GA–A24086

ADDRESSING THE ISSUES OF TARGET FABRICATION AND INJECTION FOR INERTIAL FUSION ENERGY

by
D.T. GOODIN, A. NOBILE, J. HOFFER, A. NIKROO,
G.E. BESENBRUCH, L.C. BROWN, J.L. MAXWELL, W.R. MEIER,
T. NORIMATSU, J. PULSIFER, W.S. RICKMANN, W. STECKLE,
E.H. STEPHENS, and M. TILACK

SEPTEMBER 2002

DISCLAIMER

GA–A24086

ADDRESSING THE ISSUES OF TARGET FABRICATION AND INJECTION FOR INERTIAL FUSION ENERGY

by
D.T. GOODIN, A. NOBILE,† J. HOFFER,† A. NIKROO,
G.E. BESENBRUCH, L.C. BROWN, J.L. MAXWELL,† W.R. MEIER,‡
T. NORIMATSU,◊ J. PULSIFER,∆ W.S. RICKMANN,£ W. STECKLE,†
E.H. STEPHENS,∆ and M. TILACK∆

This is a preprint of a paper to be presented at the 22nd Symposium on Fusion Technology, September 9–13, 2002, Helsinki, Finland, and to be published in *Fusion Engineering and Design*

†Los Alamos National Laobratory, Los Alamos, New Mexico 87545
‡Lawrence Livermore National Laboratory, Livermore, California 94551
◊Institute of Laser Engineering, Osaka University, Osaka, Japan
∆University of California, San Diego, La Jolla, California 92093-0417
£TSD Management Associates, Encinitas, California 92024

Work supported by
the U.S. Department of Energy
under Contracts DE-AC03-98ER54411 and W-7405-ENG-48 and
NRL Contract No. N00173-01-C-6007

GA PROJECT 39083
SEPTEMBER 2002

ABSTRACT

Addressing the issues associated with target fabrication and injection is a major part of an international program to establish the feasibility of Inertial Fusion Energy (IFE), both for laser-driven and heavy-ion driven concepts. A summary of the unique materials science and chemistry research programs associated with supplying targets for an IFE power plant is presented. The cost of manufacturing targets for commercial power applications is a significant perceived feasibility issue for IFE, and preliminary estimates of Target Fabrication Facility (TFF) costs are discussed for both direct and indirect drive systems.

1. INTRODUCTION AND BACKGROUND

A central feature of an Inertial Fusion Energy (IFE) power plant is a target that has been compressed and heated to fusion conditions by the energy input of the driver beams. The target must be accurately delivered to the target chamber center at a rate of about 5–10 Hz, with a precisely predicted target location. The relatively fragile cryogenic targets must survive injection into the target chamber without damage.

An example of a recent direct drive IFE target proposed by NRL is shown in Fig. 1. The target consists of four parts: a high-Z (nominally Au and/or Pd) coated polymer capsule of thickness ~1–5 μm, a DT filled CH foam ablator, a layer of solid DT fuel, and a core containing DT vapor [1]. Shown in Fig. 2 is an example of a heavy-ion indirect drive target proposed by Lawrence Livermore National Laboratory (LLNL) [2]. The DT fuel is contained in the central capsule, which is supported by a polymer membrane attached to the hohlraum casing. The target technology development program addresses the issues of both direct and indirect drive targets.

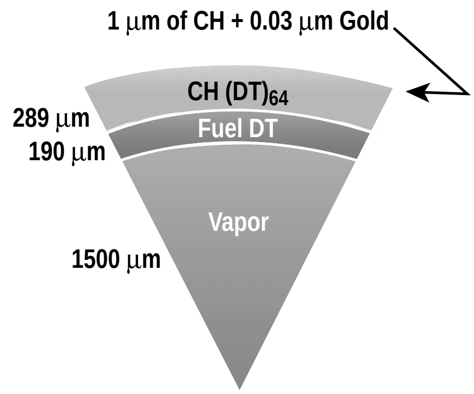

Fig. 1. Laser driven direct drive radiation preheat target for IFE designed at NRL [1].

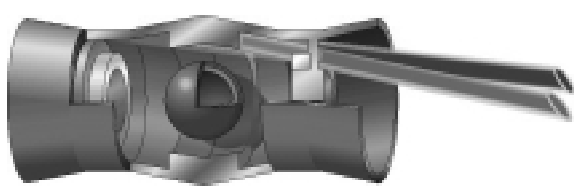

Fig. 2. Heavy-ion driven indirect drive target for IFE designed at LLNL [2]. The length of the target is 20 mm and the average radius is ~5 mm. The central fuel capsule is ~4.7 mm in diameter and consists of an ablator (capsule) surrounding a solid DT fuel layer of 0.32 mm thickness.

2. KEY TECHNICAL ISSUES AND TARGET SUPPLY REQUIREMENTS

The top-level critical issue being addressed is the ability to provide targets filled with DT ice at ~18.5 K, and meeting the geometric requirements, and deliver them accurately and repeatedly to the center of a high-temperature target chamber at a rate of about 5 to 10 Hz.

The “Target Fabrication Facility” of an IFE power plant must manufacture about 500,000 targets per day at a cost of about $0.25 to 0.30 each [3]. After manufacture, the target is injected into the target chamber at a rate of 5–10 Hz. The DT layer must survive the exposure to the rapidly increasing heat flux and remain highly symmetric, have a smooth inner ice surface finish, and reach the chamber center at a temperature of about 18.5 K.

3. RESEARCH AND DEVELOPMENT PROGRAM

The purpose of the target development program is to provide the detailed scientific basis that will be necessary for fueling of future IFE power plants. Target fabrication tasks have concentrated on investigating and developing the various materials needed by the target designs and on fabrication techniques that could eventually scale to low cost and high production rate. In the area of materials, very low-density foams doped with high-z materials, which provides the energy deposition material in the heavy-ion driven target design, have been developed [4]. Development of additional metal foam fabrication methods is underway, including laser-assisted chemical vapor deposition (LCVD) [5]. Injection molding for manufacture of foam capsules is also being evaluated for its ability to meet geometric requirements (Fig. 3). A research-scale fluidized bed that is capable of coating mandrels with relevant ablator materials (Fig. 4) has also been built to evaluate scaleup and future high-volume manufacturing methods. Micro-encapsulation is being studied for its potential to directly produce spherical shells meeting IFE capsule requirements (Figs. 5 and 6) [6]. Alloys of high-Z materials, such as Au and Pd for the outer layer of the radiation preheat target, are being optimized to give the desired properties of high reflectivity (for survival of the cryogenic target in the high temperature chamber) and high permeation (for permeation filling with hydrogen isotopes).

Models for tritium inventory in the target facility have been developed and used to project acceptable quantities of tritium for future plant operation [7]. Equipment is being constructed to develop and demonstrate accurate placement and precise tracking of targets during the injection process [8].

Fig. 3. Injection-molded 4 mm diameter hemishell with a 400 μm wall.

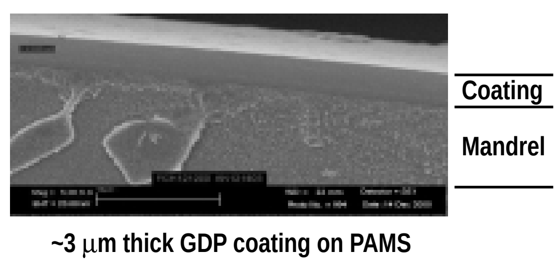

Fig. 4. A fluidized bed is a promising method for scaleup of coating production in large quantities.

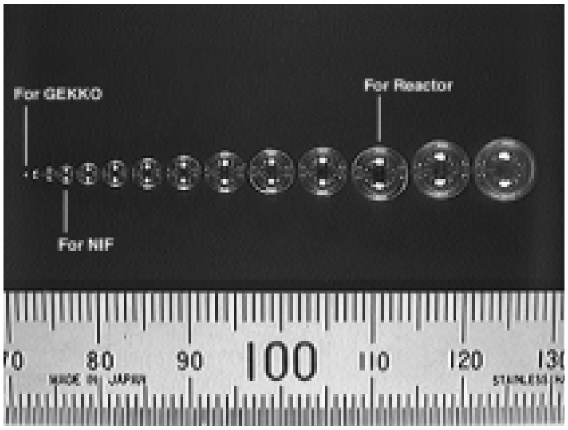

Fig. 5. Direct microencapsulation has the potential to produce spherical capsules in the sizes and tolerances needed for IFE power plants.

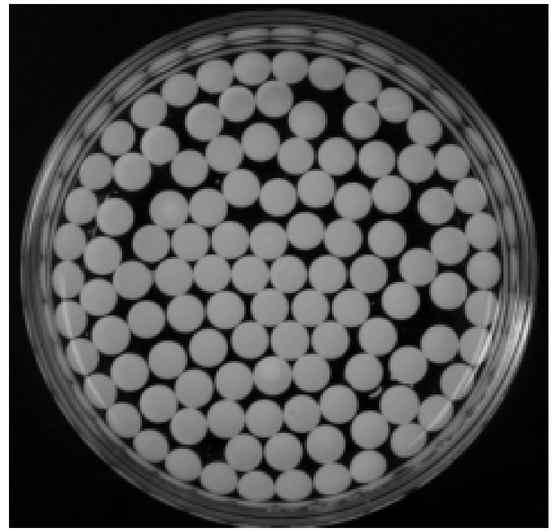

Fig. 6. Direct microencapsulation of divinyl benzene foam shells is being developed for the NRL radiation preheat target.

4. TARGET FABRICATION FACILITY DESIGN AND COSTING ANALYSIS

We must also understand the issues and factors that can lead to effective, low-cost target production – studies have consistently shown that a cost reduction of at least four orders of magnitude from current technologies will be needed for future electricity production.

4.1. DIRECT DRIVE TARGETS

We have now, for the first time, prepared a chemical engineering analysis of all of the process steps needed to mass-produce direct drive targets having gains suitable for commercial fusion in a laser driven system. This modeling of target fabrication includes process flows, mass-energy balances, plant utilities, raw materials, quality control, waste handling and recycle, capital equipment cost amortization, and staffing requirements. Results of the modeling show that the future cost goals of less than about $0.25–0.30 per target can be met, provided that the planned development programs are implemented.

4.2. INDIRECT DRIVE TARGETS

Compared to the laser direct drive target, the baseline distributed radiator heavy ion fusion design has a capsule that should be lower cost to manufacture, but has the addition of a hohlraum. Changes to the original, Ref. [3], target design to reduce manufacturing costs continue to be evaluated [9]. While final choices for the hohlraums materials are still being evaluated, selections must include consideration of (a) target design and physics, (b) target manufacturing costs, (c) ability – and costs – to remove the debris materials from the primary coolant circulating loops, (d) undesirable interactions of the materials with structural materials in the reactor, (e) activation and generation of high-level waste; and, (f) environmental safety and health. Individual target materials may or may not be recycled. Building on the work performed for the direct drive target, we have completed a partial analysis of the indirect drive target, estimating the cost of manufacturing the thick-walled polystyrene capsule, filling it with fusion fuel, and layering the DT. These steps are estimated to cost about 11 cents per target in a future commercial production basis. This result is also encouraging in that considerable cost margin remains for the manufacture of the hohlraum components and performing the hohlraum and capsule assembly steps. Future work will focus on evaluating these steps in conjunction with target designers, and arriving at cost-effective selections of materials and manufacturing processes.

5. SUMMARY AND CONCLUSIONS

The ability to economically manufacture and inject cryogenic targets is a significant feasibility issue for future inertial fusion energy power plants. The fabrication development programs are focusing on methods that will scale to mass production, and working closely with target designers to make material selections that will satisfy a wide range of required and desirable characteristics. Preliminary estimates of the costs to manufacture targets in a future commercial power plant environment indicate that cost goals for economical electricity production can be met if the planned target development programs are conducted.

REFERENCES

[1] S.E. Bodner, D.G. Colombant, A.J. Schmitt, and M. Klapisch, "Physics of Plasmas **7**, (2000) 2298-2301.

[2] D.A. Callahan-Miller, M. Tabak, Nucl. Fusion **39** (1999) 1547.

[3] J. Woodworth and W. Meier, "Target Production for Inertial Fusion Energy," LLNL Document UCRL-ID-117396, March 1995.

[4] W.P. Steckle, Jr. and A. Nobile, "Low Density Materials for use in Inertial Fusion Targets," presented at the 2nd International Atomic Energy Agency Technical Meeting on the Physics and Technology of IFE Targets and Chambers, San Diego, California, (2002), and to be published in the proceedings.

[5] J. Maxwell, L. Rodriguez and A. Nobile, "Synthesis of High Z Low Density Foams for Heavy Ion Fusion Hohlraums," presented at the 2nd International Atomic Energy Agency Technical Meeting on the Physics and Technology of IFE Targets and Chambers, San Diego, California, (2002), and to be published in the proceedings.

[6] T. Norimatsu, *et al.*, "J. Moscow Phys. Soc. **8** (1998) 71–78.

[7] M. Schwendt, A. Nobile, P.L. Gobby, W.P. Steckle, D.G. Colombant, J.D. Sethian, D.T. Goodin and G.E. Besenbruch, Tritium Inventory of Inertial Fusion Energy Target Fabrication Facilities: Effect of Foam Density and Consideration of Target Yield of Direct Drive Targets, accepted for publication in Fusion Science and Technology.

[8] D.T. Goodin, *et al.*, Nucl. Fusion **41**, (2001), 527.

[9] D.A. Callahan-Miller and M. Tabak, Physics of Plasmas **7**, (2000), 2083-2091.

ACKNOWLEDGMENT

Work in the U.S. supported by U.S. Department of Energy under Contracts DE-AC03-98ER54411, W-7405-ENG-36, W-7405-ENG-48, Grant DE-FG03-00-ER54595, and by NRL Contract N00173-01-C-6007.