Topical Meeting on
Inertial Confinement Fusion
February 7-9, 1978

PRODUCTION OF POWER PLANT INERTIAL
CONFINEMENT FUSION TARGETS*

Charles D. Hendricks
University of California
Lawrence Livermore Laboratory
Livermore, California 94550

ABSTRACT

Power plant applications of inertial confinement fusion require production of targets at rates of 1-10 per second. Techniques for setting up "factory" operations to produce both cryogenic and non-cryogenic targets are presented. Cost comparisons with integrated electronics are made.

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It
has been reproduced from the best available
copy to permit the broadest possible avail-
ability.

* Work performed under the auspices of the U.S. Energy Research and Development Administration, contract No. W-7405-Eng-48.

PRODUCTION OF POWER PLANT INERTIAL CONFINEMENT FUSION TARGETS*

Charles D. Hendricks
University of California
Lawrence Livermore Laboratory
Livermore, California 94550

Present and near-future targets for inertial confinement fusion can be fabricated by techniques which currently exist or are in the development stage. Targets such as the simple ball-on-stalk can be manufactured one by one at a relatively large cost in manpower and time. Highly characterized targets such as the ball-on-stalk cost several hundred dollars if they are really well characterized and made from high quality components. The material cost of a ball is extremely small — as low as one micro-cent. The cost of the fuel in the glass ball is not quite as low — 0.1 cent for 100 nanograms of tritium and a negligibly small amount for the deuterium. The material cost of the glass stem on which the ball is mounted is perhaps 0.1 cent or less and the cement to attach the ball to the stalk is worth perhaps 10^{-4} cents. Thus, we see that the cost of the material in this simple but often used target is perhaps 0.2 cent. It is obvious that the cost of such a target in a finished state is essentially the cost of the manpower to handle, select, fuel fill, measure, and assemble the parts.

TABLE I

Ball diameter:	Selected to ± 5 micrometers Measured to better than 1 micrometer
wall thickness:	Selected to ± 0.2 micrometer Measured to better than ± 0.05 micrometer
sphericity:	Selected to better than 1% Measured to better than 1%
surface finish:	Selected to better than $1000 \text{ \AA}$ Measured to better than 100 $\text{\AA}$ (contour mapped over entire surface if necessary)
fuel fill:	Filled to $\pm 20\%$ Selected and measured to $\pm 10\%$ (5% if necessary)
stalk:	Pulled from glass tube or rod or selected from Al_2O_3 or C fibers
cement:	Epoxy or other suitable bonding agent
assembly:	Under microscope by hand or with use of micromanipulators

* Work performed under the auspices of the U.S. Energy Research and Development Administration, contract No. W-7405-Eng-48.

As a reasonable figure for manpower cost, let us assume \$25/hour. Since ICF is still in a research mode and every experimental target must be very well characterized on an individual basis — not statistically, several parameters must be measured to a high degree of accuracy. Table I indicates some of the parameters considered and the limits on those parameters in order that a target be considered as a highest-quality part of the experiment.

Each of the parameters measured and each hands-on operation is expensive. If a target requires one man-day for parts selection, preparation, manufacture, characterization, and assembly, the cost is approximately \$200. It is difficult to conceive of a well characterized target which would require less than one man-day of effort. However, when the research mode of inertial confinement fusion is joined by the power production mode, the targets must be produced at high rates, must be of high quality and must be produced at costs of less than about 50 cents if ICF power production is to be economical.

In order to approach the problems of production of inexpensive targets, several aspects (and perhaps some truisms) of the fabrication processes which must be reconsidered are:

1. Fuel container production (glass, plastic, or metal shells or the fuel itself as its own container)
2. Layer coating
3. Surface and interface characteristics
4. Fuel state
5. Required production rate

Let us examine first the unlikely situation in which the target is a solid, cryogenic sphere of DT. Solid spheres of cryogenic materials including hydrogen have been produced at high rates. For example, Hendricks and his colleagues at the University of Illinois have generated hydrogen spheres at rates up to 10^5 per second and diameters greater than 100 micrometers. The unused spheres can be recirculated and the fuel reused.

Since simple solid spheres are unlikely targets, modifications must be considered. A target which is again somewhat unlikely in its simplest form is the simple hollow spherical shell of frozen hydrogen (DT). Such hollow shells have been experimentally produced by Hendricks' group. The shells have been generated at high rates at very low cost per target.

Such unlikely targets are only stepping stones to more realistic, more complicated targets. Consider a possible multi-shell target composed of a frozen core of fuel (DT) surrounded by several concentric shells of various materials including high Z (xenon perhaps), medium Z (neon, argon) and low Z (hydrogen). Studies leading to production of such multilayer cryogenic shells have been underway for some time with experimental success. Experimental and analytical research is being carried out on similar layered structures with a central hollow shell of DT. Such targets can be formed in a sequence of steps in a column or columns containing the coating materials. Each of the coatings is in an isolated chamber which is at a temperature suitable for condensation on the previous layer.

However, we must consider the possibility that the layered structures may not be totally cryogenic — only the innermost layer of DT fuel may be at

a low temperature. For such a target type can we still consider depositing coatings and layers on the target in a production line mode. It should be obvious that we can do so. Consider a spherical multilayer target in which the fuel is contained inside a thin hollow shell of glass as it is with current targets. By perfecting and optimizing current techniques of glass shell production such as those used by LL, KMSF, 3M, etc., it is to be expected that a high yield of target quality shells can be produced at high rates (about 10^3 per second at LL, similar rates are assumed for the KMSF processes). In a production system, the glass shells must be characterized as they come from whatever unit generates them. Computer sensed, analyzed and controlled techniques must be utilized to measure the appropriate parameters and either accept or reject the shells — all at a rate of perhaps 10^3 per second. Current technology in computerized image dissection and analysis and optical matrix sensor methods are capable of performing such tasks. For example, a hologram of an ideal spherical shell can be stored in digital form in the computer memory. As a real shell passes through a suitable optical system, a holographic image of the real shell can be produced and projected onto a matrix of sensors. The output of the sensors can then be compared with the stored image elements of the ideal shell. If the two sets agree sufficiently well, the shell is accepted and passed to the next stage of the system. If the sets do not agree, the shell is rejected. Throughout the target production process similar techniques will be used for characterization after every step. At no point in the process can we afford to manually pick up and examine or manipulate one target. At \$25 per hour, one second of manpower costs 0.69 cent. One minute of effort to "look at" or "pick up" a target costs about 42 cents.

Assume the characterization is accomplished and we have 10^3 high quality empty, hollow shells arriving per second at some point in our production line. If they accumulate for just over one day, there will be sufficient to fuel a one shot per second power plant for one year if every process in the production line were perfect. Since the various steps are not perfect, enough shells must be made that the unsatisfactory targets may be thrown away and still have sufficient targets remain for power plant operation. The shell generation system must run almost continuously to allow for some rejection of some targets at each coating step. After perhaps 10^6 satisfactory shells have accumulated, a batch DT fill process may be done. The time constant for DT filling is a few hours and to ensure uniform results, a 24 hour period should be satisfactory. Following the batch DT fill process, the individual shells would again enter the production line individually to be coated with various required layers of material. There are coating processes under development which should enable us to deposit many micrometers of polymers on glass shells in a short time. Processes exist in the chemical industry which can be adapted to our needs. Coating materials, their properties and the methods by which they can be deposited, will require creative research and development before the targets can be produced for a few cents, but it can be done.

Let me use the semiconductor industry as an example of cost reduction which may come as a result of creative research and production techniques. In 1954 and 1955 I used some very high quality (for that time) transistors which cost \$54 each. In 1974, orders of magnitude higher quality transistors in terms of bandwidth, gain, and power handling capabilities were available for a few cents each. In fact, a large manufacturer of radios

and TV sets bought them by the pound for about the cost of the materials in the transistors. An RCA integrated circuit containing almost an entire FM receiver (88 transistors, 67 resistors, 16 capacitors, 7 diodes, and all input, output and interconnection hardware) could be purchased in 1974 for \$3.63 (retail). I point this out not to suggest that the target fabrication tasks for power plants are all solved but that they can be solved. The electronics industry works in sub-micrometer dimensions when it produces integrated circuits with an entire computer on a chip a few centimeters in length and breadth and a few millimeters thick.

I should also point out that nature has been making three dimensional multilayered structures of cryogenic materials in large numbers for a long time. Doubters should observe the microscopic structure of hailstones.

Thus, by utilizing existing techniques and improving them as well as being creative we can see that fusion targets for power plants can be produced in large numbers for the required low cost of a few cents per target.