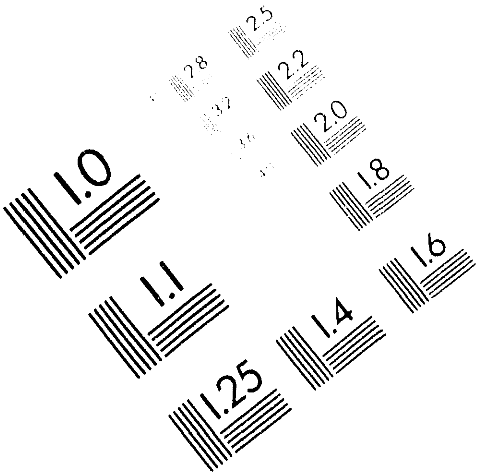

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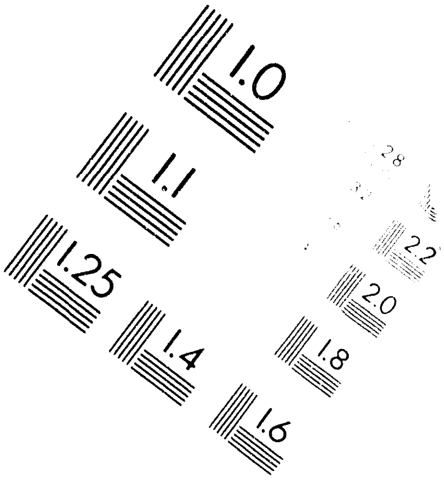

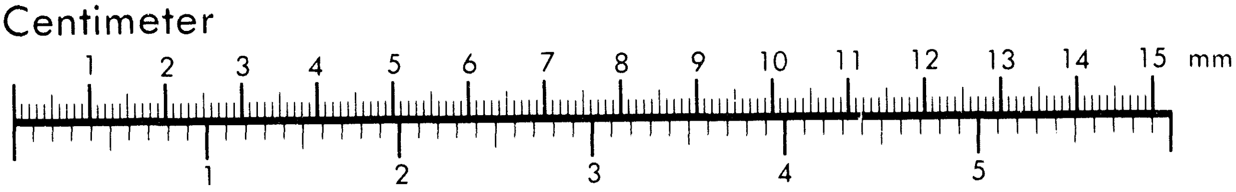

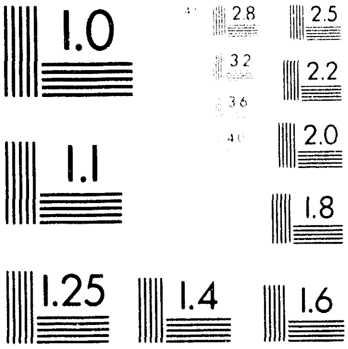

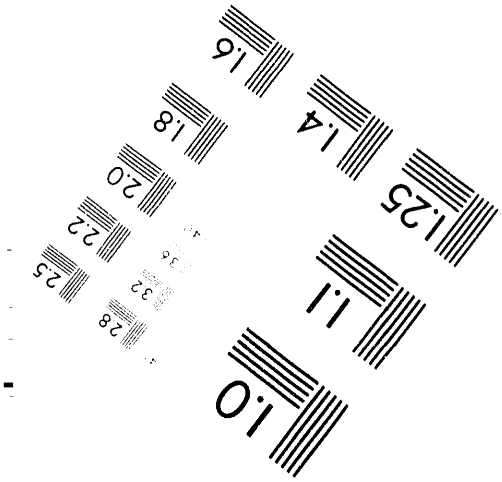

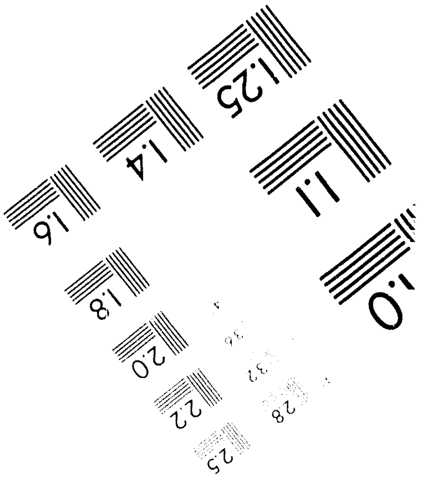

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Title: LOS ALAMOS CONTRIBUTION TO TARGET DIAGNOSIS ON THE NATIONAL IGNITION FACILITY

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LOS ALAMOS CONTRIBUTION TO TARGET DIAGNOSTICS ON THE NATIONAL IGNITION FACILITY

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ABSTRACT

The National Ignition Facility (NIF) will have a large suite of sophisticated target diagnostics. This will allow thoroughly diagnosed experiments to be performed both at the ignition and pre-ignition levels. As part of the national effort Los Alamos National Laboratory will design, construct and implement a number of diagnostics for the NIF. This paper describes Los Alamos contributions to the "phase 1 diagnostics." Phase 1 represents the most fundamental and basic measurement systems that will form the core for most work on the NIF.

The Los Alamos effort falls into four categories:

- moderate to hard X-ray (time resolved imaging
- neutron spectroscopy- primarily with neutron time of flight devices
- burn diagnostics utilizing gamma ray measurements
- testing measurement concepts (e.g., some soft X-ray ideas) on the TRIDENT laser system at Los Alamos.

Because of the high blast, debris and radiation environment, the design of high resolution X-ray imaging systems present significant challenges. Systems with close target proximity require special protection and methods for such protection is described. The system design specifications based on expected target performance parameters is also described.

Diagnosis of nuclear yield and burn will be crucial to the NIF operation. Nuclear reaction diagnosis utilizing both neutron and gamma ray detection is discussed. The Los Alamos TRIDENT laser system will be used extensively for the development of new measurement concepts and diagnostic instrumentation. Some its potential roles in the development of diagnostics for NIF are given.

I. INTRODUCTION

The National Ignition Facility (NIF) is potentially a very valuable national resource. In addition to the laser-target chamber construction, there are other important steps that must be accomplished for the NIF to reach its full potential. These include: (1) the investigation and testing of new measurement techniques and experimental concepts that will be needed for the NIF experiments. (2) the design, construction and testing of a large variety of diagnostic instruments for target experiments that must be compatible with the intensive blast, debris and radiation environments expected from the new high-energy laser beam facility. (3) the development of robust ignition-level target designs using several different approaches and target designs for various NIF applications to inertial confinement fusion (ICF) and weapons physics experiments. (4) the development of new target fabrication, materials and materials handling methods.

In this paper we report on the development and testing in the area of NIF diagnostics and materials being proposed by Los Alamos National Laboratory as part of the contribution to the NIF program. This paper is not intended to be all inclusive—other concepts are in various states of formulation with many being done in collaboration with other laboratories. The diagnostics discussed are for use with "phase 1" experiments that exclude ignition experiments. Given here also are proposed protection and testing applications that can be carried out using the Los Alamos TRIDENT laser system.

II. MODERATE-TO-HARD X-RAY IMAGING

The choice of X-ray optics in the 5 to 15 keV regime is dominated by three factors: the resolution desired, the X-ray absorption/grazing incidence angles and the cost/feasibility of building various schemes. By comparing the pinhole camera to other optical schemes we can obtain the optimum range of each method for laser fusion imaging. Pinhole imaging covers a large photon energy range. It is the simplest of all the schemes, has a broad band spectral response and can have a high signal to background signal ratio. The failings of the pinhole imaging are the low collection solid angle and the intense heat loads to obtain high resolution. To obtain higher resolution, greater collection solid angle and source standoff, the other optical schemes need to be considered.

A. New Methods Of Forming Pinhole Apertures

There are two methods that can be used to form pinhole apertures that could dramatically improve their X-ray optics.

The first method is to form a figured cylindrically symmetric hole in a material by a controlled differential etch rate down a preferential etch line. This can lead to forming many of the surfaces of a cylindrically symmetric figure that are useful for X-ray optics such as cones, ellipsoids, paraboloids, and hyperboloids. With etching charged particle tracks in polycarbonate, the preferential damage track minimum diameter is of order 7 nm. The scale of the etched track can go up to approximately 1 mm but there can be non-uniformities in the original substrate that can be accentuated with the etch. Particle straggling could also introduce random uncertainties into the final figure.

The second method is to deposit material though the precision aperture from an angular controlled vapor deposition source. This allows the original dielectric substrate to be made opaque to X-rays and make controlled adjustments to the figure and surface of the interior of the pinhole.

The immediate use of these etched particle tracks in surfaces will be to form precision optimized pinholes. Pinholes with diameters of 3.5 microns have been formed and demonstrated on the TRIDENT laser system.[1] The ideal form of a pinhole for NIF diagnostics will minimize the aspect ratio of the hole to give it the largest field of view. This leads to a conical desirable pinhole shape. For high resolution imaging with the pinhole close to the source, the pinhole is located behind a filter to absorb much of the thermal energy from the source and filled with a low Z element such as carbon to extend the hole open time. Figure 1. is an example of a close in pinhole design for NIF. The design includes protection and is discussed in Sec V.

The modeling of this type of pinhole has been done for the worst case scenario of a 2 MJ source output, and with a 300 eV source temperature. It was determined that the pinhole suffered a 55% area reduction after 1 ns. The X-ray throughput variation during this 1 ns ranges from 0.3 at 5 keV to 0.6 at 15 keV. For many of the experiments the absolute image intensity is not desired and the resolution variation, which scales with the square root of the throughput, may be negligible. The pinhole camera can satisfy such needs.

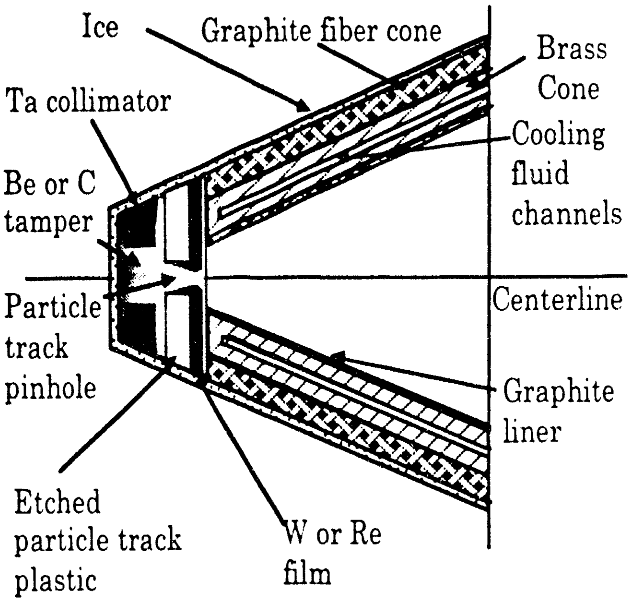

Fig. 1. Cross-sectional view of the pinhole nose cone.

B. Non-contact Construction Methods for Xray Optics

The next level of complexity in going from the figured pinhole optic is to use the figured surface to reflect and focus light. To compare pinhole optics to reflective optics it is instructive to compare their estimated source imaging resolution at an equal distance from the source. In this simple estimate only the diffraction of light and material strength properties were considered to be the factors on the obtainable resolution. At 10 cm from the source with 5 keV photons the maximum resolution for a pinhole camera was estimated to be 8 μm. For a Wolter optic with a 15 milliradian grazing angle of incidence (~50% theoretical reflectivity off Re) at the same distance from the source the resolution is .013 μm. In theory the resolution of the reflective optics far exceeds that of the pinhole. If the Wolter optics[2] are moved further back, to reduce the heat loading and survive from shot to shot, the resolution decreases due to the first order gravitational deformation of the mirror's figure. The resolution effect of figure error of the optical surface is proportional to the focal length of the optic. The effect of machined errors in the optical figure are also proportional to the focal length. Thus, the forming of the optics becomes increasingly difficult as the optics gets larger. To obtain high resolution, we propose that an intermediate scheme can be developed using small, low cost optics that one could afford to destroy on shots.

The proposed method of forming the optics is to use "naturally" cylindrically symmetric surfaces, such as glass capillary tubes, as starting substrates and build up the optical figure by geometrically controlled deposition of materials. Issues of importance are the symmetry of glass capillary tubes and the smoothness of the deposited surface. The symmetry of the capillary tubes needs to measured. To lend some credibility to this scheme investigators at Cornell University have successfully demonstrated the concentrating of 5-8 keV X-rays to a 95 nm point by using drawn leaded glass capillary tubes.[3] Initially it has been assumed that, by energy surface energy reduction, glass tubes will tend to form round tubes. If techniques from multilayer deposition are used, the tendency for films to crystallize could be suppressed. The effect may even be to smooth out any defects of the original substrate.

C. Intermediate Schemes Between Micro-mirrors and Large Mirrors

Two very simple imaging schemes that are an intermediate step between the pinholes and Wolter optics are the ring mirror and the focusing ring mirror. The ring mirror is the reflective analog to the ring aperture that has been used successfully by Lawrence Livermore National Laboratory (LLNL) on the NOVA laser facility. A further step is to give the mirror a parabolic shape or Wolter shape to focus. In both cases the mirror would be a very short to make the mirror act like a ring aperture and, in the focusing case, the aberrations of mirror focusing would be mitigated. The advantages of these schemes over the ring aperture are that high energy cutoff is eliminated, and there is a gain in intensity with the focusing. The gain due to focusing is the trading off with the reflection losses and the scattered background light . It is uncertain if a focusing ring mirror can have a resolution advantage over close in pinholes. It can, however, stand off further from the target and be reusable.

D. Micro-hole Collimators for X-ray Imaging

A significant improvement can be realized in the X-ray backlight imaging of targets if collimation were used when the object to be backlit is much larger than the backlighter and emits light that the recording media also records. To be successful the collimator should be able to "focus" on the backlighter and exclude light that is not in the direct line of sight. The simplest form of this scheme is to pinhole image or X-ray optically image both sources. There is however a tremendous loss of collection solid angle. A more elegant scheme is the use of an array of collimator tubes pointed at the backlighter. This scheme could be built using the charged particle track etching technology. It should be mentioned that "focused" collimators can also be used as a larger angular range pinhole camera. Three dimensional imaging can be obtained.

E. Gated X-ray Imaging System

Although this study is focused on the first phase of NIF operation, X-ray imaging will provide a central source of information in all phases of operation of the NIF. For example the images of the compressed cores of imploded targets will give crucial data on hohlraum symmetry, implosion stability, and general capsule performance. The designs and information presented here are adequate for the specification of imaging devices that will be used prior to ignition. The information provided can form the basis for specifying instruments that will be useful throughout most of the lifetime of the NIF. It is expected that X-ray imaging will be a pivotal diagnostic on the NIF and will provide much of the information necessary for the success of the facility. The best quality in X-ray imaging requires some special considerations with respect to the chamber environment.

The present experiments involve X-ray imaging in the moderate energy range 3-10 keV. Although moderate energy X-ray imaging will have many applications on the NIF, we believe that imaging of hohlraum driven implosions is representative and can be used to define the crucial specifications needed for the NIF. The imaging device described here will be time gated with a temporal resolution of about 50–100 ps. This is very similar to devices presently used on NOVA that are referred to as GXI for gated X-ray imager.

1. Measurement Specifications. We will first deal with the spatial and temporal requirements. For the "symmetry series" of experiments, target performance will differ somewhat from ignition designs. Convergence ratios can be modest -- probably in the range of 15-20 but still quite a bit higher than presently used at NOVA for symmetry work. There are several reasons for this. First, there is a need to measure symmetry somewhat more accurately than presently done on NOVA. The sensitivity of the implosion image to symmetry is proportional to the convergence ratio. In present NOVA work (using compression ratios of ~7) one can easily sense ~2% in the Legendre component P_2 (with 5 μm spatial resolution in the imaging systems). This would imply that a convergence ratio of 15 would be adequate on NIF for confirming $P_2 < 1\%$. A second

consideration is the sampling of the symmetry under implosion conditions reasonably close to those in ignition designs. This implies similar size targets and similar implosion velocities. NIF targets will be roughly 4 times the diameter of present targets (i.e., ~2 mm) and the compressed cores encountered in symmetry tuning would be similar to what is now encountered in NOVA work.

2. Instrument Design Specifications. In order to adequately measure the symmetry signature of imploded cores, it is mandatory to have two X-ray imaging views -- along and orthogonal to the hohlraum axis. Two positions are currently reserved on the NIF chamber; one in the equatorial plane and one in the polar. For many applications, (e.g., weapons physics) it would be desirable to have a third location. For symmetry tuning and related experiments, it is definitely mandatory to build 2 gated X-ray imaging instruments.

The gated Xray imagers are one of the few instruments that must have some parts fairly close to the target. This leads to the difficult problems of protecting the instrument and the laser system optics from the effects of debris and ablated material. From simple considerations, the energy on the NIF being 50 times that on NOVA would seem to legislate that the diagnostics similar to those in NOVA be placed about seven times further away. This, for example, would place a pinhole at about 20 cm from the target. This unfortunately is unacceptable for much of the work envisioned is the tentative NIF experimental plan.

Pinhole camera resolving power is constrained by several factors:

(a) diffraction—requiring the pinhole to be located at a certain minimum distance from the target.

(b) signal level—the available signal level will constrain the required collection efficiency and govern the signal-to-noise ratio.

(c) detector resolution—for the devices envisioned here this quantity is governed by the aperture spacing in the microchannel plate used to gate and amplify the X-ray signal.

(d) photon energy—this affects the diffraction limitation and the efficiency of the photo cathode on the MCP; there is strong impetus for going to as high an energy as possible in this application.

The diffraction constraint can be roughly expressed in terms of the distance from the pinhole to the target needed for a particular resolution at a particular wavelength. A rigorous derivation of resolving power in terms of the modulation transfer function usually results in values that differ by at most a factor of two from that obtained from the approximate formula

$$d=\frac{a^2}{4\lambda}\left[1+\frac{1}{m}\right],$$

where

d = pinhole diameter which in the present approximation is equivalent to the resolution
a = distance from the pinhole to target
m = system magnification.

In Fig. 2 are shown the diffraction constraints for a the case of 20X magnification that will be required in many NIF applications

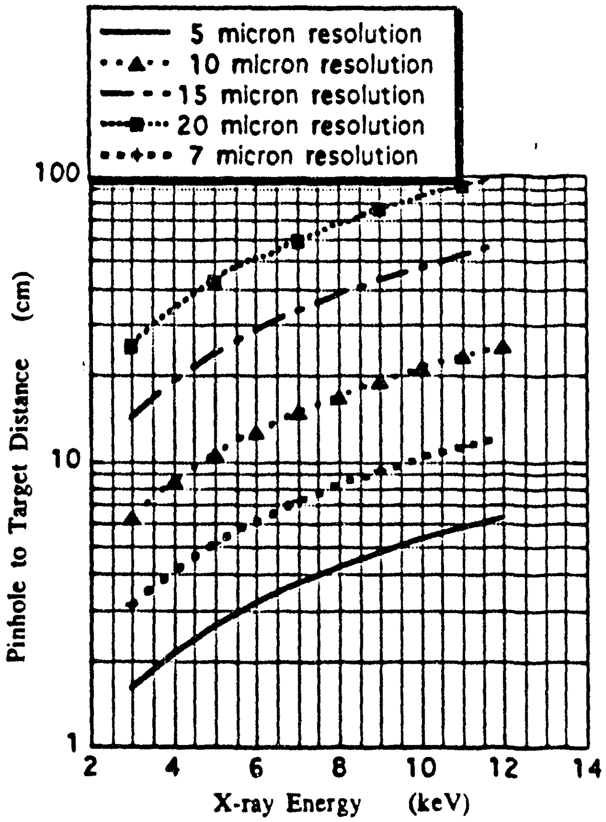

Fig. 2. Diffraction constraints on X-ray imaging.

For early operation of X-ray imaging on NIF, we propose and operating range of about 8-9 keV. This is to be compared with typical imaging work on NOVA that is usually in the 3-4 keV range. For the NIF expected temperature (7.3 keV) there should be strong line and continuum radiation in the region of 7-12 keV. As a design point we will assume 9 keV radiation. As seen from Fig. 2, at 9 keV we can operate at 10 cm and still achieve about 7 micron resolution. Given the other contributions to the total resolving power, this figure is barely adequate. On the other hand a 10 cm operating distance causes significant questions with respect to debris, ablation, etc. For this first estimate, will assume that 10 cm is the closest practical working distance.

The field of view (FOV) is also an important issue for the imaging of imploded cores. In this case the requirements on the FOV are quite modest of the order of 1 mm. For application beyond facility verification, a greater FOV would be desirable. With this in mind, we specify a detector using MCP larger (2"x4") than the standard now used in NOVA work. Some development work would be desirable insure the highest quality for this detector. Another important consideration is the imaging line of sight. The laser beam configuration is such that the hohlraum wall will be irradiated in the region where a diagnostic window would normally be placed.

III. NEUTRON TIME-OF-FLIGHT DETECTORS

The neutron time-of-flight (TOF) diagnostic for NIF Phase 1 is intended to measure the time history of either D-D or D-T neutrons over a yield range from 10^8 to 10^{15}. The diagnostic design proposed here is based on the NOVA Upgrade neutron TOF design. Two detectors are proposed, one located just outside the vacuum vessel wall ~5-m from target and the other located ~20-m along the generic neutron flight path on NIF. The detectors will provide a quick neutron yield measurement and also measure the reaction-weighted ion temperature of the fuel. The ion temperature is obtained from the TOF spread by the relation

$$T_i = (C_1 W/D)^2 ,$$

where T_i is the ion temperature in keV, W is the full width at half maximum of the neutron time distribution at the detector in ms, D is the neutron flight path in m, and C_1 is 1.3 for 2.45 me D-D neutrons and 8.2 for 14 MeV D-T neutrons. For a given temperature and distance, the D-D neutron time spread will be more than six times larger than the D-T neutron time spread. The yield will be around 100 times larger for the same type of target. As a result, the D-D neutrons will typically be measured using the 5-m detector while D-T neutrons will typically be measured using the 20-m detector. Fast recording will be used with each detector. For a 1 keV fuel temperature, the typical TOF spread will be 3.9 ns for D-D neutrons at the 5-m detector and 2.4 ns for D-T neutrons at the 20-m detector.

A. Detector Description

The detectors consist of fast plastic scintillators, such as quenched BC422, coupled to fast photodetectors. The signal durations are short, tens of ns at most, so a microchannel plate photomultiplier tube (MCP-PMT) is the best choice. Signal levels can be adjusted over a wide range by changing the high voltage applied to the detector. A detector housing similar to the EG&G PMD-42 detector is suitable. However the MCP-PMTs for which this housing was designed are no longer available, so the housing must be modified to accommodate MCP-PMTs on the market now.

B. Vacuum and Mechanical Requirements

Each detector should view the target through a thin metallic vacuum window. Materials near the lines-of-sight and around the detectors should be minimized. Solid angle for each detector is 0.01 steradians.

C. Instrumentation Requirements

High voltage up to -5 keV is supplied to each detector. High-bandwidth signal cables are required. GPIB data readout must be provided for the SCD5000 recorders. An optical fiducial with variable amplitude is introduced into each detector, similar to current NOVA practice.

IV. FUSION BURN HISTORY DIAGNOSTIC

We propose a high bandwidth gamma-ray diagnostic for D-D and D-T capsules in the NIF. The objective of the diagnostic is to determine the time evolution (bandwidth of 5-10 GHz) of the fusion burn in NIF experiments. The measured time evolution will be used to determine whether the burn begins in a hot spot and then propagates throughout the fuel, as predicted in NIF ignition calculations. In principle, both neutrons and gammas emitted directly from fusion reactions mirror the fusion burn history. However, at any practical detector distance in NIF, time-of-flight dispersion of the neutrons obscures the burn history. Fusion gammas, while non-dispersive, are produced with $\leq 10^{-4}$ branching ratio so their emission is useful only for very high burn rates. We propose instead to minimize the loss of bandwidth from neutron dispersion by observing gammas produced by inelastic neutron reactions in the compressed capsule, the hohlraum, or a nearby converter outside the hohlraum.

Most capsule pusher materials in NIF targets are (n,gamma) converters. (A notable exception is hydrogen.) Low-Z materials usually have moderate cross sections (0.1–0.5 barns) and produce high energy gamma-rays (2–5 MeV) while high-Z materials typically have several barn cross sections and ≤1 MeV gamma energies. Typical converters are carbon and mid-Z dopants in the pusher. The probability of inelastic neutron reactions in the capsule is enhanced by large pusher rho-R values. Neutron dispersion over the compressed capsule dimensions of 0.1 mm would be about 2 ps for 14.1 MeV D-T neutrons and about 5 ps for 2.45 MeV D-D neutrons. A second source of gammas is the high-Z hohlraum. For current NIF hohlraums, time-of-flight broadening from neutron interactions in different parts of the hohlraum is about 100 ps for D-T neutrons and 250 ps for D-D neutrons. Collimation to view only a part of the hohlraum can reduce this broadening. A third approach places a special converter just outside the hohlraum and uses collimation to avoid the other gamma sources. The converter would be shaped to minimize the effects of both neutron time-of-flight and finite gamma velocity.

The basic concept for this diagnostic is illustrated in Fig. 3.

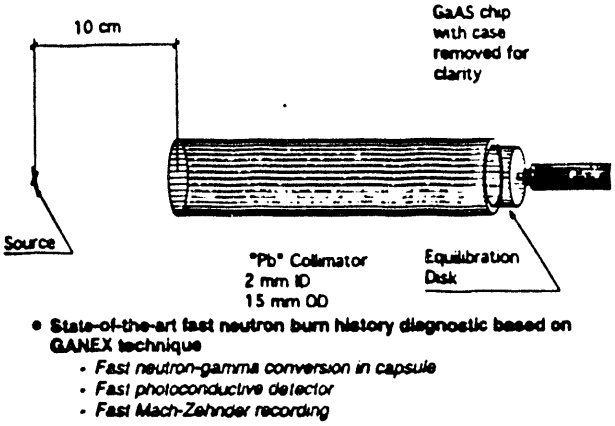

Fig. 3, Schematic of the fusion burn history diagnostic.

The snout of the collimator would be located at the minimum standoff distance from the target. Behind the collimator is located a detector package housing a 1-mm by 1-mm photoconductive detector (PCD). A few millimeters of filter material are needed to block low-energy X-rays and to maximize the gamma-ray sensitivity of the PCD which reacts primarily to electrons. The PCD occupies the end of a length of coaxial cable (about 30 cm) which carries the signal to a vacuum feedthrough and a re-entrant box containing a Mach-Zehnder (MZ) transducer. The cable also supplies bias to the detector, typically 500 V. The MZ housing must be shielded from electrical noise and, especially during phase II ignition experiments, from damaging radiation. The MZ converts the electrical PCD signal to an optical one. Signals from the MZ are transmitted an arbitrary distance via optical fibers to the recording oscilloscopes. For signals which are small compared to voltage needed to create a phase change of pi in the MZ, the MZ output is linear. For larger signals, the MZ encodes the PCD signal as a sinusoidal modulation. It is expected that this system can provide an overall raw bandwidth approaching the 5-GHz and 10-GHz bandwidth of the recording oscilloscope (SCD-5000 and KR-44, respectively) for neutron source rates of 10^{12} neutrons in 100 ps. For higher source rates -- i.e. those driving the MZ into modulation mode -- raw bandwidths of 7 or more GHz can be achieved. A system of similar design demonstrated a bandwidth of 3 GHz in a 1992 Nevada Test Site event. Current components have the bandwidths shown in Table I.

Table I

PCD detector	35 ps	10 GHz
Coax Cable	23	15
Mach-Zehnder	27	13
Receiver	23	15
Amplifier	23	15
KR-44 scope	35	10
Total (gaussian)	**69 ps**	**5 GHz**

Good quality system response measurements are available using the EG&G/SBO electron linac at Santa Barbara, which can produce electron pulses of less than 13-ps FWHM. With these measurements, we estimate predictable unfolds would provide 50 to 100% more bandwidth. We expect all of the above component bandwidths to improve with time and therefore these are minimal values on the NIF time scale.

The proposed diagnostic appears to be sensitive enough so that it can be tested on NOVA. Directly driven glass microballoons filled with D-T gas produce more than 10^{13} neutrons in NOVA experiments and are relatively free from hard X-ray background. The initial setup would consist of a collimated PCD driving high-bandwidth coax cable connected to a fast oscilloscope located just outside the vacuum chamber. A check of the signal level and a measurement of the fusion burn duration would be made. The result would be compared with data from the Neutron Temporal Diagnostic. One would also measure the background in identical targets filled with hydrogen. In a second experiment, the setup would be fielded on indirectly-driven targets (preferably filled with D-T gas) to check the background from a more realistic hohlraum environment. If D-T gas is used, a fusion burn signal might also be detected from these targets. These results would be compared with target calculations to validate the diagnostic design for the NIF.

V. DIAGNOSTICS PROTECTION

For neutron pinhole imaging, X-ray pinhole imaging, aperture collimated spectroscopy, and imaging spectroscopy, the resolution typically depends on the inverse square root of their distance from the source. This scaling implies the desirability of placing the apertures as close to the source as possible. The optimum position for these apertures will be where they just survive long enough in the X-ray blast to do their job. This leads to questions about how much debris will these invasive diagnostics introduce onto the NIF laser optics. A possible solution may be to cover the invasive diagnostics and other objects in the target chamber with a coating of material whose irradiated products are benign to the laser's optics, and which protect the apertures sufficiently to obtain useful data.

A. Ablator Covered Nose Cones

Much of the approach to designing the invasive diagnostics protection is similar to designing orbital atmospheric reentry vehicles. The outer surface will be hit with a short time duration, intense, high temperature radiation blast. The purpose of the nose cone in NIF will be to ablate minimal material with benign by products while protecting the interior instruments from shock and heat damage. The cone material must have the ability to withstand the ablation shocks, and temperature changes, and not spall. Our first design for the tip of the pinhole camera nose cone is shown in Figure 1. The purpose of the first layer of material is to absorb the energy of the bulk of the thermal spectrum from the source and vaporize as a benign material. Ice was chosen as a first choice because it appears to be a benign material for the laser optics when it is at low pressures and is relatively ubiquitous. If the nose cone is cooled down to liquid nitrogen temperatures in situ, it would be expected to draw out the residual water vapor left in the NIF chamber. An estimate of the ice layer is of order 5 μm thick on the 3 degree surface to prevent the next graphite surface from evaporating. There are other possible candidate materials for the surface ablator. For example, cellulose nitrate would thermally decompose into carbon dioxide and nitrogen gas.

The second layer is graphite a low Z material with a high heat capacity. This gives it a high figure of merit for limiting the temperature rise. It also produces non-poisonous ablation products. The thermal-mechanical properties of graphite allow it to withstand very large temperature shocks. The other candidate materials are ceramics such as aluminum oxide.

The third layer is a metal surface whose function is to be the hard X-ray shielding and the general mechanical structure. Candidate materials are aluminum, brass and tantalum. There could be a trade-off here between the shielding needed and radioactive activation half lives of the materials.

The fourth layer is the interior low fluorescence collimator layer. Its purpose is to kill any interior fluorescence and wall scattered light. This layer ideally would be a low Z element such as beryllium or carbon.

The pinhole, slit, diffraction element or X-ray optic at the tip of the nose cone would be protected behind the same type of shielding scheme taking into account that the desirable photon energies should be let through. Computer modeling has been done on the hydrodynamic behavior of close in pinholes.

B. Critical Tests

To test these concepts we propose to build close in X-ray and neutron elements and observe the dynamic failure of the components and the resulting X-ray ablation products at TRIDENT facility discussed in Sec. VI. To simulate the conditions at NIF similar X-ray spectra, surface doses and pulse time durations should be used. To maintain an equivalent surface dose we can match the pulse duration and then scale down the spot focus and radius from the target by the square root ratio of the delivered laser energy. The scaling is summarized in the following table. TRIDENT's typical delivered output is 130 J. Since this could be increased to 500 J in the future, a range of simulation dimensions is presented.

Table II. NIF-TO-TRIDENT SIMULATION SCALING

Quantity	NIF Conditions	TRIDENT Simulation
Pulse Duration	1 ns	1 ns
Total Energy	2 MJ	130-500 J
Target dimensions	1 cm diameter	86-160 μm diameter spot focus
Pinhole radius from source	10 cm	0.8-1.6 mm
Laser debris shields	8.5 meters	6.8 cm-13.4 cm

The laser optics debris shields can be simulated with glass or coated glass witness plates at the scaled distance. Deposited or ablated material thicknesses can be measured from these simulated debris shields. To carry out these experiments the most convenient method of mounting the pinhole and nose cones is as an integral part of the target stalk. This simulator with photographic film would form a miniature high resolution pinhole camera and could be quite useful for other experiments besides the simulator function.

VI. USES OF THE TRIDENT LASER FACILITY IN SUPPORT OF NIF CORE SCIENCE AND TECHNOLOGY

During the construction period of the National Ignition Facility a number of developmental issues can be expected to arise related to a wide variety of topics. The range of issues will, at minimum, cover detailed target physics issues, laser and optical evaluation issues, survivability of materials, coatings, and instruments in the harsh target chamber environment, and developmental issues concerning engineering checkout of items such as the twelve inch manipulator. The TRIDENT laser system[1] can provide a useful, scalable, tool for investigating a number of these issues. A discussion of the immediately apparent uses of TRIDENT in this context is given below. Other applications are certain to arise as the NIF project matures.

A. New Target Physics Experiments

Many new experiments are driven by questions about the physics details uncovered on target shots or during simulations. Although some details must be studied on the large facility in order to access the correct size scale for a given temperature and density, there are many experiments that can be performed on a smaller facility. The flexibility of a small facility, like TRIDENT, can aid in rapid examination of physics processes that impact on the experiments on the large facility, at a cost, and with a rapid availability not possible on the big machine. A good example of this type of small facility applicability is the experimental series done on TRIDENT that examined the effect of the F number on the degree of stimulated backscatter. As NIF progresses and during operations on NOVA, issues will continue to arise that require extensive physics examination. As in the case discussed above, the small facility can produce copious data to aid the theoretical understanding of physics issues, at low cost. TRIDENT has and will continue to play a major role in this arena.

Conditions in the NIF target chamber are very severe during high yield shots. Even during low or no yield shots, the surfaces of close in diagnostics and of optical components in the focus system can be expected to suffer damage. Evaluating materials for use in mitigating the environment in the chamber (2 MJ of X-rays in the few 100 eV range, with X-ray power of order 200 TW assuming a 10 ns X-ray burst, and fluxes resulting from this of order 10^{12} W/cm^2 at 10 cm radius and 10^8-10^9 W/cm^2 at the 5 m wall) will be an ongoing requirement during NIF design and construction. Doing scaled damage tests at TRIDENT could help define the required mitigation for use on optical and instrument surfaces. To produce scaled, NIF relevant conditions in the TRIDENT target chamber, would require moving test materials into close proximity to a target. If the full energy available at TRIDENT (500 J in 1 ns) were put on an open geometry target, the X-ray power produced, assuming perhaps 50% conversion efficiency to X-rays, would be of order 0.25 TW. To reproduce the flux level at 10 cm in NIF, for a no yield shot, would require the surface to be placed within 0.5 cm of the target. This would result in a surface test with variable conditions on a flat plate, due to the varying effective radii of different locations on the surface. This geometry would allow a range of fluxes to be tested on a given surface for each shot. If the inside surface of a sphere with entrance holes for the two drive beams were used as the test surface, the testing could be done in a spatially uniform flux radiation environment. The pulse shape and duration of such tests would not accurately reproduce NIF conditions without some modifications to the TRIDENT driveline, but such pulse shape modification is possible with modest effort. If testing requiring NIF relevant fluences on the test piece were required, multiple shots with the same surface exposed each time could be used to access a regime of damage testing significantly higher than that available single shot on TRIDENT.

B. Engineering Simulation And Testing Of NIF Target Chamber Components

1. Development and Testing of the Twelve Inch Manipulator (TIM). The instrument packages that will be dominant on NIF for all except the neutron diagnostics will center around the TIM currently under design by a LANL/LLNL team. An engineering prototype of the manipulator will need to be made before the final design. Such a prototype will need extensive testing in a real life experimental environment to determine and cure the design flaws inherent in any new electromechanical device. Such testing will involve not only TIM-based instruments, but also the retrofit boats required to field the NOVA six-inch-manipulator and the Omega-U ten-inch-manipulator based instruments. The ability to serve all three instrument classes allows the entire national program to perform instrument development and testing at TRIDENT with rapid turnaround at low cost, compared to the same testing done at LLNL or the Laboratory for Laser Energetics.

2. Testing of TIM-based Diagnostics. As mentioned above, all TIM-based diagnostics will need to be tested and used to acquire actual data prior to fielding on a NIF experiment. The high cost and low availability of NIF shots will preclude on-line development of diagnostics to a large extent. A TIM-equipped facility like TRIDENT, with a large number of available, low-cost experimental shots will allow a development cycle for diagnostics paced by the

diagnostics themselves. The facility of such realistic, off-line testing has been shown repeatedly at TRIDENT during development and verification activities for NOVA diagnostics. The case will only get stronger as the big laser becomes more expensive per shot, with fewer shots available.

3. Trigger System And Diagnostic Synchronization Testing. A problem that plagues all large systems is the need to synchronize the triggering of a diagnostic to the laser pulse with low jitter and high precision. The current generation of lasers typically is able to synchronize diagnostic triggering in the 100-200 ps range. On the NIF, if a requirement exists for higher precision, techniques must be developed to improve this. A technique developed at the University of Michigan Ultra-Fast Laser Lab using a ps laser to optically trigger diagnostics that are diagnosing plasmas created by that laser would be useful at TRIDENT and on NIF. The optical triggering used requires a short pulse laser generated in sync with the main laser chain. At TRIDENT this can be done using the chirped-pulsed amplication picosecond capability, followed by a dedicated regenerative amplifier for the trigger system, a few optical elements, and a recompression grating pair in the target area to recompress a few mJ of laser radiation to a picosecond time scale. That light is available to trigger devices in the target area with very high precision and sync. Using this technique, coupled with ever higher voltage on the deflection plates of a streak camera, the details of the X-ray emission from a plasma can be studied at improved temporal resolution with respect to present capabilities. Development of a high-speed, low jitter technique at TRIDENT, and the transfer to NIF when needed, will significantly aid the national program.

C. Advanced Diagnostic Development And Testing

The diagnostic needs of the national ICF program and the National Ignition Facility, require an ongoing development program. The role played by LANL in the program will depend critically on the ability to development new ideas and refine present tools for use in ever more hostile environments. Possible areas of testing these newly developed diagnostics on TRIDENT include (1) improved temporal and spatial resolution X-ray imaging instruments, (2) monochromatic gated imaging instruments, and high-speed streak cameras.

VII. CONCLUSION

Los Alamos scientists and technicians will continue our robust program to develop and test NIF diagnostic ideas. These efforts, in collaboration and coordination with personnel from other institutions, will prepare and solidify our joint task of readiness for initial NIF experimental programs.

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VIII. REFERENCES

1. R.G. Watt, R.B. Gibson, R.P. Johnson, J.M. Mack, and N.K. Moncur, "Trident: A New 1 TW Laser Facility," Bull. Am. Phys. Soc., **37**, 1458 (1992).

2 H. Wolter, "Verallgemeinerte Schartzchildsche Spiegelsysteme streifender Reflexion als Optiken Für Röntgenstrahlen," Annalen der Physik, Series 6, 10 (1952)

3. D.H. Builderback, S.A. Hofmann, and D.J. Thiel, "Nanometer Spatial Resolution Achived in Hard X-ray Imaging and Laue Diffraction Experiments." Science, **263**, 201 (1994).

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