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STUDY OF SCATTERED BACKGROUND NEUTRON IN NIF AND TIME-OF-FLIGHT (TOF) TO MEASURE NEUTRON

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ABSTRACT

Some of the planned core diagnostics for National Ignition Facility (NIF) will use neutron time-of-flight (TOF) spectroscopy techniques to gather information for primary neutron yield measurement or neutron imaging. This technique has been widely and routinely used at other laser facilities including Nova and Omega. TOF methods will also be used to observe target fuel areal density <ρR> (radial integral of density) via measuring the number of primary 14.1 MeV neutrons that are down-scattered to lower energies by nuclear collisions inside the compressed target core. The substantially larger target chamber size and higher neutron yield for NIF raises issues related to the large number of scattered neutrons produced by high yield deuterium-tritium (D-T) shots at NIF. The effect of primary neutrons scattered by the walls of the massive target chamber and structures both inside and outside the chamber will contribute a significant scattered background signal when trying to determine the number of neutrons down-scattered from the target core. The optimum detector locations outside the target chamber or target bay wall will be proposed. Appropriate collimators at the chamber port and the bay wall (between the neutron source at target chamber center (TCC) and detector) that maximize detection of signal neutrons while minimizing the background from scattered neutrons and neutron induced gamma rays will also be presented.

I. INTRODUCTION

One of the major missions of the neutron yield diagnostic (NYD) is to measure primary 14.1 MeV neutrons from D-T fusion reactions. The TOF spectroscopy technique has been widely and routinely used at many laser facilities including Nova and Omega to gather information for primary neutron yield measurement and neutron imaging. TOF methods will also be used to observe target fuel areal density <ρR> via measuring the number of primary 14.1 MeV neutrons that are down-scattered to lower energies by nuclear collisions inside the compressed target core. The substantially larger target chamber size and higher neutron yield for NIF raises issues related to the large number of scattered neutrons produced by high yield D-T shots at NIF. The effect of primary neutrons scattered by the walls of the massive target chamber and structures both inside and outside the chamber will contribute a significant scattered background signal when trying to determine the number of neutrons down-scattered from the target core.

The main purpose of the current neutronics analyses is to provide the optimum detector locations outside the target chamber or target bay wall that maximize detection of signal neutrons while minimizing the background from scattered neutrons and neutron induced gamma rays.

II. METHOD OF ANALYSES

II.A. Computer Codes and Calculation

TART[1] is a three dimensional multi-group neutron and photon Monte Carlo transport code, which features a 616-group neutron and 701-point gamma cross-section structures. TART was used to model the NIF chamber, its entrant equipments, and surrounding target bay wall, concrete floors and detectors for the current analysis.

Neutrons and neutron-induced gamma rays were tracked through the geometry with a time-dependence; the most significant piece of information being the amount of energy deposited from neutrons and photons into the detector to find an optimal detector location with or without collimation that will maximize the primary 14.1 MeV neutron signal while minimizing the background scattered neutron contributions.

II.B. Computational Model and Neutron Sources

To analyze the level of background scattered neutrons, a three dimensional TART model was developed to estimate scattered neutrons and gamma rays arriving at detectors located outside chamber or target bay wall. The model includes a 550 cm radius spherical target chamber, concrete floors outside chamber, and ~183 cm thickness of concrete target bay wall. The spherical target chamber consists of a target positioner (at latitude 90°:longitude 239°) or a target positioner plus other entrant equipment representing a maximum scattering inside chamber (‘full’ chamber), 10 cm of aluminum (Al-5083) chamber wall, and 40 cm of ‘shotcrete’ (concrete) surrounding the aluminum wall. Diagnostic ports (25 cm radius), D114 port (latitude 90°: longitude 315°) or D98 (latitude 116°: longitude 335°) were modeled in the concrete chamber, which are covered with a 2.54-cm thick aluminum cap. The concrete floors between chamber and target bay wall were included to account for possible neutron scattering events with concrete floors and cylindrical concrete target bay wall has 1524 cm of inner radius.

The model simulates the 2-cm thick and 5-cm diameter polyethylene detectors outside of the Al port cap (r=565 cm from TCC) or outside concrete target bay wall (r= 1707 or 1907 cm from TCC) at direction of diagnostic ports. The detectors for all cases are placed at the line-of sight (LOS), therefore, the direct primary 14.1MeV D-T neutrons through port or opening on the target bay wall can be maximized at all cases. The calculations were mainly performed with a mono-energetic D-T neutron source (14.1 MeV) and some with the continuous neutron spectrum emitted from a NIF target with a 9 MJ yield calculated by LASNEX[2].

II.C. Requirement

The estimation of the fraction of the down-scattered neutrons to lower energies by nuclear collisions (elastic scattering or (n,2n) reactions) inside the compressed target core from 14.1 MeV neutrons has been proposed as a measure of the target fuel areal density $< \rho R >$ (radial integral of density) of laser fusion targets[3]. The measurement of the target fuel ρR requires that the background at ~ 6MeV from scattered neutrons should be significantly less than 10^{-3} of the 14.1 MeV primary D-T neutron peaks [3,4].

III. RESULTS

III.A. Detectors just outside of chamber in the (116,335) direction, r=565 cm from TCC

In order to examine scattering impact of entrant equipment inside chamber, the background scattered neutron were compared for both a ‘full’ and ‘empty’ target chamber with two neutron spectra (mono-energetic and LASNEX). The ‘full’ chamber consists of all major entrant equipment: eleven Diagnostics Instrument Manipulators (DIM), two Static X-ray Imagers (SXI), and one Target Positioner. (See Figure 1.) This is expected to represent a worst case scenario for in-chamber neutron scattering. Although some variations in energy deposition were obtained for “full” or “empty” chamber with D-T 14.1 MeV mono-energetic or spectrum neutron sources as seen in Figure 2, the background levels for all cases are too high ($\sim 10^{-2}$) even with “empty” chamber and this cases did not give the minimum required 10^{-3} difference in energy deposition for 14.1 and 6 MeV neutrons to measure the target fuel areal density.

III.B. Detectors outside target bay wall in the (90,315) direction, r=1707 or 1907 cm from TCC with collimator

One way to reduce background scattered neutron contribution is to move the detector away from the concrete target chamber where a large amount of scattering is occurred. Furthermore, applying collimator between neutron source at TCC and detector can reduce the background contribution to detectors. Several cases were examined for the detectors placed outside the target bay wall, one (D1) just outside the concrete target bay wall (r=1707 cm) and the other one (D2) placed 2 m away (r=1907 cm) from the first detector, D1. Various sizes of collimators at the chamber port or target bay wall were applied to measure the effect of collimation as shown in Figure 3. All analyses were performed for the target chamber with a target positioner (latitude 90°: longitude 239°) inside with a mono-energetic (14.1 MeV) neutron source at TCC. Pure iron (Fe) and concrete materials were considered as collimators for the port or target bay wall, respectively. As shown in Figure 4 for the detector D1, the best case is the one having a tight collimator on both port on the chamber and target bay wall. The difference in primary and scattered neutron contribution for this case is more than 10^{-9}. The case having the same collimator on the target bay wall only gives a little more background contribution than the previous best case; however, this case also gives an acceptable margin of the difference in the primary and scattered neutron contribution. All cases without a collimator on the target bay wall give a large amount of scattered neutron contribution, therefore, applying a tight collimator to the target bay wall is essential to reduce background scattered neutron contributions. Moving the detector back (D2 detector cases) produces a similar trend as in the case of the D1 detector. The collimation for the D2 detector is slightly more effective as seen in Figure 4.

IV. CONCLUSIONS

The background scattered outside of chamber is too high for the measurement of the target fuel areal density <ρR> (radial integral of density). When detectors move to outside the target bay wall with tight collimation on both the chamber port and the target bay wall, the background at ~ 6 MeV from scattered neutrons is much less than 10^{-3} of the primary 14.1 MeV neutron peak.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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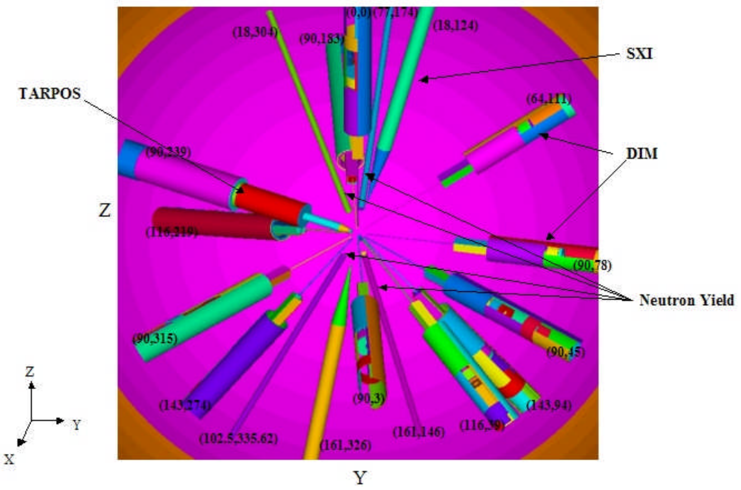


Figure1. 3-D Tart Model of NIF chamber including all major entrant equipments

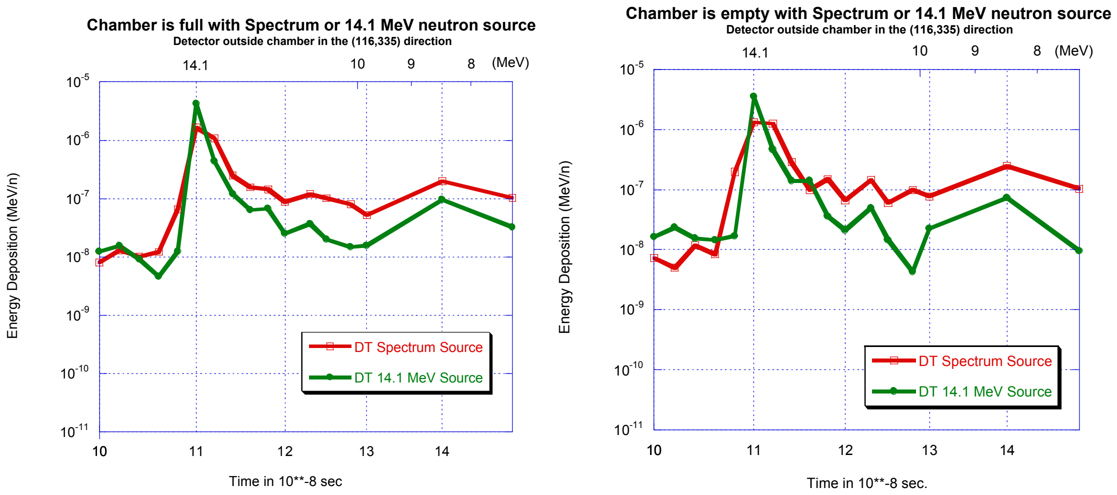
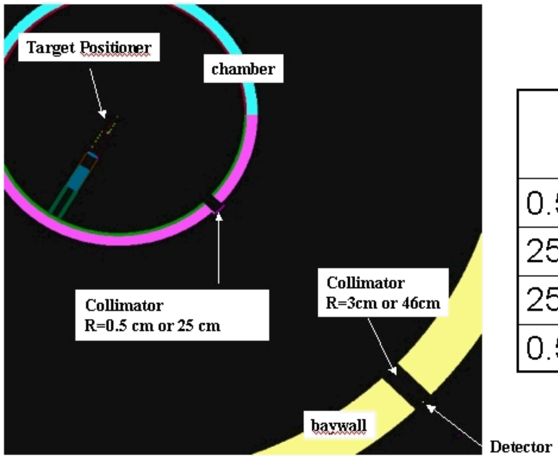


Figure 2. Energy depositions at detector outside chamber (r= 565 cm) with 'full' and 'empty' NIF chamber



Port	Bay wall
0.5 cm	3 cm
25 cm	46 cm
25 cm	3 cm
0.5 cm	46 cm

Figure 3. Various sizes of collimator applied at the chamber port and target bay wall

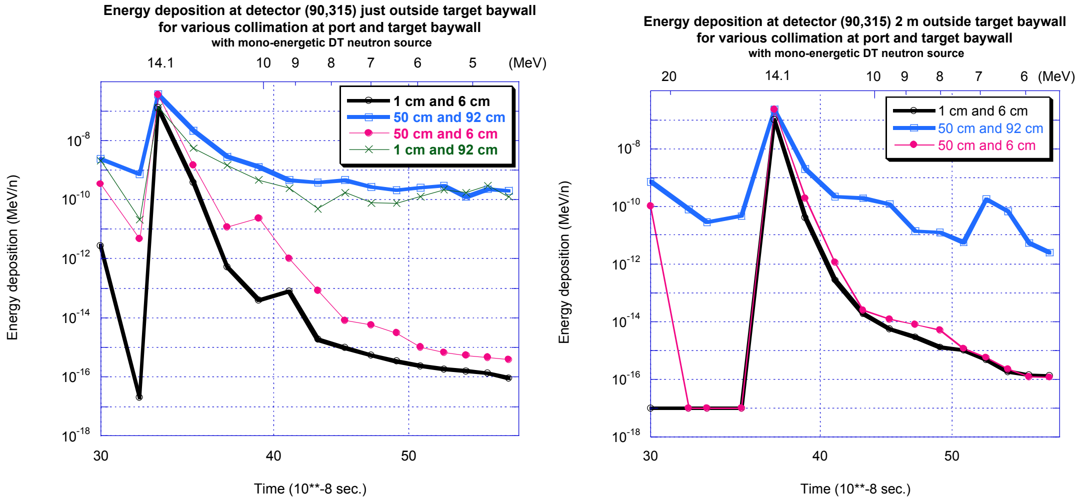


Figure 4. Energy depositions at detectors outside target bay wall with various collimators at chamber port and target bay wall (r=1707 for D1 and 1907 cm for D2)