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Calibration and Operation of a Neutron Time-of-Flight Scintillator Array on Nova

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The Tion diagnostic is a 1020-channel scintillator array on the Nova laser at Livermore. It measures the arrival time of single $d-d$ or $d-t$ neutrons at 27 m from the target with a time resolution of 4 ns. The effect of neutron scattering has been obtained from Monte-Carlo neutron transport simulations and the scattered response is convolved with a gaussian source to fit the data. The data analysis has been checked using targets which produce roughly equal numbers of $d-t$ and $d-d$ counts. The spectrum from Tion is in reasonable agreement with conventional neutron time-of-flight detectors at yields above 3×10^8 .

The neutron energy spectrum from inertial confinement fusion (ICF) targets provides important information about the distribution function of the reacting deuterium or tritium ions. For example, the spectrum may contain information about the temperature,¹ areal density,^{2,3} and fluid motion of the reacting ions.⁴ Because the neutron production time is typically ≤ 1 ns, the spectrum can be obtained from time-of-flight (TOF) measurements. In many ICF targets, the yield is too low to obtain accurate spectra using conventional current-mode TOF detectors.⁵ Single-neutron-interaction detector arrays^{6,7} can be used to increase sensitivity while maintaining good time resolution in order to extend neutron spectroscopy to low-yield targets.

The Tion (“Tee-ion”) detector array was designed to obtain neutron spectra from targets on the Nova laser at Livermore. Each detector channel consists of a scintillator, photomultiplier, constant-fraction discriminator, and time-to-digital convertor (TDC) connected to a data acquisition system. Details of the detector and electronics are available elsewhere.⁸ Tion covers neutron yields from 2×10^6 to 2×10^9 using three interchangeable sets of 1020 scintillators with volumes of 0.16, 0.79, or 3.53 cm³, thus spanning the gap between the Large Neutron Scintillator Array⁷ (LaNSA) and nTOF detectors on Nova.⁹ In this paper, we describe the detector calibration and data analysis procedure, and compare Tion results with those of a current-mode TOF detector.

The detector calibration includes the detector response time, deadtime correction, time differences between channels, and neutron scattering effects. The TDCs (LeCroy model 1879) are operated with 2.8-ns sampling in order to record x-rays as well as *d-d* neutrons within their 512-bin memory. X-rays provide a time fiducial and resolution check on most Nova shots. The width of the x-ray peak is typically 4 ns FWHM.

After receiving a “hit,” a TDC channel cannot record another signal for an interval

known as the deadtime. This deadtime is measured by generating a histogram over detector channels of the times between successive hits in a single channel. The deadtime is used to correct the data for the reduction in live channels available at each time bin.

Time differences between detector channels arise from variations in photomultiplier voltage, cable lengths, and propagation lengths within the discriminators and TDCs. The time differences are measured using a 360-kV, 5-ns, low-jitter x-ray pulser¹⁰ located 4 m from the detector. Since the time differences between channels are obtained with typical uncertainties of 1 ns (better than the TDC sampling), the time-corrected data are stored in 1.4-ns bins to prevent additional loss of resolution. A minimum of ten separate x-ray pulses is required for averaging to avoid “odd-even” asymmetries that can result from rebinning the data.

The detector response is affected by neutron scattering from a variety of sources, including the Nova vessel wall, air in the flight path, the collimator formed by a hole in the wall of the Nova building, lead shielding in front of the detector, and materials within the detector. These effects have been simulated using the Monte Carlo code MCNP¹¹ to transport d - t or d - d neutrons. The calculated time response for a delta-function d - d source is shown in Figure 1. Most of the scattered response is due to backscattering from materials used to support the photomultipliers.

The data analysis is shown in Figure 2 for a group of shaped-drive Nova implosions. The deadtime-corrected data is fit with the convolution of the scattered neutron time response, the electronic time response (a 4-ns FWHM gaussian), and the neutron arrival times from an assumed gaussian energy spectrum at the target. The data are weighted using errors determined from the square root of the number of counts in each bin (estimated from the fit) and from deadtime uncertainties. The fitting procedure was tested in numerical experiments and confirmed for spectra containing as few as 50 counts. The burn-weighted fuel temperature is

inferred from the FWHM width ΔE of the gaussian using the relation¹ $T_i(\text{keV}) = (\Delta E / (82.5 \text{ keV}))^2$. For d - t neutrons, the denominator is 177 keV.

The accuracy of the calculated detector response can be tested using targets producing both d - t and d - d neutrons. Figure 3 shows the neutron spectra from two glass microballoon targets filled with 99% deuterium and 1% tritium gas. Both spectra should reflect the same ion temperature, but the d - t peak is much more strongly affected by the detector response. The inferred temperatures for the two reactions are in reasonable agreement, but some additional modification in the tail of the scattered d - t neutron response may be required.

Temperatures from Tion have been compared with those obtained from a current-mode TOF detector, located 5.87 m from the target, in the range of yields from $0.3 - 2 \times 10^9$ where both detectors should provide accurate data. The comparison (Figure 4) shows general agreement between the two independent diagnostics, with perhaps a 10% systematic shift. It should be noted that the current-mode detector response was obtained from a d - t neutron burst and may be slightly narrower for less energetic d - d neutrons. In addition, the Tion flight path is nearly along the hohlraum axis for Nova targets while the current-mode detector is nearly orthogonal to the hohlraum axis. Therefore, the Tion and current-mode TOF detector spectra may be affected differently by mass motion in Nova targets.

In summary, the Tion diagnostic provides neutron energy spectra over a range of yields between those covered by the LaNSA and current-mode neutron diagnostics. The neutron spectra from 1% tritium, 99% deuterium targets are in reasonable agreement with the source spectra from a single ion temperature convolved with the calculated detector responses. The fuel temperatures inferred from Tion spectra are in general agreement with a current-mode TOF diagnostic in their overlapping range of neutron yields.

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Figures

FIG. 1. Monte-Carlo neutron transport simulation of d - d neutrons for the Tion diagnostic.

The separate curves indicate the effects of neutron scattering before reaching the detector, scattering within the detector, and the convolution of both sources of scattering.

FIG. 2. The d - d neutron spectrum from an ensemble of similar Nova targets. The fit is the convolution of a gaussian with the calculated detector response.

FIG. 3. Neutron spectra from two directly-driven glass microballoon targets filled with 1% tritium and 99% deuterium gas showing the (a) d - t and (b) d - d peaks.

FIG. 4. Comparison of fuel ion temperatures inferred from Tion and a current-mode neutron time-of-flight detector located 5.87 m from the target.

Figure 1
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Figure 2
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Figure 3 E4-P2-68

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