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Sandia National Laboratories Participation in the National Ignition Facility Project

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Introduction

The National Ignition Facility is a $1.1B DOE Defense Programs Inertial Confinement Fusion facility supporting the Science Based Stockpile Stewardship Program. The goal of the facility is to achieve fusion ignition and modest gain in the laboratory. The NIF project is responsible for the design and construction of the 192 beam, 1.8 MJ laser necessary to meet that goal. The project is a National project with participation by Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Sandia National Laboratory (SNL), the University of Rochester Laboratory for Laser Energetics (URLLE) and numerous industrial partners. The project is centered at LLNL which has extensive expertise in large solid state lasers. The other partners in the project have negotiated their participation based on the specific expertise they can bring to the project. In some cases, this negotiation resulted in the overall responsibility for a WBS element; in other cases, the participating laboratories have placed individuals in the project in areas that need their individual expertise. The main areas of Sandia's participation are in the management of the conventional facility design and construction, the design of the power conditioning system, the target chamber system, target diagnostic instruments, data acquisition system and several smaller efforts in the areas of system integration and engineering analysis. Sandia is also contributing to the technology development necessary to support the project by developing the power conditioning system and several target diagnostics, exploring alternate target designs, and by conducting target experiments involving the "foot" region of the NIF power pulse. The project has just passed the mid-point of the Title I (preliminary) design phase. This paper will summarize Sandia's role in supporting the National Ignition Facility and discuss the areas in which Sandia is contributing.

Conventional Facility

Sandia is providing the Conventional Facilities Associate Project Engineer who is responsible for the design, engineering, drafting, procurement, construction, inspection and acceptance of all conventional facilities required for the Laser/Target Area Building (LTAB) (Fig. 1) and the Optics Assembly Building (OAB), a total estimated cost of approximately $200M. The conventional facilities portion of the NIF project is broken down into two areas: conventional facility design, managed by an LLNL employee; and construction management, managed by another SNL employee. The design manager is responsible for the work performed by two Architectural/Engineering firms, Parsons Infrastructure and Technologies designing the LTAB and a yet to be determined firm designing the OAB. Construction Management includes the oversight of construction, and inspection and acceptance of all conventional facilities required for the LTAB and the OAB. A construction management firm, Sverdrup Facilities, has been hired to support the Construction Manager.

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A design and construction effort of this size poses several challenges. The first is the size of the project with respect to the schedule. The NIF project schedule shows completion of the Conventional Facilities construction in the year 2000. Title I engineering began in January of 1996. Collaboration with the special equipment designers requires incorporation of the special equipment requirements, and in some cases construction, into the facility. Examples of this include the nitrogen process cooling systems, laser support structures and the target chamber and pedestal. The vibration specifications to maintain laser alignment are extremely tight. The floor slab in the laser bays is limited to 1×10^{-10} g^2/hz from 1 - 200 hz. The alignment requirements also impose temperature stability requirements of 68 +/- 0.5 degrees F in the laser high bays, a room 441 ft L x 102 ft W x 50 ft H in size. The LTAB is integral part of the laser and target area system.

The schedule and cost constraints require fast tracking of the construction and its associated increased risk. Using multiple primes on the project means our coordination requirements increase significantly; it is expected that 10 to 20 prime contractors will be used for this project, some of them on site simultaneously. The simultaneous installation of hardware before completion of the facility also increases the complexity for Conventional Facilities.

Power Conditioning

Sandia has the responsibility to design, prototype, and deliver the Power Conditioning System (PCS). The PCS provides energy to the laser flashlamps which pump the main laser amplifier slabs. Each lamp pair requires a 24 kV, 25 kA, 80kJ pulse in order to provide optimum pumping of the amplifier. Challenges in the PCS include: developing a main switch which can operate at 24 kV, conduct 500 kA for thousands of shots; designing a system which can survive a fault with minimal damage; and reducing the cost of the system from current technology of $0.22/joule to the goal of $0.12/joule. Sandia expertise in high voltage and pulsed power technologies is being tapped to provide the R&D, component and subsystem design and development, and the total system integration. A team of experienced pulsed power, controls, and mechanical engineers, designers, and technicians has been formed to complete the project funded initial and final design stages of the program. In addition, a considerable R&D effort to develop and qualify components and subsystems is underway at Sandia, Livermore, and several industrial/commercial sites funded by the Inertial Confinement Fusion Program. Facilities in place at Sandia include a switch development lab, where candidate PCS switches can be tested at the full NIF parameters of up to 25 kV and 500 kA with the properly-shaped NIF pulse. Under construction is a prototype NIF testbed where system components and subsystems will be integrated over the next two years into the final NIF prototype PCS module. LLNL is supporting the PCS effort with capacitor and other component test facilities, and in cooperation with Sandia, is overseeing testing and design contracts with several commercial partners.

The PCS will consist of four multi-module capacitor banks, each driving 1080 series/pairs of flashlamps - 660 in the main and 420 in the booster amplifiers. Each of the four banks must deliver a total current of approximately 27 MA, and store more than 85 MJ. The present design breaks each bank into 60 smaller banks, each storing 1.6 MJ and delivering 500 kA - enough to drive twenty series pairs of lamps per bank. Critical to the success of this design is the development of a switch that can reliably operate at the required voltage, current, and charge transfer with a lifetime of thousands of shots. Presently available switches have yet to demonstrate all of these capabilities; the above-mentioned Sandia facility is testing candidate commercial and developmental switches and technologies for the 500kA NIF application. With the exception of the main switch for the PCS modules and potential system interactions (i.e. grounding and shielding schemes, crosstalk, synchronization of switching), there are only modest extensions in the state-of-the-art required for the NIF application in the areas of capacitors, power supplies, controls, diagnostics, and transmission systems. Considerable engineering effort is being expended, however, to minimize the cost of these items for the NIF procurement in FY98-99. The hardware cost goal for the system is $0.12/joule of energy stored. Simplifying requirements, qualifying multiple vendors, taking advantage of large-volume buying, and making use of custom designs where cost-effective will ensure a NIF system with optimum cost/performance balance.

Target Area

Sandia has a multifaceted role in the target area. Sandia is responsible for the target chamber and support pedestal, the target area vacuum systems, several target diagnostic instruments, the integration of the target diagnostic instruments and the target diagnostic data acquisition system.

Target Chamber

The target chamber is a 10 m diameter sphere which serves many functions. It must provide a stable mounting platform for the final optic assemblies; the target inserter and positioner, and the target diagnostic instruments. It must serve as a vacuum chamber (10^{-6} torr) and withstand the effects of a 20 MJ yield from a fusion capsule. It must provide access for fielding large experiments and for servicing the components inside the chamber. It must be made of a low activation material and provide radiation shielding to workers servicing components outside the chamber.

The design to achieve these requirements is relatively simple. The chamber will be made of 10 cm thick aluminum alloy 5083. This alloy has very low neutron activation. A 40 cm thick borated concrete outer shell will provide worker radiation protection to gamma ray decay of the activation that does occur and to minimize activation of surrounding structures and equipment . Stability will be achieved by mounting the sphere on a stable pedestal and providing side support from the target area building. Numerous ports will be placed to provide final optic mounting locations for both indirect and direct drive, for diagnostic mounting and for access to the chamber. The inside wall will be covered with "first wall" panels consisting of a plasma sprayed coating on thin aluminum sheets. This coating is being developed by LLNL to resist the effects of x-rays and shrapnel.

At this point in time, several options exist for the manufacture of the chamber. It's size prohibits easy transport from a manufacturer, so on site fabrication methods are being considered. The chamber may be built outside the building and then placed in the building or may be fabricated in place. Either method requires early and extensive coordination with the Conventional Facility portion of the project.

Vacuum System

The target area vacuum systems include a system to evacuate the 10 m diameter target chamber, the final optics assemblies, each of the target diagnostic instruments and the target insertion mechanism. The design for each of these systems is designed to reach a pressure of 5×10^{-5} torr within two hours and have an ultimate capability of 10^{-6} torr. Integral in each of these systems is an interface with the facility tritium recovery system. The NIF targets designed for ignition or moderate gain will each contain approximately __ grams of tritium.

The current design for the target chamber vacuum system uses oil-free Roots blowers as roughing pumps, turbo/drag pumps for the medium range and to pump non-condensables, and 48 inch cryopumps for the high range. Also under consideration in a cryo-condensation coil for water pumping to minimize pumpdown time. The diagnostic instruments will have a common roughing system pumped by smaller Roots blowers and individual high vacuum cryogenic pumps.

Critical to the operation of the vacuum system are the outgassing rates of the chamber components. The "first wall", which consists of individual panels covering the interior surface of the chamber to mitigate the effects of x-ray and shrapnel, could consist of plasma sprayed coatings on aluminum panels. The plasma sprayed coating can be very rough and could be a major source of outgassing. The responsibility for this component lies at LLNL and this is an example of one of the many interfaces that cross laboratory lines.

Diagnostics

Sandia has responsibility for four baseline target diagnostic systems: the soft x-ray power diagnostic; the active shock breakout diagnostic; the soft x-ray imaging diagnostic; and the total neutron yield diagnostic.

The Soft X-ray Power Diagnostic (SXSS) will measure the x-ray power radiated through a diagnostic hole in NIF hohlraums. It will be used to determine the time-history of the radiation temperature inside the hohlraum. It consists of transmission gratings as the spectral dispersing element and diamond photoconductors as the x-ray radiation detector. The transmission grating is constructed of free-standing gold bars with an open gap between each pair of bars. The SXSS will measure the x-ray flux with an accuracy of 10% and have a time resolution of 200 psec. The diagnostic will have a total of 16 spectral channels. Eight channels will be optimized for measuring the radiation temperature during the foot of the laser pulse and 8 channels will be optimized for measuring the radiation temperature during the peak of the laser pulse. The SXSS provides critical information which will enable experimenters to "tune" the NIF hohlraums and laser power to optimize the radiation field that drives NIF capsules.

Active Shock Diagnostic

The primary mission of the Active Shock Breakout Diagnostic (ASBO) is to measure the uniformity and velocity of the x-ray ablation-driven shock wave that propagates through an aluminum or gold diagnostic witness plate on the wall of the NIF hohlraum. A low-energy pulsed laser will illuminate the rear surface of a stepped or wedge witness plate at normal incidence. Prior to the time that the shock wave reaches the rear surface, the witness plate will reflect the laser into the passive SBO collection optics where it will be relayed to a visible streak camera. When the shock wave reaches the back surface of the witness plate, it will rapidly heat the surface which will cause the reflectivity to drop dramatically. Shock pressures as low as 0.5 Mbar in aluminum targets (which corresponds to shock velocities of 0.8 cm/μsec and radiation temperatures of 60 to 70 eV) were measured by A. Zigler, et. al. almost a decade ago (J. Phys. E, 19, 309 (1986)) using this technique. Data from the ASBO will enable experimenters to infer the intensity and symmetry of the x-ray drive inside NIF hohlraums to an accuracy of a few percent. The ASBO will provide critical information on the hohlraum radiation temperature which will allow "tuning" of the NIF hohlraums and laser power to optimize the radiation field that drives NIF capsules.

Soft X-ray Imaging Diagnostic

The primary mission of the soft x-ray imaging diagnostic (SXRI) is to measure the time-dependent size of the SXSS diagnostic hole in NIF hohlraums (as discussed in the SXSS diagnostic description, the SXSS diagnostic hole is used to infer the radiation temperature in NIF hohlraums). As a secondary mission, the SXRI will also be used to study the spatial symmetry of the radiation drive in NIF hohlraums. The SXRI uses normal-incident multilayer mirrors as the imaging optics and individually-gateable microchannel-plate-intensified (MCP) x-ray cameras as the detectors. The imaging system will consist of 8 Cassegrain telescopes. Four of the telescopes will use multilayer mirrors whose reflectivity is optimized at an x-ray energy of 250 eV and 4 of the telescopes will use multilayer mirrors whose reflectivity is optimized at an x-ray energy of 500 eV. Eight individually gateable MCP x-ray cameras, one for each telescope, will be used to record the x-ray images. The diagnostic will have a spatial resolution of 30 μm at the object plane. The MCP detectors will integrate over a 300 psec time interval. The SXRI will provide critical information which, when combined with the data collected from the SXSS, will help determine the time-history of the radiation drive in NIF hohlraums. This information will enable experimenters to "tune" the NIF hohlraums and laser power to optimize the radiation field that drives NIF capsules.

NIF Target Diagnostics Integration and Data Acquisition System

Sandia has two additional major responsibilities associated with overall support of the NIF Target Diagnostics. The first is Target Diagnostics Integration (TDI), and the second is the Target Diagnostics Data Acquisition System (TDDAS). The two projects must be closely coordinated because much of the design criteria information gathered and established for the Target Diagnostics to meet Title 1 Design requirements is common to the design of both subsystems.

Target Diagnostics Integration

Because the NIF is to be a national user facility, considerable flexibility must be incorporated into the target area instrumentation design to allow integration of user experiments with minimal operational impact. The goal of the TDI is to develop a flexible integrated support subsystem for all of the NIF Target Diagnostics. The items identified to be supported include cables for power, bias, triggers, data recording, vacuum system interface, system grounding, emp and radiation shielding, etc. The conceptual design of the NIF target area instrumentation system also poses unique technical challenges.

The Title I portion of the project requires the gathering of input on the type and number of diagnostic measurements to be fielded by experimenters from LANL, LLNL, SNL, and URLLE. The information gathered includes: verifying target chamber locations of each target diagnostic measurement; definition of signal parameters (pulse shape), bandwidth requirements; number of analog or digital data recording channels required, space requirements; and control, bias voltages, excitation requirements for each detector output on the diagnostics. These diagnostic requirements will also be phased through the life of the NIF. The challenge is to design a flexible, integrated design meeting a large list of requirements which will evolve.

Sandia has unique experience with diagnostic grounding and shielding, system integration and has developed a process for updating requirements as they evolve. These capabilities are a result of past involvement in the Underground and Above-Ground Test Programs.

Target Diagnostics Data Acquisition System

The TDDAS will work in conjunction with the cable and shielding portions of the Target Diagnostics Integration subsystem to provide controls, bias power, and timing information to the NIF Target Diagnostics and to read data from the diagnostics. The TDDAS will consist of a large number of computer controlled data recorders and ancillary support equipment. The system will be required to acquire data from both one dimensional (voltage vs time) and two dimensional (imaging) recorders. We have presently identified the need for approximately 100 recording channels. The ancillary equipment will provide special high voltage bias voltages and a wide variety of trigger and gating pulses to the diagnostics. As part of the TDDAS, Sandia is also responsible for the local instrument control computer systems and the instrument control software. The system will have major interfaces to the NIF Integrated Computer Control System (ICCS), particularly to the computer network, the supervisory level control software, and the timing distribution subsystems. The present strategy is to implement the instrument control software using the same Object Oriented Design methodology and the programming language ADA being used throughout the ICCS. The major technical challenges anticipated are in the areas of grounding and shielding, wide bandwidth, wide dynamic range, precision timing, and handling large amounts of two dimensional data.

Internal Pulse Shaped Target

Two other areas of Sandia involvement come as extensions of the Light Ion Fusion Program at Sandia. These are the design of an Internal Pulse Shaped target for the NIF and target testing in the "foot" portion of the NIF pulse on Sandia's pulsed power machines.

In the Light Ion Fusion concept, it is necessary to develop targets which are insensitive to the temporal history of the ion beam pulse striking the target. The implosion of the target needs to occur in a nearly isentropic fashion to achieve the very high compression required. A high power ion beam generates shock waves in the target which are then modified by passing through different material layers to produce the final shock wave configuration required for the compression. The baseline NIF target uses a precise input laser pulse shape to generate this shock wave configuration. The Internal Pulse Shaped target design offers a backup option for achieving ignition and moderate yield on the NIF.

"Foot" Testing

The baseline NIF laser pulse has a "foot" at the beginning of the pulse which provides a low-temperature initial compression of the target. The hohlraum temperature rises to 50 to 70 eV and is held for 10 to 15 ns before rapidly rising to the 300 eV final drive temperature 20 ns into the pulse. This initial "foot" area is critical in determining how the target compresses during the main pulse. This radiation temperature and pulse length are readily achievable on the Saturn and PBFA-Z (under construction) pulse power machines at Sandia. Initial tests on Saturn have proven encouraging and these tools will be applied to the study of the NIF target designs.

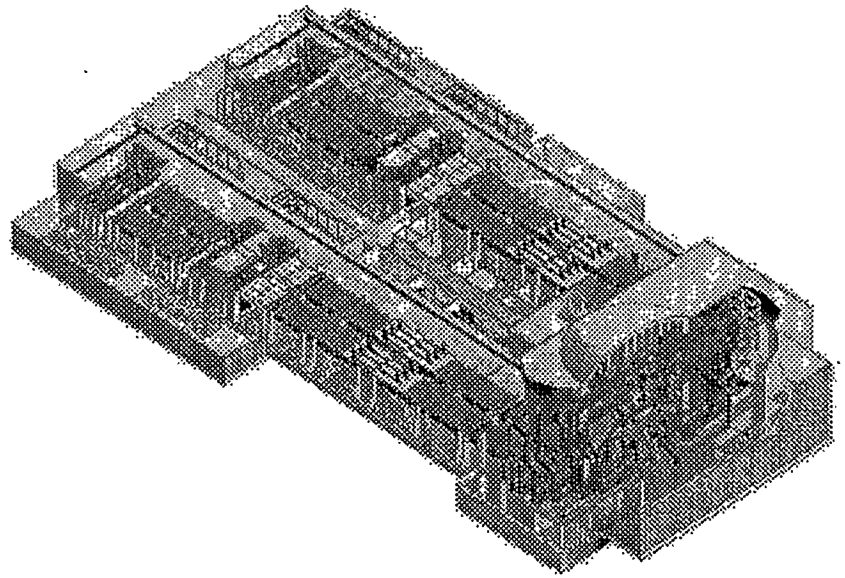

Figure 1.
NIF Building

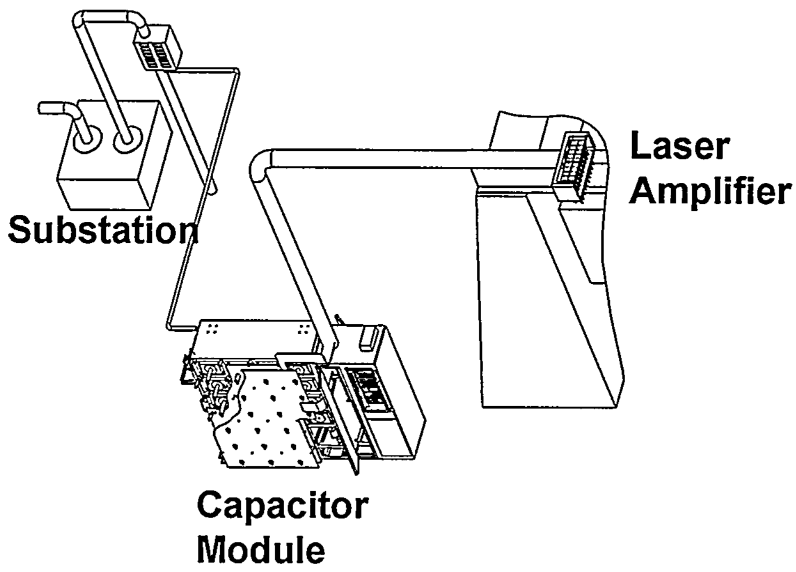

Figure 2.
Power Conditioning System Module

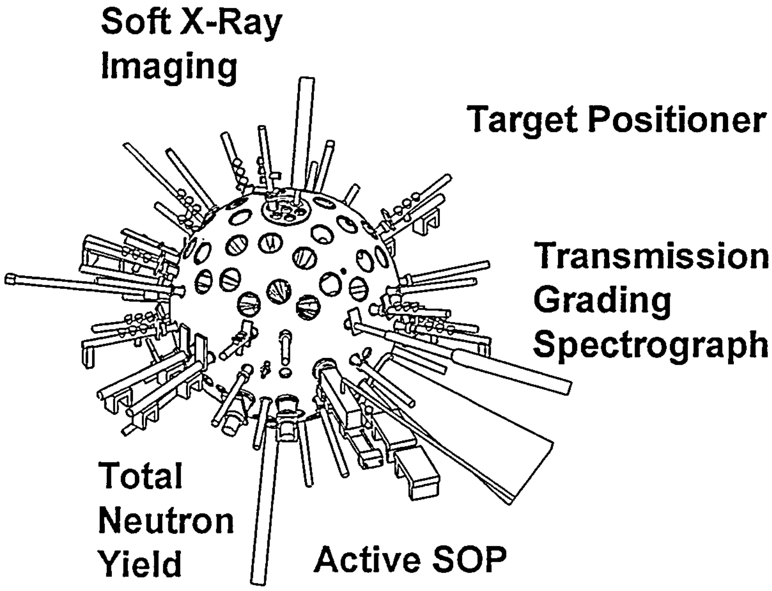

Figure 3.
Target Chamber and Target Diagnostic Instruments