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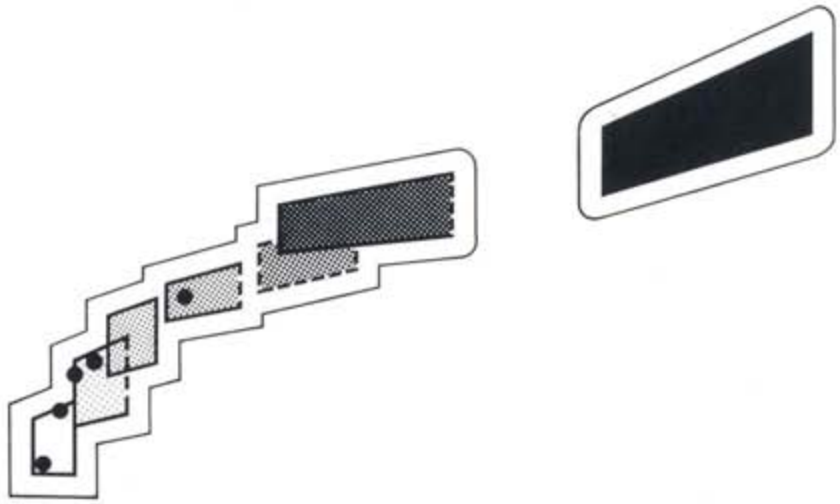

NATIONAL SECURITY

Laser Fusion Program Overview

In the last three years, we have witnessed extremely rapid advances in the theoretical and experimental understanding of laser fusion. Our program is structured to proceed through a series of well defined fusion milestones to proof of the scientific feasibility of laser fusion with the Shiva Nova system. Concurrently, we are studying those key technical areas, such as advanced lasers, which are required to progress beyond proof of feasibility. We have identified and quantified the opportunities and key technical issues in military applications, such as weapons effects simulations, and in civilian applications, such as central-station electric power production. In this issue of the *Energy and Technology Review*, we summarize the current status and future plans for the laser fusion program at LLL, emphasizing the civilian applications of laser fusion.

Fusion research is being vigorously pursued at LLL and other laboratories throughout the world with the ultimate goal of generating power from controlled thermonuclear reactions. The two major approaches to controlled fusion are magnetic confinement and inertial confinement, both of which require heating a deuterium–tritium mixture to an ignition temperature of about 10^8 K. The magnetic confinement technique uses magnetic fields to confine a low-density D–T plasma for the long time required for efficient burn of the low-density fuel: 10^{14} ions per cm^3 confined for a few seconds. In contrast, the inertial confinement fusion process uses laser or particle beams to compress a small thermonuclear fuel pellet (target) to between 1000 and 10 000 times liquid density for an extremely short time (10^{26} ions per cm^3 for 10 ps). At such high densities, the fuel burns so rapidly that efficient burn is achieved before the pellet blows apart and cools.

For civilian (energy-producing) applications and most military applications of inertial confinement fusion, the microexplosions must produce much more thermonuclear energy than that required to ignite the reaction. To achieve high-energy-gain microexplosions, our calculations with the LASNEX code indicate that the driving energy

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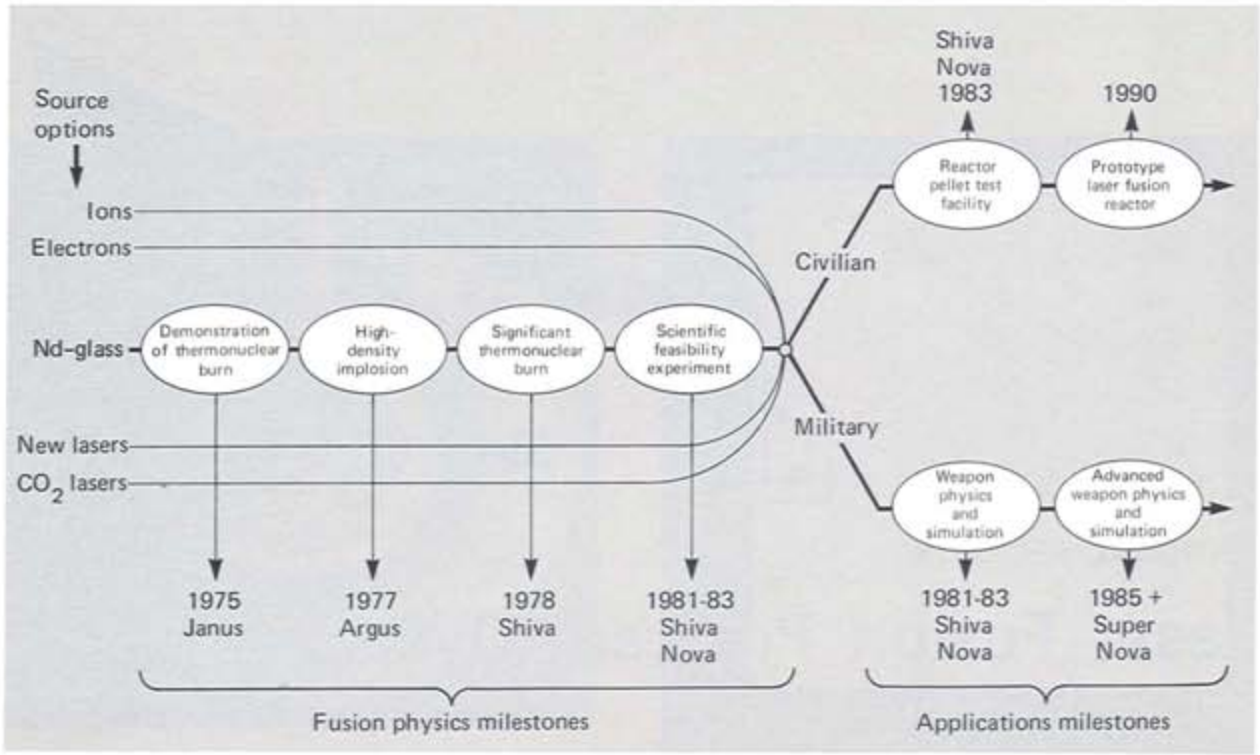

Fig. 1. **The development plan for inertial confinement fusion proceeds through a sequence of fusion-physics milestones, culminating in the proof of scientific feasibility with the Shiva Nova laser in the early 1980's. As the most advanced high-power driver technology, neodymium-glass lasers will first achieve each of the fusion-physics milestones as well as the early applications. Proof of scientific feasibility—that is, demonstration of a high-gain microexplosion—with neodymium-glass lasers will establish scientific feasibility for the other possible driver sources, such as ion beams, electron beams, or other lasers. These other sources will be developed in parallel until optimum choices for various applications can be determined.**

source will have to provide 200 to 300 kJ of energy at a power of 200 to 300 TW.

The laser was the first driving source seriously considered for fusion microexplosions, and the major fusion experiments and proof of scientific feasibility will be accomplished with lasers (see Fig. 1). It appears possible, however, to use various types of particle accelerators as drivers of fusion microexplosions. These might include heavy-ion accelerators that produce high-current beams of 50- to 100-GeV ions (such as uranium); light-ion accelerators that produce 10-MeV deuteron beams; and electron accelerators that produce tens of millions of amperes of 1- to 5-MeV electrons. Ultimately, in inertial-confinement fusion power plants, the driver must achieve the following characteristics:

- 300 to 3 000 kJ at 100 to 300 TW.
- 1 to 10 pulses per second.
- Efficiency greater than 1% (5% is desirable).
- Ability to focus on the target from 5 to 20 m away.
- Low capital cost (less than $100/J).
- Long operational lifetime.

To a large extent we can divide inertial confinement fusion problems into two parts: development of an appropriate driver source and demonstration of the physics of the fusion microexplosion. Thus, achieving high-energy-gain microexplosions with a laser driver will, in large measure, prove scientific feasibility for all kinds of inertial confinement fusion. This set of circumstances allows us to pursue parallel efforts to develop an appropriate driver for a reactor and to demonstrate microexplosion fusion physics.

To prove the scientific feasibility of laser fusion,

we have chosen neodymium–glass lasers as the key research tool because they are by far the most advanced in their ability to produce high peak power and to produce it at low capital cost. Thus, our inertial confinement fusion program (see Fig. 1) has been structured to achieve the key fusion-physics milestones with neodymium–glass lasers and will culminate with proof of scientific feasibility with the Shiva Nova laser. After this milestone, Nova will fill a dual role as a reactor-pellet test facility and a military applications facility.

The power and energy (200 to 300 TW, 200 to 300 kJ) required for a feasibility demonstration of laser fusion was at first far beyond the capabilities of existing lasers. Thus, LLL established the laser development program shown in Fig. 2 and the projections of target performance at each level that are also shown. Each system we undertook represented a major step in laser technology and in target performance. How well we have achieved these goals is shown by the actual experimental data points. The rapid progress we have made in the laser fusion program results from the mutually supportive relationship between the predictive and analytic capability of LASNEX and our sequence of increasingly powerful lasers.

Janus, our first small two-beam laser system, produced 0.4 TW of power. With Janus, laser-driven D–T implosions yielded 10^7 neutrons and allowed us to prove the thermonuclear nature of the reaction. The Cyclops laser, the developmental test bed for the Janus, Argus, and Shiva systems, was the first single-beam laser to deliver 0.6 to 1.0 TW. Argus II, designed as a 3-TW system, actually has delivered 4.6 TW. Neutron yields with Argus II have exceeded 10^9, permitting us to use neutron time-of-flight spectroscopy to confirm the thermonuclear nature of the D–T reaction. The Shiva

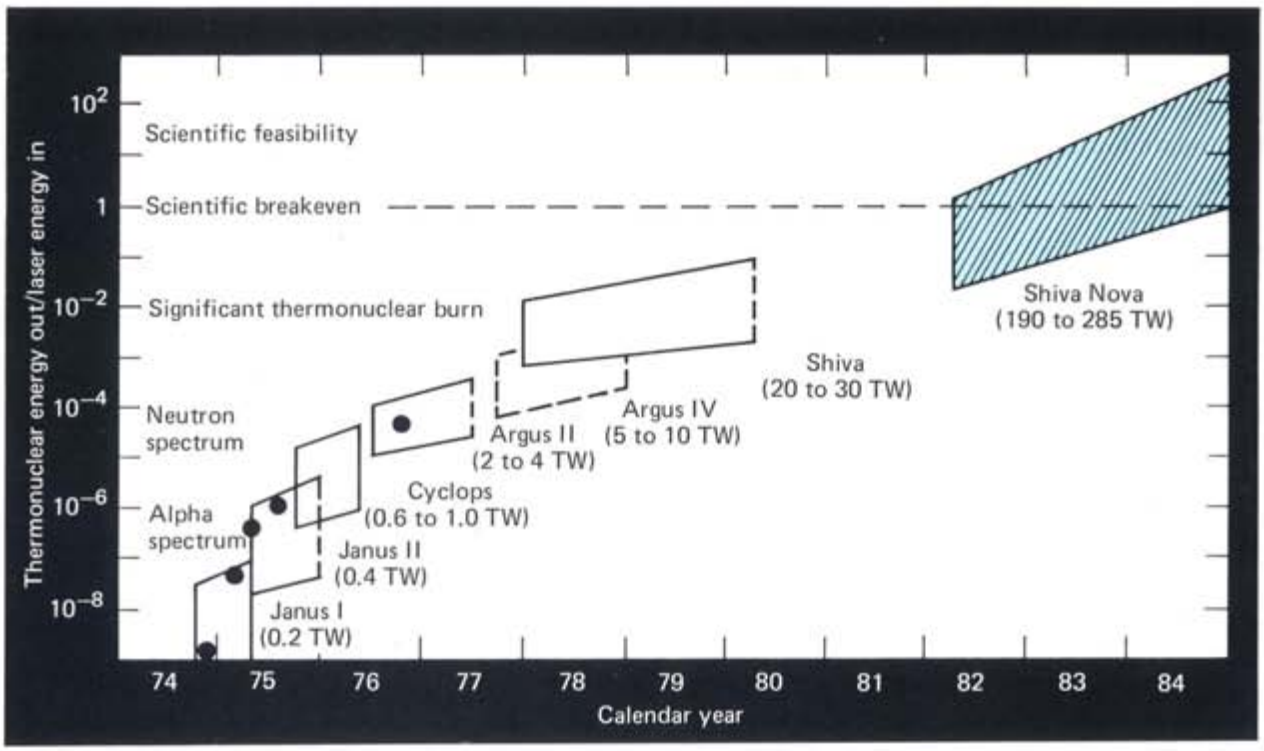

Fig. 2. This plan for a series of neodymium–glass lasers of increasing power was laid out in 1974. The vertical extent of the boxes associated with each laser indicates the range of target gains expected with that laser power. Key physics milestones leading to proof of scientific feasibility are indicated on the left. The horizontal extent of the boxes indicates the time of operation of the system. Representative data points show how well these projections have been achieved. Janus II and Argus II continue in operation today; Argus IV was never built because of funding limitations.

system at 20 to 30 TW is being completed in 1977 and is expected to achieve significant thermonuclear burn within the next two years.

Shiva Nova has been designed to provide the power needed to drive high-energy-gain microexplosions. Its technological base has been systematically developed as we built the lasers that preceded it. It will produce 10 to 15 times the power and 20 to 30 times the energy of Shiva. Architectural and engineering funds have been appropriated for the Nova project in FY 78, and we hope to be funded to start construction in FY 79.

Our advanced laser program has conceived and evaluated a wide variety of new laser candidates for fusion reactors. From among the options available, a candidate will be chosen for development to the larger scale required for commercial laser fusion power.

In the following articles, we discuss the status and key projections for each of the major activities of the laser fusion program. The final article discusses an unusual approach to the design of a laser fusion power plant. This design illustrates many of the unique features possible with the inertial confinement approach to fusion power.

Key Words: laser fusion; lasers.