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PREPRINT UCRL-82120

Lawrence Livermore Laboratory

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December 29, 1978

Prepared for the Proceedings of the Heavy Ion Fusion Workshop, Argonne National Laboratory, September 19-26, 1978.

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THE LAWRENCE LIVERMORE LABORATORY
HEAVY ION FUSION PROGRAM*

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In the large fusion program at Livermore we are actively doing research in most areas of inertial confinement fusion. The areas in which we are funded for research specific to heavy ion fusion are:

- I. Target Design
- II. Energy Conversion Chamber Design
- III. Ion Beam Propagation in the Combustion Chamber

Target Design

There are two main thrusts to the target design effort:

1. Development of targets which are optimally suited to heavy ion fusion power production.
2. Fundamental studies of the beam-target interaction.

Target Development

For the accelerator designer, the measure of target development is the input requirements. These requirements have not changed significantly in the last year.¹ In particular, input energies ≥ 1 MJ at power levels ≥ 100 TW are required for power production. During the past year, progress has been made in target design which increases our confidence in these input requirements.

In some ways it would be advantageous if the input requirement could be significantly lower. Analyses based on idealized target models indicate that targets having energy gains of about 1000 at input energies of 100 kJ are possible. Such targets would only require about 20 TW of power.² Unfortunately, detailed numerical simulations have so far usually shown much larger input requirements than the idealized models. Furthermore, smaller targets require lower energy ions and smaller focal spot sizes and may not be compatible with reasonable accelerator technology. For power production, smaller targets impose more severe requirements on pulse repetition rate and target fabrication costs, but may ease some energy conversion problems.

Taking all of these things into consideration, we conclude that 1 MJ and 100 TW still represent reasonable minimum requirements for power production.

*Work performed under the auspices of the U.S. Dept. of Energy at the Lawrence Livermore Lab. under contract number W-7405-ENG-48.

Beam-Target Interaction

Our studies of the beam target interaction have established the following conclusions:

1. The range of heavy ions in matter will not be appreciably longer than we have been assuming.
2. Target preheat will be at an acceptable level.

The conclusion regarding the range of the ions is discussed in a separate paper in this report.

Target preheat increases the energy required to compress the fuel, and if sufficiently severe, can prevent ignition and burn. For ion beams, we have calculated preheat from the following mechanisms:

- a. Suprathermal electrons
- b. X-rays from beam and target
- c. Charged nuclear reaction products
- d. Neutrons
- e. Gamma rays.

Preheat increases with increasing ion energy, but is acceptable for reactor targets up to ion energies in excess of those allowed by the range limit. So far, this conclusion is based on particular target designs. We plan to refine our calculations and extend them to a wider selection of targets in the future.

Energy Conversion Chamber Design

Most of the effort in energy conversion has gone into a conceptual design study of a 1050 MW_e electrical power plant.³ The fusion power is provided by 2700 MJ yield pellets (gain 900) fired at a rate of one Hertz. The concept chosen utilizes a liquid lithium blanket which is injected into a chamber to provide protection between the fusion pellet and structural walls. The blanket consists of a dense array of jets and provides effectively a one-meter thickness of lithium. It is completely re-established between pulses. The blanket attenuates and moderates the neutrons sufficiently to allow the steel structure to last the lifetime of the power plant. The lithium is at a temperature of 500°C, leading to a background vapor pressure in the chamber of 10 to 5 x 10⁻² torr. This may be supplemented by the addition of a background noble gas to achieve the required ion beam propagation conditions.

Ion Beam Propagation in the Combustion Chamber

Efforts in ion beam transport theory at Livermore in the past year have been focussed on two areas: the filamentation instability and classical beam transport.

Filamentation Instability

The filamentation instability is predicted for a very broad range of beam and chamber parameters. At the point of injection the beam has large radius and low transverse velocity spread. The process of collapse into filamentary magnetic pinches causes a considerable increase in velocity spread, with concomitant increase in emittance. Spot size on target is proportional to emittance. Several methods are available to eliminate filamentation. Conceptually, the most straightforward approach is the use of multiple beams, thereby reducing current density of the individual beams and making them "magnetically stiff". Increasing the radius at injection and reducing the ion charge state have the same effect. A second class of cures involves propagation in a self-pinch state with large or small initial radius, and there is also the possibility of propagation in a focusing field created by an auxiliary electric discharge. A sample calculation of the filamentation instability is given in an appendix by E. P. Lee in this report.

Classical Beam Transport

The classical beam transport calculations follow the evolution of the ion beam together with the beam-generated plasma channel with all instability effects excluded. The size and shape of the ion beams at the target area are determined quantitatively in our transport codes. These studies are prerequisites for a more detailed instability analysis since the growth rates of instabilities depend on the evolving state of the beam and the plasma channels. The feasibility of propagating the beam in a self-pinch state, which is less prone to the filamentation instability is also investigated.

Two sets of transport codes are being developed at LLL. The 1-D codes are relatively fast, and are useful for parameter searches. A 2-D code is also being developed which maps out the detailed radial profiles of the electromagnetic fields and the plasma channels. The models, together with some numerical results from both the 1-D and the 2-D models, are reported in an appendix by S. S. Yu, H. L. Buchanan, E. P. Lee and F. W. Chambers.

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