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PREPRINT UCRL- 81537

CONF-781125--1

Lawrence Livermore Laboratory

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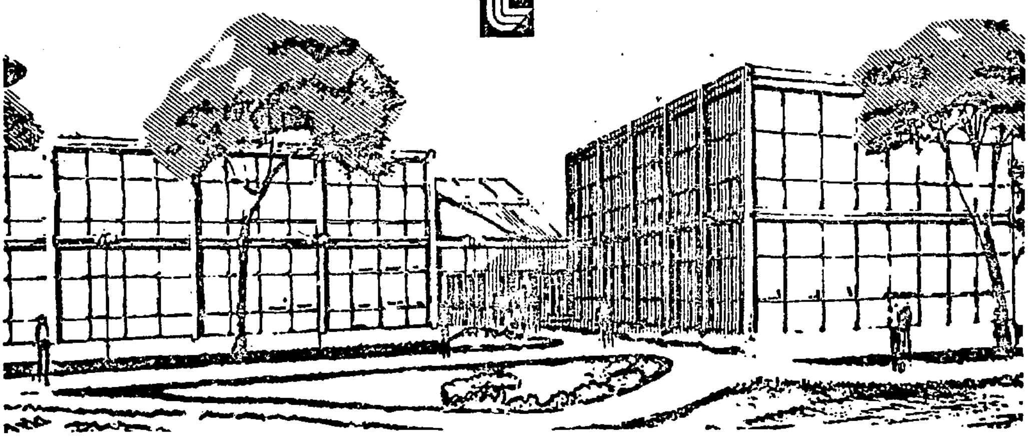
September 26, 1978

This paper was prepared for submission to
The Institute of Electrostatics, Japan, TOKYO
NOVEMBER 26, 1978



ELECTROSTATICS, SMALL PARTICLES AND LASER FUSION TARGETS

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Introduction

The success of any Inertial Confinement Fusion system for the production of useful power depends critically on the production of suitable targets. This is true whether the arrangement is that proposed by Nuckolls et al.[1] or some other arrangement. The target must have characteristics such as material composition, structure, and surface finish which are tailored to the laser pulse length, energy, peak and average power and pulse shape. To provide useful power on a continuous basis, it is likely that the repetition rate will be 1.0 to 10 per second. Thus, in a 24 hour running period 864,000 targets may be necessary and one must be placed at the focal point of the laser every tenth of a second. For economic operation it is necessary that the targets be produced at costs of less than $1.00 per target.

Present Targets

In the developmental phase of laser fusion, to be able to study the physics of the interaction of laser pulse and target, a number of different types of targets have been necessary.

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*Work performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore Laboratory under Contract Number W-74505-ENG-48.

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Preliminary studies of x-ray yields and acceleration of mass by means of the pressures and blowoff of material from surfaces employed simple foil targets of various materials. These targets included thin (7-25 μm) polyethylene (CH_2) films, polyethylene films with various metallic coatings such as copper, gold, indium, etc., and very thin CH films (500 Å paralene) with 50-200 μm diameter, 1-30 μm thick microdots placed on the CH surface.

For alignment purposes it is necessary that targets of various kinds be provided: flat, reflecting microdot targets; solid spheres of copper, glass, tungsten, stainless steel, etc.; and hollow glass spheres. Each of these targets must be securely mounted on a small (1-5 μm diameter) fiber support which in turn must be mounted on a suitable holder for placement in the target chamber at the laser focus.

Targets which are currently used for studies of neutron production require mounting on fibers and holders since they are, as the others mentioned, still research targets meant to be used to study the basic physics and engineering of the laser-fusion processes. Such research requires that every laser-target interaction be very well instrumented so that the characteristics of each laser pulse will be well known and the results of each shot can provide the maximum information upon analysis of good data. This requires that each target must be characterized as well as the current state-of-the-art allows. For example, our measurements of the hollow glass spheres used for targets provide information on the parameters given in Table I to the accuracy indicated. Figs. 1-4 are examples of targets with which we work. The characterization methods used include optical microscopy, scanning and transmission microscopy, optical interference microscopy, proportional counting, and mass spectroscopy.

Future Targets

It is quite obvious that the cost of hollow glass sphere targets produced and measured by current techniques will be prohibitive in any operation laser or electron beam fusion power system of the future. One commercial source of the glass sphere targets (spheres only--unmounted) offered to supply them at a cost of $25 each for a minimum of 10,000 spheres in the first order and $1-$5 each thereafter. Even at the lowest price, the cost is a factor of 10^2 higher than can be tolerated in a power system.

As a result of the high cost of glass sphere targets ~~we~~ it was concluded that a more economical means of production must be found. ~~I should~~ It should be emphasized that any production-delivery scheme must produce the targets with appropriate surface finish (surface irregularities less than 100 Å peak-to-valley amplitude) and deliver the targets to the laser focal point with an error which is within acceptable limits (the center of the target sphere must be within a sphereical region of space which is about 10 μm radius). As was mentioned in Section I, the target production-delivery system must deliver targets into the focal region at a rate of at least 10 targets per second. Research by Hendricks and his group at Illinois has led to the development of techniques which are being applied to the problems of target generation rates, qualities, and accuracies which meet the criteria for our future targets.

Target Generation Method

The physics of the formation of uniform liquid drops from a cylindrical jet has been studied for over a century. Lord Rayleigh wrote a number of papers on the subject; and Niels Bohr, for his doctoral research, used the technique described by Rayleigh as a means of measuring liquid viscosities. More recently, Hendricks and his co-workers have developed and employed the techniques of jet breakup and electrostatic control to produce uniform particles for research in space craft electric propulsion, cloud physics, aerosol studies, fusion targets, etc. The materials from which the spheres have been made include plastics; organic and inorganic liquids and solids of many kinds; and various cryogenic materials, including nitrogen, oxygen, argon, and hydrogen.

Several methods an be used to produce hollow glass spheres for laser targets. One which has been used with great success uses the liquid drop generator system developed by Hendricks and his colleagues (as shown in Fig. 5). An aqueous solution of glass-forming components is dispersed into uniform drops which fall through a vertical tube furnace to be dried and fused into glass. The electrostatic charge on each drop is controlled and deflecting fields are used to select the specific drops which form the glass shells. The sequence of events occurring in the tube furnace ~~are~~ is shown in Fig. 6.

To produce cryogenic target particles by the liquid jet method we have chosen to start with hydrogen isotopes in the gaseous form.[2,3] The hydrogen is introduced to a series of heat exchangers cooled by liquid and cold gaseous helium. In the final heat exchanger, the hydrogen is liquified and then expelled in the form of a liquid jet from a suitably small orifice. Rayleigh has described the breakup of a liquid jet into uniform drops upon the application of a capillary wave to the surface of the jet. As a result of surface tension forces, the amplitude of a disturbance of appropriate wavelength on the jet will grow until the varicosity cuts the jet into segments. The segments become spherical after some dynamical oscillations which are damped by viscous forces in the liquid. Since the wavelength and flow rates can be accurately controlled, each drop resulting from the process is very nearly the same size. The standard deviation of the diameter distribution can be made about 10^{-3} of the mean radius--a very narrow size distribution.

The surface of the spherical drops is very smooth since it is a free liquid surface with no externally applied disturbances and sufficient damping is present to remove quickly any motion resulting from the formation process. Optical observations fail to show surface structure and we can infer the surface is at least as smooth and free from disturbances as the liquid mercury surfaces used by R. W. Wood in 1908 and 1909 as astronomical telescope mirrors. His surfaces were probably smooth to better than 1/10 wavelength of sodium light on a large scale and much better than that on a small scale. In all probability, our free liquid drop surfaces have a smoothness better than 100 Å.

A similar technique may be used for the production of multilayered targets and for hollow spherical shells.[4]

In the case of layered targets, multiple annular coaxial fluid jets can be employed to produce a target of one material, e.g. DT with a layer of a second material, say neon, surrounding the first. By also introducing a controlled jet or stream of bubbles of deuterium, tritium, hydrogen, or helium in the inner material, it is possible to form hollow shells. Hollow shells of hydrogen have been produced with outer diameters of up to 150 μm and inner diameters of up to 130 μm.

Layered spheres of various materials have also been produced. Research and development on refinement of all these techniques is currently in progress. A diagram of a system to produce layered cryogenic laser fusion targets is shown in Fig. 7.

Drops from a 50-μm-diameter orifice are about 100 μm diameter and are produced at a rate of about 10^5 per second. By electrically charging the drops and using electric deflection fields and relatively standard pulse technology, it is possible to select any number of the 10^5 per second to be utilized, leaving the remainder to be collected and the material recirculated in the system to produce new particles.

The target particles produced by this technique can be directed to a location in a target chamber (the laser focal spot) with great accuracy. Experimental results indicate that the center of the target sphere can be placed in a pillbox-shaped volume measuring about 1 μm radius and about 2 μm thick. The timing error of target arrival at the chosen location can be made less than 1 microsecond.

We thus have the means of producing and delivering spherical, smooth-surfaced target particles of chosen size to an accurately located point in space and time. With a production rate of 10^5 per second and with unused material recirculation possible, the cost per particle used (at say 100 per second) is essentially the cost of the deuterium and tritium in each particle.

Several electrostatically-influenced processes occur in target fabrication systems. Since the glass shells have large surface-to-mass ratios, surface charge and relatively small external fields can strongly influence the shell behavior. "Clumping" of particles and wall effects because of charging can be serious problems during the handling of the glass spheres. Self charging which results from the emission of the beta particles by tritium decay has also been the source of some difficulties.

In a power production laser-fusion system it is probable that DT spheres approximately 1 mm in diameter will be used as targets. Our production rates of particles this large is about 1000-2000 per second. In a five-year operational period at a rate of 60 pulses per second,* 9.5×10^9 targets will be required. In each of the 1-mm-diameter spheres, there will be about 6.6×10^{-8} kg of tritium and 4.4×10^{-8} kg of deuterium. Assuming tritium breeding in the reactor and a reasonable recovery system, a cost of $100-$150 per gram for tritium can be expected. The target particles will then cost from 0.66-1.0 cents each.

The costs of operating power, labor, and equipment required for the target fabrication are about .002 cents per target in an operational system. Present systems require 10-15 kW of electrical power for their operation--the power being primarily for vacuum pumps and a small amount for electronics systems.

A conceptual system for production of laser fusion targets is shown in Fig. 8. Control of the spheres during the characterization and coating processes is by quadrupole electric field systems or by electric curtain techniques developed by Masuda and his co-workers.

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*It may be that with current operating-line frequencies of 60 hertz, it would be wise to operate a laser fusion system at a pulse rate of 60 per second to better match line frequency.

TABLE I. HOLLOW GLASS SPHERE TARGET SPECIFICATIONS

PARAMETER	TYPICAL RANGE	VARIATION PERMITTED
Outside diameter	50-2000 μm	± 1%
Wall thickness	0.5 - 30.0 μm	± 5%
Inner-outer surface Concentricity		± 3% of wall thickness
Sphericity		± 1% of radius
DT fill	2-50 x 10^{-3} gm/cc	± 10%
Surface smoothness		100-300 Å peak-to-valley

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2. C. D. Hendricks, "Hydrogen Pellet Generation for Fusion Research," Bull. Am. Phys. Soc., II, Vol. 19, p. 915, October, 1974.
3. A. L. Hunt, C. C. Damm, R. K. Goodman, C. D. Hendricks, "Production of Solid Pellets for Laser Initiated Target Plasma in BB II," Bull. Am. Phys. Soc., II, Vol. 19, p. 963, October, 1974
4. C. D. Hendricks and C. Foster, "Hollow Hydrogen Shells for Laser-Fusion Targets," Bull. Am. Phys. Soc., II, Vol. 19, p. 927, October, 1974.

FIGURE CAPTIONS

1. Gold disk target used for alignment purposes with a 25 μm hole being drilled through the disc.

2. A thin-walled glass microsphere filled with DT mounted on a hollow glass fiber ready for use as a laser fusion target.

3. A DT-filled glass microsphere mounted on a large circular glass plate to form a target used with laser light incident only from ~~the~~ ~~left~~ one side of the disc.

4. Glass microsphere mounted in a thin, large-diameter disc for use as a laser fusion target with irradiation from both sides of the disc.

5. A liquid drop generation system for production of hollow glass microspheres.

6. A diagram of the processes occurring during production of hollow glass microspheres by the liquid droplet technique.

7. A system for the production of layered cryogenic targets for a laser fusion system.

8. A block diagram of a factory configuration for the production of high-quality, low-cost inertial confinement fustion targets.

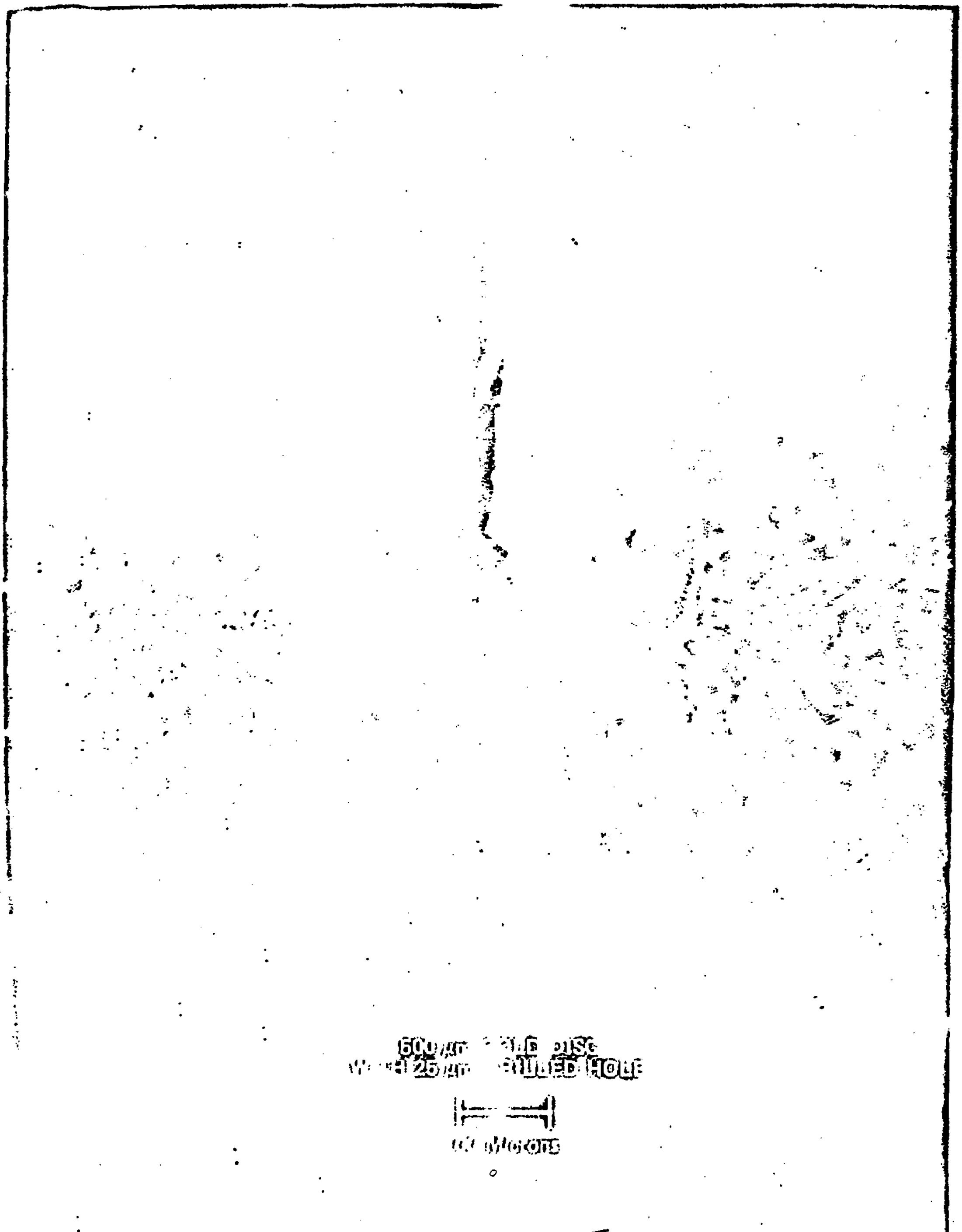

Fig 1

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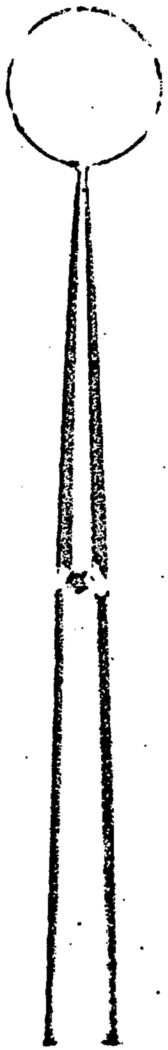

Fig 2

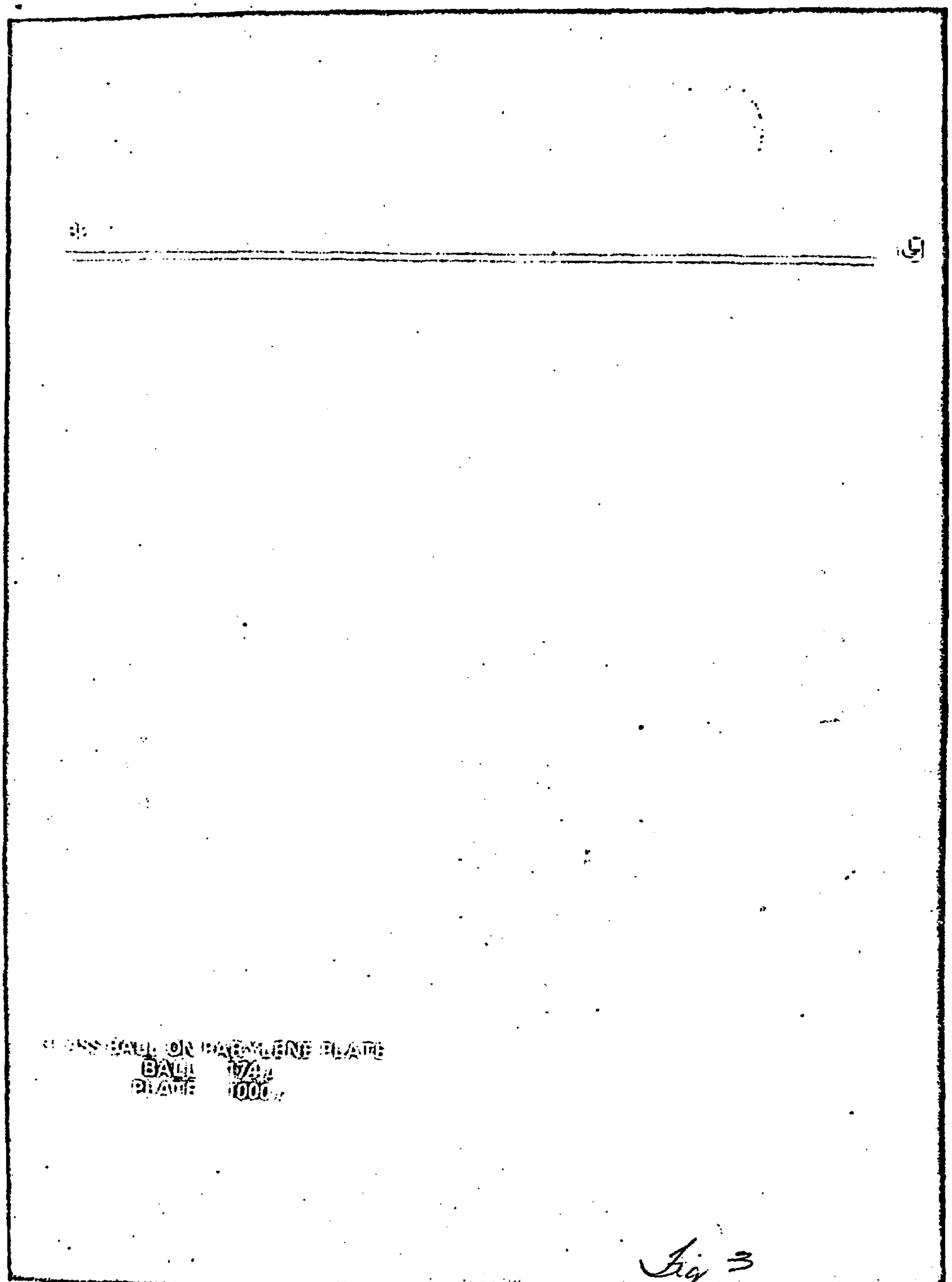

Fig 3

[illegible]
SHIVA'S FIRST 20 ARW TARGET [illegible]

View from x-ray microscope:

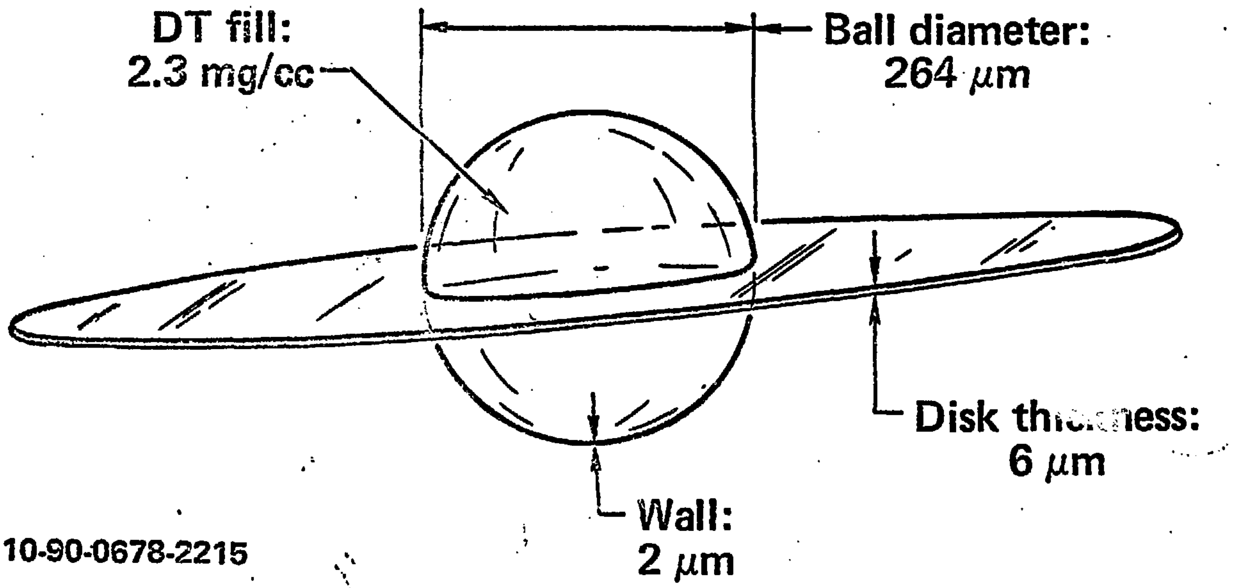

Fig 4

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THE DROPLET GENERATOR IS A MICRODISPENSER

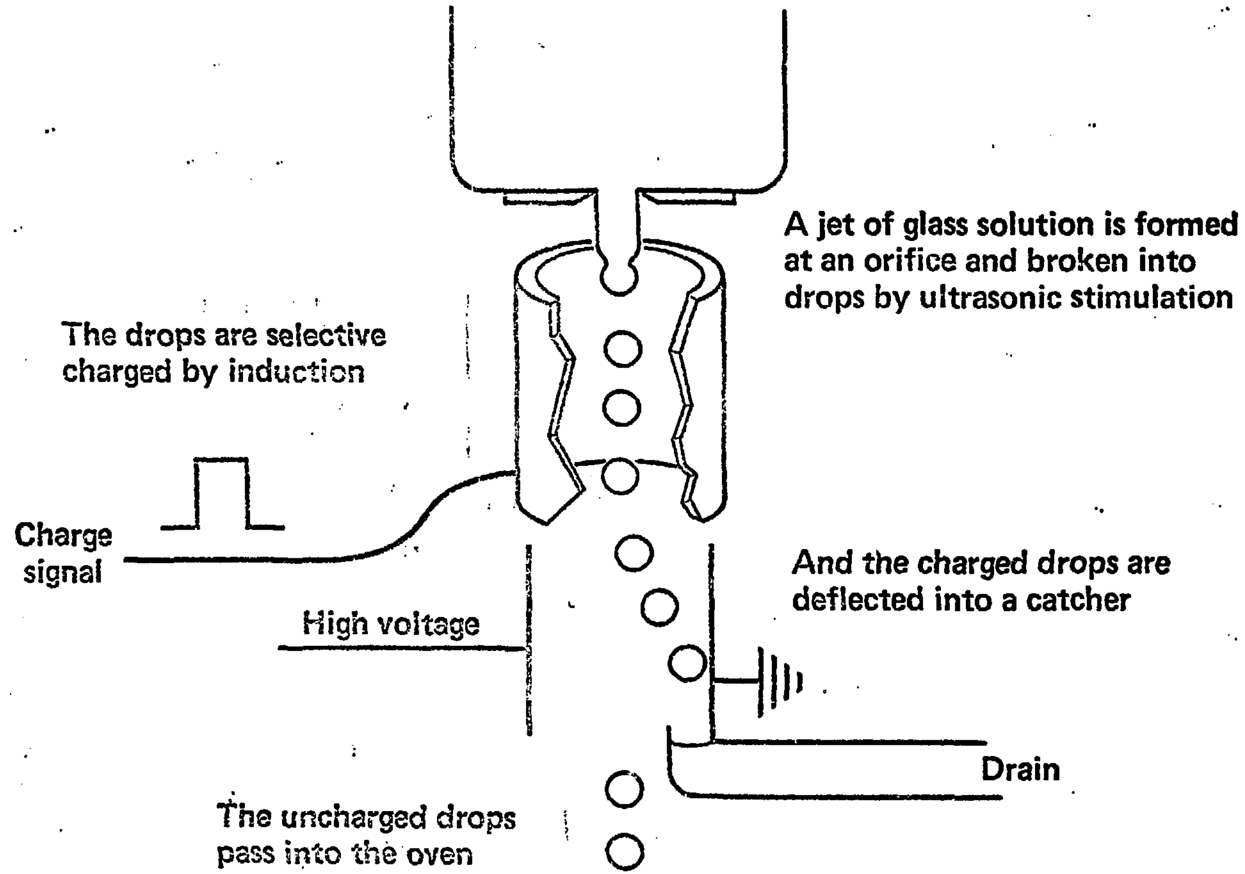

Fig. 5

LIQUID-DROPLET SYSTEM

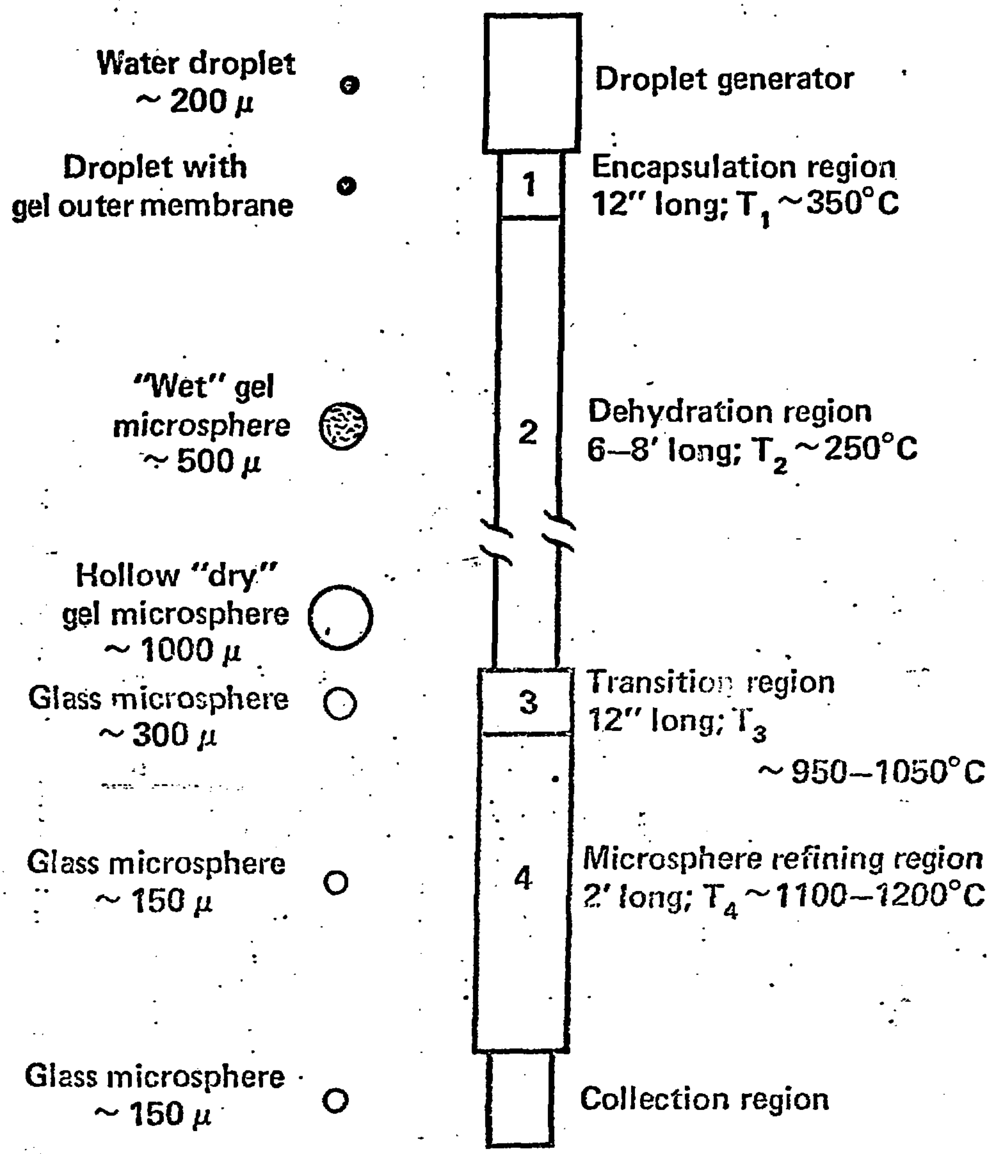

Fig 6

MULTILAYER CRYOGENIC REACTOR TARGET PRODUCTION

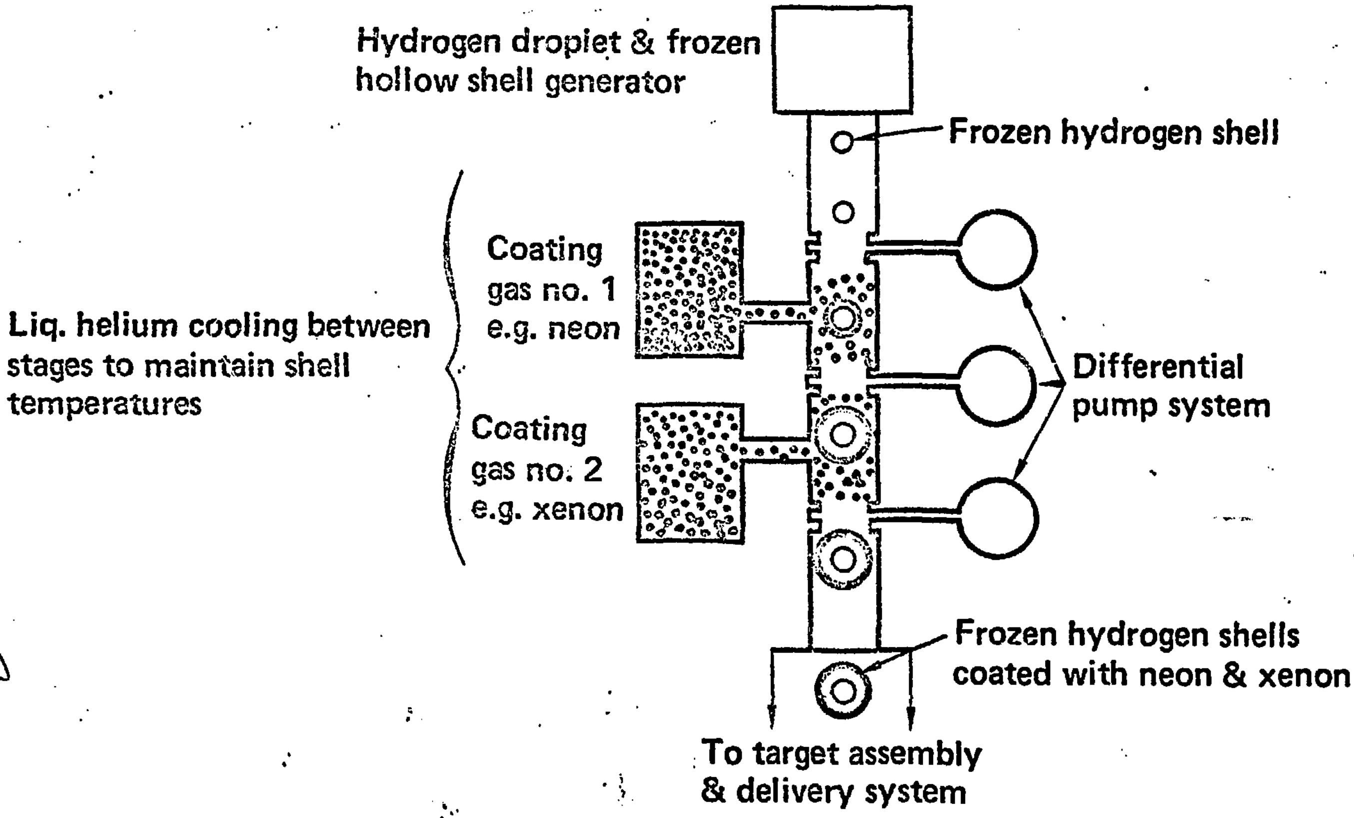

Fig 7

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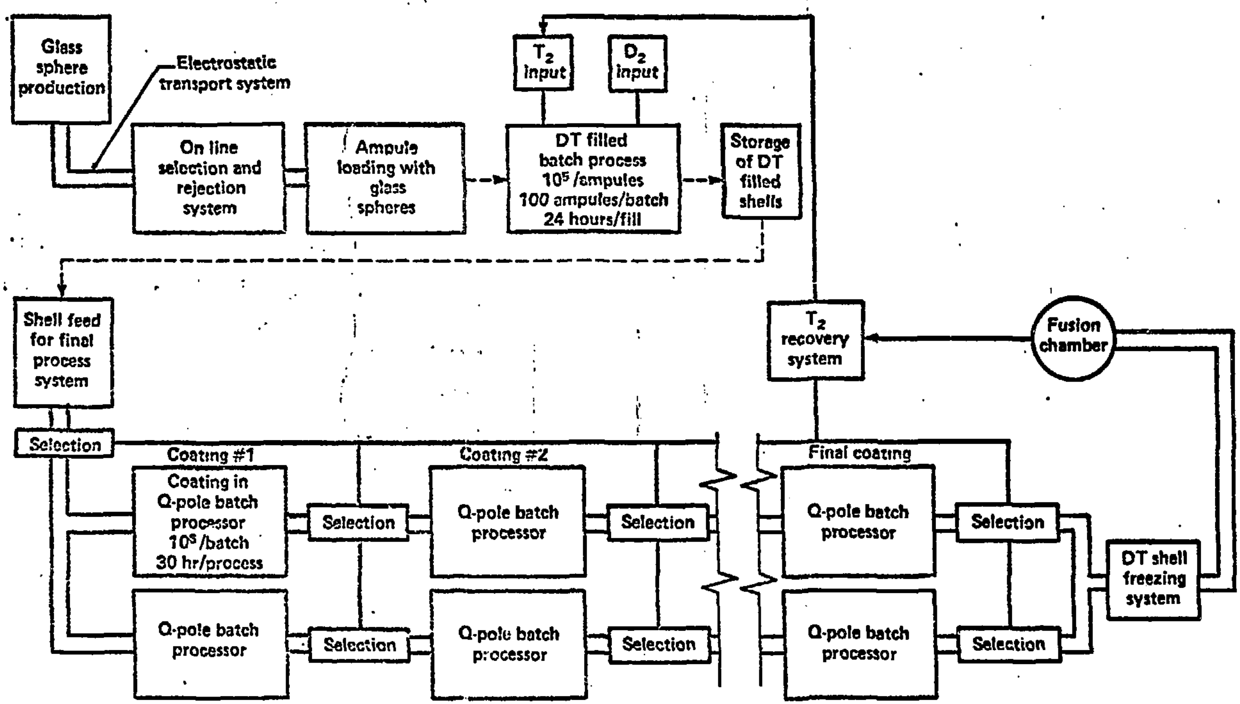
INERTIAL CONFINEMENT FUSION TARGET PRODUCTION SYSTEM



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