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KrF LASER PATH TO HIGH GAIN ICF LABORATORY MICROFUSION FACILITY

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The krypton-fluoride laser has many desirable features for inertial confinement fusion. Because it is a gas laser capable of operation with high efficiency, it is the only known laser candidate capable of meeting the driver requirements for inertial fusion energy (IFE) production. Los Alamos National Laboratory has defined a program plan to develop KrF lasers for IFE production This plan develops the KrF laser and demonstrates the target performance in single-pulse facilities. A 100-kJ Laser Target Test Facility (LTTF) is proposed as the next step, to be followed by a 3 to 10-MJ Laboratory Microfusion Facility (LMF). The LTTF will resolve many target physics issues and accurately define the driver energy required for the LMF. It is also proposed that the technology development required for IFE, such as the high-efficiency, high-reliability, repetitively pulsed driver, the reactor, mass production of targets, and the mechanism of injecting targets be developed in parallel with the single-pulse facilities

1. INTRODUCTION

Inertial confinement fusion (ICF) is a technique where a small fuel capsule containing deuterium and tritium is compressed to fusion conditions through the use of a laser or particle beam *driver* Applications of ICF include the study of high-energy-density matter, studies of x-ray interactions with matter, and in the long term, energy production The energy production application is the only one that requires a high-efficiency, repetitively pulsed driver The drivers being developed in the U S include KrF lasers, Nd glass lasers, and light- and heavy-ion accelerators The Nd glass laser is not considered a candidate for energy production

The KrF laser is being developed for ICF research throughout the world Los Alamos National Laboratory is the lead laboratory for KrF laser fusion in the U S Avco Research Laboratory has constructed several major KrF and other excimer lasers and the Naval Research Laboratory is also constructing a KrF laser-fusion system Other major KrF laser programs can be found in the United Kingdom, Canada, Japan, and the Soviet Union

The KrF laser has several significant advantages for ICF applications [1,2] The nondamaging gaseous lasing medium allows for repetitive laser pulsing and provides for smooth beams Direct operation at short wavelength allows the KrF laser to couple efficiently to the target [3] allows broad bandwidth operation and flexible and accurate high dynamic range pulse shaping Broad bandwidth appears to be an effective solution to control of laser plasma instabilities,[4] and recent analyses indicate that accurate, high-dynamic-range pulse shaping appears to be the best approach for achieving high gain [5] Both of these techniques need to be tested further Additionally, recent advances such as echelon-free induced spatial incoherence[6] allow the KrF laser to be suitable for both direct and indirect drive approaches.

This paper will describe the strategy proposed by Los Alamos for the development of KrF lasers for both single-pulse applications and energy production We will then describe the two single-pulse facilities that are on the path to energy production in more detail

2 KrF DEVELOPMENT STRATEGY

The Los Alamos proposed development path for KrF lasers for both single-pulse and energy applications is shown in Fig 1 Aurora is the KrF laser at Los Alamos that is currently operational at the ~2-kJ level We propose that the next major U S KrF laser-fusion facility be in the 100-kJ class We call this facility the Laser Target Test Facility, or LTTF After successful operation of

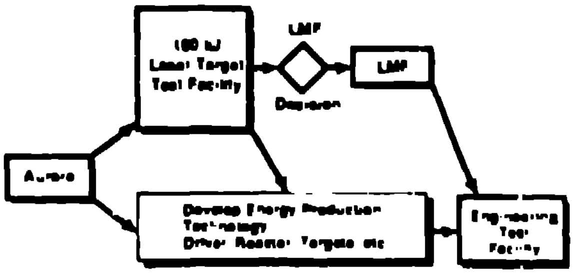

FIGURE 1
Proposed program plan that develops KrF lasers for single pulse applications in parallel with development of IFE technologies

the LTTF, it is appropriate to make a decision for construction of the Laboratory Microfusion Facility, or LMF.

In *parallel* with the single-pulse development of KrF lasers, we propose to develop the technologies needed for ICF energy applications. This includes the high-efficiency, high-reliability, repetitively pulsed, low-cost KrF laser, IFE reactor technology, and the technology of mass production of ICF targets at low cost. After demonstration of high target gains in the LMF and development of the IFE reactor technology, it is appropriate to proceed to an engineering test facility

3. AURORA

Aurora is the KrF laser system currently operating at Los Alamos National Laboratory. The Aurora laser is currently configured to deliver 48 beams to target with a maximum energy of 5 kJ in 5 ns. An upgrade of the facility could put all 96 beams on target. It has recently become operational, and is currently performing target coupling and laser experiments. Aurora and the experimental plans are described in more detail in a companion paper[7].

Aurora is representative of future KrF laser-fusion systems:

- A front end generates a single shaped pulse,
- The pulse is multiply split and delayed to form an end-to-end train of pulses,
- The pulses are sent through a series of amplifiers (for high efficiency, KrF laser amplifiers need to be pumped and extracted over times long compared to the target illumination time, thus the need for pulse stacking), and
- The time delay is removed in a demultiplexer, and the pulses are individually delivered simultaneously to the target.

The layout of Aurora is shown in Fig. 2. A low-energy pulse is generated with the desired pulse shape and bandwidth in the front end. This pulse is then divided into 12 beams (in the 12-fold encoder), and passed through the Small Amplifier Module (SAM). The beams are then each sent through the 8-fold encoder, making a total of 96 beams. These beams are then passed through the Preamplifier (PA) and Intermediate Amplifier (IA) and are directed to the LAM feed array. The SAM, PA, and IA are all single-pass e-beam-pumped amplifiers. The 96 beams are directed from the LAM feed array to the LAM and are expanded en route to completely fill the 1 x 1 meter LAM aperture. The LAM is a double-pass, double-sided e-beam-pumped amplifier with a long-radius-of-curvature spherical mirror in the back that compresses the beams as they travel to the recollimator array. At the recolimator array, 48 of the beams are terminated, and the other 48 beams are directed to the decoder optics, which remove the time delay imposed by the encoder. The beams are then directed to the final target optics and individually delivered simultaneously to the target.

The Aurora target chamber has diagnostics to measure the performance of both the laser and target. Laser measurements include the energy, pulse shape, spot size, and bandwidth. Current target experiments include measurement of x-ray

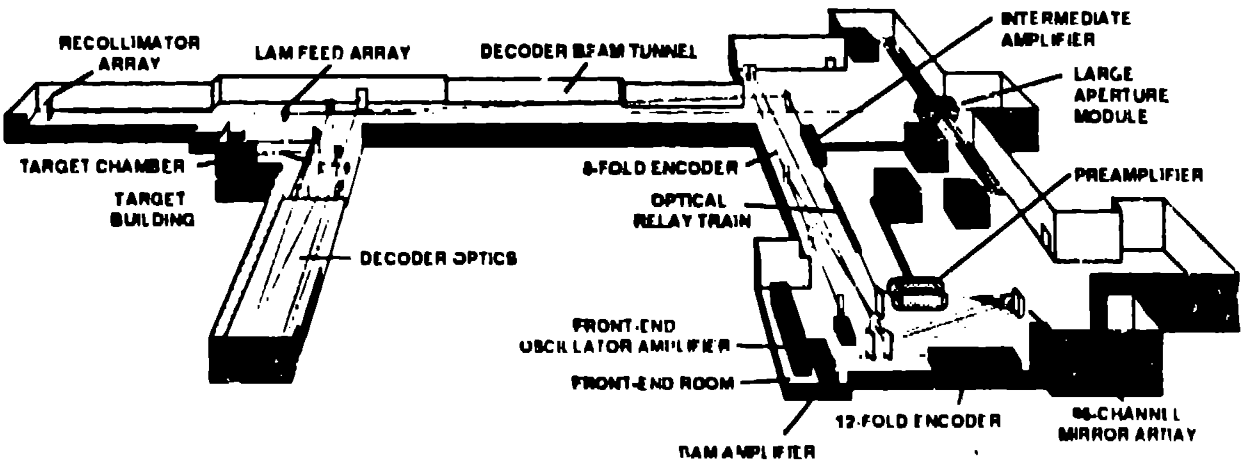

FIGURE 2
Layout of the Aurora laser system showing the locations of the amplifiers, the decoder/beam tunnel, and the target chamber, where the 48 beams arrive simultaneously.

conversion efficiency and shock breakout timing from shaped pulses. Future experiments will include measurement of laser-plasma instability thresholds as a function of laser intensity, bandwidth, and beam smoothness. Additional diagnostics and laser performance improvements will occur over the next 2 years to bring the laser to the 5-kJ level with 48 beams delivered to target.

4. LASER TARGET TEST FACILITY

The Laser Target Test Facility (LTTF) is proposed to be the next major KrF ICF facility in the U.S. The LTTF will accomplish several tasks:

- Demonstration of the laser performance (bandwidth, pulse shaping, beam quality, alignment, etc.) needed for the LMF,
- Further the understanding of both direct and indirect drive target physics in order to more accurately specify the driver requirements of the LMF, and
- Perform experiments in high-energy-density physics.

The LTTF was submitted to the U.S. Department of Energy for consideration as a budget line item in 1990. If funding is made available soon, the LTTF could come on line as early as 1997.

The LTTF is designed to deliver 100-kJ of energy to the target with uniform balanced pulses of variable bandwidth up to 0.5% with a wide variety of pulse shapes. The LTTF is also designed to be upgradable to the LMF.

The LTTF, shown in Fig. 3, uses two 60-kJ amplifier modules as the final gain stage of the laser system. The pump volume of these amplifiers is 1.2 x 2.6 x 3.1 meters, roughly five times the volume of the LAM with the main difference being a factor of 2.6 scaling in the vertical direction. The two main amplifiers have an aperture of about 2:1 in order to aperture combine the output beams to form a square beam consisting of two beamlets. The other laser amplifiers in the system are similar to those demonstrated on Aurora.

The optical system for the LTTF is somewhat different than that demonstrated on Aurora, and is more similar to the system incorporated in the Nike laser under construction at the U.S. Naval Research Laboratory. One major difference is the use of interstage temporal encoding, where the beams are split between the early gain stages to reduce prepulse on target. Delaying the encoding of beams makes it possible to run earlier amplifiers at shorter pump pulse lengths and higher stage gains. This is unlike Aurora where the beams are split early in the amplifier chain and *then* passed through the amplifiers. A complete description of the LTTF can be found in Reference 8.

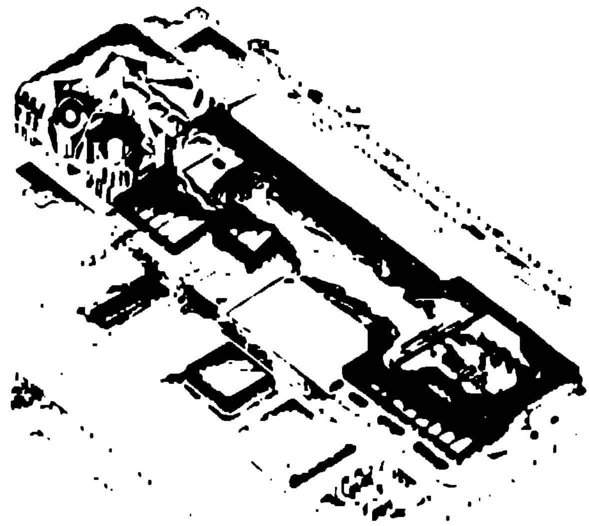

FIGURE 3
Artists depiction of the 100-kJ Laser Target Test Facility, showing the location of the two 50-kJ amplifier modules, the demultiplexer area, and the target area with capability for both direct and indirect drive experiments.

The target area, as shown in Fig. 3, shows two different target areas for performing experiments. One chamber is optimized for use with direct-drive target experiments, and the other is for indirect drive. Resolution of the optimum method for imploding ICF targets is one of the most important tasks for the LTTF.

Target performance with direct-drive is expected to be near ignition. This is an interesting regime for target experiments because it allows new investigations of charged particle coupling and fusion product burn propagation. It is also expected that this facility will open up new regimes of interest for the study of high-energy-density physics.

5. LABORATORY MICROFUSION FACILITY

The Laboratory Microfusion Facility (LMF) is the principle goal of the U.S. ICF program for several reasons.[9] Upon achievement of high target gain, it will demonstrate the scientific feasibility of ICF. With high gain, it will open up yet another interesting regime of high-energy-density physics. Also, a high-gain target will be a useful source of x rays to allow the study of x-ray interactions with matter.

The Los Alamos design of the LMF is based on an upgrade of the LTTF. As shown in Fig. 4., the LMF consists of the LTTF target building, the laser building, and three additional laser arms. A new, larger target chamber will replace the two target chambers used in the LTTF. The laser system will for the most part be replaced, though some parts, such as the control room equipment, front end, small amplifiers, and oil and water systems, will be reused.

The LMF has similar output spectra requirements as the LTTF, except at higher energy. The broad bandwidth, accurate and flexible pulse shaping, and good beam balance is needed for achievement of high gain. The driver energy needed for the LMF currently has great uncertainty, possibly in the range of 3-10 MJ. We are optimistically working with the lower value until the results of the LTTF target experiments indicate a more accurate value.

The 3-MJ LMF uses three 250-kJ amplifier modules in each arm of the laser building. These amplifiers have dimensions of 1.3 x 3.9 x 3.75 meters. The three amplifiers have an aperture with ratio 3:1 in order to aperture combine the output beams to form a square beam. As with the LTTF main amplifiers, the major scaling is with the height of the amplifier. The design basis for the LMF amplifiers will be verified by the LTTF amplifier performance.

The LMF optics layout will be nearly identical to the LTTF layout. The design of the early gain stages and optics design uses interstage temporal encoding similar to that used in the LTTF. The optics downstream of the main amplifiers will be significantly larger than those used in the LTTF, but the number of beams will only be approximately a factor of two greater than the LTTF due to the longer pulse durations required by the target.

The experimental area of the LMF presents some difficult challenges because of the high laser energies and high target gains. Final optics have to be protected from x rays, charged particles, and hypervelocity projectiles emitted from the target and any surrounding material.[10] This may require puffing of gas into the target chamber and fast closing shutters. Neutron activation is a serious concern that places strict requirements on the choice of materials and shielding used in the experimental area.[11] Diagnostics for the target performance will also be a challenge in this environment.

The target gains predicted by Los Alamos range from 30-200 for the LMF. Much theoretical work and experiments on the LTTF are required to reduce the uncertainties in the target performance for the LMF.

6. SUMMARY

The KrF laser appears to be an attractive candidate for the driver of an IFE electric power plant, and is currently the only laser (except for

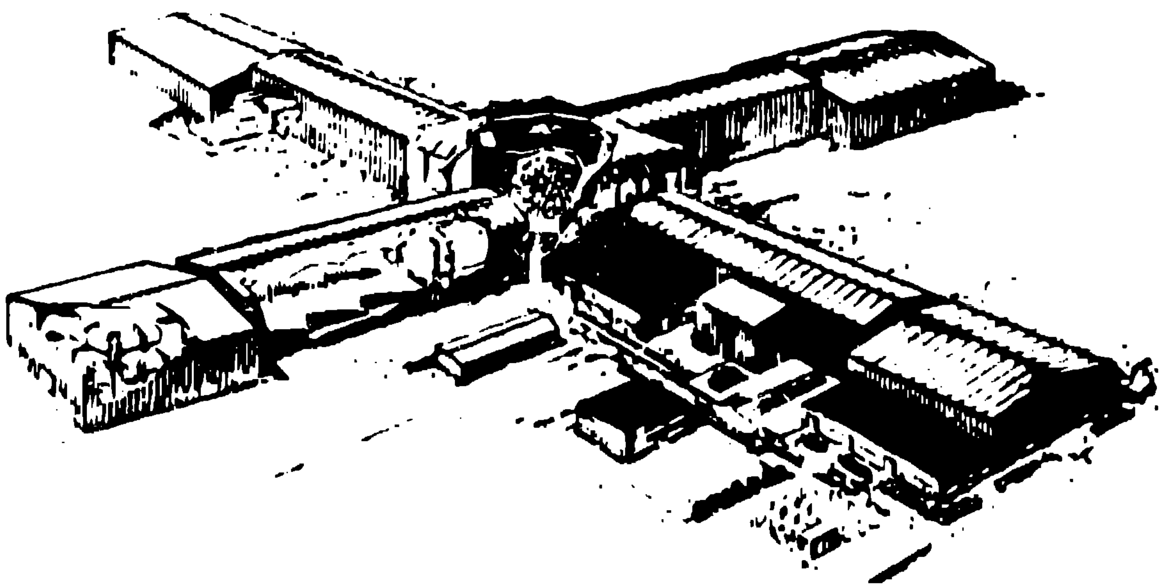

FIGURE 4

Artists depiction of a 3-MJ Laboratory Microfusion Facility, showing the central target area surrounded by four amplifier and demultiplexing buildings. The amplifiers for the LMF are four triplet clusters of 250-kJ modules other excimers, which KrF appears optimum) that has the potential to meet all of the driver requirements. Because the KrF laser uses a gaseous medium, cooling will not be a problem at the required 5-10 Hz operation needed for an IFE plant. The short wavelength, broad bandwidth, good beam quality, and accurate pulse shaping assures high coupling efficiency to the target.

A KrF development strategy has been described. Single-pulse facilities to demonstrate target physics and laser performance should be developed in *parallel* with the technologies needed specifically for IFE. After demonstration of high gain in the LMF, an engineering test facility can be built.

Los Alamos proposes a 100-kJ Laser Target Test Facility to be the next major step after Aurora. The LTTF will provide needed driver development and understanding of target physics. Following the LTTF, an LMF could be built to demonstrate high target gain and perform high-energy-density physics experiments.

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