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Abstract. The National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) is nearing completion of construction and is preparing for the National Ignition Campaign (NIC) with potentially significant yield in 2010. The design of a wide range of yield diagnostics in and outside the target-bay of the NIF must consider scattered background neutrons and neutron-induced gamma rays to measure neutrons and x-rays from target. The large and complex target chamber and facility make the calculation of scattered neutrons and gamma rays extremely challenging. The NIF was designed with shielded locations for many of the yield diagnostics including the neutron alcove and four diagnostic mezzanines. Accurate calculation of the background levels in these shielded locations requires advanced Monte Carlo techniques, e.g., variance reduction. Placement, size, and materials of collimators on the line of sight (LOS) through the shielding must be evaluated to trade off signal levels and unwanted backgrounds. The background at these locations is also affected by neutrons that pass through the laser beam tubes and scatter off of structures and walls in the switch yards. Detailed 3D Monte Carlo analyses are performed to determine neutron and gamma fluxes for some of the yield diagnostics.

1. Introduction

The National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) is nearing completion of construction and is preparing for the National Ignition Campaign (NIC) with potentially significant yield in 2010. Various yield diagnostics will be deployed in and outside the target chamber to assure that the goal of fusion ignition is successful. The design of a wide range of diagnostic components in and outside the target-bay of the NIF must consider scattered background neutrons by the walls of the massive target chamber and structures both inside and outside the chamber and neutron-induced gamma rays to measure accurate neutrons and x-rays images/energy spectrums. There is a more than 10 orders of magnitude range in neutron and gamma fluxes depending on location in the facility. For example, sensitive electronic components in the diagnostic mezzanines and switch yards (SY) outside target-bay wall can require auxiliary shielding for high-yield shots even though they are greater than 17 meters from target chamber center (TCC) and shielded by ~2 m-thick target-bay wall. The majority of the ignition diagnostics are designed to provide data over a particular yield range and to survive over a range of higher yields. At relatively low yields (10-100 KJ); a wide range of diagnostics provides data used to understand the reasons for the low yield. At the highest yield, up to 10^{19} DT neutrons (20 MJ), a number of diagnostics are required to survive but only a very small number need to provide data to verify ignition and yield. We give results for two of those diagnostics.

Detailed 3D Monte Carlo simulations are essential to understand the impact of neutron and neutron-induced gamma fluxes to diagnostics and are critical to determine neutron and neutron-induced gamma fluxes for all diagnostics. Results of these simulations are used to optimize diagnostic locations and collimators size. In some cases auxiliary shielding is needed to block radiation reaching the diagnostics indirectly through penetrations, e.g., laser beam tubes, and subsequent scattering. These simulation codes are also used to determine prompt radiation doses and activation levels of structures needed to evaluate personnel exposure and access controls for the facility.

In section 2, we discuss the 3D NIF Monte Carlo model and simulations. In section 3, we discuss neutron background levels for two yield diagnostics located at different lines of sight (LOS). We conclude in section 4.

2. Calculational Model

For the majority of our Monte Carlo simulations we use the MCNPX[1] developed by Los Alamos National Laboratory. It is a three dimensional general purpose Monte Carlo radiation transport code that tracks neutrons, photons, and electrons over a wide range of energy. To analyze the level of background scattered neutrons and neutron-induced gammas and to evaluate the related radiation damages from neutrons and gammas at individual yield diagnostics, a three dimensional NIF MCNP model was developed. The model includes a 550 cm radius spherical target chamber having a 10-cm thick aluminium (Al-5083) wall covered by 40 cm of 'shotcrete' (concrete shielding), all concrete floors with openings between chamber and target-bay wall to allow beams to be configured for both indirect (current mode) and direct drive operation., ~2 m thickness of concrete target-bay wall with an additional ~2 m of concrete at the location of the beam path openings, and the two SY as seen in Figure 1. To improve the Monte Carlo statistical uncertainties in the calculated particle flux behind the ~2 m-thick concrete target-bay wall, particles splitting variance reduction technique was applied to every ~30 cm of target-bay concrete wall.

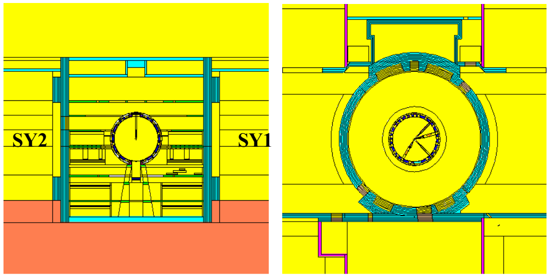

Figure 1. NIF MCNP model, Front (XZ) and Top (XY) views.

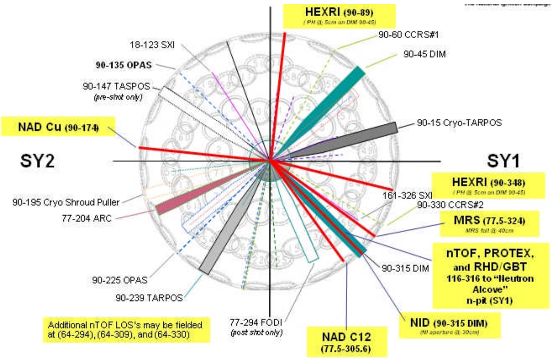

Figure 2. Current NIF yield diagnostics layout

The current ignition yield diagnostic layout inside chamber is seen in Figure 2. The spherical target chamber consists of two target positioners (at latitude 90°: longitude 15° and 239°) plus three diagnostic instrument manipulators (DIM) (at latitude 90°: longitude 45° and 315° and polar DIM at latitude 0°: longitude 0°). All indirect and direct drive laser ports and diagnostic ports in the chamber wall are modelled. The model has an approximate model for the 48 final optic assemblies (FOA's), which are attached to the indirect drive ports, that has the correct mass of the different components. We calculate radiation levels in the below ground neutron alcove pit in SY1 (at latitude 116°: longitude 316°). A number of diagnostics will be located in the alcove and we give results for the neutron time of flight (nTOF) detector. Additional yield diagnostics are located in SY1 with some at the same elevation as TCC. The magnetic recoil spectrometer (MRS) detectors (at latitude 77.5°: longitude 324°) is one such diagnostic. All collimators inserted in chamber ports and the target-bay walls for each yield diagnostics are also included in the current model. Calculations use a neutron and gamma spectrum obtained from inertial confinement fusion (ICF) simulations or a user specified spectrum. The calculations discussed below used a mono-energetic deuterium and tritium (D-T) neutron source (14.1 MeV) at TCC. The vast majority of neutrons leaving the target are very close to this energy and almost all of the gamma ray background is from neutron induced gamma production in structures inside and outside the chamber. Thus we use a mono-energetic source for most of our background calculations except when we calculate backgrounds for tritium and tritium (T-T) reactions, where a spectrum is required.

3. Results

3.1. Neutron Fluence at nTOF detector

The neutron alcove (at latitude 116°: longitude 316°) is located at -29’6” level (~10 m below ground level) outside target-bay wall in SY1. The nTOF detector will be placed at one LOS in the alcove to measure primary 14.1 MeV neutrons from target chamber. The flight distance from TCC to the nTOF detector will be ~21 meters and the time of flight for primary 14.1 MeV neutrons would be ~410 ns. To reduce the scattered neutron contribution to the detector in the alcove from both inside and outside chamber, two collimators are used. One is at the chamber port (radius = 0.6 cm) and one in the ~2 m-thick concrete target-bay wall (radius = 2 cm) as seen in Figure 3.

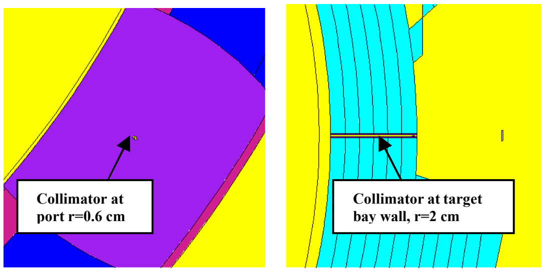

Figure 3. Collimator applied at port (left) and target bay wall (right) for nTOF detector in the neutron alcove

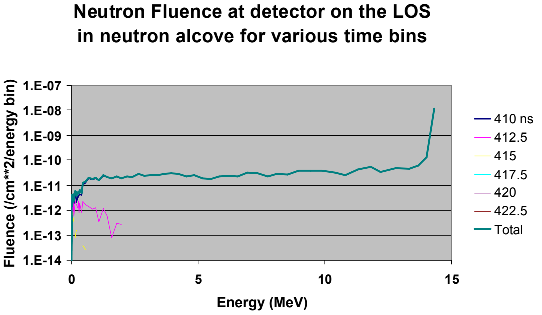

Figure 4. Neutron background at nTOF detector in neutron alcove. (The size of the energy bin varies, ~0.5 MeV for E> 10 MeV and ~0.2 MeV for E>1.0 MeV)

The neutron fluence calculated for a detector placed 2 meters from the target-bay wall is seen in Figure 4. High peak primary 14.1 MeV neutron flux is seen at the LOS detector and the ratio of neutron spectrum between the primary and scattered neutron around 6 MeV is ~700. This is the contribution of down-scattered neutrons inside detector and it does not significantly affect time response of the detector. A similar analysis[2] shows the current collimator design provides sufficient required <ρR> measurement margin (10^{-9}) between 14.1 and 6 MeV background [3, 4].

3.2. Neutron Background at MRS CR39 detectors

The MRS detector will be placed in SY1 outside target-bay (at latitude 77.5°: longitude 324°). Two collimators at the chamber port (cylindrical shape with radius=8.89 cm) and target-bay wall (rectangular shape , 6.3x3.2 cm^2), the thin stainless steel tube from port to magnet outside target-bay wall, and the MRS magnet were modelled to calculate scattered neutron background at two off-LOS

CR39 detectors having different facing angles toward MRS magnet. (See Figure 5) The MRS measures absolute neutron spectrum (6-10 MeV) with a desired ratio of the signal to background higher than 10. In order to achieve this requirement, the integrated background neutron fluence above 100 KeV should be lower than ~5×10^{-12} /cm^2 (Ref. 5). Figure 6 shows the calculated background levels for two CR39 detectors. It may be noted that the CR39 detector (back CR39 detector, see Figures 5 and 6) facing more toward target-bay penetration has higher high-energy neutron flux than the other detector as expected. The integrated backgrounds above 100 KeV are 6.7×10^{-12} and 5.14×10^{-12}/cm^2 for both front and back CR39 detectors, respectively. Modest amount of auxiliary shielding or tighter collimator could be considered to reduce background to desired level.

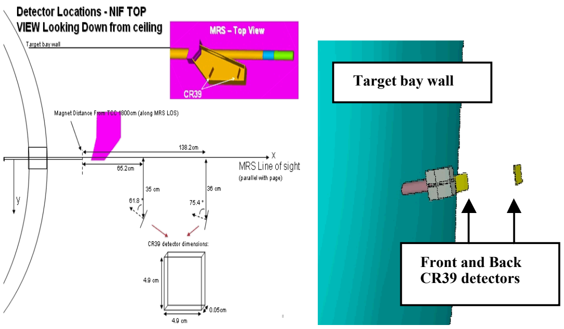

Figure 5. MRS CR39 detectors outside target bay wall

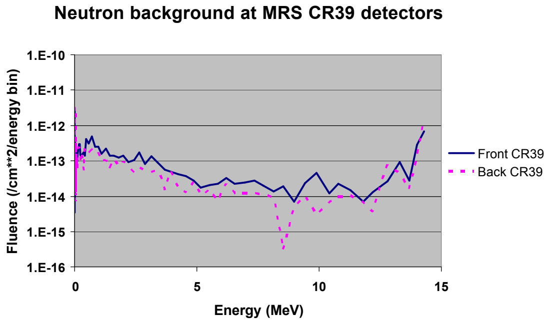

Figure 6. Neutron background at two MRS CR39 detectors. (The size of the energy bin varies, ~0.5 MeV for E> 10 MeV and ~0.2 MeV for E>1.0 MeV)

4. Conclusion

Detailed three dimensional MCNP Monte Carlo analyses were performed to determine neutron backgrounds for two NIF yield diagnostics. The current collimator design provides sufficient required <ρR> measurement margin (10^{-9}) and the contribution of down-scattered neutrons inside detector does not significantly affect time response of the detector. The background level for MRS CR39 detectors with current collimator configuration is slightly higher than required. However, tighter collimators or auxiliary shielding is being considered to reduce the background.

5. Acknowledgments

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6. References

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[5] Johan Frenje, Private communication.