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# NOVA: THE LASER FUSION BREAKEVEN EXPERIMENT

by

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## Introduction

The Nova glass laser system, which is now under construction at Lawrence Livermore Laboratory, is expected to demonstrate target ignition and scientific breakeven for inertial confinement fusion in the mid-1980's. At that time, the Nova laser system is expected to operate at its full 300 kJ energy level.

This milestone represents the culmination of a long series of experiments with increasingly more powerful laser fusion systems at LLL. The Nova laser is an extension and upgrade of the 30 TW Shiva laser which has been in operation since 1977.(1) In order to achieve an early 1983 operational capability at 80 to 120 kJ or 80 to 120 TW ($10^{12}$ watts), with minimum facility downtime, the Nova laser is being constructed in two phases.

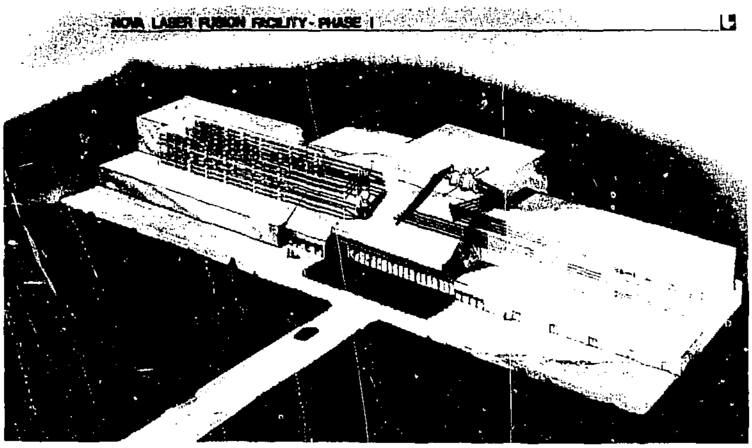


Figure 1 - Artist's concept of the Phase I Nova Laser Fusion Facility. The 20 beam Shiva laser system is shown on the left side and the new Nova laser system is shown on the right side.

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A new laboratory building is being constructed adjacent to the Shiva laser to house the Phase I $137M ten-beam Nova laser and a target chamber designed for twenty beams. The first ten beams (right side of Figure 1) will be operational in early 1980. Following Phase I, it is planned that the Shiva laser (shown on the left side of Figure 1) will be shut down and upgraded into ten Nova laser beams. These beams will then be combined with Nova Phase I beams to provide the full twenty beams having a minimum output energy of 300 kJ in a 3 ns pulse, or a power capability of 300 terawatts ($10^{12}$ watts) in a 100 ps pulse. This paper will describe the Phase I engineering project.

## Project Description

The Nova Phase I laser is a major engineering project requiring the efforts of a large number of physicists and engineers from both LLL and industry. This construction project consists of a conventional facility (buildings) and a special facility (the laser). The conventional facilities are being designed by an architect and engineering firm and the construction is being accomplished by multiple fixed-price contracts under the direction of a construction management firm.

The laser system is being designed at LLL by both laboratory and industry personnel. All the hardware will be fabricated by industry. LLL provides overall project management and performs final system integration and activation. Each of the major elements of the laser system will be described below.

## Laser System

Phase I Nova is a neodymium-doped glass laser system consisting of ten linear laser chains driven in parallel by a single master oscillator. The Nova chains have been optimized to provide the maximum power and energy per dollar, and sized to stay within the technology of optical component fabrication. In addition, the laser has been designed to allow future upgrades through the addition of more amplifiers as optical coating and surface technologies improve. Short wavelength capability will be provided in the future with the addition of harmonic generation crystals.

Nova laser chains are similar to those of the Argus and Shiva chains, except that they utilize laser amplifiers with diameters up to 46 cm and have 180 meters of optical propagation path. The Nova chains also utilize a new neodymium-doped fluorophosphate laser glass which has a nonlinear index of refraction which is approximately 35% of that of the silicate laser glass used in the Shiva system. This improved laser glass, combined with the more cost-efficient larger aperture amplifiers, allows the Nova system to achieve significantly greater performance per unit of cost than previously attained with the other glass laser systems.

The ten Nova laser chains are driven by a pulsed oscillator of appropriate pulse shape for a particular experiment. This shaped pulse is preamplified and split into the ten beams required to drive the individual laser chains. These chains consist of rod amplifiers, disk amplifiers, spatial filters, Pockels' cells, and Faraday rotator isolators. The initial stages are rod amplifiers with 5 cm clear aperture, followed by the optical components shown schematically in Figure 2. This design consists of laser disk amplifier stages with clear apertures of 94 mm, 150 mm, 208 mm, 315 mm and 460 mm. These stages are separated by beam expanding spatial filters and contain Faraday rotator isolation stages where necessary. From the 94 mm aperture through the 208 mm laser disk amplifier this chain is similar to Shiva, except for the addition of another 150 mm amplifier and a 150 mm isolation stage, and two additional 208 mm amplifiers. Following expansion to 315 mm, the laser chains are folded prior to further amplification. The 315 mm and 460 mm disk amplifiers are designed with a new rectangular pumping geometry that is more efficient and easier to assemble than those used on previous systems. Each of these new amplifiers contains two laser disks. In addition, the 46 cm disks are split, as will be described later in the paper. The output beams from the final disk amplifiers are expanded to 74 cm and directed, by a series of turning mirrors, to lenses mounted on the target chamber. These lenses focus the beams on the target.

This laser configuration has been selected as a result of extensive design studies and optimization efforts during the past three years. To provide the maximum output energy with a minimum probability of laser damage to optical components, a combination of coated and uncoated optics is used. The three types of optical coatings are: anti-reflection coatings, polarizing coatings, and high reflection coatings. Of these, the ones currently most susceptible to laser damage are the anti-reflection coatings.[2] The Nova amplifier stages (between spatial filters) have been designed so that input fluence density to the amplifiers is just below the AR coating damage level of the output lens of the spatial filter/beam expander. The amplifiers then increase the fluence density to a value just below that of the uncoated input lens of the spatial filter. The beam is then expanded to lower the fluence density once again.

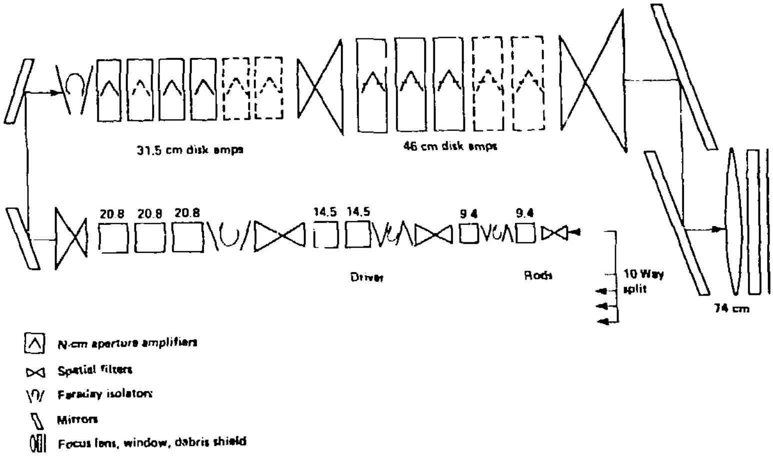


Figure 2 - Optical Schematic of a Nova Phase I Laser Chain.

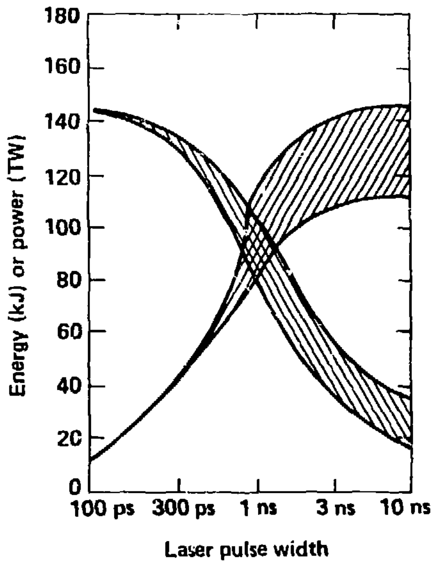


Figure 3 - Performance of the Ten Beam Nova Laser System.

Figure 3 shows the projected Phase I Nova laser performance as a function of pulse width.

## Nova Configuration

The Phase I Nova laser system is configured as shown in Figure 1. The ten Nova laser chains are folded in the laser bay at the 315 mm aperture. The ten 740 mm diameter beams emerge from the laser bay in two columns of five beams and enter an area identified as the switchyard, where the beams are directed into the target room. The Nova target room is 50' x 100' x 69' and has 6' thick concrete walls to provide containment of the neutrons from fusion experiments.

The target chamber room contains the target chamber, support structures, beam turning mirrors, target positioner, and optical elements required to focus the beam onto the target. A few target diagnostics sensors are mounted within the target room, but most are outside of the target room in an area identified as the diagnostics loft. The location of this loft has been selected to provide radiation shielding for electronic components.

## Mechanical Subsystem

The mechanical subsystem consists of the following major hardware:

| | |
|---|---|
| Spaceframe | - Laser bay, switchyard, target room |
| Laser Amplifiers | - 160 units |
| Spatial Filters | - 80 units |
| Isolation | - 50 units |
| Gimbals & Mounts | - 65 units |

Most of the 160 laser amplifiers are similar to those used on Shiva; however, the 315 mm and 460 mm disk amplifiers use a rectangular pumping geometry which has a higher pumping efficiency than previous round amplifier pumping configurations. In addition, the 460 mm amplifier incorporates a split laser disk.(2) Normally, a laser disk is a single piece of elliptically shaped glass which is mounted in the amplifier at Brewsters' angle. The dimension of the major axis of the disk is nearly twice that of the minor axis and the beam diameter. Amplified spontaneous emission along this major axis represents a loss of pumping energy. This "de-pumping" limits the inversion or gain present in the laser disk. In the past, this loss has made large aperture amplifiers less attractive.

In order to reduce this loss, the 460 mm aperture elliptical disks are split along the short axis and edge cladding applied between the two halves. This reduces the maximum internal laser de-pumping length by approximately a factor of 2. This means the 460 mm amplifier is much more efficient and can be pumped to nearly the same inversion value as the smaller 208 mm amplifier.

Because of the split disk, the laser beam encounters a thin obscuration across its diameter. Ordinarily, beam diffraction effects from this obscuration would cause unacceptable nonlinear laser intensifications following the amplifier. However, with apodizing, image relaying and spatial filtering, this effect is reduced to an acceptable level.

The spatial filters between amplifier stages provide the functions of filtering, image relaying, ASE reduction, and beam expanding. As a filter, they remove the high-frequency spatial noise present on the laser beam. This reduces the near-field spatial modulation peaks and allows further amplification without component damage. The spatial filter f-number and pinhole diameters are chosen to prevent closure when high energy 3 ns pulses are propagated through the spatial filters.

As an optical relay, the first spatial filter relays an image of the hard apodizer at the front of the chain to the input lens of the next spatial filter where it is again relayed to the next filter and so on. This image relaying reduces the diffraction path length to zero and allows a nearly square spatial beam profile to be propagated through the laser chain. This provides a high "fill factor" throughout the laser chain, which results in efficient energy extraction at lower fluence levels. Spatial filtering and image relaying both reduce the peak to average beam intensity along the laser chain.

The spatial filters also expand and re-collinate the beam between amplifier stages.

## Optical Subsystem

The optical subsystem consists of all the active and passive optical elements used in the Nova laser. The quantity of optical components are:

| | |
|---|---|
| Laser Glass | 2,000 liters |
| Rotators | 25 liters |
| BK-7 and fused silica beam optics | 1,500 liters |
| BK-7 mirror and diagnostics | 7,000 liters |
| | 10,525 liters |

This glass weighs about 30 tons and has a polished area of approximately the size of a tennis court.

The small optics (< 10 cm) are procured as finished and coated elements. The large optical elements are purchased in the form of raw glass, then fabricated under separate finishing and coating contracts.

This procedure minimizes the cost risk to any one supplier and reduces our dependence on a single firm.

## Alignment and Computer Control System

The Nova laser system, as with the Shiva laser system(3), utilizes a distributed multi-level computer system for alignment and control. The computer system architecture was selected following a tradeoff of the relative cost, complexity and difficulty of one central computer versus a number of distributed units.

The Nova computer control system is divided into three functional entities. One computer subsystem performs automatic laser alignment. The second computer subsystem performs a combination of laser diagnostics and target experiment diagnostic functions. The third computer subsystem controls the power conditioning system. All three of these subsystems are tied together into a central computer system and share a common control language.

The alignment control computer subsystem interfaces directly with the operator and interacts with a variety of micro-processors that are located adjacent to the sensors and actuators used to align the laser chains. The laser alignment functions on Nova can be broken down into the following categories: 1) oscillator alignment; 2) chain input alignment; 3) along the chain alignment; 4) chain folding alignment system; and 5) chain output alignment system. These functions are similar to those used previously in Shiva, with the addition of the chain folding alignment system for Nova. In addition, Nova will use charge coupled devices (CCD's) as video sensors and provide automatic alignment for all the above functions.

The integrated diagnostics computer control subsystem provides diagnostic information relating to laser power, energy, and pulse shape at various points along the laser chain and handles target diagnostic information. To diagnose the laser system performance prior to and during a shot, there are optical sensors located along the chain at various amplifier stages. These sensors provide a determination of the gain between stages. A sensor that determines the power and energy going into the target chamber is located at the output of each laser chain. In addition, there is a sensor that determines the laser power and energy reflected from the target during a target shot. The data from these sensors are processed and recorded by the integrated diagnostics computer. Target diagnostic information is also recorded by this computer subsystem.

The power conditioning controls computer is responsible for providing all timing and firing signals associated with the laser system and also controls the power conditioning subsystem.

## Power Conditioning Subsystem

This subsystem provides the pulsed energy required to drive the Xenon flashlamps which pump the laser amplifiers. The 13.8 kV 60 cycle utility power is converted into 20 kV DC, which is used to charge about 60 megajoules of high-energy storage capacitors. These 6400 capacitors are then switched by 143 ignitrons into the 4050 flashlamps which excite the laser system. The 21 power supplies, which are a combination of 100 kVA and 1.5 MVA sizes, charge the capacitors in less than 30 seconds.

This subsystem also provides the electrical drive to the pulsed optical shutters used to provide laser isolation and protection from retro-reflection from the target.

## Target Chamber Subsystem

The target chamber subsystem consists of a 1.5 meter radius aluminum vacuum vessel which contains the fusion reactions, a target positioner, focus lens positioner, support structure, vacuum system, and target diagnostics.

## Acknowledgments

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