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THE ASSURANCE MANAGEMENT PROGRAM FOR THE NOVA LASER FUSION PROJECT

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ABSTRACT

In a well managed project, Quality Assurance is an integral part of the management activities performed on a daily basis. Management assures successful performance within budget and on schedule by using all the good business, scientific, engineering, quality assurance, and safety practices available. Quality assurance and safety practices employed on Nova are put in perspective by integrating them into the overall function of good project management.

The Inertial Confinement Fusion (ICF) approach is explained in general terms. The laser ICF and magnetic fusion facilities are significantly different in that the laser system is used solely as a highly reliable energy source for performing plasma physics experiments related to fusion target development; by contrast, magnetic fusion facilities are themselves the experiments.

The Nova project consists of a 10-beam, 74 cm aperture neodymium-glass laser experimental facility which is being constructed by the Lawrence Livermore National Laboratory (LLNL) for the U.S. Department of Energy. Nova has a total estimated cost of $176M and will become operational in the Fall of 1984. The Nova laser will be used as the high energy driver for studying the regime of ignition for ICF.

The Nova assurance management program was developed using the quality assurance (QA) approach first implemented at LLNL in early 1978. The LLNL QA program is described as an introduction to the Nova assurance management program. The Nova system is described pictorially through the Nova configuration, subsystems and major components, interjecting the QA techniques which are being pragmatically used to assure the successful completion of the project.

Inertial Confinement Fusion - What is it?

One technical approach to the problem of controlling thermonuclear fusion reactions is to bring small deuterium-tritium (D-T) fuel pellets to very high temperatures and densities in such a short time that the thermonuclear fuel will ignite and burn before the compressed core disassembles. This approach, known as inertial confinement fusion (ICF) relies upon a driver (e.g., a laser) to deliver the extremely high power, short duration burst of energy required. Energy is released in the form of energetic neutrons as the deuterium and tritium nuclei fuse into helium. A wealth of technical information on this subject is found in reference (1); appropriate material in this paper is derived from these publications.

The Laser Fusion Program at LLNL - Its history and status

Over the past several years, LLNL has built and operated a series of increasingly more powerful and energetic laser systems to study the physics of ICF targets and laser-plasma interactions (Figure 1).

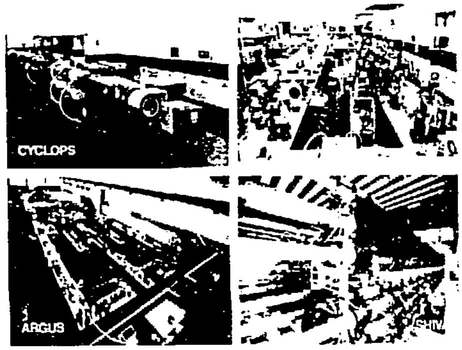

Figure 1

Solid-state neodymium lasers were selected because this technology was most advanced with respect to producing high peak power. Nova, the latest in this series, will consist of 10 beams capable of concentrating 80-120 TW of power (in 100 ps) and 80-120 kJ of energy (in 3 ns) on experimental targets by the mid 1980's. Like its predecessors, Nova will be a neodymium-glass (Nd:glass) laser system with a working wavelength near 1.05 μm. However, in experiments at the University of Rochester,[2], and at LLNL[3] the frequency of the fundamental 1.05 μm light from high-power Nd:glass lasers was doubled and tripled with efficiencies exceeding 70% by using the nonlinear optical properties of potassium dihydrogen phosphate (KDP) crystals. Since shorter wavelengths are much more favorable for ICF laser target physics, this option will be implemented in the Nova facility. Nova will thus be able to focus approximately 80 kJ of green (0.53 μm) or "blue" (0.35 μm) light onto laser fusion targets. The total cost of the Nova project, including an office building and a laboratory building, will be $176 million and the experimental facility will be available to start fusion experiments in the Fall of 1984. It is expected that Nova when operated using blue light will have sufficient energy to study the regime of thermonuclear ignition.

The Nova Laser System

Nova is an example of a large design, construction and installation project conducted in a research and development laboratory. It is a one-of-a-kind facility which will be operated by the same people who designed and constructed it. The Nova project management strategy is to maintain responsibility for the design and to assume the inherent risks. The management strategy is to award greater than 70% of the total project cost to

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industrial suppliers who fabricate Nova hardware on build-to-print contracts using well established fabrication and inspection techniques for their industry. The net result is reduced risk for the suppliers and reduced costs for Nova. Contracts for critical components are awarded to multiple suppliers whenever possible. This assures management that unforeseen problems will not jeopardize the Nova schedule and that competitive, fixed price contracts can be awarded.

The Nova laser system has a master oscillator power amplifier (MOPA) architecture. As shown in Figure 2, a laser pulse of requisite temporal shape is generated by the oscillator, preamplified, and split into 10 beams. After traversing an adjustable optical delay path (used to synchronize the arrival of the various beams at the target), the pulse enters the amplifier chain where (1) amplifiers increase the pulse power and energy, (2) spatial filters maintain the spatial smoothness of the beam profile while expanding its diameter, and (3) isolators prevent the entire laser from breaking sponteneously into oscillations that could drain its stored energy and damage the target prematurely.

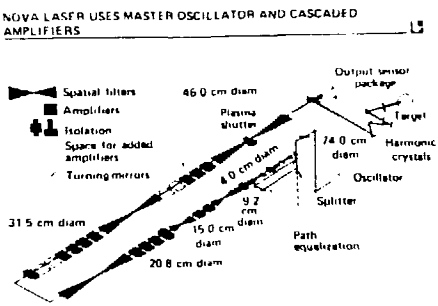

Figure 2

When the pulse exits from the final beam-expanding spatial filter, it has been amplified to an energy level of 8-12 kJ, and its diameter is 74 cm. Turning mirrors direct the beam to the target chamber, where a focusing lens concentrates it on the target. For operation at the second or third harmonic frequency, KDP crystal arrays are located just in front of the fused silica focus lens on the target chamber vessel.

An artist's cutaway drawing of the Nova layout is shown in Figure 3.

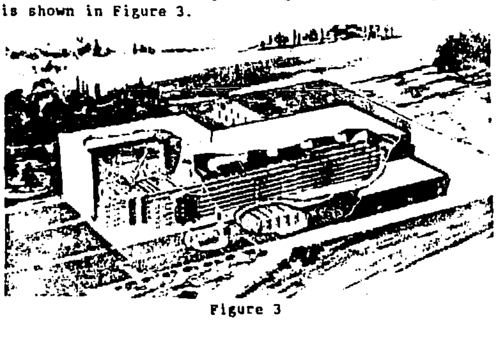

Figure 3

The Foundations of the Nova Assurance Management Program

The Nova laser assurance management program is based on the policies of the formal LLNL quality assurance (QA) program established in March 1978. LLNL's approach to QA is shown in Figure 4 and emphasizes assigning responsibility for QA to the line organization, i.e., the person responsible for the quality of the results. The line organization has responsibility for both achieving and assuring its organizational objectives. The approach uses planning to prevent incidents and defects. It provides feedback through the independent audit process which leads either to correction or improvement depending upon the level of quality most appropriate to the organization's programmatic objectives. The approach uses the existing "tools of quality" and "good engineering practices" which have sustained LLNL's successful achievements prior to their being formalized through the current LLNL QA program. Several of these "tools of quality" and "good engineering practices" will be described later in this paper.

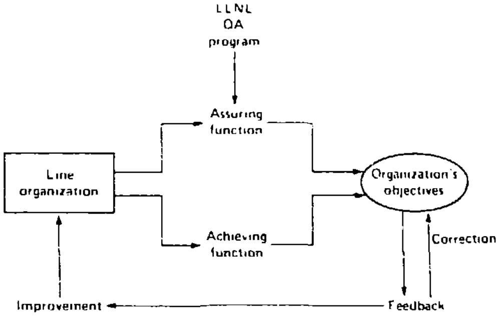

Figure 4

The LLNL QA program is documented in a 14 page manual which scopes management responsibilities and provides guidelines for implementation [4]. A small staff of engineers (5 people) is assigned to the LLNL Quality Assurance Office to assist the line organization with planning, training, audits, and to prepare and maintain the laboratory's QA manual.

The lack of a formal DOE policy or regulation on QA allowed sufficient latitude to invent a QA program which was tailored to the Nova project. Nova's assurance management program is an integrated approach which addresses QA functions, personnel and system safety, and configuration management in a single document. Historically, these assuring activities are addressed in separate plans. Including all assuring activities in one plan greatly reduced the redundancy inherent in separate plans, the length of the plan, and the effort to implement the plan. The Nova laser assurance management program evolved from the LLNL QA Program and was initially released in September 1979. The LLNL QA office provided professional support to help Nova's project management and engineers prepare their assurance plans. The controlling document is the Nova Master Assurance Plan.

Examples of Nova's Major Subsystems Showing How Effective Assurance Techniques are Being Applied

Figure 5 shows the building blocks that depict the system configuration of Nova. The laser chain components described earlier are shown in the bottom row of boxes. The chain is supported by (1) power systems which provide electrical energy to the amplifier flashlamps, (2) alignment and diagnostics which direct the laser beams to the target and measure the laser's performance, and (3) data acquisition systems which measure the results of the experiments. All these subsystems are activated and monitored by a hierarchical computer control system. The next several figures will pictorially present some of these subsystems and major components. Various features of the Nova laser assurance management program will be interjected in the narrative to graphically demonstrate how effective QA techniques are being implemented for Nova. A more extensive description can be found in Reference 5.

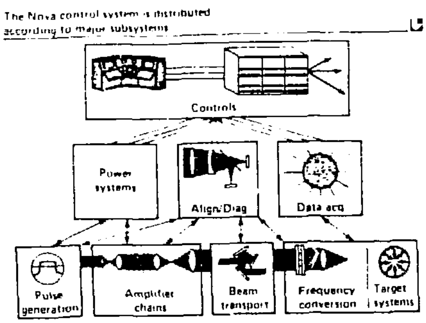

Figure 5

Nova is a huge optical system and requires very stable optical supports for mounting and aligning the laser components. The south laser bay spaceframe shown in Figure 6 is 62 meters long, 3 meters wide and 10 meters high. There are two parallel spaceframes and the components for five (5) laser chains will be mounted on each frame. Additional large mechanical spaceframes are in the Optical Switchyard and Target Bay.

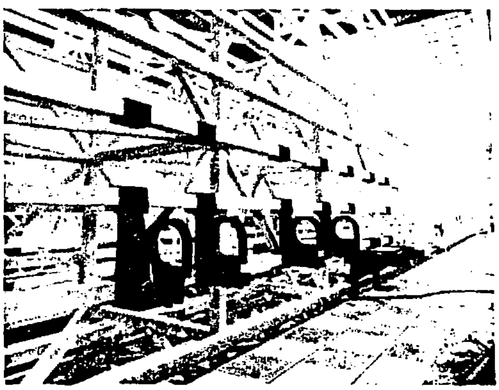

Figure 6

LLNL mechanical engineers designed all the spaceframes and presented their designs during formal design reviews attended by a broad cross-section of Nova project management and engineers. Safety issues and corrective actions were presented in preliminary hazards analyses. Approvals to proceed with each phase of the design were obtained through the review process and design review minutes and action items were prepared. Extensive use was made of computer codes which modeled the loads and seismic forces on the frames and their resonant frequencies. The Nova spaceframe designs are similar to Shiva's. An unscheduled verification test of the Shiva seismic design features occurred during a 5.5 Richter earthquake in January 1980. The seismic anchors released as designed and there was no damage to any optical component in all 20 beams.

The Nova spaceframes were fabricated off-site in modules which were field-welded in the Nova laboratory building. The resultant overall accuracy of the as-welded frame was measured to be 3 mm over the entire 62 meter length of the laser spaceframe. Shim plates provide the final mechanical pre-alignment accuracy of $\pm$ 1.5 mm over the entire vertical plane of the spaceframe. Harmonic resonance tests of the spaceframes confirmed computer code predictions for all the spaceframes.

Nova when it is completed will be the world's largest op·.cal instrument. The finished optical surface area of all the Nova optical components is ten times that of the 200 in. reflecting telescope on Mt. Palomar. Some of the 109 cm diameter borosilicate turning mirror blanks produced by Schott Optical are shown in Figure 7. These mirror surfaces are subsequently finished by either Eastman Kodak or Zygo Corporation to front surface accuracies of better than 1/12 wavelength at 633 nm. This represents flatness to within 5 μm.

Figure 7

As part of the procurement process, a series of pre-bid and pre-award reviews are conducted in a similar fashion to the formal design reviews described earlier. Suppliers included on the qualified bidders list are asked to bid on Nova procurements. This list was developed based on experiences with predecessor laser systems. During the procurement reviews, management not only selects the supplier(s) to be awarded the contracts, but also the strategy for splitting the quantities such as to assure a fallback position if difficulties are encountered. The reviews are documented and provide the basis for notifying the buyer to proceed with the awards.

Engineers in the Optics group make frequent visits to check on the suppliers' progress. Source inspections are used for acceptance because of the extensive amount of handling and shipping among the optics fabricators, finishers, and coaters. Detailed acceptance test reports are prepared and delivered with each optical component. Final acceptance of the as finished or as-coated optic is confirmed at LLNL using inspection equipment common to that at the suppliers' facilities.

The Nova amplifiers combine mechanical, optical, and power systems designs. The Nova prototype 46 cm amplifier shown in Figure 8 is the largest amplifier in the system; there are four 46 cm amplifiers in each Nova laser chain. Each amplifier has split disks which are mounted at Brewster's angle to minimize reflections. The disks are fabricated by Hoya Optics and Schott Optical and are finished by Kodak and Zygo. The phosphate based neodymium doped laser disks are split to suppress internal oscillations which drain the energy stored in each disk. The flashlamps run along two opposing sides of the rectangular mechanical structure, facing the installed disks. Each flashlamp is backed by a silver-plated crenulated reflector, which reflects the light into the disk faces. An electroform process is used to "grow" these reflectors. Flat, silver-plated walls form the top and bottom walls. Careful design of the rectangular Nova amplifiers has made possible an efficiency improvement of a factor of two over the cylindrical amplifiers used in the Shiva laser system. This full scale prototype was tested to confirm the design criteria prior to release for bidding of the mechanical, laser glass and flashlamp drawings.

THE LARGE NOVA/NOVETTE 46 cm SEGMENTED AMPLIFIERS HAVE A SMALL SIGNAL GAIN OF TWO AND STORE 8 kJ OF OPTICAL ENERGY

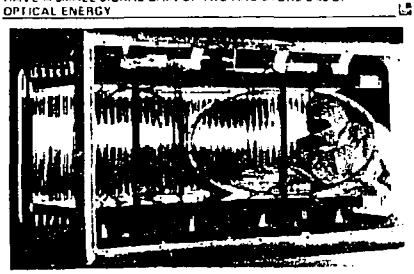

Figure 8

The plasma physics experiments on Nova related to fusion target development will be performed inside a 4.6 m diameter evacuated target chamber. Mounted on the target chamber will be ten (10) frequency conversion arrays and focusing lens positioner assemblies; one of which is shown in the artist cutaway (Figure 9). The aspheric focusing lenses serve as the vacuum barrier and are finished by Eastman Kodak and Tinsley Laboratories to surface accuracies of better than 1/4 wavelength at 633 nm. Since each lens must travel several centimeters to focus the various operating wavelengths on the fusion targets, a precision drive mechanism capable of moving this massive optic against atmospheric

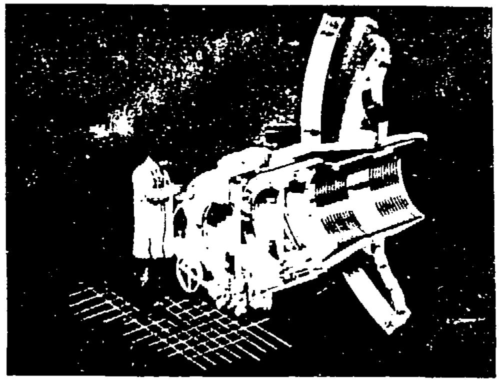

Figure 9

pressure was designed and full scale prototypes were fabricated and tested.

The multi-optical-element KDP frequency conversion array is located outside the vacuum barrier and consist of two sets of KDP crystals sandwiched between transparent fused silica windows. Corning Glass Works and Heraeus Quartzschmelze are the suppliers of the high quality, essentially bubble-free, fused silica blanks for the windows and the focusing lenses. A 77 cm clear aperture prototype array is shown in Figure 10. The KDP crystals are located in a 3x3 matrix in the array. These crystals are being grown as large boules by Cleveland Crystals and Inrad. Growth of the boules from their seed crystals requires several months of continuous growth under carefully controlled conditions.

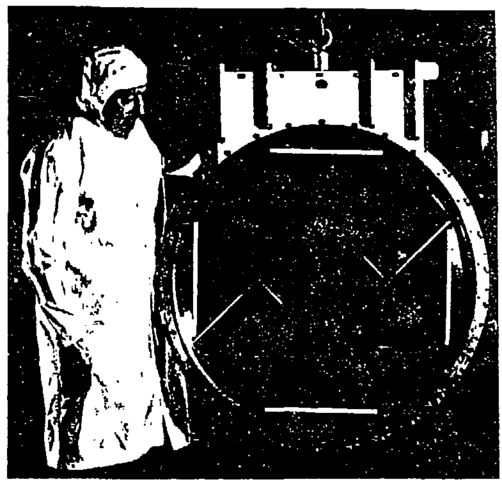

Figure 10

In order to achieve the desired second and third harmonics of the fundamental neodymium wavelengths, the KDP crystals must be cut to within 30 µrad of the appropriate phase-match angles. The finished KDP crystals for Nova are 1 cm thick and 27 cm x 27 cm square. The sides and faces of the plates are micro machined using single-point diamond turning technology which has been proven at LLNL with full size crystals and formally technology transferred to U.S. industry. The machining accuracy is ± 1 μm and the surfaces of the plates must be parallel to within ± 1.5 μm. LLNL has developed laser phase-matching equipment which uses a KDP crystal whose phase-match angle is known to within ± 5 μrad as the reference standard for measuring all other crystals. Identical phase-matching inspection equipment is located at Cleveland Crystals and Pneumo Precision, the two suppliers selected to diamond turn the crystals.

Nova has an effective and demonstrated assurance management program - Novette

In August 1981, Laser Program management decided to construct a two beam laser system named Novette. Novette was required to continue laser-target experiments after the Shiva system was shut down. Novette uses two arms of Nova each of which has the total energy capability of all 20 beams of Shiva. In addition, Novette operates at the second harmonic (green light) which is essential to confirm target yield scaling at shorter wavelengths. Novette was constructed in the Argus system laser building.

Novette is an operating test bed for Nova. Each of Novette's arms has demonstrated short-pulse (100 ps) operation at 1.05 μm of 12 to 13 TW and subsequent conversion to 6 to 7 TW at 0.53 μm. Novette is currently operating in a longer pulse (1 nsec) configuration and has delivered >5kJ of 0.53 μm light to targets. Initial experiments are confirming the Nova system design parameters.

In December 1981 the Argus laser system was completely removed from its building and Novette construction began. In January 1983, thirteen months later, Novette was performing laser fusion plasma experiments. The assurance techniques developed for Nova were used on a day-to-day basis to successfully construct Novette; proof positive that Nova has an assurance program that works.

Summary - An effective QA program can result from formalizing and properly performing a significant few assurance actions.

The Nova project is an excellent example of how quality assurance techniques can be effectively applied to a state-of-the-art, one-of-a-kind, large research and development project. The Nova laser assurance management program applies these techniques primarily where they are most beneficial, ie., to design and procurement as was described in this paper. The effect on the Nova project is positive and is assisting management toward the successful completion of the project in the Fall of 1984.

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