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Radiation and EMI Effects in the NIF Environment

by Pete Stathis

ABSTRACT

In order to determine the magnitude of the noise problem in the target chamber area of the National Ignition Facility, a literature search was conducted to determine the sensitivities of various components that would be exposed to the radiation and electro magnetic interference fields in the target chamber area. Additionally, Test Program experience and data were also used in determining some of these sensitivities. Using the predicted fluences, it was found that there will be significant effects on fibers, cables, and electronic components inside the target chamber; radiation hardening will be required. In the area between the target chamber walls and the target room walls, there will also be some hardening required. Some estimates of electro magnetic interference were made that indicate shielding will need to be incorporated in the design.

INTRODUCTION

The radiation and Electro Magnetic Interference (EMI) levels that will be encountered in the area of the target chamber of the National Ignition Facility (NIF) could be much higher than the levels that were experience on the NOVA Facility. This report summarizes the results of literature searches, discussions with L-Division physicists, and measurements made for the Nuclear Test Program and on NOVA. The data in this report will be organized in radiation and EMI sections and then by components reviewed.

RADIATION EFFECTS

ASSUMPTIONS

The flux levels expected to be encountered at various locations in the NIF target chamber area are summarized in Appendix A.^{1,2} As can be seen from this data, the neutron and gamma levels on the 21.8 megajoule shot will be five and one half orders of magnitude higher, and X-ray levels will be two orders of magnitude higher than NOVA. The following assumptions were made for Appendix A, the flux table.

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1. Neutron rate was based on 1 nanosecond full width at half maximum pulse. Time of flight spreading will probably make the rates somewhat lower at the target room wall.
2. The existence of 8 keV black body radiation on the 21.8 MJ shot was predicted by Mike Tobin. For simplifying the calculations, all of the energy was assumed to consist of 25 keV photons instead of the normal black body curve. The attenuation is for 4 inches of aluminum, using the mass attenuation coefficient for 30 keV photons. The 16 inches of concrete shielding brings the levels down even more than indicated in Appendix A.
3. The 17.4 MeV fusion gamma radiation was a 10^{-4} branching of the DT fusion process. From this it is assumed that the fusion gamma levels would be proportional to the total neutrons for lower yields.
4. The gamma mean free path and neutron attenuations for the target chamber wall were obtained from Jeff Latkowski.
5. The 40 kilojoule (optical power) NOVA shot assumes a 100 picosecond FWHM neutron pulse.

The data in this report is intended to reflect the order of magnitude of the problems that will be encounter on NIF. I believe that they are generally good within a factor of 3.

COAXIAL CABLE NOISE

There were a number of measurements made by the Nuclear Test Program to determine the radiation sensitivity of cable to gamma^{3,4,5,6,7,8}, neutrons^{9,10} and X-rays³. These sensitivities are summarized in Appendix B. The actual X-ray sensitivity of cable will be lower, since the numbers in the literature are for 100 keV X-rays.

Appendix C summarizes the expected noise voltages. The data in this table is the product of the fluxes in Appendix A and the worse case sensitivity in Appendix B. The numbers assume no shielding around the cables. The worst case is 7/8 inch foam cable. The RG-213/214 type cable will generate approximately 20 per cent of the voltage than the 7/8 inch cables generate. Miniature microwave cable, such as Gore P6 and insulated wire 2251,^{11,12} generate 10 and 4 percent of the 7/8 inch cable voltage, respectively, when exposed to gamma radiation.

As can be seen from the Appendix C, an unshielded cable in the target chamber is subject to tens of kilovolts of radiation induced noise. On a 21.8

megajoule NIF shot approximately 20 to 30 kilovolts would be generated on each meter length of cable inside the target chamber near the wall. The data in Appendix B was generated by exposing cables to radiation flux perpendicular to the cable axis. Gamma and X-ray sensitivities will vary with orientation, since they depend on Compton effect. No data exists for cable sensitivities when the cable is exposed to a field axially. Neutron sensitivities will not vary with orientation since the signals generated are caused by a bulk material effects. Radiation hardening of the cable plant inside the target chamber is recommended.

A 1.9 megajoule NIF shot would produce noise voltages of approximately one hundred volts on an unshielded cable inside the target chamber. A 40 kilojoule NOVA shot would not generate significant noise on unshielded cables.

Outside of the target chamber, the neutron and gamma flux on a 21.8 megajoule NIF shot are still sufficiently high so as to produce nearly a kilovolt of noise on an unshielded cable running from the target chamber wall to the target room wall. Hardening of the cable installation is recommended. A 1.9 megajoule NIF shot would produce several volts of noise on an unshielded cable.

Applying a 5 kilovolt bias to a cable increases the radiation sensitivity by a factor of 20 to 100, independent of bias polarity.^{6,10} Single cable biased detectors are discouraged. For example, using the signal line to bias a detector is the equivalent of removing 4 inches of lead shielding between the source and the cable.

There is no radiation sensitivity data available for multiconductor cables. Twisted pair cables should be relatively insensitive to noise between conductors. However, very large common mode voltages should be expected.

CCD CAMERAS and MICRO CHANNEL PLATE INTENSIFIERS

CCD cameras are probably the most sensitive component to be exposed to the NIF radiation field. Unpublished measurements, that I made for Test Program on several CCD's, indicate that the sensitivity of CCD cameras is on the order of 1×10^{-4} stars/neutron. Although this data was contaminated with X-ray noise from the neutron generator, it is still within 50 per cent of the sensitivity measured by LANL.¹³ Appendix D is a summation of the number of stars that would occur at various locations and flux levels on an unshielded CCD camera. This also assumes that the CCD chip area is 1 cm². A star is defined as a neutron/silicon interaction that causes charge transfer. Stars typically occupy an area of 1 to 10 pixels.

As can be seen from Appendix D, there is a major problem if the CCD camera is inside the target chamber. Outside of the target chamber the problem is still major; however, there is room available to provide shielding. Thus, it would appear, if any diagnostics are to be done with CCD cameras on NIF, off axis or fiber transmission of the data to the input of the CCD must be considered.

The sensitivity of individual models of CCD chips varies widely. Factors such as surface passivation and circuit geometry cause the sensitivity to vary by more than an order of magnitude. Thus, the specific model of CCD used to record data should have its radiation sensitivity determined.

The gamma and X-ray sensitivity of CCD cameras has not been measured at this Laboratory. However, measurements made by LANL¹³ indicated that there is a two per cent background increase with a dose rate of 56 rads/sec. For a 21.8 megajoule NIF shot the dose rate will be 1.4×10^{14} rads/sec at the inside wall of the target chamber. The total dose that the camera would receive would be 1.4×10^5 rads. Outside of the target chamber shield wall, the flux rate would be 6×10^{12} rads/sec and the total dose would be 6×10^3 rads. Here again, as with the neutrons, shielding will be essential.

The sensitivities of micro channel plate image intensifiers (MCPI) has not been measured extensively. The literature indicates that the gamma and X-rays appearing at the photo cathode are amplified by the same gain as the visible photons.¹³ It also indicates that neutrons do not generate stars, but contribute to the background. A 2×10^7 neutron/cm² flux will produce an increase of 10 per cent in the background. A 57 rad/sec. gamma exposure appears to yield a similar background increase. The same precautions that are required for the CCD camera will be required for MCPI intensifiers. Further measurements should be made to confirm these sensitivities.

FIBER OPTICS

Another major component that could be used on a target diagnostics system is fiber optic cable. A number of studies have been done on steady state exposure^{14,15,16,17,18} and pulse exposure^{19,20} of fiber optic cables. Appendix E summarizes the effects on fibers. The darkening factors for fibers are approximate averages from several reports. It can be seen that the neutrons will cause very little darkening compared to the gamma radiation. It can also be seen that the only choice of fibers is radiation hardened fiber, since it displays a factor of 100 less darkening at 800 nanometers.

The darkening of the fiber is a function of the wavelength of the light being transmitted through the fiber. The attenuation of light in the 400 to 550 nanometer wavelength is between 5 and 10 times worse than at 800 nanometers. At the 1300 to 1500 nanometer communication window, the attenuation is approximately half of the attenuation at 800 nanometers. These

characteristics have some serious ramifications for the use of fiber for transmitting images and data out of the target chamber. Many of the common fluor materials and phosphors emit in the 400 to 550 nanometer spectral range.

Cherenkov light presents another problem. In Appendix E the light levels generated²¹ inside the target chamber on a 21.8 megajoule NIF shot are enough to overwhelm most optical signals. Because of the nature of Cherenkov light, it may be possible to take advantage of optical filtering to reduce these levels.

Outside of the target chamber, the darkening and Cherenkov effects are less, but still sufficient to cause problems on 21.8 megajoule NIF shots. Fibers inside the target chamber and inside the target room will require shielding. For 1.9 megajoule shots it is unlikely that there is a need for shielding outside of the target chamber. Inside of the test chamber some shielding will be necessary.

Fiber optics data link transmitters and receivers are also subject to degradation.¹⁸ Total dose exposure of a 1300-1500 nanometer fiber optics transmitter to 10^6 rads produces 3.5 dB of reduction in output. The matching receiver sensitivity is reduced by 1.5 dB for a total exposure of 10^8 rads. Outside of the target chamber, noticeable transmitter degradation would not start occurring until after the sixteen 21.8 megajoule shots have taken place. The 3.5 dB would occur after approximately one hundred sixty 21.8 megajoule shots have taken place.

STREAK CAMERAS

There is no data available on the radiation sensitivities of streak cameras. Typically in the Test Program, the cameras were coupled at very short range to MCP's and CCD's and were not considered a problem. Streak camera radiation sensitivity measurements need to be made.

COMPUTERS AND OTHER ELECTRONICS

There has been discussion of using computer and memory systems in the target room. There are some sources of information in the published literature regarding single event upsets and damage to memory and CPU chips.

The single event upset of a memory chip appears to be determined by the brand of memory chip chosen.²² The error threshold for some Dynamic RAMS (DRAMs) is at 4×10^{10} neutrons/cm². Others have thresholds greater than 2×10^{12} neutrons/cm². Static RAMS (SRAMS) again are a function of brand and design. These vary from a threshold of 6×10^8 neutrons/cm² to no

effect at 1×10^{12} neutrons/cm². The devices under test in the above reference were 64K and 256K DRAMS and 16 and 64K SRAMS. In the intervening eight years, the density of RAM memory chips has significantly increased to the point where 4 Meg and 16 Meg DRAM chips are now common. The structures in these chips are much smaller and much more densely packed than the chips tested. I believe, the probability of a neutron/silicon-dopant reaction taking place in an active part of the chip is now higher. The flux of NIF at the outside wall of the test chamber is 1×10^{11} neutrons/cm².

I have not found any gamma ray sensitivity measurements of commercial RAM chips. However, there have been measurements made on individual structures that comprise these chips.²³ The effects on these parts appear to start at 1×10^9 rads/sec. It should be noted here that these parts were selected as radhard parts. The flux rate for a 21.8 MJ NIF shot would be 6×10^3 rads divided by the pulse width of one nanosecond. This yields a rate of 6×10^{12} rads/sec at the exterior of the target chamber wall. As can be seen from these numbers, memory circuits will have to be shielded from both neutrons and gamma rays.

Although I did not finish the literature search for microprocessors operating in a radioactive environment, there was one reference that I found. This report dealt with the exposure of an 80286 chip to gamma rays.²⁴ A dose of 6×10^3 rads will yield a 3 to 10 per cent probability of a permanent failure of the chip. This damage level is very dependent on temperature and clock rate. At twice this clock rate and the same temperature, it takes 2×10^4 rads to produce the same probability of failure. Obviously, the level at which single event upsets would occur will be lower than the damage flux level. Single event upsets in a microprocessor can take many cycles to make their appearance.²⁵ Again, shielding will be necessary.

At this point, it is worth noting that both silicon and gallium-arsenide technologies are equally susceptible to single event upsets.²⁵

DMOS FET power switching devices are also susceptible to large conduction currents during exposure to radiation.²⁶ These devices, when exposed to a dose rate of 1×10^{10} rads/sec, go from the nonconducting to the conducting state during the pulse. Other MOSFET switching devices may or may not have similar characteristics.

EMI EFFECTS

ASSUMPTIONS

There was not sufficient time to work on determining the model for the increase in EMI from NOVA to NIF. However, some assumptions can be made for a worse case scenario to establish a probable upper limit. One of the first assumptions is that the EMI will scale linearly with the neutron and gamma flux. In round numbers this is approximately six orders of magnitude higher than NOVA. All voltages induced on cables assume that the cable in question is one meter long.

EMI SOURCE TERM

The EMI source term is not well defined for NIF. The measurements taken on NOVA were at one location.²⁷ These measurements indicated that the field outside of the NOVA target chamber was 15 volts/meter. That number was based on free space assumptions, which do not necessarily apply, as was recognized by the author of the reference. If this number is scaled directly for 21.8 MJ NIF shot, the E field would be 15 megavolts/meter. The aluminum walls of the NIF target chamber are twice as thick and are covered by 15 inches of concrete type shielding. In theory, the doubling of the thickness of the chamber aluminum walls should lead to a 40 dB increase in shielding.²⁸ The addition of the 15 inches of shielding should provide additional 30 dB.²⁹ However, there are a number of ports in the target chamber. This will reduce the effectiveness of the wall as a shield. For the sake of worse case argument, let this attenuation be 20 dB. The estimates below are based on a field of 1.5 megavolts/meter.

There are no estimates for the field strength inside the target chamber, since there were no measurements made inside the NOVA target chamber. The shielding effectiveness of the NOVA target chamber is not known, so no estimates can be made that are accurate within several orders of magnitude.

CABLE AND EQUIPMENT SHIELDING EFFECTIVENESS

The amount of voltage induced in the center conductor of a cable, when exposed to an external field, is defined as the shielding effectiveness (SE). The SE's for RG-213 and RG-214 are 45 and 60 dB respectively.^{30,31,32} The literature indicates that there may be two values for the SE for solid outer conductor coax. The SE is either 100 dB^{30,31} or 700 dB.^{28,32}

In the area just outside the target chamber, the voltages on RG-213, RG-214, and 1/2 inch foam are 8.5 kilovolts, 1.5 kilovolts and 15 volts respectively. The target room wall is made of concrete and is six feet thick. The estimated SE is on the order of 120 dB,^{29,33} which would indicate a field outside of the

walls of 1.5 volts/meter. This would produce about 8 millivolts of noise on an RG-213 cable.

On a 1.9 megajoule NIF shot the EMI levels will be about 50 dB. lower. In the area just outside the target chamber, the voltages on RG-213, RG-214, and 1/2 inch foam are 30 volts, 5 volts and 50 millivolts respectively.

From these estimates, the installation of an EMI shield around the cables appears to be necessary. A shield of 40 thousandths of an inch thick aluminum or copper will provide 700 dB or 35 orders of magnitude SE.

Equipment located in the target room will require EMI shielding. Outside of the target room the fields will be sufficiently reduced, so screen rooms or screen room techniques will not be required.

CONCLUSIONS AND RECOMMENDATIONS

When larger amounts of fusion occur, the NIF environment will have much higher noise levels than NOVA. Inside the target chamber, unshielded cables and fibers could generate tens of kilovolts and tens of milliwatts of power respectively. It will be necessary to provide shielding to all diagnostic systems. In some cases, the flux will be high and the space limited so the lead may not provide adequate shielding. It may be necessary to use denser materials such as tungsten. Outside of the target chamber, induced noise will be lower, but still a problem when fusion is achieved.

CCD cameras and MCPI intensifiers will be a problem at much lower levels of flux than cables and fibers. Care must be taken to protect these instruments from radiation saturation. Most other electronic system components located inside the target room annulus will require shielding at the higher fusion levels.

The radiation sensitivity data is limited for CCD cameras and MCPI intensifiers. It is nonexistent for streak cameras. I recommend that these areas be investigated further.

I recommend that a layered shielding design be used. This allows the installation of the appropriate shielding as each higher level of radiation is reached. This also allows spreading the cost of shielding over several fiscal years.

Shielding against EMI is considerably less space consuming than shielding against radiation, but just as necessary. However, at present, the magnitude of the problem is not well defined. I recommend that the EMI characteristics of NOVA be studied further. I also recommend that an attempt be made to, at least, crudely model the EMI characteristics of the NIF target chamber.

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Appendix A

Flux Levels

21.8 Megajoule Shot

	Source	Inside TC	Inside TC	Outside TC	Inside TR
Distance	0 Meters	2.5 Meters	5.0 Meters	5.5 Meters	13 Meters
Radiation				Attn: 26.5:1	
Neutrons (N/cm ²)	1.00E+19	1.27E+13	3.18E+12	1.00E+11	2.00E+10
Neutron Rate(N/cm ² sec)		2.00E+22	3.18E+21	1.00E+20	1.33E+19
				Attn: 13:1	
Fus. Gamma (MEV/cm ² sec)		7.00E+22	1.75E+22	7.70E+20	1.54E+20
				Attn: ∞	
X-ray (MEV/CM ² sec.)	350 eV BB	6.00E+22	1.50E+22	0.00E+00	0.00E+00
				Attn: 4" Al only (25KeV)	
X-ray (MEV/CM ² sec.)	8 KeV BB	6.00E+20	1.50E+20	2.00E+08	4.00E+07

1.9 Megajoule Shot

	Source	Inside TC	Inside TC	Outside TC	Inside TR
Distance	0 Meters	2.5 Meters	5.0 Meters	5.5 Meters	13 Meters
Radiation				Attn: 26.5:1	
Neutrons (N/cm ²)	3.50E+16	4.50E+10	1.12E+10	4.20E+08	8.40E+07
Neutron Rate(N/cm ² sec)		4.50E+19	1.12E+19	4.20E+17	8.40E+16
				Attn: 13:1	
Fus. Gamma (MEV/cm ² sec)		2.40E+20	6.10E+19	2.70E+18	5.40E+17
				Attn: ∞	
X-ray (MEV/CM ² sec.)	170 eV BB	1.50E+22	3.75E+21	0.00E+00	0.00E+00

40 Kilojoule Nova Shot

	Source	Inside TC	Inside TC	Outside TC	Inside TR
Distance	0 Meters	2.5 Meters	5.0 Meters	5.5 Meters	13 Meters
Radiation				Attn: 26.5:2	
Neutrons (N/cm ²)	2.00E+13	2.54E+07	x	x	x
Neutron Rate(N/cm ² sec)		4.00E+17	x	x	x
			x	x	x
Fus. Gamma (MEV/cm ² sec)		1.40E+17	x	x	x
			x	x	x
X-ray (MEV/CM ² sec.)	≈200 eV BB	3.20E+20	x	x	x

Appendix B

Cable Radiation Sensitivity			
Type of Cable	Radiation	Sensitivity	Units
7/8" Foam	Gamma	1.00E-20	(A/M)/(MeV/Cm ² sec.)
7/8" Low Density Foam	Gamma	2.00E-23	(A/M)/(MeV/Cm ² sec.)
7/8" Air Helix	Gamma	2.00E-21	(A/M)/(MeV/Cm ² sec.)
RG-8/RG-58	Gamma	2.00E-21	(A/M)/(MeV/Cm ² sec.)
Gore P-6	Gamma	1.00E-21	(A/M)/(MeV/Cm ² sec.)
IW-2251	Gamma	4.00E-22	(A/M)/(MeV/Cm ² sec.)
7/8" Foam	100 KeV X-rays	1.00E-19	(A/M)/(MeV/Cm ² sec.)
RG-213	14 MeV Neutrons	1.00E-19	(A/M)/(N/Cm ² Sec.)

Voltage Levels

21.8 Megajoule Shot

	Source	Inside TC	Inside TC	Outside TC	Inside TR
Distance	0 Meters	2.5 Meters	5.0 Meters	5.5Meters	13 Meters
Radiation				Attn: 26.5:1	
Neutrons (V/M of cable)		1.00E+05	1.59E+04	5.00E+02	6.65E+01
				Attn: 13:1	
Fus. Gamma (V/M of cable)		3.50E+04	8.75E+03	3.80E+02	7.70E+01
				Attn: ∞	
X-ray (V/M of cable)	350 eV BB	0.00E+00	0.00E+00	0.00E+00	0.00E+00
				Attn: 4" Al only	
X-ray (V/M of cable)	8 KeV BB	3.00E+03	7.50E+02	1.00E-09	2.00E-10

1.9 Megajoule Shot

	Source	Inside TC	Inside TC	Outside TC	Inside TR
Distance	0 Meters	2.5 Meters	5.0 Meters	5.5Meters	13 Meters
Radiation				Attn: 26.5:1	
Neutrons (V/M of cable)		2.25E+02	5.60E+01	2.10E+00	4.20E-01
				Attn: 10:1	
Fus. Gamma (V/M of cable)		1.20E+02	3.05E+01	1.35E+00	2.85E-01
				Attn: ∞	
X-Ray (V/M of cable)	170 eV BB	0.00E+00	0.00E+00	0.00E+00	0.00E+00

40 Kilojoule NOVA Shot

	Source	Inside TC	Inside TC	Outside TC	Inside TR
Distance	0 Meters	2.5 Meters	5.0 Meters	5.5Meters	13 Meters
Radiation				Attn: 26.5:2	
Neutrons (V/M of cable)		2.00E+00	x	x	x
			x	x	x
Fus. Gamma (V/M of cable)		7.00E-02	x	x	x
			x	x	x
X-ray (V/M of cable)	≈200 eV BB	0.00E+00	x	x	x

CCD Star Levels

21.8 Megajoule Shot

	Source	Inside TC	Inside TC	Outside TC	Inside TR
Distance	0 Meters	2.5 Meters	5.0 Meters	5.5 Meters	13 Meters
Radiation				Attn: 26.5:1	
Neutrons (stars/cm ²)	1.00E+15	1.27E+09	3.18E+08	1.00E+07	2.00E+06

1.9 Megajoule Shot

	Source	Inside TC	Inside TC	Outside TC	Inside TR
Distance	0 Meters	2.5 Meters	5.0 Meters	5.5 Meters	13 Meters
Radiation				Attn: 26.5:1	
Neutrons (stars/cm ²)	3.50E+12	4.50E+06	1.12E+06	4.20E+04	8.40E+03

40 Kilojoule NOVA Shot

	Source	Inside TC	Inside TC	Outside TC	Inside TR
Distance	0 Meters	2.5 Meters	5.0 Meters	5.5 Meters	13 Meters
Radiation				Attn: 26.5:2	
Neutrons (stars/cm ²)	1.00E+09	1.27E+03	x	x	x
512x512 =	2.60E+05	pixels			

Fiber Effects

21.8 Megajoule Shot

[illegible]

Fiber Effects

1.9 Megajoule shot

[illegible]

Fiber Effects					
40 Kilojoule Nova shot					
	Source				
Distance	0 Meters	2.5 Meters			
Radiation					
Neutrons (N/cm ²)	2.00E+13	2.54E+07			
Neutron Rate(N/cm ² sec)		4.00E+17			
Darkening					
Radhard (dB/M)@ 600 nm		<.001			
Nonradhard (dB/M) @ 600 nm		<.001			
Radhard (dB/M)@ 800 nm		<.001			
Nonradhard (dB/M) @ 800 nm		<.001			
Permanent Darkening					
Radhard (dB/M)@ 600 nm					
Nonradhard (dB/M) @ 600 nm					
Radhard (dB/M)@ 800 nm					
Nonradhard (dB/M) @ 800 nm					
Fusion Gamma (MEV/cm ² sec)		1.40E+17			
Total One Shot Dose (Rads)		1.12E-01			
Darkening					
Radhard (dB/M)@ 600 nm		<.001			
Nonradhard (dB/M) @ 600 nm		<.001			
Radhard (dB/M)@ 800 nm		<.001			
Nonradhard (dB/M) @ 800 nm		<.001			
Permanent Darkening					
Radhard (dB/M)@ 600 nm					
Nonradhard (dB/M) @ 600 nm					
Radhard (dB/M)@ 800 nm					
Nonradhard (dB/M) @ 800 nm					
Cherenkov (watts/meter)		1.45E-07			

DATE

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9 / 14 / 94

END