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Karla Hagans
Pete Stathis
Jay Wiedwald
Don Campbell

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TARGET AREA ACQUISITION AND CONTROL SYSTEM SURVIVABILITY FOR THE NATIONAL IGNITION FACILITY

Karla Hagans, Pete Stathis, Jay Wiedwald, Don Campbell
Lawrence Livermore National Laboratory
P.O. Box 808, L-479
Livermore, CA 94551
510-423-9294

ABSTRACT

The hardening of instruments to survive NIF target emission environments presents a significant challenge. Neutron flux is predicted to be as much as six orders of magnitude greater than the highest achieved neutron flux on NOVA. Notwithstanding the high prompt radiation fields, the specifications for the instruments are demanding requiring high resolution imaging and sub nanosecond transient measurements. We present an analysis of the sensitivity of the proposed NIF instrumentation design to EMP, X-rays, gamma rays, and neutrons. Major components assessed include fiber optic cable transport, high bandwidth cable and charge coupled detector (CCD) imaging systems.

INTRODUCTION

The conceptual design of the NIF target area instrumentation system demands that the instruments must survive in a hostile X-ray, neutron, gamma ray, EMI and debris environment. In addition, data integrity must be maintained for high resolution images and sub-nanosecond transient signals while maintaining a demanding operational shot schedule. We must develop hardening techniques to allow the required diagnostics instrumentation to survive target area emission and record data from the required diagnostics in each phase of the NIF experimental plan. The NIF experimental plan has four major phases which are: (1) start up activities, (2) hohlraum tuning experiments, (3) cryogenic and pre-ignition experiments, and (4) ignition shots. Each of these phases requires different diagnostics and generates different emission source terms.

NIF ENVIRONMENTS

Table 1 shows present predictions of prompt radiation fluxes for several areas of the target area for a 21.8 megajoule NIF shot. In some cases these flux levels are as much as six orders of magnitude higher than the prompt radiation levels presented by the Nova system. Prompt radiation generates photocurrents in cables and semiconductor devices, electric fields in oxides, and can cause permanent degradation of device characteristics by neutron or other displacement producing radiation. The two most prominent effects of ionizing radiation on semiconductors and dielectrics are:

- Ionizing radiation creates charge carriers in insulators and reversed biased junctions where there were previously almost no carriers.
- Radiation, particularly neutron radiation, produces defects in the lattice structure. These defects act as traps and recombination centers to reduce the free carrier life time and carrier density.¹

In addition to the transient radiation environment there will be at least three sources of EMP in the NIF facility. First is the prompt gamma dose that ionizes air both inside and outside the chamber. Second are the electrons driven off of hohlraum and shielding material near the target supporting chamber diagnostics. Last are the charge separations that will be generated when two materials with different electron yields to gamma radiation are adjacent and are exposed to roughly the same gamma ray dose rate.

Table 1 - Predicted Flux Levels for a 21.8 Megajoule NIF shot at various locations in the target room

Radiation	Source	Inside Target Chamber 5.0 Meters	Outside Target Chamber 5.5 Meters	Inside Target Room 13 Meters
	0 Meters			
Neutrons (N/cm ²)	1.00E+19	3.18E+12	1.00E+11 attn: 26.5:1	2.00E+10
fus. gamma (MEV/cm ² sec)		1.75E+22	7.70E+20 attn: 13:1	1.54E+20
X-Ray (MEV/CM ² sec)	350 eV BB	1.50E+22	0.00E+00 attn: ∞	0.00E+00

INSTRUMENTATION

The heart of the NIF instrumentation and control system is the diagnostics instrumentation system. This system supports a diverse set of plasma and fusion burn diagnostics such as the measurement of X-ray drive and conversion efficiency as a function of X-ray spectral energy, time resolved X-Ray spectroscopy, and the number and energy distribution of fast electrons in the hohlraum. In total, a suite of eleven diagnostics based on streak cameras, gated micro-channel-plate CCD imaging systems and high-bandwidth detectors paired with transient recorders are planned for Phase I.

Electronically, these instrument systems can be divided in two generics subsets; data acquisition of current vs. time from a detector system and imaging diagnostics based on CCD cameras. For the first type of instruments, analog currents from the detector are transported via high bandwidth electrical cable to the digitizing recorder.

Depending on the bandwidth requirements of the diagnostics, the digitizer is either in a protected area in the target area room or in a diagnostic instrument alcove located in the instrumentation rooms in the switch yard.

Figure one shows the instrumentation areas in the switchyard. Since each area services one quarter of the target bay, cable lengths can be far less than fifty feet enabling a 3 GHz bandwidth requirement to be maintained in most cases even with the digitizer outside the target bay. Diagnostics that require greater than 3 Hz bandwidth will be located inside the target bay.

Improvements in high speed digitization could eliminate the need for cable transport, simplifying the instrument

design and allowing the digitizer to be integrated with the detector package. The imaging diagnostics are to be recorded by CCD cameras. The imaging diagnostic concept is that the camera control and digitization electronics are packaged in the CCD camera system. A digital fiber optic communications link sends the digital data from the local instrument memory to a computer system for analysis and display.

INSTRUMENT SUSCEPTIBILITIES

Much of the data required to assess the instrument susceptibilities is available from testing in the weapons effects and nuclear test communities, but because the instrumentation systems that we plan on NIF are not widely used, much of this data does not exist. Table 2 shows the sensitivity data available to date.

Table 2 - Radiation sensitivities of instrumentation components

Component	X-Ray	γ -Ray	Neutron	Cerenkov
Cable, 7/8" foam	10^{-19} A/m γ -MeV/cm ² sec	10^{-20} A/m γ -MeV/cm ² sec	10^{-19} A/n cm ² sec m	NA
Fiber	NA	NA	NA	10^{-26} watts/cm γ -MeV/cm ² sec
CCD cameras	NA	NA	10^{-4} stars neutron	NA

Numerous factors can effect the cable direct drive transient radiation response reported in Table 2. Several sources² indicate that a cable with 5 Kilovolts bias on it will be between one and two orders of magnitude more sensitive to gamma and neutron radiation than an unbiased cable. This is independent of high voltage polarity. Also, the cable response can vary by as much as a factor of ten for different pieces of nominally identical cables. Cable response may also depend on previous cable history and handling. We will analyze all available data and perform additional tests to establish a basis for the NIF cable designs.

Susceptibility data is sparse for the rest of the NIF instrumentation. In some cases, only one measurement has been taken and the sensitivity quoted cannot be corroborated by any other sources. In particular, the quoted CCD neutron sensitivity is based on only one data point and the projected instrument vulnerability based on this sensitivity is very high.

INSTRUMENT VULNERABILITY

Based on our initial assessment, we anticipate that hardening technology development will be required. For example, if the CCD neutron sensitivity in Table 2 (10^{-4} stars/neutron) is accurate, then the sensitivity of CCD cameras is an issue for NIF. A star in this context is one neutron-silicon interaction. This interaction can cover anywhere from one to 10 pixels. Table 3 shows the predicted neutron vulnerability for a 512 x 512 (2.6×10^5 pixels) CCD camera at locations inside the target chamber wall, just outside the target chamber and target chamber shielding and at a location of 13 meters from the target chamber center in the target bay. These vulnerabilities are calculated without additional shielding and will provide the basis of the diagnostics shielding design. In most cases, there are more stars than pixels indicating loss of all data pixels for the camera in that location without additional shielding. As expected, the camera fares the best at the target bay location 13 meters from target chamber center for a 1.9 megajoule yield shot. At this location, the camera loses up to one third of the data pixels indicating that significant additional shielding even under these favorable conditions is required for high resolution images.

Table 3 - Predicted neutron vulnerability for a 512x512 (2.6×10^5 pixels) CCD camera at various locations in the NIF target room for a 1.9 and 21.8 Megajoule shot.

1.9 Megajoule shot

	Source	Inside Target Chamber	Outside Target Chamber	Inside Target Bay
Location	0 Meters	5.0 Meters	5.5 Meters	13 Meters
Neutrons (N/cm ²)	3.50E+16	1.12E+10	4.20E+08	8.40E+07
Neutron upsets (stars/cm ²)	3.50E+12	1.12E+06	4.20E+04	8.40E+03

21.8 Megajoule shot

	Source	Inside Target Chamber	Outside Target Chamber	Inside Target Bay
Location	0 Meters	5.0 Meters	5.5 Meters	13 Meters
Neutrons (N/cm ²)	1.00E+19	3.18E+12	1.00E+11	2.00E+10
Neutrons upsets (stars/cm ²)	1.00E+15	3.18E+08	1.00E+07	2.00E+06

A second potential problem area based on our initial cursory assessment is Cerenkov fiber sensitivity. The Cerenkov sensitivity of fibers is 1×10^{-26} watts/(γ -MeV/cm²) per cm. of fiber. With an X-ray flux of 2.4×10^{22} γ -MeV/cm² sec., this would lead to 24 milliwatts of optical power for each centimeter of fiber in the target chamber. Since projected signal levels are less than 1 milliwatt, this calculation allows us to begin to bound the instrument vulnerability.

This prediction assumes no additional shielding and the instrument location is at the chamber wall. In the NIF, additional shielding will be required for most diagnostics in many different geometries. Future work will enable us to account for the wide variety of conditions to make confident recommendations regarding the type and amount of shielding that will be required in each phase of the experimental plan.

While it is not possible to predict the outcome of the assessment of diagnostic vulnerability, it is likely that hardening will be required. Imaging cameras and diagnostics entrant to the chamber are likely candidates. The major risk in our assessment is primarily in the uncertainties of the source term predictions. Another issue is that some diagnostics components are difficult to harden, and as a result, alternative diagnostic designs using scattered signals or off axis imaging might be required.

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2. Ibid, p. 64.

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