by the small number of any one design that are made, and because of the thorough characterization required of each target, a completed target can cost about $2500. For a power plant to be economically competitive, the target cost must be reduced to about $0.25. Consideration of the various ICF target fabrication processes leads to the conclusion that some of these do extrapolate well to IFE, some do not, and all will require some level of development, as shown on Table 3.

Target injection and tracking has been demonstrated at an accuracy within the reach of beam-steering mechanisms with target simulants at room temperature. Demonstration of the ability of prototypical IFE targets to withstand the forces of acceleration during injection is needed.



a. Direct drive targets



b. Indirect drive target

Fig. 3. Typical IFE target designs.

Fabrication Step	ICF Process	Extrapolate to IFE?		Alternatives	Unknowns
		Specs?	Cost?		
CAPSULES					
— Indirect Drive	PAMS-GDP	Probably	Probably Not	Direct microencapsulation , Alt. deposition processes and materials	
— Direct Drive	PAMS-GDP	Probably	Probably		Equipment scale-up?
FOAMS	Microencapsulation	Probably	Yes		Strength at low density?
HOHLRAUMS	Machine-plate-leach	Yes	No	Stamp, mold	Alternative materials
ASSEMBLY	Micro-manipulation	Yes	Yes (Automate)		
CHARACTERIZATION	Extensive "pedigree"	Yes	Yes (Statistical sampling)		Key parameters?
FILLING	Permeation	Yes	Yes	Injection fill	Tritium inventory?
LAYERING	Beta layering, IR and µW enhanced	Yes	Probably	Fluidized bed	Tritium inventory?

Table 3. Some ICF target fabrication processes extrapolate to IFE, some do not, all require some development.

Fuel Capsules. The heart of an inertial fusion target is the spherical capsule that contains the DT fuel. Capsules for current experiments are ~0.5–1.0 mm in diameter and ~2 mm diameter capsules for the NIF are under development. These must meet stringent specifications including out-of round ($d_{max} - d_{min} \leq 1 \mu m$), wall thickness uniformity ($\Delta w \leq 0.5\ \mu m$) and surface smoothness (≤200 Å RMS) that are frequently represented by a power spectrum of the Legendre modes for the spherical capsule.

ICF capsules are currently made using the “PAMS-GDP decomposable mandrel process” Microballoons of poly(α−methyl styrene) (“PAMS”) are made by density-matched microencapsulation. Droplets of water, each surrounded by a droplet of PAMS dissolved in solvents, are dropped into a water bath where the solvents evaporate and the shells cure, giving a wall thickness of a few µm. Density-matched microencapsulation gives excellent sphericity, but less perfect wall uniformity. After drying, the PAMS shells (“mandrels”) are coated with a few microns of amorphous polymer in a glow-discharge polymer (GDP) coater. The GDP process gives a coating with excellent wall uniformity and surface smoothness. The coated mandrel is heated in vacuum, decomposing the PAMS which permeates out of the GDP shell, leaving a finished GDP shell with excellent sphericity, wall uniformity and surface finish. This can be coated with additional GDP to add ablation layers and/or doped diagnostic layers. Current experiments use ablation layers of about 50 µm. The NIF and IFE will need an ablation layer of about 100 µm for indirect drive, while for direct drive the DT ice itself will serve as the ablator and no additional polymer will be added to the GDP shell.

Polymer fuel capsules can be readily made by the density-matched microencapsulation process (Fig. 4) in the size needed for IFE, but they cannot meet the strict specifications for sphericity and wall uniformity that will be needed. As the capsule size is made larger, the gravity- and hydrodynamically-induced forces that cause non-uniformity get larger relative to the thermodynamic (primarily surface tension) forces that encourage uniformity. Because of the success of the PAMS/GDP process in producing excellent capsules for ICF experiments, and because of the flexibility this process offers for changing dimensions and compositions to respond quickly to the needs of the experimental program, it is the primary technique used in the US. The present GDP technique uses small batch sizes in expensive equipment and produces coatings at the rate of only a quarter micron an hour. It does not extrapolate directly to IFE well. Development will be needed to scale up batch size and coating rate while retaining product quality. Effort should also be devoted to understanding and improving the microencapsulation process. If adequate quality could be achieved at the sizes needed for IFE, this process would extrapolate well to economic production.

Several of the issues described above are concerns that will require development and hard work to resolve. Several, however, are issues that may be very difficult to resolve and that may posed a severe limitation on the performance of an IFE power plant. For these,an innovation of some kind will be a major advantage. The main concern is the ability to produce targets that meet extreme uniformity and smoothness specifications and yet can be made cheaply. The reason the specifications are so strict is that hot spot

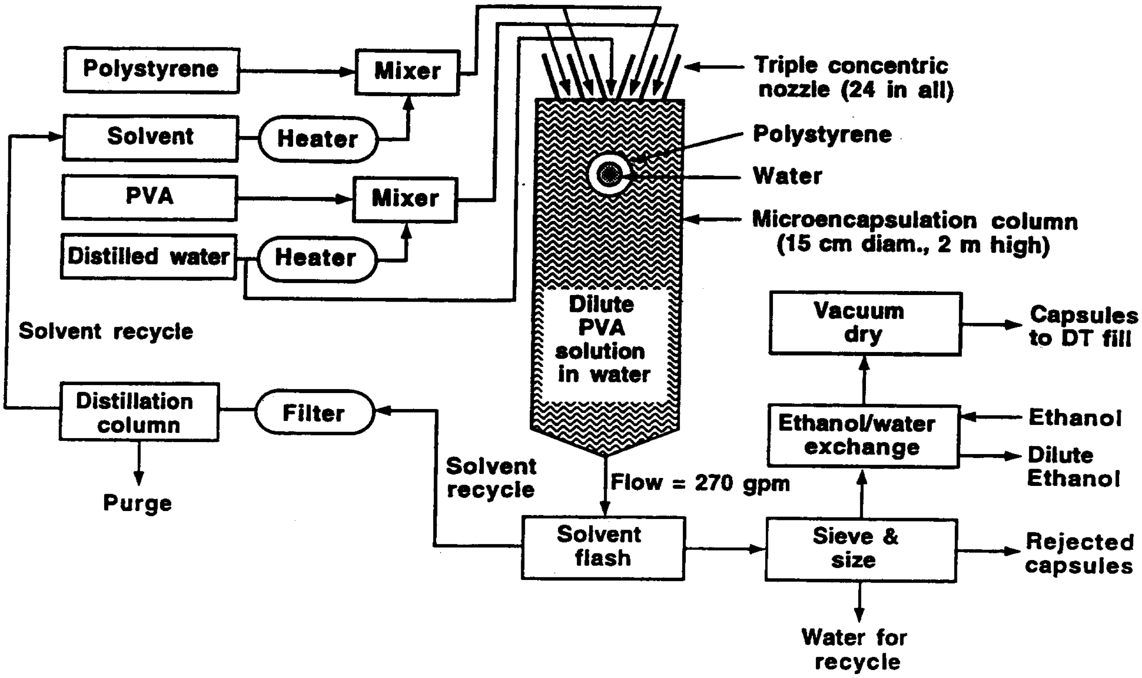


Fig. 4. Schematic of possible IFE capsule fabrication process using microencapsulation. (UCRL-ID-117396).[5]

ignition requires significant compression of the capsule in a basically unstable configuration of the dense outer layers compressing the light core. Any small perturbation will trigger Raleigh-Taylor instabilities and allow the cold outer layers to mix with the hot core, extinguishing the hot spot before ignition can be achieved. A major innovation for IFE is the concept of "fast ignition". In this concept, a DT capsule is compressed without a central hot spot gas core. An extremely intense laser beam is then used to start a propagating burn at the outside of the compressed fuel. This concept is much less susceptible to instabilities and less sensitive to the effects of mixing since there is no hot core. Fast ignition thus could significantly relax the uniformity and smoothness requirements imposed on IFE targets. Fast ignition has major other advantages also; it would allow a higher target gain to be produced by a lower driver energy which would improve the economics of IFE. Fast ignition is just beginning to be studied seriously and has no experimental verification yet. If this concept is validated it could have significant benefit to IFE target fabrication.

The quality of the fuel capsule could pose a severe limitation to IFE. If the stringent specifications currently foreseen for hot spot ignition capsule sphericity, uniformity and surface finish cannot be achieved with an economical mass production technique, the fusion yield could fall precipitously, and could be quite variable from shot to shot. It is vital that the target gain curve be well mapped, and the variability in that curve with target quality be understood. This could be done with IFE target experiments in the NIF. It may be possible to develop the current PAMS/GDP process into a mass production technique and microencapsulation holds great promise for producing IFE quality capsules very economically. If these techniques cannot meet the challenge, innovative processes such as interfacial poly-condensation may provide a solution, although those processes currently envisioned share many of the limitations of the current techniques. It is possible that changing the capsule materials would help. It appears that use of a beryllium capsule would allow the surface finish specifications to be relaxed, although this material would introduce a host of other concerns. The most promising innovation is fast ignition which could relax the capsule specifications to the point that existing techniques could mass produce capsules of adequate quality.

Hohlraums. For HIB targets, the capsules are mounted inside a thin metal hohlraum. For current experiments, the hohlraums are a few millimeters in diameter and length. For the NIF these dimensions will be just under a centimeter; for IFE they will be just over a centimeter. The wall thickness is about 25 µm, although very thin metal walls (~2 µm) backed with epoxy for support are also used to minimize debris. ICF hohlraums are currently made by electroplating the hohlraum material, generally gold, onto a mandrel, generally copper, that has been turned in a very high precision lathe called a diamond turning machine. This lathe is computer controlled and uses a gem-quality diamond cutting tool to achieve dimensional tolerances of <1 µm and surface finish better than 200 Å. After plating, the mandrel is dissolved, leaving the empty hohlraum shell.

For IFE, a new process such as stamping, die casting or injection molding must be used with cheaper materials such as lead. Fortunately, this does appear to be practical. The tolerances required do appear to be within reach of these mass-production processes. What is needed is cooperation between the target designers and target fabricators to develop designs that promise to give good performance and to use practical fabrication techniques, and then to build and test these designs.

Target Assembly. ICF targets are assembled manually. The hohlraums are cut in half before the mandrel is dissolved. The capsules are mounted between two sheets of extremely thin (~0.3 µm) Formvar plastic, which are then placed between the two halves of the hohlraum, and the assembled target is fastened together with UV-cured epoxy. Assembly is done using micro-manipulators under a microscope. Placement of the capsule at the center of the hohlraum must be accurate to within 25 µm.

Target assembly for IFE will have to be fully automated, as opposed to today's completely manual operations. The accuracies required and the throughput rates needed appear to be attainable with currently envisioned equipment. The principal concern for automated assembly is the extreme fragility of most of the target components. Simply touching the surface of a capsule or a hohlraum mandrel with any foreign object will cause scratches that will render the part useless. With sufficient care and development, automated target assembly for IFE should be achievable.

Target Characterization. Precise target characterization is vital to ICF target fabrication. Batch characterization is used during the production process to verify that the target dimensions meet the acceptable parameter range for delivery. Individual characterization of every shell is needed to prepare the complete "pedigree" that accompanies each target that is delivered. The diameter and wall thickness of capsules are measured using a white light interference microscope with a precision z-stage. The location of the successive layers in the wall can be determined with an accuracy of <0.1 µm. Non-concentricity and out-of-round are measured with the same instrument. The elemental composition of doped capsules is determined with x-ray micro-fluorescence. The final measure of capsule surface characteristics is made with an atomic force microscope (AFM) spheremapper, which rotates the shell on a precision air bearing against an AFM head. Three mutually orthogonal sets of three parallel traces around the shell are taken and the Fourier transforms of these traces are averaged to obtain the power spectrum of the capsule. These procedures are very laborious but yield the precise characterization of every target demanded by the ICF experimentalists.

For IFE, the production processes will have to be refined to the point where only a small percentage of the components manufactured can be allowed to not fully meet spec. Each component or target will not be inspected. Characterization will only be used as part of the QA process, measuring a few components every now and then to keep the production line adjusted properly. The basic characterization techniques now used manually are for the most part amenable to full automation.

DT Filling. Targets for ICF experiments are filled by permeation. The capsules are placed in a pressure vessel which is first evacuated and held at vacuum overnight to pump out residual air, and then filled with DT gas at the required pressure for the shot — generally a few tens of atmospheres. The capsules may be heated to speed the permeation and the pressure may have to be raised in several controlled steps to avoid crushing the shells. For cryogenic targets, the capsules are filled to high pressure and then cooled to condense the fuel. The very thin shells (<3 µm) and the very high pressures (>1100 atm) that will be needed for cryogenic shots on OMEGA require a very careful sequence of gradually stepping up the pressure and then gradually stepping down the temperature to fill and cool the capsules without crushing or bursting them. The fill-cool sequence can take as long as 80 hours for thin-walled cryogenic capsules.

The principal concern for scale up of the DT fill process to IFE is the tritium inventory that will be needed and the vulnerability of that inventory. For diffusion fill requiring a day or two, the minimum inventory to provide 5 targets per second approaches 10 kg, all of which would be vulnerable, that is, at high pressure in gaseous form. While this is clearly a manageable inventory, total release would have an impact on the safety rating of the power plant. Techniques such as injection fill of the capsules using micro-hypodermic needles have been proposed(1) that could significantly reduce the inventory.

DT Layering. After the capsules are filled and cooled to condense the fuel, the DT must be formed into a uniform, smooth spherical shell layer on the inside of the capsule. If the exterior of the capsule is maintained at a uniform temperature of about 19.5 K, the natural beta decay energy of the tritium will accomplish this through a process known as "beta layering". The very low energy beta particles from tritium decay deposit their energy very close to the location of the original tritium atom. This means that a region that is thicker will generate more heat than a thinner region and the DT will tend to sublime from the thicker zones and deposit on the thinner ones until a uniform thickness is achieved. This requires very precise temperature uniformity (<25 µK) around the capsule, but will produce very uniform layers. The inner surface of the DT ice layer must be very smooth. For indirect drive targets a surface smoothness of <1 µm RMS is expected to be needed. Direct drive may require smoothness as good as 0.1 µm RMS. The surface roughness is due to crystallites in the DT ice and may be controlled by adjusting the temperature at which beta layering is done and the rate of cooling of the layer. Surface smoothness of about 1 µm RMS can be achieved, which should be adequate for HIB indirect drive targets.

The primary issue for DT layering for IFE is confirming the DT ice inner surface finish requirement. It appears that 1 µm is sufficient for HIB indirect drive and this can be achieved by unassisted beta layering.

Target Injection and Tracking. Design studies of target injection were done as part of the several IFE power plant studies completed in the early 1990's. A gas gun system was proposed for injection with crossed dipole steering magnets to direct the beams. More recently, analyses of target injection and tracking systems have been carried out at LLNL and predicted that IFE targets could survive the mechanical and thermal environment during injection. A gas gun indirect drive target injection experiment was then constructed and operated at LBNL[6] (Fig. 5). The results showed that relatively simple gas gun technology could repeatably inject a simulated indirect drive target to within about 5 mm of the driver focus point, easily within the range of laser or beam steering mechanisms to hit, but not sufficient to avoid the need for beam steering. Photodiode detector technology was adequate to detect the target position with sufficient accuracy that the driver beams should be able to achieve the ~±200 µm accuracy needed. This work has recently been extended to show similar results for low speed (~100 m/s) injection of simulated direct drive targets at room temperature, using a sabot.

Recommended Target Fabrication, Injection and Tracking Research Program

The following tasks need to be done to address the issues of IFE target fabrication, filling, layering, injection, and tracking:

FY99 and FY00. Thoroughly review existing target designs with IFE and ICF target designers at LLNL, LBNL and NRL. Work closely with the IFE Labs to determine the characteristics and requirements placed upon targets. Explore, with them, the current understanding of target requirements for IFE applications. Finally, with their concurrence, define common elements and structures required for IFE targets.

Fig. 5. IFE Target Injection Experiment at LBNL.[6]

Develop materials and processes which may be required to satisfy unique IFE target requirements. An example might be low density, high strength foams for IFE capsules that will stand up to the rigors of cryogenic handling, filling and injection.

Evaluate laboratory and commercial processes that have the potential to manufacture the required elements and structures at high rates, with high precision and at reasonable costs. Provide feedback to the target designers of the impact of the various target design decisions.

With the advice and concurrence of the target designers, and working with the target fabrication R&D activities at the ICF labs, select a simple set of specific components which could form the basis of a practical IFE target and which have the potential for low cost manufacture.

Propose one or more integrated manufacturing schemes that have the possibility for fabricating the desired components and estimate the cost of manufacture under an optimistic scenario.

Delineate the major obstacles to cost effective target manufacture and define means for overcoming those obstacles. Prepare a work package to prototype key manufacturing steps.

Begin investigation of IFE target filling techniques and integrate the results of this study into an overall target system design effort and into feedback to IFE target designers.

Demonstrate hitting a hohlraum during injection using the existing (gas gun) injection equipment. This demonstration will consist of hitting a scintillator-coated hohlraum with a low current ion beam, to show how beam steering can correct for random target placement uncertainties, as controlled by the optical tracking system.

Begin the design, procurement, and fabrication of experimental equipment to perform injection and tracking demonstrations at higher accelerations and higher velocities. This experimental accelerator (Fig. 6) is being constructed as part of an integrated program to support both laser-driven and HIB fusion. While direct drive target injection has more serious issues with regard to target heating and survival as compared to indirect drive (due to the surrounding protective hohlraum), this equipment will be utilized to demonstrate the ability of proposed HIB targets to withstand the acceleration forces of injection.

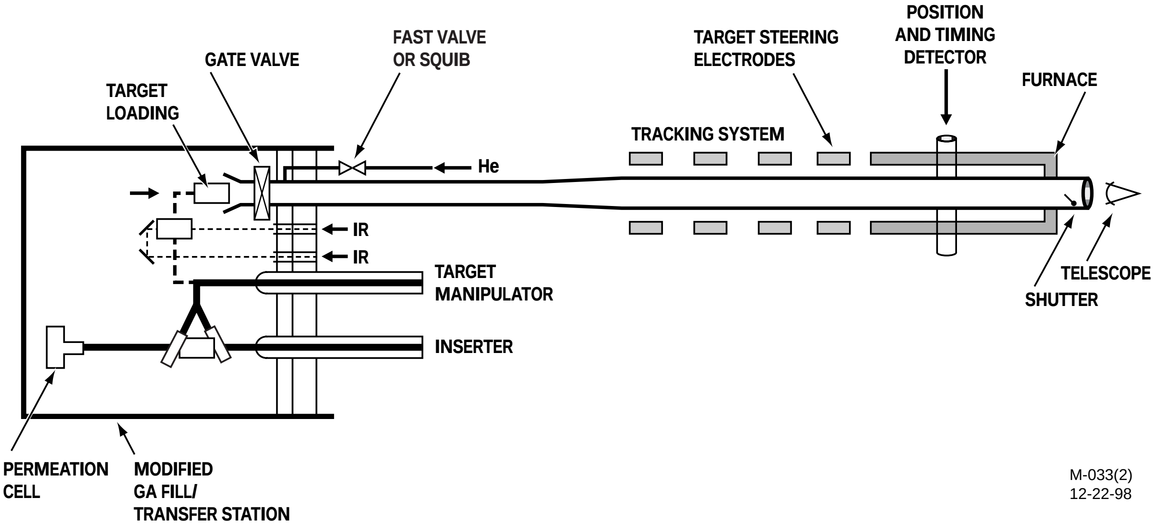


Fig 6. Simplified schematic of experimental system to address IFE target survivability.

FY01. Further investigate alternative fabrication techniques for each of the components and processes associated with inertial fusion energy targets. This includes consideration of alternate materials, alternate configurations, and alternate target specifications. Work closely with the ICF Labs in developing ideas for targets that can be fabricated on a mass production scale in an economical manner. Begin small-scale experiments to fabricate prototypical components of inertial fusion energy targets, by either laboratory or commercial means, as appropriate. In so doing, determine the capabilities of the processes needed for fabrication of proposed targets. The prototype targets will be available for use in target filling, layering and injection experiments.

Continue investigation of target filling techniques and begin the investigation of alternative filling and layering techniques. Compare and contrast the alternative techniques with those used for ICF to select methods to pursue for IFE.

Complete the design of the experimental system to determine the effects of acceleration on targets, as well as completing the related fabrication and procurement tasks. Measurements of the strength of hydrogen isotope ice under representative conditions will also be carried out.

FY02. Continue, on a larger scale, experiments on alternative fabrication techniques for IFE target components. Evaluate the results of the fabrication studies and provide feedback to IFE target designers. This will provide the basis for IFE targets that promise potential economic feasibility while achieving the technical requirements for ignition and burn. The significant quantity of prototype targets produced in this effort will permit high rep rate target injection studies. Continue the investigation of alternative filling and layering techniques. Complete target fabrication, filling and layering cost studies, which will be used to support the decision to proceed with the Phase II budget increases for an Integrated Research Experiment (IRE). Perform assembly and shakedown testing of the accelerator systems and conduct room temperature injection runs. Data on accuracy as a function of injection velocity will be available.

Subsequent years. Direct the target fabrication studies towards the goal of developing prototype IFE targets for testing in NIF in about FY06. Pursue proof-of-principle demonstrations of IFE target filling and layering techniques. Recommend to inertial fusion target designers an integrated IFE target production system, and the design directions and design constraints that economic fabrication will impose.

Complete the construction of experimental equipment for cryogenic target filling, layering, handling, and loading systems for injection and tracking demonstrations. Integrate these systems with the high-temperature furnace and inject cryogenic targets into the simulated chamber. Parametric injection and tracking experiments with a variety of target designs, both direct and indirect drive will be performed with the objective of verifying the effect of thermal radiation and chamber gas environments on the capability to inject and track targets, and on the condition of the target upon reaching the shot position in an IFE plant.

IFE Target Fabrication, Injection and Tracking Program

IFE target fabrication, injection and tracking is being developed as a part of the IFE Chamber and Target Technology element of the US DOE Office of Fusion Energy Sciences “Virtual Laboratory for Technology”. The work is being done cooperatively by a team of individuals from Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Lawrence Berkeley National Laboratory, University of California Berkeley, Naval Research Laboratory and General Atomics. Our plans for FY 99–02 are to demonstrate that a credible pathway exists for development of low cost IFE target fabrication, filling, layering, injection and tracking, in order to support the decision at the end of FY 02 on whether to proceed with an IFE Integrated Research Experiment, and if so, how to proceed. The proposed budget for this activity is approximately $3M/year.

References

1. Meier, W.R., *Osiris and Sombrero Inertial Fusion Power Plant Designs — Summary, Conclusions and Recommendations.* Fusion Engr. and Design, 1994. **25**: p. 145-157.
2. Moir, R.W., *et al.*, *HYLIFE-II: A Molten-Salt Inertial Fusion Energy Power Plant Design — Final Report.* Fusion Technology, 1994. **25**: p. 5-25.
3. Tabak, M., *et al, Fast Ignition by Petawatt Lasers*, Phys. Plasmas, 1994. **1** 5: p. 1626.
4. Presentation by E. M. Campbell, US Fusion Workshop, Madison, Wisconsin, July 1998.
5. Woodworth, J.G. and W.J. Meier, *Target Production for Inertial Fusion Energy,* Lawrence Livermore National Laboratory report UCRL-ID-117396, March 1995.
6. Petzoldt, R.W., *IFE Target Injection and Tracking Experiment,* Fusion Technology, 1998, **34**: p. 831-839.