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Design of a north pole Neutron Time-of-Flight (NTOF) system at NIF

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Abstract. A north pole NTOF system for neutron spectroscopy is being implemented at the NIF. The design is centered around a fast scintillator with low mass housing fielded 21.6m from target chamber center at $\theta = 18°$, $\phi = 304°$. The line-of-sight (LOS) features a primary port collimator, two secondary collimators in the intervening concrete floors, and a beam dump with a backscatter shield. Because the detector is being fielded on the roof of the NIF building, diagnostic options such as optical and electrical attenuation are remotely controlled, saving setup time and increasing shot rate. The expected performance of the diagnostic is excellent with high sensitivity to both high-energy reaction-in-flight neutrons as well as lower energy down-scattered neutrons.

1. Introduction

For several years now, observed asymmetries of the NIF cryogenic DT layered implosions have been discussed at great length because of their impact on the performance (yield) of these experiments. Recently, a fully 3D simulation, with a significant P1 asymmetry imposed upon it, shows drastic anisotropies in ion temperature, down-scattered neutron (DSN) ratios, and neutron activation as well as DD and DT neutron peak shapes, consistent with observed data[1]. The changes in peak shapes can be so prominent that a new ad hoc parameterization, that includes elements of skew and kurtosis, was created to better describe the emerging neutron spectrum in velocity space [2] and is currently being incorporated into the NTOF data analysis[3]. Concurrently, the flange neutron activation diagnostic (FNAD) has shown that the cryogenic layered implosions exhibit a systematic collection of fuel mass at the north pole[4], but no other neutron detector is located there to confirm this observation.

As a result, the NIF is deploying a spectroscopic NTOF detector atop the target chamber at NIF (θ=18°). The detector package is identical to the other three LOS of spectroscopic neutron detectors ($\theta - \phi$ = 90°-174°, 116°-316°, and 151°-56°) that are based on a low-mass (low scatter background) "JacBlac" housing and an octagonally-shaped, bibenzyl organic scintillator 10cm across by 2.5cm thick [5]. The LOS penetrates the target chamber, two floors, the target bay ceiling, and terminates in a hut on the roof of the NIF building.
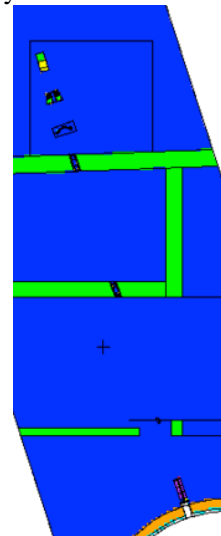
2. System Overview

The system was designed to produce maximum sensitivity to desired neutrons while minimizing scattered and background radiation. The detector is placed 21.6m away from target chamber center

(TCC) and will occupy the 18°-304° LOS on the NIF. A port collimator is located between 6 and 7 meters from TCC. The LOS penetrates two floors, one steel, the other concrete, and the NIF ceiling before intercepting the detector and terminating in the beam dump. **Figure 1** shows the engineering rendering/drawing of the LOS, and **Figure 2** shows the simplified MCNP6 [6] model. The modeling activities drive the design requirements and ultimately the layout of the LOS elements.
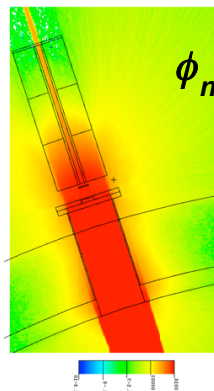

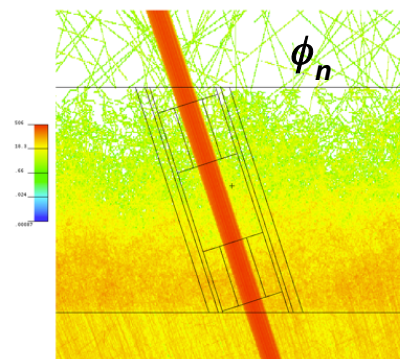**Figure 1.** LOS layout. Primary neutron beam is the red line and terminates on the detector.

Figure 2. Two-dimensional slice from MCNP6 model of Fig. 1.

3. Collimation

The port collimator defines the beam. The port collimator is 33" long (constrained by facility layout) and consists of borated HDPE with a copper sleeve insert. The sleeve has a cone-shaped aperture that matches the divergence of the beam to minimize intra-collimator neutron scattering and gamma-ray production. The collimator endplate is made of tungsten to reduce the flux of the 477 keV gamma-rays at the scintillator created by low-energy neutron capture in the boron in the borated HDPE.

Figure 3. Port collimator simulation showing neutron flux and emergence of beam at downstream end.

Figure 4. Floor collimator simulation showing a beam of neutrons that has been formed by passing through the port collimator.

Simulations of the LOS with a directed neutron beam demonstrate the efficacy of the collimator (**Figures 3, 4**). The flux of neutrons and gamma rays through the sides of the collimator is attenuated by more than a 1000 times, more than that provided by the target chamber aluminum and concrete.
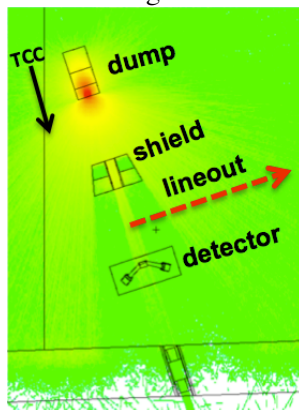
4. Detector and recording

The detector is based on the JacBlac design [5] and is designed to optimize the signal to background. The detector assembly is mounted on a light-weight frame 1 meter above the floor to minimize scatter background.

Several features of the detector mount are unique to this north pole NTOF installation. The neutral density filters are automatically insertable, mounted on a wheel that is remotely controlled. Programmable electronic attenuators are also used. Tektronix DPO7254 scopes will record the photodetector (Photek photomultiplier and photodiode tubes) signals after approximately 10m of LMR600 cable. The system is similar to other fielded NTOF systems described elsewhere [7].
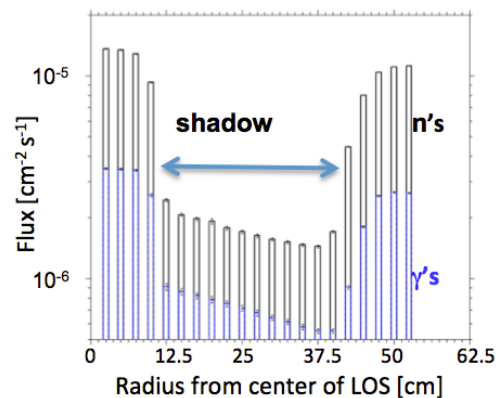
5. Beam dump and backscatter shield

A beam dump and backscatter shield combination stops the beam while shielding the PMTs from backscattered radiation from the dump. The beam dump is constructed of 18" of steel and 12" of concrete in the beam direction, and is a 12" square in cross section. The backscatter shield is constructed of 8" of lead plates and a truncated cone of concrete .

The efficacy of the backscatter shield can be judged by looking at the shadow cast upon the PMTs. **Figure 5** shows the gamma ray flux from a MCNP6 simulation where neutrons are striking the beam dump. The PMTs clearly reside in the shadows of the backscatter shield. The shield casts a "shadow" on the PMTs and the background reduction within the shadow is approximately 4x (**Figure 6**).

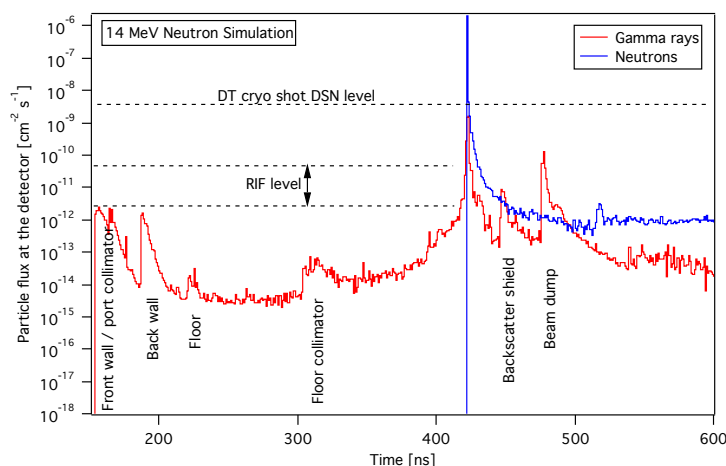**Figure 5.** Gamma ray flux showing shadowing of PMTs from backscattered radiation from beam dump.

Figure 6. Flux vs radius from center of LOS behind the backscatter shield (lineout of Fig. 5). The depth of the "shadow" cast by the shield is about 4x for both neutrons and γ-rays.

6. Expected Performance

The NP NTOF LOS is designed using MCNP6 simulations to keep scattered radiation to levels lower than true diagnostic signal levels. **Figure 7** shows a simulation of the temporal flux of neutrons and gamma-rays arriving at the detector. The simulation starts DT neutrons (E=14.029 MeV) at *t=0*. The bumps in the gamma-ray flux (red) are created when neutrons strike objects in the LOS. For a cryogenic layered DT shot, both high and low energy neutrons carry diagnostic value. The down-scattered neutrons in the range of 10-12 MeV are a measure of the compression/convergence of the capsule and the subsequent ρR of the fuel over the burn duration. Note that the background radiation

in that time window from 455-498ns is lower by at least an order of magnitude. The high energy neutrons arriving before the primary DT neutrons are "reaction-in-flight" (RIF) neutrons, coming from up-scattered D and T fusing with stationary fuel atoms creating higher energy neutrons up to 32 MeV. Those neutrons are hard to measure due to the low levels (typically ~10^{-5} of the primary neutrons) and are a very sensitive measure of cold fuel areal density and mix [8]. Figure 7 shows that the background radiation should not be a significant issue for measuring the RIF neutrons. Even accounting for possible errors of up to 2.5x in the simulation, the RIF window (from 283 to 408 ns) provides a high signal to background ratio.

Figure 7. Neutron (blue) and gamma-ray (red) flux at the detector.

7. Summary

A north pole NTOF LOS is being built and will provide high fidelity neutron spectral measurements from NIF implosions. The LOS has been carefully designed to minimize background radiation from interfering with sensitive diagnostic measurements such as DSN and RIF, while maximizing sensitivity to the neutron signal of interest.

8. References

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