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D. C. Eder, P. M. Song, J. F. Latkowski, S. Reyes, D. W. O'Brien, F. D. Lee, B. K. Young, J. A. Koch, P. W. Watts, J. R. Kimbrough, E. W. Ng, O. L. Landen, B. J. MacGowan

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·LLNL, P. O. Box 808, L-463, Livermore, CA, USA
deder@llnl.gov

Abstract *The design of a wide range of components in and near the target bay of the National Ignition Facility (NIF) must allow for significant radiation from neutrons and gammas. Detailed 3D Monte Carlo simulations are critical to determine neutron and gamma fluxes for all target-bay components to allow optimization of location and auxiliary shielding. Demonstration of ignition poses unique challenges because of the large range (~3 orders of magnitude) in the yield for any given attempt at ignition. Some diagnostics will provide data independent of yield, while others will provide data for lower yields and only survive high yields with little or no damage. In addition, for a given yield there is a more than 10 orders of magnitude range in neutron and gamma fluxes depending on location in the facility. For example, sensitive components in the diagnostic mezzanines and switchyards require auxiliary shielding for high-yield shots even though they are greater than 17 meters from target chamber center (TCC) and shielded by the 2 m-thick target-bay wall. In contrast, there are components 0.2 to 2 m from TCC with little or no shielding. For these components, particular attention is being made to use low-activation material because of the extremely high neutron loading levels. Many of the components closest to target center are designed to be single use to reduce worker dose from having to refurbish highly activated components. The cryogenic target positioner is an example where activation and ease of component replacement is an important part of the design. We are developing a design process for all target-bay systems that will assure reliable operation for the full range of planned yields.*

I. INTRODUCTION

The high level of neutron and gamma radiation during ignition experiments at the National Ignition Facility (NIF) and Laser MegaJoule (LMJ) must be taken into account in the design of all diagnostics and other target-bay systems. The number of systems that are expected to operate is function of the yield. A large fraction of the ignition related experiments will generate little or no yield (below 2×10^{12} DD neutrons). All systems are expected to operate for yields in this range. A limited number of experiments will use TT capsules with an expected yield of 5×10^{14} neutrons. The primary diagnostics for these experiments are two x-ray streak cameras (SXD's) that are located inside the target chamber. We discuss shielding that is required for their operation below. In the attempts to reach ignition high yields will be generated (of order 5×10^{16} DT neutrons, 100 kJ) even for implosions that failed to ignite. It is particularly important that a number of diagnostics operate and provide data to measure signatures indicative of failure modes. For these shots there

are no sensitive components, e.g., CCD cameras, in the target chamber and the majority of the sensitive components are behind the 2-m thick target bay wall in one of the four diagnostic mezzanines. At higher yields up to 10^{19} DT neutrons (20 MJ), all diagnostics are required to survive but only a subset need provide data to verify ignition and yield.

Understanding the impact of the yield environment on target area systems starts with detailed 3D Monte Carlo simulations to determine neutron and gamma fluxes for target-bay components for their expected range of operation. Optimization of location and auxiliary shielding can then be provided. These simulations are also used as input into activation codes that calculate the time-dependent gamma emission from activated material. To keep worker dose at acceptable levels, particular attention is given to choice of materials that minimize activation. We discuss this issue below when we summarize modeling of the ignition target positioner.

The majority of the radiation leaving an ignition capsule is in the form of neutrons but a large amount of gamma radiation is produced when the neutrons interact with material. These gammas can produce Compton electrons inside diagnostics and other target-bay systems. The resulting system generated electromagnetic pulse (SGEMP) can cause damage to electronic components and/or loss of data. This form of EMP is harder to shield than field transmitted EMP (FTEMP) where Faraday shielding is generally effective.

In section II, we discuss 3D Monte Carlo simulations and the expected radiation levels at various locations. In section III, we describe shielding needed to field diagnostics in the chamber during TT shots. In section IV, we discuss modeling of the ignition target positioner. We briefly discuss automating the production of Monte Carlo geometry input from CAD models. In section V, we describe some

issues associated with EMP. We conclude in section VI.

II. RADIATION LEVELS

The calculation of radiation levels is difficult because of complexity of the target bay inside and outside of the target chamber. However, the rapid advance of computing capability makes 3D Monte Carlo with over 10^9 particles possible. As an example, we show the input geometry for the NIF target bay and chamber without optics in Fig.1. The concrete flooring has numerous openings to allow beams to be configured for both indirect (current mode) and direct drive operation. Optics are treated at different levels of detail depending on application. The full 3D model has only an approximate model for the 48 final optic assemblies (FOA's) but has the correct mass of the different components. However, to calculate worker dose associated with changing optics we use a very detailed model for a single FOA. One of our Monte Carlo codes, TART, and its use in calculating appropriate location and shielding for a neutron time of flight detector is discussed in another paper[1]. That paper also shows the model that is used for all the entrant equipment inside the chamber. For high-yield shots most of this equipment will be removed except for the target position, discussed in section IV, and diagnostic manipulators (DIM's) holding passive objects such as an imaging aperture.

Location	n dose	γ dose
1 m from TCC	95000	9000
5 m from TCC	6900	3900
Outside chamber (open LOS)	2000	480
Outside chamber (shielded)	140	150
Inside target-bay wall (15 m)	50	55
Switchyard - TB wall (17 m)	0.001	0.001

Table 1. The neutron and gamma dose in rads (Si) for 20 MJ yield.

To determine the impact of neutron and gamma radiation on diagnostics one generally calculates the absorbed energy per unit mass in silicon expressed as Rad-Si, where 1 Rad is 0.01 J/kg. For 14 MeV neutrons, 1 neutron/cm^2 gives an absorbed dose of 1.2e-9 Rad-Si. In Table 1, we give the absorbed dose for a 20 MJ shot at various locations in and out of the target chamber. The major contribution in the switchyards is from neutron scattering through the laser beam tubes and not from neutrons passing through the 2-m thick target-bay wall. The majority of the gamma dose in all locations comes from the interaction of the neutrons with target chamber/bay components. Very near target chamber center (TCC) the neutron dose dominates over the gamma dose. Table 1 illustrates the advantages of locating equipment outside the target bay shield wall. These numbers can be scaled for lower DT yields, e.g., for a 1 MJ shot divide by 20. However, DD and TT experiments require additional simulations because of differences in the initial energy of the neutrons. (For TT shots, there is a broad spectrum of initial energies with two peaks because the reaction energy is shared between two neutrons.)

III. CAMERA SHIELDING (TT SHOTS)

Shock timing experiments are planned that require cryogenic targets and beta layered fills. Using pure T_2 or a mix of T_2 and H_2 will reduce the yield to less than 5×10^{14} neutrons but the radiation and SGEMP environment inside the two DIM mounted x-ray streak cameras (SXD's) is still challenging. A redesign of SXD to allow substantial shielding is being studied. We summarize the initial attempt that appears promising but issues remain. We use a glancing angle (0.5°) high-Z mirror to redirect the x rays that will be imaged. This allows for the placement of approximately 60 cm of polyethylene (PET) shielding between target chamber center and the CCD camera. A large number of neutrons scatter off the inside of the target chamber and 6-8 cm of additional PET

shielding is placed around the detector. The shielding reduces the neutron fluence at the camera by approximately a factor of 50. The expected number of "neutron stars" at this fluence is low enough such that the images of the implosion should meet the time and space resolution requirements of the shock timing measurement. To protect the electronics from SGEMP, we also add 2.5 cm of Pb shielding around selected components. There are some issues that must be resolved. The weigh of the shielding is at issue but the shielding placement/thickness has not yet been optimized. The x-ray mirror is placed in a snout approximately 5 cm from TCC. Survivability of this mirror and potential shrapnel generated by the snout must be assessed. However, it appears that measurements inside the chamber at this level of yield may be possible.

IV. IGNITION TARGET POSITIONER

We have made detailed calculations to determine the activation of the ignition target positioner. The model used in the Monte Carlo simulations is shown in Fig. 2. The relative importance of different activated isotopes in the positioner varies as a function of time after a shot. For short times (minutes), ^{62}Cu and ^{27}Mg with 10 minute half-lives dominate. For intermediate times (hours – days) the dominant isotope is ^{24}Na with a 15-hour half-life. For long times (weeks), ^{54}Mn and ^{60}Co dominate with 312 day and 5 year half-lives, respectively. Depending on the yield, the time a worker would be exposed to the target positioner varies from hours to ~1 week. The dose rate for a potential worker location after the positioner has been retracted from the chamber following a 20 MJ shot is approximately 5×10^3, 9×10^2, and 3×10^{-1} mrem/hr at 1 hour, 1 day, and 1 week, respectively. This means that the dose rate 1 hour after a 1kJ yield shot is approximately the same as the dose rate 1 week after a 20 MJ yield shot. These numbers are only preliminary since final design of the positioner is in progress. In addition, to reducing dose by changing materials

in the design we also explore the benefits of single-use components that would not have to be handled following a shot.

A significant amount of work is required to change the input geometry for Monte Carlo calculations when objects/systems are initially modeled or redesigned. In many cases the majority of the time spent in doing a calculation is setting up the input geometry. We are starting to explore automated methods to go from CAD models to Monte Carlo input geometries. We give an example of this in Fig. 3, where we show an input geometry for the clamshell approach for the cryogenic shroud puller. (The opposed port shroud puller is still an option.) The initial data for the design was in a Pro|Engineer model and was converted into an input model for the TART Monte Carlo code. The model had 1059 surfaces and 2308 zones. Raytheon developed the code, TOPACT, which was used for the conversion. The initial results are promising but significant challenges remain. In particular, the level of detail in the CAD models is generally more than what is desired in the Monte Carlo simulation.

V. ELCTROMAGNETIC PULSES

The number of neutrons leaving an ignition capsule for a high yield shot (20 MJ) is $\sim 10^6$ times the number of neutrons on an Omega DT shot. One consequence of these neutrons is SGEMP, where neutron generated gammas produce Compton electrons inside diagnostics and target bay systems. The SGEMP can cause damage to electronic components and/or loss of data. Experiments by CEA at Omega have shown that some aspects of SGEMP can be studied on Omega by placing components, e.g., coaxial cables, close (~20 cm) from TCC[2]. The neutron fluence at this location is only an order of magnitude less than we would have at some relevant locations in the NIF target bay following a 20 MJ shot. Using these and similar experiments will allow us to validate our SGEMP models that will in turn be used to develop mitigation techniques for NIF high-yield operation.

There is another EMP issue associated with plans to convert 1 or 2 NIF beam lines to short pulse operation as part of the advanced radiographic capability (ARC). There is a general problem with damage to electronic components and/or loss of data at many short-pulse facilities. To insure reliable operation on NIF for ARC shots it is important that we understand EMP from short-pulse lasers interacting with target materials. This interaction generally produces a large number of energetic (MeV) electrons. A small fraction of these electrons are expected to escape and generate transient currents. The FTEMP associated with these currents at short-pulse facilities has been measured to have frequencies in the 0.05 – 5 GHz range[3]. The lower frequencies are believed to be associated with modes of the target chamber generated when the escaping electrons strike the chamber. Higher frequencies are potentially associated with smaller structures on and inside the target chamber. We plan to model and measure FTEMP on a new short pulse facility at LLNL, Titan. The Titian target chamber is shown in Fig. 4. We plan to model the fields in the chamber with the 3D electromagnetic code EMSolve[4]. The calculated fields will be compared with measurement for a wide range of experimental configurations and a corresponding wide range in number escaping electrons. The energetic electrons also generate gammas that produce SGEMP. Our EMP measurements are designed to distinguish between FTEMP and SGEMP.

VI. CONCLUSIONS

A plan has been developed for yield operation on NIF that includes making the number of systems that are expected to operate be a function of the yield. Operation of some diagnostics inside the chamber during shock timing shocks using TT capsules and yields up 5

10^{14} neutrons is possible provided that appropriate shielding can be fielded. Monte Carlo simulations are required for many aspects of our radiation mitigation efforts. Preliminary results on automating the needed input geometries are promising. Finally, issues associated with EMP require additional effort. In particular, SGEMP and FTEMP associated with ARC operation on NIF should be studied.

VII. ACKNOWLEDGMENTS

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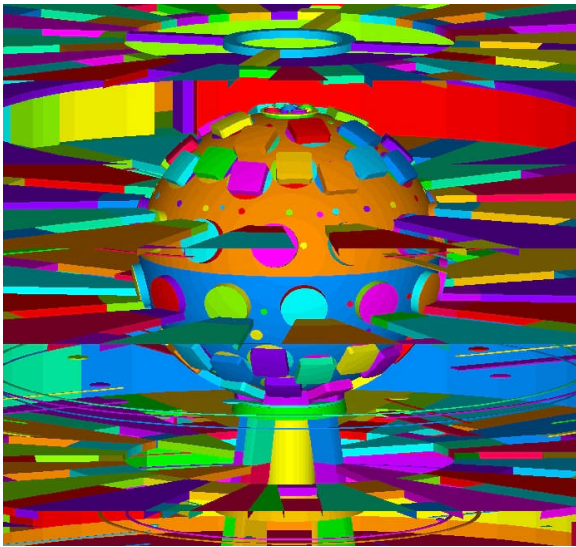[4] R. Rieben, G. Rodrigue, D. White, Journal of Computational Physics **204**, 490 (2005).
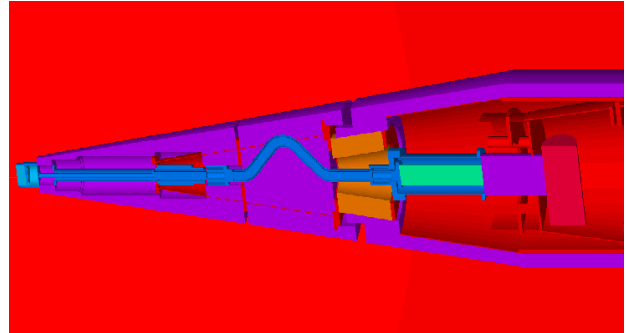
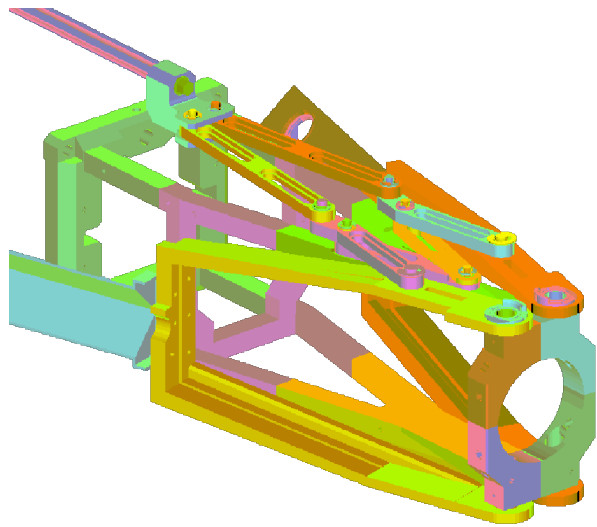**Figure 2. Input geometry used for MC calculation of NIF ignition target positioner.**

Figure 3. Input geometry for NIF clamshell generated automatically from CAD model.

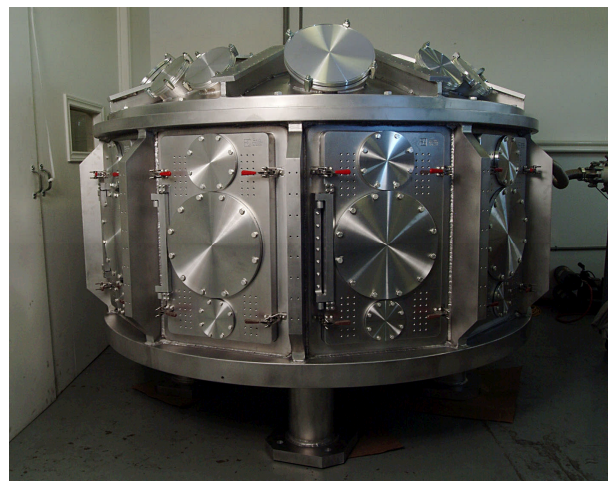**Figure 1. Input geometry for MC calculation of NIF target bay without optics.**

Figure 4. Titan target chamber.