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To cite this article: L Dauffy et al 2008 J. Phys.: Conf. Ser. 112 032085

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Gamma Background Calculation for the HEXRI Diagnostic at the National Ignition Facility

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Abstract. The National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory is nearing completion and the commencement of experiment campaigns leading to ignition. Different parameters of an implosion, such as the neutron yield and images of the target, will be inferred from the measurement of emitted neutrons, gammas, and x-rays using different diagnostics. The High-Energy X-Ray Imager (HEXRI) is one of these diagnostics and will be used on cryogenic Deuterium-Tritium implosions at NIF to provide data on the size and shape of the imploding inertial confinement fusion (ICF) capsules. These data are fundamental for understanding the reasons for ignition failure. Following an implosion, the background from neutrons and photons can be very large and can affect the quality of HEXRI images in terms of lowering the signal-to-background ratio below the threshold of 1. In this work we present Monte Carlo simulations of the n-gamma background from the components present inside the target chamber, i.e. the cryogenic target positioner, the Laser Plasma Interaction collimators, the neutron and HEXRI pinholes, and the hohlraum. We found that the ratio of the self-emission x-ray signal to n-gamma background signal stays well above 1 in all cases, allowing a good HEXRI image quality.

1. The High-Energy X-Ray Imager system
The HEXRI system within the NIF facility is represented in figure 1 and is composed of two scintillators placed on the equatorial plane (θ=90°) at φ=89° and φ=348.7°, at 6 m from the target chamber center (outside the target chamber wall). The angle φ is represented on figure 2. The signal is transmitted through a periscope to the time-gated optical camera that is behind the target bay wall at 20 m from the target chamber center.

1.1. Signals in the HEXRI detector
The system is intended to provide x-ray core images of an imploding ICF capsule by recording the core self-emission x-rays, which are soft x-rays peaking at 13 keV, spreading up to about 100 keV, and produced in the hot fuel of the capsule during implosion. Different signals recorded by the HEXRI, the self-emission x-rays signal S and the background signal B, are the result of the multiplication of an intrinsic signal by the detector’s response and filter function. Background signals are produced by three main sources. The first of them is neutrons, whose spectrum will peak at 14 MeV, and whose yield will be up to $10^{19}$ neutrons emitted in $4\pi$. The second background radiation is the Laser Plasma Interaction (LPI) x-rays, which will be produced in the hohlraum wall by the interaction of the laser beams irradiating the gold, and which will have energies from 10’s to 100’s of keV. The third source is...
gamma rays produced by \( (n,\gamma) \) interactions in components inside the target chamber and whose energies go up to 20 MeV.

Figure 1. Drawing of the HEXRI system as well as other diagnostics, and inner-target-chamber components such as the target positioner.

1.2. Minimizing the different backgrounds

To assure optimum quality of HEXRI images, the signal-to-background ratio, SBR, should be above 1 and as high as possible, thus minimizing the different backgrounds is essential to obtain a HEXRI image with low uncertainty. The SBR is calculated by integrating the recorded core self-emission signal over energy for a certain neutron yield (giving the deposited energy in the detector in MeV/cm\(^2\)), and dividing it by the energy-integrated total background signal. This latter signal is the addition of all background signals such as the ones in figure 4, weighted by the detector and filter function, integrated over energy, and multiplied by the neutron yield.\(^2\)

The first source of background is the 14 MeV neutrons that will take about 120 ns to reach the HEXRI locations (6 m from target chamber center). Time gating on a shorter time will consequently eliminate neutron background. The results presented in this work are calculated within a 50 ns time window, which will allow only photons to have time to reach the HEXRI scintillator. The second source of background, LPI x-rays, will be shielded with two platinum/tantalum collimators in the HEXRI lines of sight (see figure 2), minimizing LPI x-ray background but also creating \( (n,\gamma) \) in the collimators. The contribution of these collimators to the \( (n,\gamma) \) background is presented in the results and discussion section.

The third source of background, neutron-induced gammas \( (n,\gamma) \), is the subject of this study since it cannot be time gated and shielding is sometimes difficult, consequently affecting the HEXRI image quality by decreasing the signal-to-background ratio. Neutrons produce gamma rays when they interact with components, and if this interaction happens within about 2 m from the source (located at target chamber center), then the neutron-induced gammas can reach the detector within the 50 ns window, thus generating background. Indeed a 14 MeV neutron will travel 2 m in about 40 ns and a gamma-ray will travel the remaining 4 m to the HEXRI detector in about 12 ns. Ways to minimize the number of \( (n,\gamma) \) when needed are presented in the results and discussion section.

2. Methods

We used the Monte Carlo code TART to calculate the \( (n,\gamma) \) flux produced in both HEXRI detectors by a 14 MeV neutron source placed at target chamber center, from components present within about 2 m from the center (figure 2). These apparatus are the cryogenic target positioner, the 750 \( \mu \)m Pt / 750 \( \mu \)m Ta LPI collimators (H:10 mm x W:6 mm), the 15 cm x 1 cm x 1 cm Pt neutron pinhole, and different designs of hohlraums (10 \( \mu \)m, 30 \( \mu \)m, and 50 \( \mu \)m thick with and without the structural aluminum can
surrounding the hohlraum, and with and without the silicon cryogenic cooling rings on top and bottom of the hohlraum). The \((n,\gamma)\) flux created in the HEXRI pinhole is not significant and will therefore not be presented in this work.

**Figure 2.** Drawing of the Monte Carlo simulation setup: hohlraum, LPI collimators, target positioner, neutron pinhole, and HEXRI detectors are on the equatorial plane.

**Figure 3.** Drawing of the target, the hohlraum, the aluminum can surrounding the hohlraum, and the silicon cryogenic cooling rings.

Figure 3 represents the ICF target, the hohlraum, the aluminum can, and the silicon cooling rings. Several hohlraum designs have been tested to check the influence of hohlraum and Al can thicknesses on the \((n,\gamma)\) production. The U/Au cocktail is composed of 75% U + 25% Au, and the inner layer Au/B cocktail is composed of 80% Au + 20% B. The 4 hohlraum designs have in common the 0.6 mm thick Si cooling rings, the structural Al can that is 310 \(\mu\)m on the diagnostic band (on the equatorial plane) and 190 \(\mu\)m elsewhere, and the 0.2 \(\mu\)m inner Au/B cocktail layer. The 4 hohlraum designs vary as following (thickness of outer and middle layers): design #1 (2.8 \(\mu\)m Au, 7 \(\mu\)m cocktail), design #2 (23 \(\mu\)m Au, 7 \(\mu\)m cocktail, design #3 (0 \(\mu\)m Au, 30 \(\mu\)m cocktail), design #4 (0 \(\mu\)m Au, 50 \(\mu\)m cocktail).

3. Results and discussion

**Figure 4.** \((n,\gamma)\) flux in HEXRI detectors within a 50 ns window, per \(n_{\text{source}}\), per MeV, produced by the target positioner, hohlraum design #2, neutron pinhole, and hohlraum design #2 + LPI collimators (a). Self-emission x-rays flux in HEXRI detector (for yield = 4.1e16 \(n\)) and HEXRI response function (b).

Figure 4 (a) presents the flux of \((n,\gamma)\) in units of \(\gamma / (\text{cm}^2 \text{ MeV} \ n_{\text{source}})\), reaching the HEXRI (90,89) detector within a 50 ns window, which scales with the yield of source neutrons. Results for the HEXRI
(90,348.7) are similar to those for HEXRI (90,89) and are therefore not shown in these figures. Only curves of \((n,\gamma)\) produced in the target positioner, the neutron pinhole, the hohlraum design #2 (which is the most typical design), the hohlraum design #2 + LPI collimators at 4.6mm and 8mm are shown. Results for other hohlraum designs are presented in table 1 in terms of SBR. Figure 4 (b) shows on the left hand side the self-emission x-ray signal for a 4.1e16 neutron yield (failed ignition caused by 12% too much ablator), signal that does not scale with the yield of source neutrons, and on the right hand side the HEXRI detector’s response. This response has been multiplied to all curves of photon flux, and the signals S and B were obtained by integrating the resulting weighted graphs over the photon energies.

Table 1. Signal-to-Background ratio, SBR, for 3 typical failure modes, for the TARPOS, the hohlraum design #2 + LPI collimators, the neutron pinhole, and the different hohlraum designs.

| Yield \((n \text{ in } 4\pi)\) | SBR \((n,\gamma)\) |
|-----------------------------|------------------|
| TARPOS | #2+LPI col. @ 4.6 mm | #2+LPI col. @ 8 mm | Neutron pinhole | #1 | #2 | #2 w/o (Al+Si) | #3 | #4 |
| 2.6e17 | 90 | 65 | 110 | 28423 | 287 | 204 | 490 | 215 | 172 |
| 1e17 | 30 | 21 | 37 | 9480 | 96 | 68 | 164 | 72 | 58 |
| 4.1e16 | 9 | 6 | 11 | 2853 | 28 | 20 | 48 | 21 | 17 |

Table 1 shows the results for three typical ignition failure modes, with neutron yields ranging from 4.1e16 to 2.6e17 neutrons emitted isotropically. The worse SBR, equal to 6, is found to come from the hohlraum design #2 + LPI collimators placed at 4.6 mm from target chamber center in the 4.1e16 yield case. This SBR is well above the HEXRI image quality threshold of 1. Two target positioners will be placed inside the chamber, thus the \((n,\gamma)\) contribution from both can be conservatively estimated to twice the individual contribution. The SBR from both TARPOS is then about 5, which is also well above the threshold. Furthermore, the TARPOS \((n,\gamma)\) background can be lowered significantly by shielding the apparatus, and the background produced by the LPI collimators can also be lowered by increasing the source-to-collimator distance (for instance 8 mm) and by decreasing the thickness of the collimators. The other components do not produce a significant \((n,\gamma)\) background as can be seen in figure 4 and table 1. The neutron pinhole contribution is irrelevant (at worse 2800 times lower than the main signal), and \((n,\gamma)\) will be produced in the hohlraum at a much lower level than that of the main signal, with at worse a SBR of 21. Using a thinner hohlraum (#1: 10mm vs. #2&3: 30mm or #3: 50mm) or decreasing the thickness of the aluminum can around the hohlraum (#2 w/o Al+Si) decreases the \((n,\gamma)\) flux.

We can therefore be confident that the combined background of these main contributors will not affect the quality of the HEXRI self-emission x-ray images.

Acknowledgements
This work has been performed under the auspices of U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48. UCRL-ABS-234481.

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