Measurement of DT Fusion and Neutron-induced Gamma-rays using Gas Cherenkov Detector

Y Kim, H W Herrmann, S Evans, T Sedillo, J R Langenbrunner, C S Young, J M Mack, A McEvoy, C J Horsfield, M Rubery, Z Ali, and W Stoeffl

1Los Alamos National Laboratory, Los Alamos, NM 87545, USA
2Atomic Weapons Establishment, Aldermaston, Reading, RG7 4PR, UK
3National Security Technologies, Livermore, CA, 94550, USA
4Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

E-mail: yhkim@lanl.gov

Abstract. A secondary gamma experiment was carried out using a Gas Cherenkov Detector (GCD) at the OMEGA laser facility. The primary experimental objective was to simulate neutron-induced secondary gamma production (n-γ) from a NIF implosion capsule, hohlraum, and thermo-mechanical package. The high-band width of the GCD enabled us to detect time delayed and Doppler broadened n-γ signals from five different puck materials (Si, SiO$_2$, Al, Al$_2$O$_3$, Cu) placed near target chamber center. These measurements were used for MCNP & ITS ACCEPT code validation purposes. By a simple change of the GCD CO$_2$ gas pressure the system can effectively eliminate signals induced by n-γ reactions and thereby allow quality measurements of DT fusion γ-rays that are produced at NIF (National Ignition Facility).

1. Introduction

A Gamma Reaction History (GRH) diagnostic which measures 16.75 MeV DT fusion γ-rays (DT-γ) has been developed by Los Alamos National Laboratory in collaboration with Lawrence Livermore National Laboratory, Atomic Weapons Establishment, and National Security Technologies [1]. The fast time response of the GRH will make it an important instrument for fusion studies at NIF. A complete system impulse response with a single-stage, micro-channel plate (MCP) photomultiplier tube (Photek PMT110), Mach Zehnder transmission line, and 12 GHz digitizer (Tektronix TDS5124) has been measured to be 93 ps fwhm with 62 ps 10%-to-90% rise time; fast enough to measure the 80-150 ps burn widths expected from the THD campaign planned for the Spring of 2010 at NIF. The GRH signal performance could possibly be compromised by an interference of various neutron-induced secondary γ-signals (n-γ) with the primary DT-γ output. For instance, indirect-drive NIF implosions produce 14 MeV DT neutrons that induce the production of n-γ from 1) implosion capsule (e.g., $^3$C, $^{16}$O, Be, etc.), 2) hohlraum (e.g., Au, U, etc.), and 3) thermo-mechanical package (TMP) (e.g., Si, Al, etc.). Experimental characterization of the GRH response to these various gamma rays is necessary to ensure accurate measurements of NIF fusion reaction history.
The primary experimental objective was to simulate n-γ production from a NIF implosion capsule, hohlraum and TMP materials. A secondary gamma experiment (a.k.a., “hockey puck” experiment) was carried out using a Gas Cherenkov Detector (GCD) at the OMEGA laser facility. Three groups of pucks were placed between TCC and GCD: 1) SiO$_2$, Al$_2$O$_3$, and BeO pucks for glass and Be implosion capsule n-γ; 2) Au and Cu pucks for hohlraum n-γ; 3) Al and Si pucks for TMP n-γ. This paper describes the n-γ characteristics measured by the GCD and how the GCD can minimize DT-γ interference from n-γ.

2. Experimental Methods

The GCD used for these studies is described in greater detail elsewhere [2]. Briefly, fusion gammas are converted to relativistic electrons primarily through Compton scattering and pair production in a beryllium converter on the front of the detector. Electrons traveling faster than the speed of light in the gas then produce Cherenkov radiation as they travel through a pressurized CO$_2$ gas cell. The pressure of CO$_2$ in the gas cell determines the index of refraction and thus speed of light in the medium, hence establishing a variable energy thresholding capability. This UV/visible light is then collected onto an ultra-fast PMT and the signal is recorded on high bandwidth recorders. Figure 1 shows a schematic of the GCD converter and associated secondary γ-ray puck. Pucks were placed between TCC and GCD at a distance d = 5.8 cm (or 5.665 cm, depending on the type of puck). The pucks had a diameter D =$30$ mm (or 25.4 mm), and a thickness t = 5 mm (or 6.35 mm). A puck holder made of Aluminum was used to hold a puck and attached to the nose corn of the GCD. The GCD nose cone was located 20 cm away from TCC.

3. Experimental Results

Figure 2(a) shows time-dependent gamma-ray signals from DT-filled plastic capsule implosions measured without puck and puck holder to serve as a baseline (black curve, shot 54449, DT-n yield = 2.67e13), and with a Si puck in the holder (red curve, shot 54453, DT-n yield = 2.50e13). 60 laser beams were used with a total energy of 23 kJ of UV light on target. Silicon puck (D = 25.4 mm, t = 6.35 mm) was placed 5.665 cm away from TCC for shot 54453. The CO$_2$ gas pressure in the GCD was fixed at 100 psia, which corresponds to a threshold energy ($\gamma_{th}$) of ~ 6.3 MeV. Both γ-signals are normalized by neutron-yield and a MCP gain value of 521. Time zero is placed at the highest peak of signals (peak B) for convenience.
Without puck (black curve), reproducible DT-γ signals are measured and served as baseline for n-γ study. As explained in ref 2, a precursor (peak A) and a DT-γ (peak B) are detected. With puck (red curve), new signal peak (peak C) was observed at the 948 ps later. The time interval measured between peaks B and C (= 948 ps) is quite consistent with the expected time-of-flight difference between DT-γ and 14 MeV neutrons (~ 163 ps/cm) incident on the Si puck (= 163 ps/cm × 5.665 cm = 923 ps). Si n-γ signal shape was compared with that of DT-γ by normalizing each peaks (B and C) with their own peak height and overlaying peak C and B. Shown in Fig. 2b, full-width half maximum (FWHM) of the Si n-γ signal was 205 ps, which is wider than that of DT-γ signal (166 ps). The measured Si n-γ FWHM was quite close to the estimated value (~ 207 ps = (166^2 + 16^2 + 123^2)^1/2 ps) by taking account of 1) measured DT-γ FWHM (= 166 ps), 2) neutron Doppler broadening time (~ 16 ps at 5.665 cm) and 3) geometrical temporal spreading as the neutrons penetrate the puck (~ 123 ps). High-band width of the GCD enabled us to detect time delayed and Doppler broadened n-γ signals from the puck.

Four more puck materials (SiO_2, Al_2O_3, Al, and Cu) were tested with E_θ kept at 6.3 MeV. Two shots were carried out for each puck. Each n-γ signal is normalized by corresponding neutron-yield and MCP gain. The baseline-subtracted n-γ signals are overlaid and shown in the vicinity of peak C in Figure 3. The silicon puck produced the strongest secondary signal ratioed to the DT-γ signal (n-γ/DT-γ ~ 27 %). The n-γ/DT-γ of SiO_2 and Al_2O_3 were similar at ~12 %. The n-γ/DT-γ of Al was ~ 9 %. Copper produced the weakest n-γ above 6.3 MeV at n-γ/DT-γ ~ 7 %. Measured n-γ signals for the five puck materials are used as simulation codes validation purpose such as a MCNP (Monte Carlo N-Particle) code for n-γ production and an ITS ACCEPT code for GCD spectral sensitivity.

Using the Si puck, we changed the GCD threshold energy from 6.3 MeV (= 100 psi) to 8 MeV (= 64.5 psi) and 10 MeV (= 42.3 psi) to investigate relative sensitivity of the GCD to DT-γ at 16.7 MeV and n-γ’s primarily above E_θ. Figure 4 shows three measurements of DT-γ and Si n-γ as a function of GCD E_θ. Precursors (peak A) are not affected by changing E_θ.
of GCD due to the fact that precursor is caused by prompt DT-γ and capsule n-γ, or their relativistic electrons, shining directly onto the PMT without incurring the 0.5 ns delay associated with a folded path in the GCD Cassegrainian optics. DT Cherenkov gammas (peak B) are reduced as the overall sensitivity of the GCD drops with increasing $E_{th}$. However, the Si n-γ signals are reduced much more significantly than the DT-γ signal. At $E_{th} = 6.3$ MeV, n-γ/DT-γ was about 27%. At $E_{th} = 8$ MeV, the ratio dropped to ~ 9%. At $E_{th} = 10$ MeV, the secondary signal was very small and the ratio was < 3%. This threshold energy scan result demonstrates that secondary gammas can be thresholded out by changing gas pressure of the GCD. The GCD sensitivity to n-γ was simulated using MCNP for the Si n-γ spectrum (red curve in Fig. 4b) and using ITS ACCEPT for the GCD responses to various γ-ray energies (black curve in Fig. 4b) for varying $E_{th}$. Secondary n-γ spectrum decreases as energy increases, with little n-γ occurring above 10 MeV. Therefore, secondary gammas can be thresholded out by increasing $E_{th}$, while the sensitivity to DT-γ at 16.75 MeV is only marginally reduced.

Figure 4a: Three measurements of DT-γ and n-γ as a function of GCD threshold energy.

Figure 4b: Si n-γ spectrum simulated by MCNP (red curve) and GCD sensitivity as a function of threshold energy (black curves).

4. Conclusion

Characteristics of n-γ signals were experimentally studied using a GCD. High-band width of the GCD enabled us to detect time delayed and Doppler broadened n-γ signals from five different puck materials. Excellent GCD sensitivity was shown by measuring five n-γ signals, which were used for MCNP & ITS ACCEPT code validation purposes. By a simple change of GCD gas pressure, the system can effectively eliminate signals induced by n-γ reactions and thereby allow quality measurement of DT fusion γ-rays.

References

[1] Herrmann H W, et al., these proceedings
[2] Mack J M, et al., 2006 Rad. Phys. Chem. 75 551 and references therein