THE STATUS OF THE U.S. ICF PROGRAM

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Introduction

The U.S. inertial fusion program is making important progress towards an understanding of the fundamental physical processes and the technical developments required to realize the great potential of inertial fusion energy. Recent experimental results show encouraging evidence of the validity of many of the theoretical assumptions on which we have been working intensively for a decade. We have developed technical approaches to removing the largest obstacles to success in inertial fusion research, the development of powerful and flexible drivers for experiments and applications. The major uncertainties concern the driver energy required to initiate high gain microexplosions. We believe drivers with the required energies can be built in the coming decade. Conceptually, the problems of containment in a suitable reactor environment also appear to be capable of solution. I would like to summarize these areas of progress in the U.S. program since they will be described in detail by other speakers.

(Vugraph 1 - Fusion Development Plan)

The U.S. Department of Energy's policy for the development of fusion energy was laid out last year by John Deutch, then Director of Energy Research. He described the goal of both fusion programs as the development of the highest potential for use of fusion energy. Developing the highest potential requires that we proceed at a measured pace through a balanced development plan, rather than plunging ahead with all our chips down on a single horse. There remain many attractive competing approaches in both of the programs, and these need to be fully evaluated; at the same time,

we must expand the function of the research programs that are devoted to problems more properly labeled engineering than scientific, looking toward the day when they will be dominant. We expect that fusion power will reach its Initial Operating Capability around 2025, when it will be delivering about 0.1 Quad/year to the power grid--about 3-4 GWe stations. The stated intent of the policy is to stress realistic, sober appraisals of our status and prospects, both technical and fiscal.

Magnetic fusion is expected to achieve the major near-term milestone of "scientific feasibility", which is the achievement of more energy out of fusion reactions than was supplied to the fuel, about 1984. Inertial fusion is expected to demonstrate scientific feasibility in the late 1980's. The programs will then move into their development phases with the construction of Engineering Test Facilities (ETFs). These facilities will be intermediate to the current generation of large scientific experimental devices and the first Engineering Prototype Reactor (EPR), shown here as being begun in the late 1990's. An ETF could produce significant electrical energy, and be capable of testing requirements for and specifying all the major components of an EPR. The EPR itself, combining all the tested elements into a pilot plant producing usable net power gain, will be necessary to resolve the remaining difficulties of economically efficient reactor design.

(Vugraph 2 - Program Accomplishments)

My second vugraph summarizes the present status of the U.S. program through results that have been reported at recent technical meetings. We have achieved routine operation of two lasers capable of delivering over 10 kJ in subnanosecond pulses. This has enabled us to begin to address the relatively unknown issues of ablative compression. Although the targets

used today are very small because of the relatively low energy available compared to what will be required for feasibility demonstration, the results, both on Helios and Shiva, have been in reasonably close agreement with the predictions of our computer models. We are continuing to study some fundamental target physics using these large lasers and a number of smaller glass lasers more intensively at the Naval Research Laboratory, KMS Fusion, and the University of Rochester. Efforts to develop light and heavy ion technologies at Sandia and a number of high energy physics laboratories are also progressing well.

(Vugraph 3 - Shiva)

The Shiva laser is our primary experimental facility, performing short-pulse experiments with up to 7 kJ on target. Modifications in the laser chains and optics will shortly permit long-pulse operation on the order of two nanoseconds for further ablative compression experiments. Livermore has achieved as high as 25 shots in one month of operation. Many of these are diagnostic or physics experiments rather than fuel pellet experiments. They will be directed over the next two years toward demonstrating fuel compression as high as 1000 times liquid density.

(Vugraph 4 - Nova)

Last May we began construction of Nova, a nominal 100 kJ laser facility built adjacent to Shiva. It will consist of 10 beamlines, each with 46 cm disk amplifiers using fluorophosphate glass. Our present projections are that this facility would begin operation in 1983.

(Vugraph 5 - Fusion Projections)

This next vugraph is a representation of the Livermore strategy to reach high gains from high density target compressions using the Shiva and Nova lasers. We are confident that the 100 times liquid density milestone has

been attained. In the Shiva experimental campaigns over the next few years, we will attempt to reach target gains on the order of a hundredth of breakeven using both exploding pusher and ablatively driven targets.

This Livermore plot is a useful graphic representation of the general program experimental strategy. As Los Alamos gains experience with the operation of the Helios laser, which is also a 10 kJ machine, we would expect to accomplish comparable experiments using Helios.

(Vugraph 6 - Helios)

The Helios carbon dioxide laser at Los Alamos is now capable of delivering about 4 kJ on target. It has been used extensively to develop diagnostics and to achieve good characterization of the laser performance. Experiments already conducted on Helios have reached on the order of 20 times liquid density using relatively short pulses with plastic-coated microballoons.

(Vugraph 7 - Antares)

This slightly dated photograph of the Antares facility shows the layout of the nearly completed buildings. Tests of the first laser components delivered are now under way. It will be some time before the first laser module is installed. The scheduled facility completion date is 1984.

The laser as designed would produce 100 kJ in a nanosecond, comparable to the Nova glass laser at Livermore. We are interested in further scaling of CO₂ laser technology provided that the beam-target interaction at long wavelength proves to be acceptable.

(Vugraph 8 - PBFA)

The Particle Beam Fusion Accelerator at Sandia is now partially assembled. The first beamline has been received and tested successfully at its design parameters. Complete assembly of the accelerator is scheduled for July 1980

at the 30-terawatt level in the ion mode. Significant progress has recently been made in focusing light ion beams to $0.5 \text{ terawatts/cm}^2$. Experiments with light ion beams have produced exploding pusher velocities of 10-20 cm/ μs with good symmetry. Upgrading the accelerator to the 100-terawatt level depends on demonstrations of adequate beam focusing and transport.

(Vugraph 9 - KrF laser)

Pictured here is a short wavelength gas laser that is representative of the state of rare gas halide laser development in the U.S. We have narrowed our search for a short wavelength laser suitable for fusion applications to very few candidates, of which KrF is a leader. We plan to evaluate both optical multiplexing and Raman pulse compression as complementary methods of shortening the pulse to meet experimental requirements.

(Vugraph 10 - Heavy Ion Source)

Vugraph 10 shows a photograph of the preaccelerator tank containing an ion source and 1.5 megavolt power supply developed at Argonne National Laboratory for the rf-linac-based heavy ion concept. The Argonne group has achieved 30 milliamps of xenon ions at 1 million volts in a well collimated beam. Lawrence Berkeley Laboratory has developed similar sources for the induction linacs under study there. We plan to develop heavy ion drivers in parallel with short wavelength lasers over the next few years, as two candidates which are capable of being scaled economically to the beam energy and repetitive operation requirements of fusion applications.

(Vugraph 11 - HYLIFE Concept)

Livermore has evolved a simple and attractive reactor cavity concept shown here. It is suitable for high yield/low pulse rate operation. No first wall replacement would be required for the life of the plant, and low cost ferritic steel could be used. Either a very large laser or a heavy ion

accelerator would be appropriate with this concept. Both the lithium flow dynamics and significant materials testing can be accomplished using existing facilities to validate this concept over the next few years in support of a decision to build an Engineering Test Facility in accordance with the DOE Fusion policy.

(Vugraph 12 - Foster Panel)

During the past year the U.S. program has undergone a detailed technical review by a panel chaired by Dr. John S. Foster. Its charge, and its main recommendations, are shown here. The key recommendations, that the level of support for the program should be substantially increased and the development of scalable drivers begun as soon as practicable, are being implemented.

(Vugraph 13 - Foster Panel Observations)

I would like to close with what I believe is a very strong endorsement of the ICF approach to fusion energy by the Foster panel. This is, I believe, significant not only for the U.S. program but also for others. It means that we are more confident than at any time in the past that practical fusion power can be achieved by inertial confinement. The technical problems of driver, fuel pellet and reactor cavity development have been examined critically and competently, and they appear to be soluble using approaches that we are already developing in the U.S. program.

Fusion Development (Reference Budget Case)

Figure 1

INERTIAL CONFINEMENT FUSION RECENT ACCOMPLISHMENTS

- LLL HAS ACHIEVED 50 – 100 X LIQUID DENSITY IN THE COMPRESSED FUEL WITH THE SHIVA NEODYMIUM: GLASS LASER
- LASL HAS ACHIEVED 20 X LIQUID DENSITY IN THE COMPRESSED FUEL WITH THE HELIOS CO₂ LASER
- SLA HAS ACHIEVED IN EXCESS OF 400K AMPERES/CM² OF LIGHT IONS WITH A MAGNETICALLY INSULATED DIODE ON PROTO 1
- ANL AND LBL HAVE DEMONSTRATED ION SOURCES AND PREACCELERATORS APPROPRIATE TO ADVANCED HEAVY ION DRIVERS
- TARGET FACILITIES ACCOMPLISHMENTS INCLUDE:
 - ROUTINE USE OF SHIVA AS TARGET SHOOTER
 - ROUTINE USE OF HELIOS AS TARGET SHOOTER
 - COMPLETION OF ZETA (LLE), PHAROS (NRL), AND CHROMA 1 (KMS) LASER SYSTEMS
 - INITIATION OF NOVA CONSTRUCTION

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

HELIOS –Eight Beam CO₂ Laser

Figure 7

Antares Construction

Figure 8

PARTICLE BEAM FUSION ACCELERATOR

Figure 9

Figure 10

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Figure 11

AD HOC FUSION EXPERTS (FOSTER) GROUP

CHARGED BY DOE TO EVALUATE:

- MINIMUM ENERGY NEEDED TO ATTAIN PROPAGATING BURN IN SCALABLE TARGETS
- DEFINITION, SELECTION AND DEMONSTRATION OF HIGH EFFICIENCY, LOW COST DRIVER
- UNDERSTANDING OF EFFICIENT DRIVER ENERGY COUPLING TO TARGETS
- ECONOMICAL FABRICATION TECHNOLOGY FOR MASS PRODUCED TARGETS
- DEFINITION OF A PRACTICAL REACTOR CONCEPT APPROPRIATE TO SELECTED DRIVER AND PELLET

RECOMMENDS:

- ACCELERATION OF PHYSICS EXPERIMENTS AND DEVELOPMENT OF ALTERNATE DRIVERS
- CONSTRUCTION OF NOVA I (100 KJ GLASS LASER AT LLL) WITH CAPABILITY TO OPERATE AT SHORTER WAVELENGTHS
- LARGER BASELINE BUDGET IN ORDER TO MEET URGENT NEED TO DETERMINE PRACTICALITY OF INERTIAL FUSION AND BRING INTO BALANCE DOE'S OVERALL FUSION PROGRAM (INERTIAL AND MAGNETIC)

Figure 12

FOSTER GROUP OBSERVATIONS

"FROM OUR REVIEW OF THE ICF APPROACH AS A COMPLETE SYSTEM, WE CAN SEE A SUCCESSFUL PATH TO ENERGY PRODUCTION. WE SEE NO SCIENTIFIC OR TECHNOLOGICAL PROBLEMS THAT WOULD PREVENT DEMONSTRATION OF FEASIBILITY. ADMITTEDLY, IT COULD TURN OUT TO BE OTHERWISE. THERE IS AN URGENCY TO KNOWING WHETHER OR NOT ICF IS A REAL ENERGY OPTION."

Figure 13