PROGRESS TOWARDS DEMONSTRATING IFE TARGET FABRICATION AND INJECTION

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DISCLAIMER

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Progress Towards Demonstrating IFE Target Fabrication and Injection

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High-gain target designs have been proposed for laser-driven and heavy ion beam IFE power plants. Developing the technology to supply these targets represents a challenging multi-disciplinary optimization. Requirements are derived from considerations of target physics, materials fabrication, filling of the target with DT, layering of the DT fuel, target injection, costs, and environmental/safety concerns. The challenging scientific and technological issues associated with target fabrication and injection are being addressed with a multi-organizational program. Since some materials employed in the target designs have not been previously fabricated, new materials synthesis techniques are being developed or extended. An emphasis is being placed on methods that have the potential for extrapolation to high-volume production. Survival of the cryogenic target during acceleration and during its transit across the high-temperature target chamber is also an issue. A combination of thermal analyses, modeling, materials property measurements, and demonstration tests with representative injection equipment is being employed to demonstrate successful IFE plant fueling. This paper summarizes the requirements and critical issues for IFE target fabrication and injection, reviews the results from previous studies, discusses the development program now underway, and presents the current status of and results from that program.

1. Introduction

A number of IFE power plant conceptual designs have been published over the past several decades [1,2]. IFE plants are pulsed power systems that typically operate in the range of ~6 to 10 Hz. The basic requirement for the target supply system is to provide about 500,000 targets per day (at ~6 Hz) with precision geometry, and with precision cryogenic layered DT fuel. Target fabrication for inertial fusion is being investigated by a number of institutions throughout the world, including Russia, Japan, China, France, and the USA. While demonstrating the actual production of 500,000 prototypical targets per day over the next ~3–5 years is not a realistic goal, demonstrating a "credible pathway" for economical mass-production of targets is [3]. This means conducting experimental demonstration programs of scaleable processes, evaluating industrial processes for application to target fabrication, preparing chemical process flowsheets, initial equipment sizing calculations, and estimating costs [4] for equipment, material, and operations. Overall, a credible fabrication pathway must be defined and detailed. This paper describes our progress to achieving this near-term goal.

2. Critical Issues for IFE Target Technology

Target fabrication is defined to include not only the fabrication of capsules and materials, but also filling of targets with DT fusion fuel, layering of the DT, and all storage and handling up to handoff to the target injection system. The critical issues for target fabrication are:

- Ability to fabricate target capsules and hohlraums
- Ability to fabricate them economically
- Ability to fabricate, assemble, fill, and layer at the required rates

Target injection and tracking has the following critical issues:
- Ability to withstand the acceleration during injection
- Ability of the target to survive the thermal environment during injection
- Accuracy and repeatability of injection and tracking

3. Potential Target Designs and Fabrication Processes

We are addressing issues for both laser-driven direct drive radiation preheat targets [5,6] and for heavy-ion driven indirect drive targets [7]. These target designs are illustrated in Fig. 1. Additional advanced ablator designs of potential interest for IFE include an "empty outer foam" target (~250 mg/cc outer foam layer with the DT fuel positioned inward of the foam) and the classical "thick ablator" target. Potential fabrication processes or methodologies include microencapsulation (for foam shells and thick ablators), injection molding (for higher density foam shells), sputter-coating (for depositing high-Z coatings), fluidized beds (for deposition of seal coats and for ablators), casting and doping (for foams in the distributed radiator target), permeation (for DT filling), cryogenic fluidized beds (for layering of individual capsules), tube-layering (for in-hohlruam layering), use of a gas-gun or electromagnetic accelerator (for injection). Progress for some selected examples of these processes is described below.

4. Microencapsulation

Microencapsulation [8,9] is a very versatile process for IFE targets. It basically consists of a droplet generator that can produce capsules at rates as high as 30 per second. Microencapsulation is being extended to the divinyl benzene (DVB) chemical system (Fig. 2). This system is of great interest to the radiation preheat targets due to the absence of oxygen and nitrogen in the foam, and its potential to reach low densities (10–100 mg/cc) while maintaining very small pore sizes (~1–2 μm). Microencapsulation is also a good mass-production process that can be used to make mandrels [8] for fluidized bed coating (discussed below). Finally, recent advances in controlling non-concentricity and sphericity in microencapsulation of large shells suggests that this process could be used to make IFE-size capsules directly. Chemical process modeling of microencapsulation has also been initiated at LANL. Treating the Target Fabrication Facility (TFF) as a chemical process plant is exactly the approach that will be needed in the future. The near term goals of this modeling is to understand the equipment inputs and sizes that will be required in order to effectively address cost reduction.

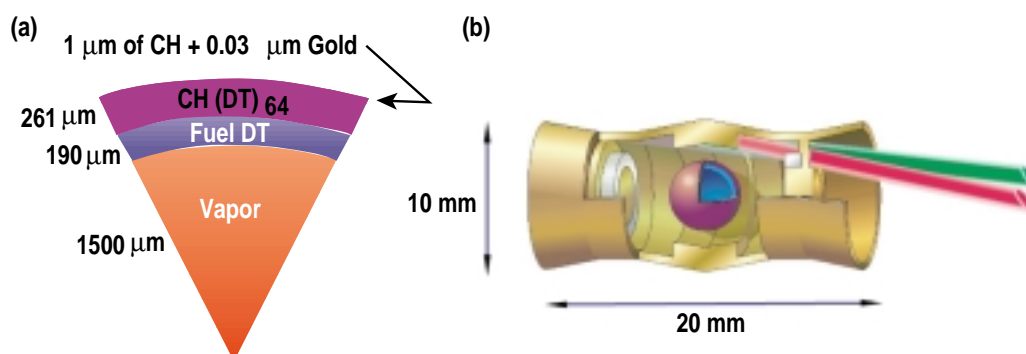

Fig. 1. (a) Potential "baseline" targets for IFE include the laser-driven radiation preheat target designed by Naval Research Laboratory and (b) the heavy-ion driven distributed radiator target designed by Lawrence Livermore National Laboratory.
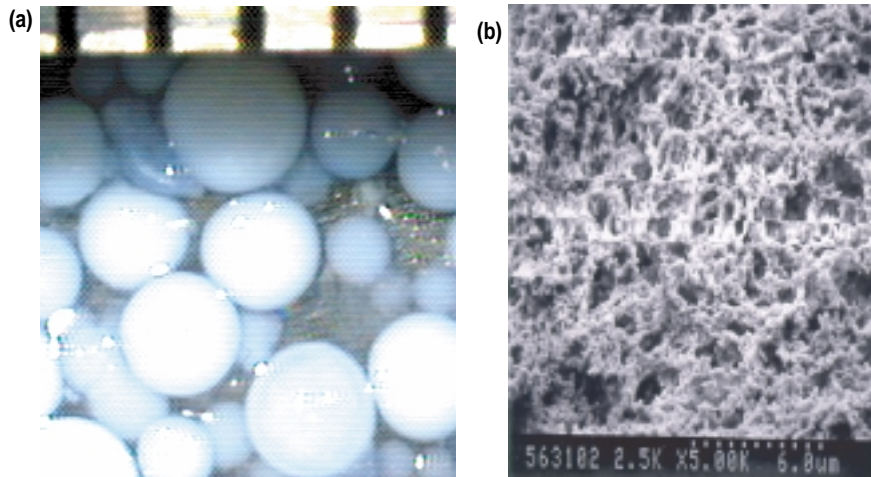
Fig. 2. Samples of DVB foam. (a) Foam beads and 10 mg/cc cast foam with ~1.6 µm pore size (photos courtesy of D. Schroen, Schafer Laboratories).

5. High-Z Coatings

This seemingly simple component of the radiation preheat target has a surprisingly large number of multi-disciplinary functions and requirements. It must consist of the proper element for target design, but also meet environmental and activation requirements, allow permeation filling of the target, be fabricable in a cost-effective manner, allow energy input for layering, be stable during cooldown, and be highly reflective in the IR to allow survival of the cryogenic target during its transit across the high-temperature reactor chamber. Gold was one of the first elements proposed for this layer. It has many advantages; it is easily coated, effective in target design, and highly reflective. However, gold (based on calculations using bulk gold properties) has the potential to greatly slow the deuterium-tritium filling process. Actual experience is that permeation barriers of this thickness (~300 Å) do not make effective seals. Thus, some samples of gold were prepared by sputter-coating onto flats and spheres. It was found that multiple spheres in a bounce pan stuck together during coating, but not to the pan. This is good news, as a large pan with individual "dimples" each containing one sphere in a large industrial sputter-coater can easily be used for mass production. Samples were very smooth (unchanged from the substrate), uniform (~10% variability as measured by x-ray florescence), and the permeation was found to be slowed by only a factor of ~8. This can certainly be considered a success. There is an ongoing effort to minimize the tritium inventory in the TFF,[1] so alternative elements with higher permeation were also examined. Palladium is a well-known diffuser in tritium applications and target designers are finding that Pd can be effective in reducing the laser imprint. Samples of Pd on Si and on polymer spheres were prepared. It was readily coated, had very high permeation (no difference could be measured between the Pd coated and non-coated spheres), and had higher than expected reflectivity.[2] In addition, the Pd samples on polymer shells did not exhibit the well-known phase-change and expansion that was observed with thin films on Si (Fig. 3). It is believed that strong bonding between the Pd and the hydrocarbon prevented buckling of the Pd film.

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[1] Shorter filling times results in lower tritium inventories in process at any one time.

[2] While gold has an integrated reflectivity of about 96% for a blackbody spectrum (reactor first wall temperatgure) of 1000°C, palladium samples had a reflectivity of about 82% at 665°C. These two wall temperatures were calculated to be the allowable values to ensure target survival during injection for the respective targets (assumes 400 m/s injection velocity, 4.5 m chamber radius, 10 mTorr Xe pressure, initial temperature of 18 K, and target survival to 19.8 K).

Further work with alloying of Pd with gold to increase reflectivity while retaining high permeation is planned.

6. Industrial Technologies for Target Fabrication

Fluidized beds are established in industry as a cost-effective mass-production technique [10]. Experiments to extend the Glow Discharge Polymer (GDP) coating technique (previously used with a few cm diameter bounce pan) were conducted. The fluidized bed was used to deposit GDP coatings on polymer mandrels (Fig. 4). The coatings were

Fig. 3. Samples of Pd coated onto polymer spheres showed very high permeation, higher than expected reflectivity, and appeared smooth and uniform.

smooth and uniform (Comparable to the bounce pan technique) and were very reproducible. This method is a promising method for reducing the cost of GDP targets. Solution spray-drying, widely used in the pharmaceutical industry, was also utilized with a fluidized-bed to produce polyimide coatings. A nebulizer providing 4–8 µm droplets of polyamic acid in dimethyl sulfoxide was utilized. While still too rough to meet target requirements, methods to smooth the shells are being pursued. Given the potential for relaxed ablator roughness with indirect drive IFE targets [11], injection molding is another industrial method that is being pursued for foam shells. Initial testing with ~100 mg/cc foam hemishells at LANL has been successful.
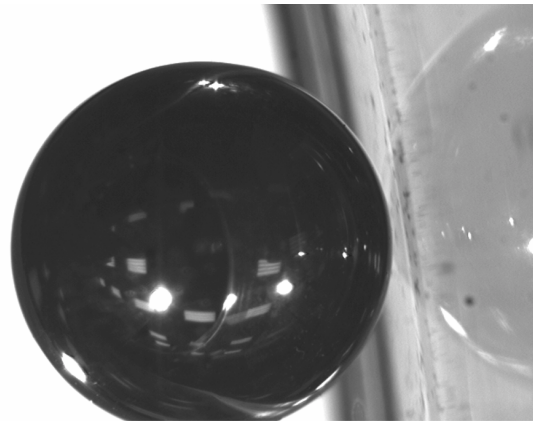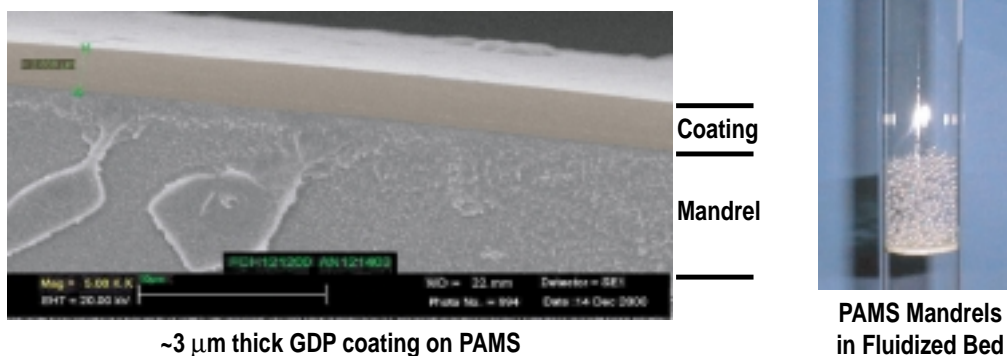

~3 µm thick GDP coating on PAMS

PAMS Mandrels in Fluidized Bed

Fig. 4. GDP coatings were deposited onto PAMS (poly(α–methyl styrene) mandrels in a ~2.4 cm diameter fluidized bed. Coatings were of high density and uniform.

7. Target Filling and Layering

Cryogenic implosion experiments using foam shells with gas barriers were done at ILE, Osaka in the early 1990's [12]. The OMEGA cryogenic target system at the University of Rochester [13] is the world's first full cryogenic target filling/layering system with IR heating. The system design basis is to deliver four filled and layered targets per day. Extrapolation of the high-pressure permeation cell used at OMEGA to one for mass-production results in equipment sizes that are reasonable for a production plant (a cell of 36" i.d. by 40" tall with trays for void volume reduction can hold ~ 300,000 targets). Layering by the use of individual layering spheres, as used at OMEGA, is not suitable for mass-production but other methods are available. A cryogenic fluidized bed is one such technique

being explored experimentally at GA. The basic concept is for the fluidized bed to rapidly randomize the targets, yielding a very uniform time-averaged surface temperaure. Room temperature surrogates were used to evaluate fluidized bed layering and gather initial operational data. These surrogates allow the use of room temperature characterization methods and allow an initial appraisal of the technique. Figure 5 shows samples that were layered in a fluidized bed with injection of IR energy. Oxalic acid crystals were mircroencapsulated into polymer shells and neo-pentyl alcohol was injected into shells with a needle and the hole sealed with epoxy.
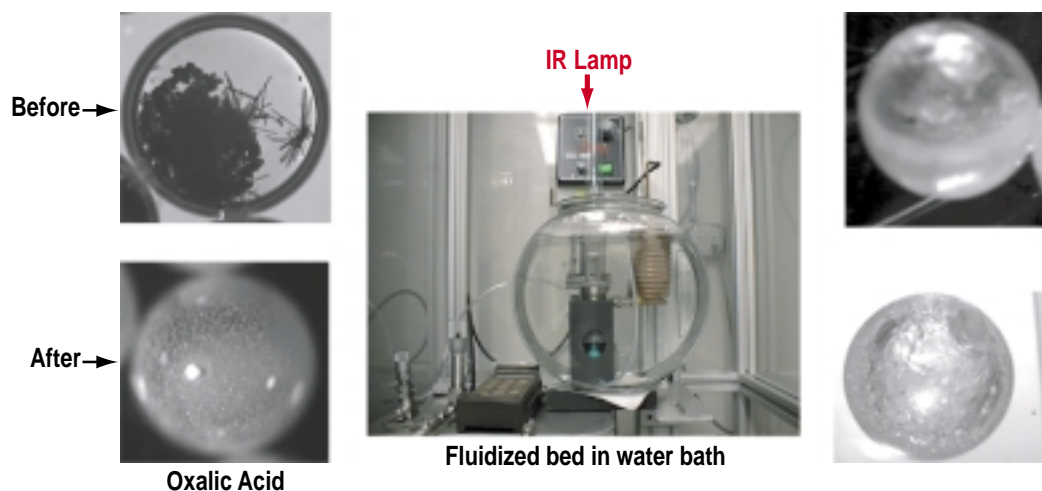

Fig. 5. Surrogate materials were layered in a fluidized bed to demonstrate proof of principal for the cocncept. These surrogates are solid at room temperature and allowed room temperature characterization.

8. Fueling of Z-Pinch Driven IFE

Fueling concepts for a Z-pinch driven IFE power plant are being developed (Fig. 6). Given the proposed rep-rate of about 0.1 Hz, design concepts indicate time frames for cyogenic target assembly and handling are feasible. More details are given in Ref. [14].

Fig. 6. Concepts have been developed to provide cooling to the Z-pinch target during the fueling process.

9. Target Injection and Tracking

Development of IFE target injection and tracking is following a detailed and integrated plan that was documented in Ref. [15]. A summary of this plan, along with recent progress is contained in Ref. [16].

10. Summary

Programs are underway to demonstrate a credible pathway to IFE target fabrication and injection. Critical issues have been identified, documented, and are being addressed with both analytical and experimental programs. While much progress has already been made, a significant development program will be needed to demonstrate mass-production of economical IFE targets.
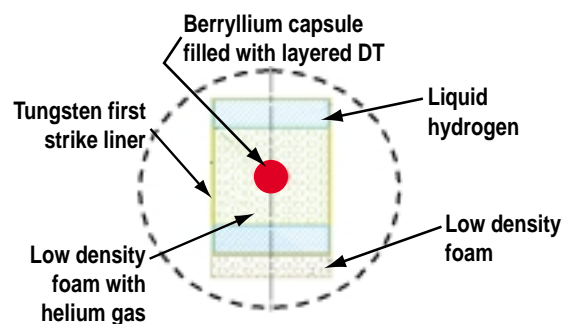
Acknowledgment

References

[1]   W.R. Meier, "Osiris and Sombrero Inertial Fusion Power Plant Designs — Summary, Conclusions and Recommendations," Fusion Eng. and Design **25** (1994) 145.

[2]   R.W. Moir, et al., "HYLIFE-II: A Molten-Salt Inertial Fusion Energy Power Plant Design — Final Report. Fusion Technology," Fusion Eng. and Design **25** (1994) 5.

[3]   K.R. Schultz, et al., "IFE Target Fabrication and Injection – Achieving 'Believability'," Nucl. Inst. and Methods in Physics Research A, Vol. 464, No. 1–3, (2001) 109–117.

[4]   D.T. Goodin, et al., "Reducing the Cost of Inertial Fusion Energy Targets," Inertial Fusion Sciences and Applications, September, 2001, Kyoto, Japan, these proceedings.

[5]   S.E. Bodner, D.G. Colombant, A.J. Schmitt, M. Klapisch, Phys. Plasmas **7**, (2000) 2298.

[6]   D.G. Colombant, et al., Proc. 26th ECLIM 2000, SPIE 4424 (2001) 224.

[7]   D.A. Callahan-Miller and M. Tabak, "A Distributed Radiator, Heavy Ion Driven Target Driven by Gaussian Beams in a Multibeam Illumination Geometry," Nucl. Fusion **39** (1999) 883.

[8]   B.W. McQuillan, et al., "The PAMS/GDP Process for Production of ICF Target Mandrels," Fusion Technol. **31** (1997) 381.

[9]   T. Norimatsu, et al., "Fabrication of Vacuole-Free Polystyrene Shells Over a Wide Diameter Range Using a W/O/W Emulsion Method," J. Moscow Phys. Soc. **8** (1998) 71–78.

[10] D.M. Parikh (Niro Inc.), "Fluid-Bed Processing in the 1990's," http://www.niroinc. com/html/pharma/pfbarticle.html.

[11] D.A. Callahan-Miller, "Target Designs for an Inertial Fusion Energy Power Plant Driven by Heavy Ions," Inertial Fusion Sciences and Applications, September, 2001, Kyoto, Japan, these proceedings.

[12] A. Richard, et al., "Implosion of D2 Temperature-Controlled Cryogenic Foam Targets with Plastic Ablators," Phys. Rev. E, **49** (1993) 1520–1526.

[13] D.T. Goodin, et al., "Status of the Design and Testing of the OMEGA Cryogenic Target System (OCTS)", Proc. of the 20th Symp. on Fusion Technology, Marseille, France, Vol. **2**, (1998) 949.

[14] G. Rochau, et al. "ZP-3, A Power Plant Utilizing Z-Pinch Fusion Technology," Inertial Fusion Sciences and Applications, September, 2001, Kyoto, Japan, these proceedings.

[15] D.T. Goodin, et al., "Experimental Plan for IFE Target Injection and Tracking Demonstration," General Atomics Report GA–C23241 (1999).

[16] D.T. Goodin, et al., "Developing Target Injection and Tracking for Inertial Fusion Energy Power Plants," Nucl. Fusion **41**, (2001) 551.