Light Ion Beam Fusion Target Development Facility Preconceptual Design Studies

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March 1988

UWFDM-760

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FACILITY PRECONCEPTUAL DESIGN STUDIES

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March 1988

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Submitted to IBM CAD/CAM Grantee School Report

ABSTRACT

Engineering analyses of the target explosion, structural response of the target chamber, and radioactivity analysis of the whole light ion fusion target development facility have been completed at the preconceptual design level. In the later stages of this engineering research the use of the CATIA solid modeller executing on our IBM 4341 has proven to be invaluable to the conceptualization of the facility.

INTRODUCTION TO INERTIAL CONFINEMENT FUSION

As the limitations of the Earth's resources of conventional fuels have become more apparent, scientists have turned their attention toward the stars for a new source of energy. It has been known for several decades that *nuclear fusion* reactions are a major energy source in stars. In this process the nuclei of light elements are fused together at very high temperatures to produce more tightly bound, heavier nuclei, releasing energy in the process.

An example of such a reaction is that which occurs when the two heavier isotopes of hydrogen, deuterium (D) and tritium (T), combine to produce helium plus a neutron. This fusion reaction releases 17.6 MeV of energy, which is carried off as kinetic energy by the reaction products. The energy content of such fusion fuels is truly enormous. A thimbleful of deuterium would release as much energy from fusion as the combustion of 20 tons of coal. The natural deuterium contained in one liter of water would produce the fusion energy equivalent of 300 liters of gasoline.

The potential of such reactions for generating large amounts of energy is evident. We need only look at any star to see a massive example of fusion energy release. In a sense, nuclear fusion can be regarded as the most primitive form of solar power, since it is also the energy source of our sun. Hence it was natural for scientists to wonder whether fusion might be employed as a terrestrial energy source.

But the difficulties involved in igniting and controlling a fusion reaction are formidable. The light nuclei that must fuse together are positively charged and strongly repel one another. To overcome this repulsion, we must slam the two nuclei together at very high velocities. One way of doing this is to take a mixture of deuterium and tritium and heat it to such high temperatures that the velocities of thermal motion of the nuclei are sufficient to overcome charge repulsion and initiate the fusion reaction.

But simply heating the fusion fuel to enormous temperatures is not enough to ignite the fusion reaction. For most of the time, when the nuclei run into each other, they simply bounce off or scatter without fusing together. Indeed, such scattering collisions are a million times more probable than fusion events. So somehow we have to hold the high temperature fusion fuel together long enough to allow the nuclei to collide the millions and millions of times necessary to induce the fusion reactions.

Therefore to achieve thermonuclear fusion energy we must solve two problems: (1) produce and heat a plasma fuel to thermonuclear temperatures, and (2) confine it long enough to produce more fusion energy than we have expended in heating and containing the fuel.

Most fusion research to date has been directed at confining a dilute fusion fuel using cleverly designed magnetic fields. However, during the past decade an alternative approach known as *inertial confinement fusion* has begun to receive considerable attention. In this approach intense laser or charged particle beams are used to rapidly compress a tiny pellet of fusion fuel, typically from 1 to 5 mm in diameter, to the enormous densities and temperatures like those found in the sun. If the fuel pellet is compressed to sufficient densities, then it will burn so rapidly that appreciable fusion energy will be released before it can blow apart; it will be "confined" during the fusion burn by its own inertia.

THE LIGHT ION BEAM APPROACH AND THE TARGET DEVELOPMENT FACILITY

One possible source for the intense beams required to heat and compress the fusion fuel pellet is the acceleration of light ions such as protons or lithium to energies of 4-30 million electron volts (MeV). When focused onto a fusion pellet with sufficient intensity these ions could ignite the fuel and result in "thermonuclear burn." State-of-the-art experiments are about a factor of ten short of the intensity believed to be necessary to demonstrate the feasibility of this fusion approach. One might ask, why build such an experiment that falls short of the goal? The reason is that these experiments require facilities (i.e. ion accelerators) that are very costly. Current facilities cost 50 million dollars and it is expected that the next facility will cost around 500 million dollars. Such expensive facilities must be planned very carefully.

The initial designs of the next ion accelerator, called the Target Development Facility (TDF), are currently underway. Before a detailed engineering design is completed there must be a preconceptual design, followed by a conceptual design. The difference in these designs comes in the level of detail. While the engineering design must have enough detail to proceed with construction, its two precursors are less detailed and more broadly focused. The conceptual design usually involves about 50 man-years of effort and is a point design that leads to the engineering design. The preconceptual design is less detailed and usually covers a number of possible options. The results of the preconceptual design allow tradeoff studies between the various options.

The University of Wisconsin Fusion Technology Institute has worked closely with Sandia National Laboratory-Albuquerque (SNL) for the past seven years on the preconceptual design of the light ion beam fusion target development facility (TDF).[1-4] During the past three years we have used an IBM 4341 computer running the CATIA solid modeller on a workstation to represent the facility. Two alternative designs are shown as line drawings in Figures 1 and 2. The TDF is axisymmetric with 12 pulsed power accelerators in groups of two surrounding a "target chamber" where the fusion pellet is burned. The accelerator design is the responsibility of SNL while the design of the target chamber is ours. Figure 1 shows a cylindrical target chamber with a diameter of six meters and a height of about six meters. The chamber is made of welded aluminum 6061-T6 and has a wall thickness of five centimeters (~ 2 inches). This gives it sufficient strength to withstand the fatigue of 15,000 target explosions over a five year lifetime. The target energy yield is 200 million joules per explosion. An alternative design, Figure 2, uses the same accelerator but has a two meter diameter spherical target chamber with a five centimeter wall thickness. The spherical shape is better matched to the spherically expanding explosion and it also has greater inherent strength; thus this smaller chamber is also capable of withstanding 15,000 shots.

Upon closer inspection (Figure 3), we see that the larger chamber has an additional feature that is important to such "nuclear facilities." Inside the chamber is a 50 centimeter thick layer of graphite called a moderator. The graphite scatters the high energy neutrons created by the fusion process and thus slows them down (moderates them). These slower neutrons do not activate the aluminum chamber to the same level of radioactivity as the high energy neutrons would have. Thus the larger chamber can be serviced in a "hands-on" maintenance mode. The smaller chamber does not have this graphite layer

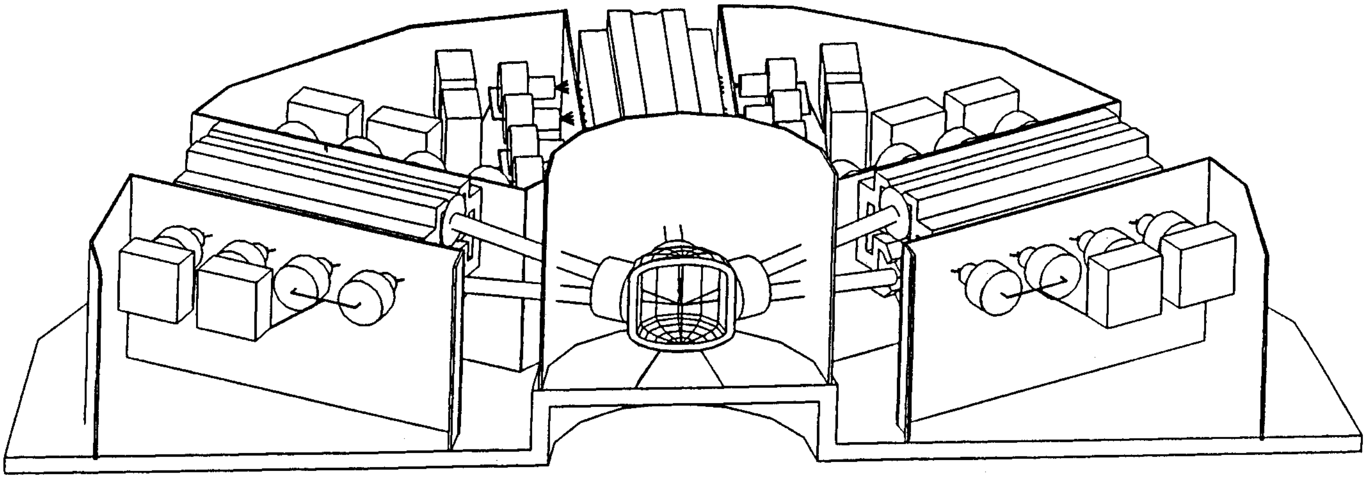

Fig. 1. Preliminary design of the Light Ion Fusion Target Development Facility.

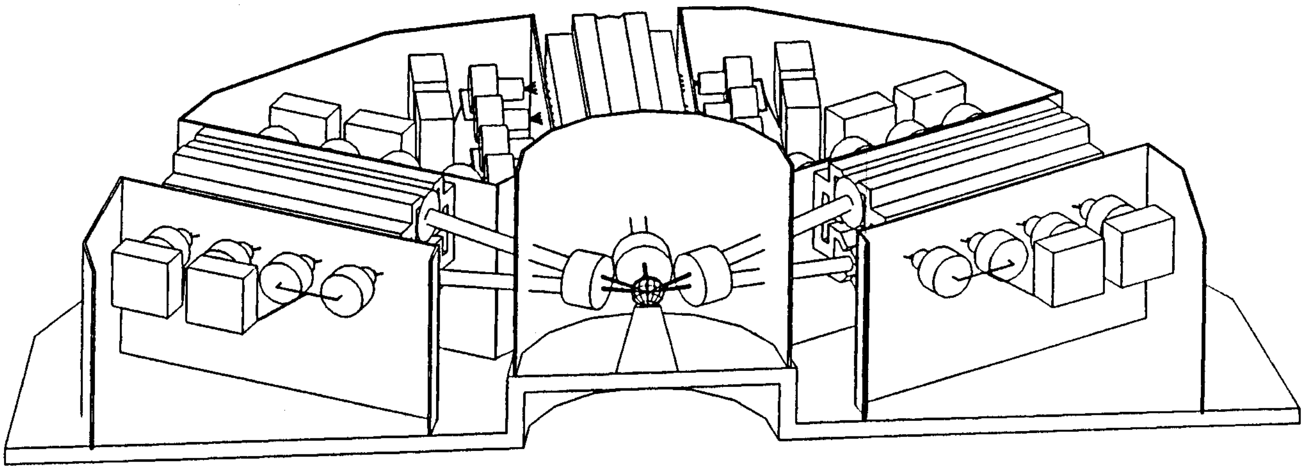

Fig. 2. TDF chamber design with two meter diameter chamber.

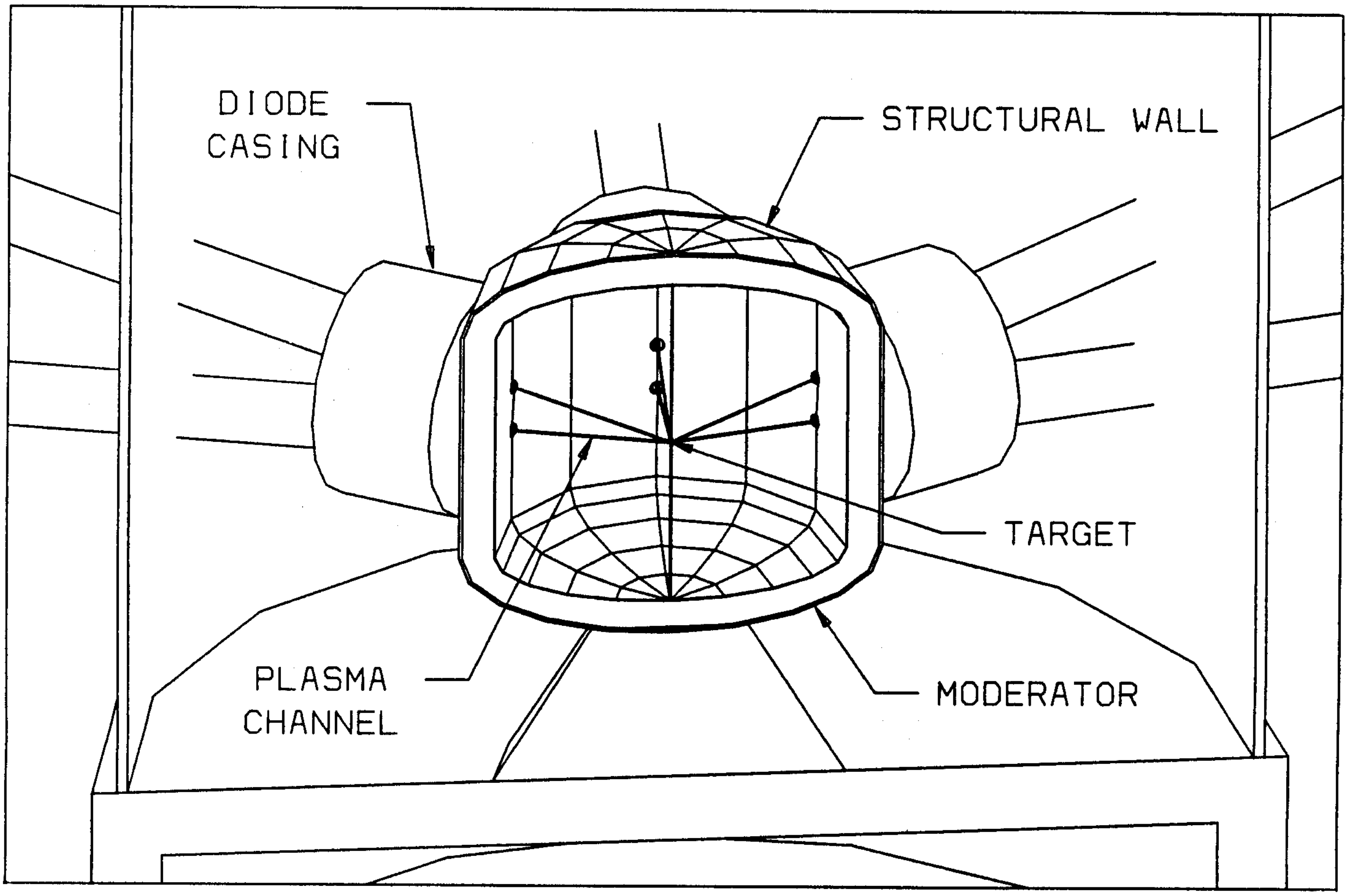

Fig. 3. Target chamber design with graphite neutron moderator. The distance from the target to the moderator is 2.5 meters.

(Figure 4), and the target chamber becomes very radioactive. In this case the maintenance must be done remotely, but it is more convenient to do on a smaller chamber. Thus there is a tradeoff between the size of the target chamber and the ease of its maintenance.

ACKNOWLEDGEMENT

Support for the work has been provided by Sandia National Laboratory.

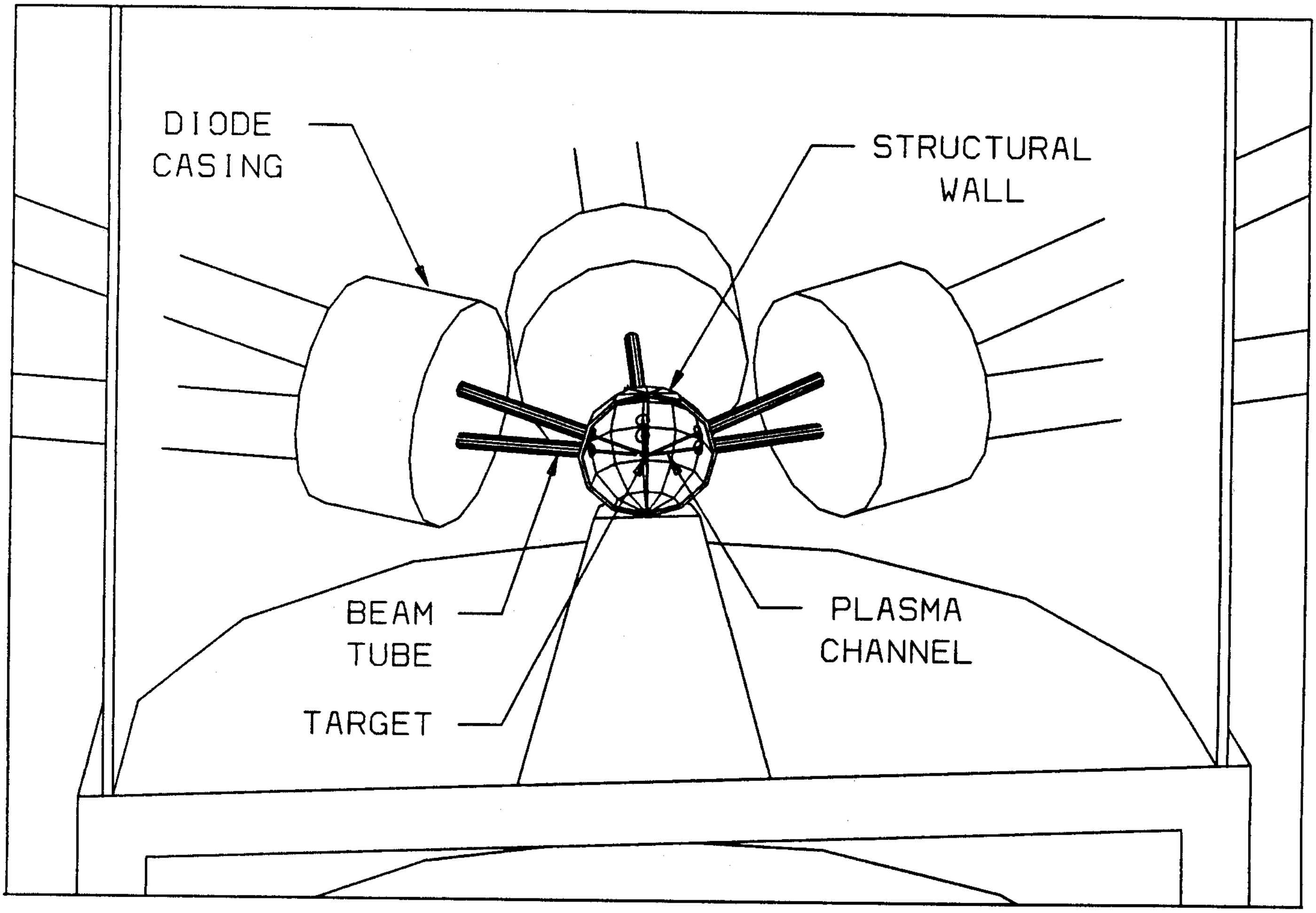

Fig. 4. Target chamber design without neutron moderator. The distance from the target to the first surface is one meter.

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