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Generation of debris from targets and by x-ray ablation of surrounding materials will be a matter of concern for experimenters and the operations staff at the National Ignition Facility (NIF). Target chamber and final optics protection, for example debris shield damage, and efficient facility operation drive the interest for the NIF staff. Experimenters are primarily concerned with diagnostic survivability, separation of mechanical versus radiation induced test object response in the case of effects tests, and radiation transport through the debris field when the net radiation output is used to

benchmark computer codes. In addition, radiochemical analysis of activated capsule debris during ignition shots can provide a measure of the ablator $<\rho r>$. Conceptual design of the Debris Monitor and Rad-Chem Station, one of the NIF core diagnostics, is presented. Methods of debris collection, particle size and mass analysis, impulse measurement, and radiochemical analysis are given. A description of recent experiments involving debris collection and impulse measurement on the OMEGA and Pharos lasers is also provided.

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INTRODUCTION

Debris generation from NIF experiments is important for a variety of reasons: target chamber and final optics protection,[1] interpretation of radiation effects test results,[2,3] diagnostic survivability , and computer simulations of net radiation output. In addition, radiochemical analysis of debris collected from ignition shots is diagnostic of capsule performance. The Debris Monitor and Rad-Chem Station addresses these interests by collecting debris for characterization of mass and particle size distribution, measurement of debris impulse, and radiochemical analysis of activated debris. The diagnostic is composed of a suite of collectors and sensors that may be placed at various locations on the target chamber to cover multiple lines of sight. Capabilities of the diagnostic will be fielded in stages, the first being mass, particle size distribution, and impulse measurement. Detailed techniques for performing radiochemical analysis of collected samples remain to be developed as specific experiments are defined. As a result the capability is being protected as "not to preclude", meaning that implementation of debris collection will not unreasonably constrain the ability to perform radiochemical analysis on collected samples. This paper describes the conceptual design of the Debris Monitor and Rad-Chem Station and recent experimental experience at the University of Rochester OMEGA and the Naval Research Laboratory Pharos laser facilities with debris collection and impulse sensors.

DEBRIS MASS AND PARTICLE SIZE

Debris mass and particle size distribution analysis will be accomplished by collection of debris onto a glass slide or silicon wafer housed in a clean box, followed by optical inspection. The clean box is loaded in a class 100 clean room, then placed on a diagnostic instrument manipulator (DIM) [4] cart. The DIM allows insertion of diagnostics into the NIF target chamber and the cart is a removable portion for offline diagnostic loading, alignment, etc. Figure 1 shows a schematic of the clean box with two collectors. Once the chamber/DIM is under vacuum the clean box is opened remotely. It is kept open for one or more shots, then remotely closed and removed from the DIM cart. The box is then transported to the clean room, placed on a microscope, and automated counting of sizes and shapes is performed. The slide is returned for further analysis as needed. Specifications for the debris mass and particle size analysis are presented in Table I.

Another collection mechanism that has been recently investigated is medium- and high-density silicon aerogel obtained from NASA.[5] This approach has the advantage of preserving the particle track so that an analysis of its velocity can be performed in addition to mass and size. We have fielded a pair of these collectors on OMEGA shots. Figure 2 is a schematic of the experimental set up and Fig. 3 shows particulate that was collected during these shots. The exposure area of each aerogel was 5 cm^2, with nominal thickness of 3 cm. Post-shot inspection of the surfaces of the aerogels indicate the importance of maintaining clean conditions for quantitative measurements. Analysis of the particulate tracks and composition is currently being performed by NASA.

DEBRIS IMPULSE

Passive impulse gauges fielded on the Nova laser demonstrated the capability to make this type of measurement using a simple technique, free from electrical noise issues often associated with a high-power laser environment.[6] On NIF however, automation of diagnostics is highly desirable and we are focusing our efforts on active methods using a variety of sensors, allowing a large dynamic range to be covered. In general, the sensor is imbedded into a puck whose equation of state is well known. The puck is placed into NIF via a DIM cart. Pressure waves in the puck generated by impacting debris are measured by the sensor and the impulse of the debris is backed out from the data utilizing the equation of state of the puck. The diagnostic is remotely controlled by computer and the pressure signal is recorded on a scope.

Three types of sensors are currently under evaluation, etalon probes[7], ruby sensors, and polyvinylidene fluoride (PVDF) gauges.[8] The etalon probes consist of microchip interferometers attached to 50 μm core optical fibers and have a sensitivity range of ~1 – 1000 bar. Ruby sensors (custom mated to fiber optics by NRL) are sensitive to higher pressures, covering ~2 – 100 kbar. The piezoelectric PVDF gauges compliment the etalon probes and ruby sensors, with operational pressure range of ~0.5 –500 bar. Table II contains the specifications for the debris impulse measurement.

Impulse measurement experiments have recently been carried out on the OMEGA and Pharos lasers. On OMEGA, a PVDF sensor was fielded on Au hohlraum shots and demonstrated operation in a laser environment with very low noise (<1 mV). A schematic of the PVDF sensor is shown in Fig. 4. On the Pharos laser, an experiment was performed that compared an etalon gauge with an electrical carbon gauge on the same shot. The shock was generated by focusing a laser beam into water, so that the electrical environment was that of a laser. Figure 5 shows the results. The first pulse on the etalon trace is laser light at t=0, the second pulse is the pressure response, and the third pulse is a reflection from nearby material. The carbon trace shows a small pressure pulse and a much larger set of signals arising from electrical noise.

RADIOCHEMISTRY

The (n,2n) production of ^{62}Cu and ^{64}Cu from naturally occurring ^{63}Cu and ^{65}Cu in the Cu-doped Be ablator is proportional to the ablator <ρr> and neutron yield.[9] The measurement would be performed by capturing a fraction of the capsule explosion debris and counting the decay of activated copper, then using a chemical analysis of Cu or Be in the sample to determine the capsule fraction obtained. The collected sample would be counted quickly because of the relatively short half-lives of ^{62}Cu and ^{64}Cu (9.7 min and 12.9 hr respectively).

Both ^{62}Cu and ^{64}Cu decay by positron emission, accompanied by annihilation radiation (511 keV), and each emits discrete gamma rays that may be used for identification and quantification. Coincidence counting of the annihilation radiation covering a period of a few half-lives is an established method for measuring ^{62}Cu and ^{64}Cu activation.[10] This method has the advantage of being most sensitive to lower yields, but lacks the unambiguous isotope identification that comes from measuring discrete gamma rays, which may be performed with a high-purity intrinsic Ge detector. Recent experiments on the Petawatt laser at Livermore have demonstrated the feasibility of measuring ^{62}Cu and ^{64}Cu directly via the 1173-keV and 1345-keV gamma rays respectively, at levels well below those of nominal full yield on NIF.[11] Yields as low as 1E-6 of nominal full yield will produce enough activity for ablator <ρr> determination using the coincidence counting technique. We also anticipate that radiochemical analysis of a variety of activation products will be useful in diagnosing experiments well before ignition is achieved on NIF. Table III presents specifications for the Rad-Chem Station.

SUMMARY

The Debris Monitor and Rad-Chem Station is being developed for the National Ignition Facility as one of the core diagnostics. Methods of debris collection proposed and under current investigation include glass slides, silicon wafers, and silicon aerogels. Impulse sensors to cover a wide dynamic range are being evaluated and include etalon probes, ruby sensors, and PVDF gauges. Radiochemical analysis of activated debris will enable a measurement of the ablator <ρr> for ignition shots as well as providing a general capability to diagnose experiments that produce activation products. Offline development and testing on the OMEGA and Pharos lasers will continue so that the diagnostic may be completed and operational for first use on NIF in 2004. Table IV shows the current schedule of milestones based on the recently announced NIF startup schedule.

ACKNOWLEDGEMENTS

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TABLE I. Specifications for debris mass and particle size analysis

Debris size distribution	1 – 500 μm
Mass limit	1 μg
Temporal response	None
Collector area	>1 cm^2

TABLE II. Specifications for debris impulse measurement

Pressure range	1 bar – 100 kbar
Gauge diameter	< 500 μm – 2 cm
Temporal response	<15 ns

TABLE III. Specifications for radiochemical analysis

Geometric collection efficiency	>1E-6
Maximum removal time	2 – 20 min.
Detector resolution	<2.5 keV @ 1173 keV
MDL (atoms)	
^{62}Cu	1E4
^{63}Cu	1.3E11
^{64}Cu	1E5
^{65}Cu	6E10
^{9}Be	~1E11
^{10}Be	~1E11
Temporal response	None

TABLE IV. Milestones for the Debris Monitor and Rad-Chem Station

Milestone	Description	Date
M1	Conceptual design review	1/101
M2	65% design review	6/1/01
M3	100% design review	10/1/01
M4a	Fabrication complete, begin offline testing	9/1/02
M4b	Offline testing complete, ship to NIF	4/1/04
M5	Dry run review	9/1/04
M6	First use on NIF	12/1/04
M7	Functional operation	1/1/06
M8	Facility acceptance	7/1/06

FIG. 1. Schematic of clean box and debris collection surfaces. Box is housed in a DIM and opened remotely before shot.

FIG. 2. Experimental set up for the aerogel collectors at the OMEGA laser facility.

FIG. 3. Aerogel debris collector showing particle and associated track. This sample was recently collected from a Au hohlraum target shot on the OEMGA laser.

FIG. 4. Schematic of the PVDF impulse gauge recently fielded on OEMGA.

FIG. 5. Etalon probe results versus carbon gauge for a laser-induced shock in water at the Pharos laser facility at the Naval Research Laboratory.

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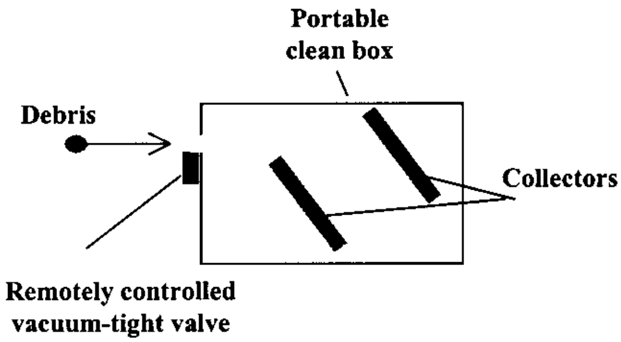

Fig 1 M.C. Miller et al., Rev. Sci. Instrum.

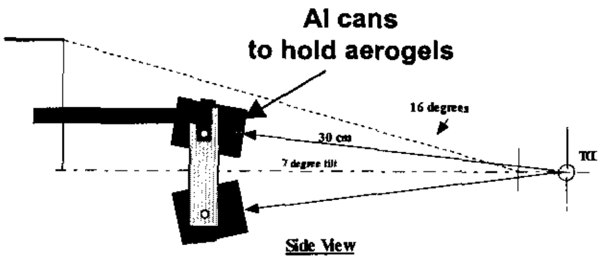

Fig 2 M.C. Miller et al., Rev. Sci. Instrum.

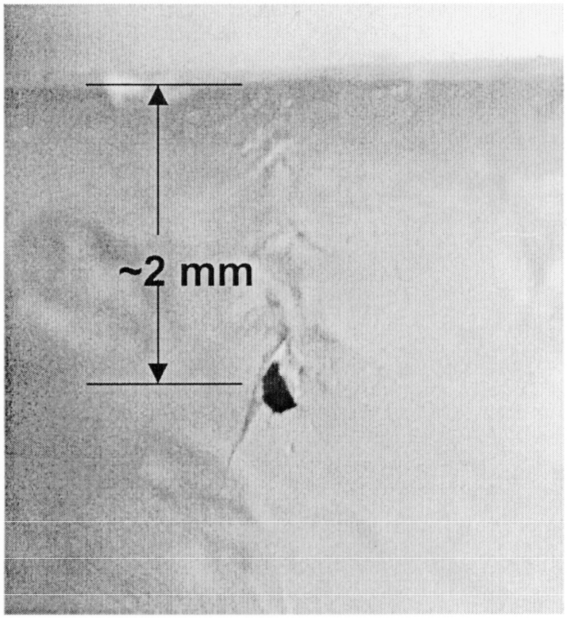

Fig 3 M.C. Miller et al., Rev. Sci. Instrum.

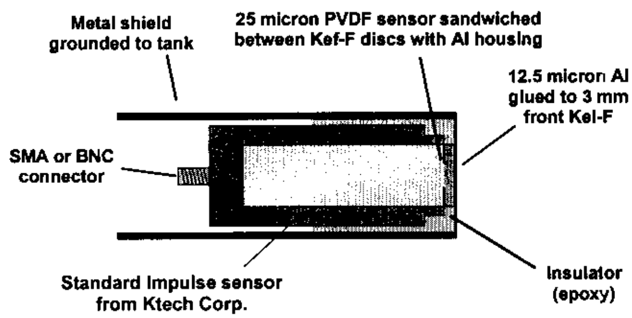

Fig 4 M.C. Miller et al., Rev. Sci. Instrum.

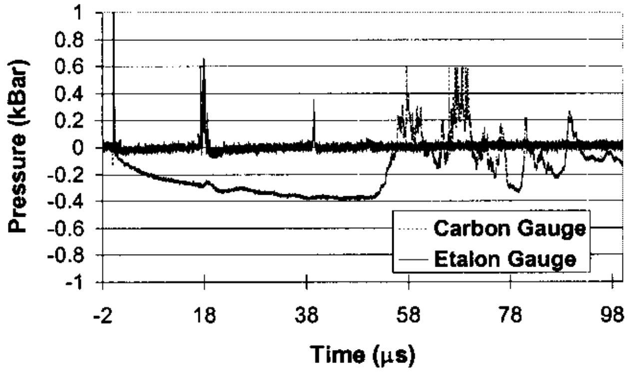

Fig 5 M.C. Miller et al., Rev. Sci. Instrum.