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SUMMARY OF THE STATUS OF LASERS FOR INERTIAL CONFINEMENT FUSION

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Summary of the Status of Lasers for Inertial Confinement Fusion

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Laser systems designed for plasma research are operating in many laboratories throughout the world. The laser performance itself has become reasonably consistent from laboratory to laboratory and the focusing properties of the laser beams are understood. The plasma physics data, obtained with these systems, also appears to be reasonably self-consistent and is of great interest for inertial fusion applications. These lasers are commonly providing output powers of $0.5 - > 2$ TW, and power densities on target of $10^{13} - 10^{16}$ W/cm², pulse durations on the order of 100 psec to 3 nsec, wavelengths between 0.5 μ and 10 μ , and focal spot sizes of 100 μ or larger where focal spot "edge effects" are becoming less dominant. In addition, spurious target responses due to such behavior as pre-pulses, self-focusing, or imprecise focal spot measurement are being observed less often. The technical problems of large multi-beam systems, performing at the 10 TW level, have been overcome and these systems (e.g. the Shiva and Helios lasers) are providing high density compression data with ablative targets. The next step in laser design, the 100-300 kJ systems, are under construction and 1 MJ lasers are being contemplated. Table I reviews the status of laser development.

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TABLE I

Review of Fusion Laser Development

Early Work - The fusion lasers built in the early 1970's provided ≤ 0.1 TW of power and were very expensive per unit output power because they were research projects in themselves. There was a poor understanding of the laser constraints and there was a poor understanding of the fusion/laser interaction. Nevertheless, these lasers were used to produce the first inertial fusion neutrons from exploding pusher targets and provided a great deal of basic information.

Present Status - Today, 10 TW lasers have been engineered and successfully directed onto high density ablatively driven targets. There is a good understanding of propagation limitations and focal properties for 1μ and 10μ systems. Laser systems at the 1-10 TW level are treated as engineering projects and their costs should be considered to be mostly capital hardware costs.

Future - Systems designed and being constructed at this date are 100 TW, 100 kJ facilities with 1 MJ facilities being contemplated. These systems are planned to study scientific break-even and high thermonuclear gain target development. The physics and engineering of these devices is well understood and the $> \$100M$ required for their construction is primarily for capital equipment and facilities.

For this review, the laser systems are classified into three categories: 1) small < 10 cm diameter research lasers of ~ 0.1 TW performance; 2) intermediate 10-20 cm output diameter, 1 TW class lasers; and 3) large, multi-beam >10 TW class lasers. The first category systems are often transversely excited CO₂ lasers as they are economical and provide an access to interesting plasma physics regimes at lower power levels than would be required with glass laser systems. An example is the NRC system in Ottawa, Canada. The pulse duration for these systems is usually ~1 nsec and output energies are 5-50 J. Glass lasers in this category, such as the 2 beam, 9 cm diameter output rod system manufactured by Quantel and CILAS for Ecole Polytechnique in Paris, have been designed to provide short, ~0.1 nsec, ~10-50 J pulses for high focused power, 10^{15} W/cm², target physics experiments. The versatility and convenience of experimentation with lasers of this size has led to a great deal of data being produced.

The second category of laser systems, for example the Rutherford Laboratory laser system, the LLL Argus system, the Osaka GEKKO IV and GEKKO XII modules, the Rochester Zeta system, the laser at KMS Fusion, the Octal System at Limeil, etc., are usually two (or more) beam systems which are used for compression experiments. (See Figure 1 for an example). Exploding pusher experimentation as well as transition experiments to the ablative target regime are being conducted with these systems. The devices are complex and require a small, but dedicated, team of professionals (and budget) to operate. As a result, they are usually associated with an institute whose task is to investigate inertial fusion or high temperature, high density physics.

The third class of lasers, the large beam-area, multi-beam systems, such as Del'fin at the Lebedev Institute, Shiva at the Lawrence Livermore Laboratory, and Helios at Los Alamos Scientific Laboratory, are capable of irradiating ablative targets to provide respectable compressions, in excess of 15x liquid DT density. They are expensive, highly engineered devices requiring a dedicated team of professionals and a large budget to use these systems at their full potential. Special experiments take a longer time to perform than on small devices because of experimental set up time and data evaluation. The technical status of the most widely used lasers, CO₂ and Nd:glass, is shown in Table II.

TABLE II

Comparison Between 1 μ and 10 μ Lasers

<u>1.05μ</u>	<u>10.6μ</u>
10 TW, 10 kJ output	10 TW, 10 kJ output
Multi-beam, cascade geometry	Multi-beam and multi-pass geometry
1-5 J/cm ² optics damage threshold	1-5 J/cm ² optics damage threshold
Main focal limitation is non-linear, self-focusing	Main focal limitation is cumulative linear aberrations
Experiments use pulse variability, harmonic generation and bandwidth flexibility	Experiments are emphasizing laser plasma coupling physics issues

Cost of large systems at either 1 μ or 10 μ are approximately equal.

Laser systems for reactors will probably be flowing gas systems, although some recent attention is being given to gas cooled solid systems. They must provide ~1 MJ level of energy at 100 TW. The beam diameters will be > 1 meter in order to limit the number of laser beams (based on expected damage thresholds of $< 20 \text{ J/cm}^2$). Table III shows a list of problems expected as lasers are developed for reactor applications.

TABLE III

Future Laser Problems (Ignoring Target Physics)

<u>< 0.35μ</u>	<u>0.53-1.3μ</u>	<u>10.7μ</u>
Technical development of large diameter optics	Diameter of optics Cooling Induced aberrations and birefringence in laser host material	Diameter of optics Isolation
Complexity associated with Non-Storage-Eximer laser media	Cost of Rare Earth Crystalline host materials	Cost of large diameter Crystalline Optics
UV Compatible Materials		
Expense of Pulse Power		
Chemistry of Flow	Efficiency	Focusing over long distances

Lasers are continuing to become more reliable and to provide increasingly interesting data. In the coming year, laser focusing systems should be improved to provide larger focal spots and better focal spot control. This will improve measurement of power density and the thresholds for the onset of plasma physics effects. Glass lasers will be modified to provide the harmonics at 0.53, 0.35, and 0.26μ for laser-plasma irradiation studies. In addition, bandwidth modification will be applied to examine its effect on the growth of the Brillouin backscatter instability. CO_2 laser systems will be used to clarify plasma physics issues and to resolve wavelength scaling laws for light/plasma interaction. Laser designers will work to favorably resolve the issues raised in Table III. These efforts will be directed toward developing cost effective laser systems for future 1 MJ class drivers, and later, for efficient repeatable pulses for reactor systems.

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FIGURE 1

Dr. Yamanaka,

Please provide a good picture of the GEKKO IV laser system.

J. F. Holzrichter

The 4 beam GEKKO IV laser system provides > 2 TW on target in 100 psec pulse.

FIGURE 11

The 20 beam Shiva laser provides > 20 TW on target in 100 psec pulse and up to 15 kJ on target with 1 nsec pulse.

FIGURE 17

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