

Debris and shrapnel assessments for National Ignition Facility targets and diagnostics

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Abstract. High-energy laser experiments at the National Ignition Facility (NIF) can create debris and shrapnel capable of damaging laser optics and diagnostic instruments. The size, composition and location of target components and sacrificial shielding (e.g., disposable debris shields, or diagnostic filters) and the protection they provide is constrained by many factors, including: chamber and diagnostic geometries, experimental goals and material considerations. An assessment of the generation, nature and velocity of shrapnel and debris and their potential threats is necessary prior to fielding targets or diagnostics. These assessments may influence target and shielding design, filter configurations and diagnostic selection. This paper will outline the approach used to manage the debris and shrapnel risk associated with NIF targets and diagnostics and present some aspects of two such cases: the Material Strength Rayleigh-Taylor campaign and the Mono Angle Crystal Spectrometer (MACS).

1. Introduction

High-energy laser experiments at the National Ignition Facility (NIF) can create debris and shrapnel capable of damaging laser optics and diagnostic instruments [1, 2]. An important aspect of NIF operations, particularly with increased shot rates, is the identification and management of risks to the facility posed by debris and shrapnel. The NIF Debris & Shrapnel Working Group is charged with assessing potential risks, identifying the generation, nature and velocity of shrapnel and debris and the effect they may have on laser optics and target diagnostics and recommending strategies for managing these risks.

The formal approach to debris and shrapnel risk management is captured by the Risk Management Flowchart in figure 1. Hazards are largely due to two sources: 1. Diffuse, consisting mainly of so-called debris wind loads and 2. Local Effects, including shrapnel effects and x-ray ablation. Identification of these hazards for a given experiment may involve previous experience, analytic models, or detailed numerical simulation. The consequences of the identified hazards—potential damage to laser optics and target diagnostics—are then evaluated in terms of severity and probability. These are the risks. The appropriate risk reduction strategy—Avoidance, Mitigation, or Transference—can then be selected. Avoidance modifies the design (target, diagnostic, etc.) to minimize the potential risk. Mitigation applies controls to minimize the impact of risks (required minimum filtration, restrictions on diagnostic reuse, debris tests, inspections, etc.), or Transference (transferring risk to the facility to be accepted). The following case studies present examples of the risk assessment, analysis and management strategies outlined in figure 1.



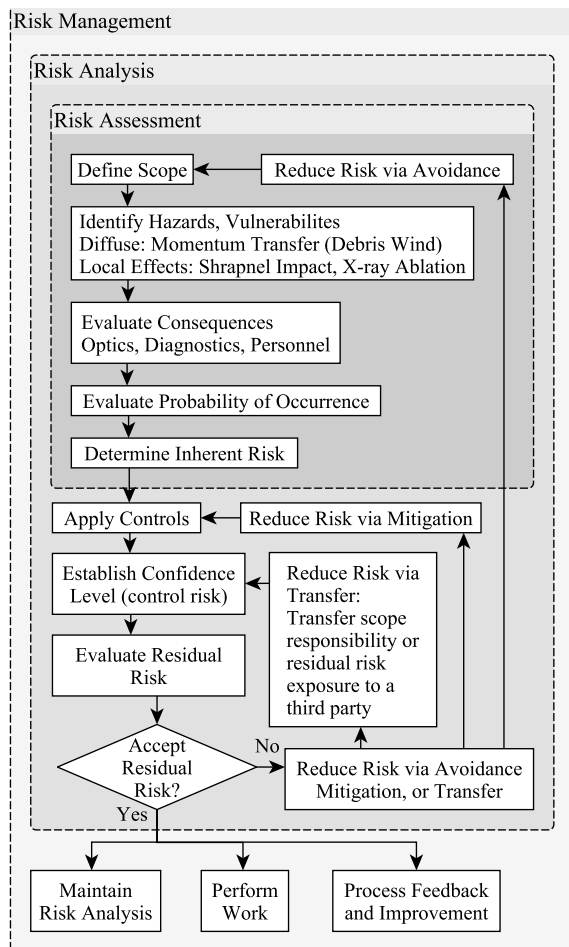


Figure 1: Flowchart of NIF Debris and Shrapnel Risk Management Approach.

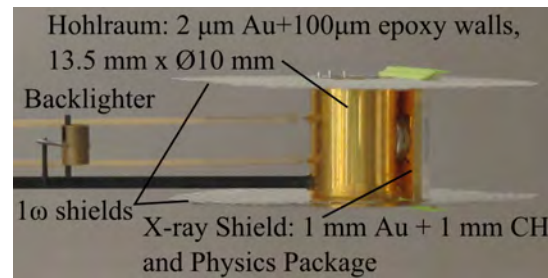


Figure 2: Final Material Strength Rayleigh-Taylor Target design.

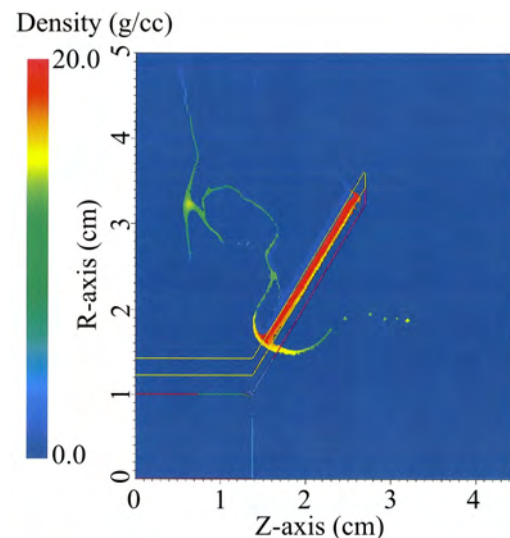


Figure 3: density plot from axisymmetric simulation of large shield MatStrTaRT at 5.5 μ s (z-axis is horizontal and overlay shows initial material boundaries).

2. Case Studies

2.1. Material Strength Tantalum Rayleigh-Taylor (MatStrTaRT)

The MatStrTaRT target, shown in figure 2, is a warm, thin-walled, gold-epoxy target 13 mm long with inner and outer diameters of 10 mm and 10.224 mm, respectively (2 μ m Au+110 μ m CH walls). An 800 kJ laser pulse indirectly drives a planar ablator and tamper to produce Rayleigh-Taylor instabilities in a rippled sample. An x-ray backlighter produces face-on 2D point-projection radiographs of the instability growth and reference samples on image plates in the High Energy Imaging Diagnostic (HEIDI) [3]. These measurements are used to develop material strength models at high pressures and strain rates [4, 5, 6]. HEIDI has a multilayer shielded enclosure (aluminum, tungsten, and hevimet) to reduce fluorescence and high-energy x-ray background. The open hevimet aperture (nominally $\varnothing$ 10.75 mm) is positioned 62.5 mm from TCC.

Background x-ray emissions from the hohlraum and LEH are blocked from entering the HEIDI aperture by a flat 1 mm thick gold shield attached to—and covering the full extent of—the side of the hohlraum. The physics package is mounted in an aperture in this shield. LEH emissions are blocked by extending the shield above and below the LEH at 30° to avoid drive beam interference (see figure 2). Additional dimpled unconverted light shields minimize specular reflections of 1 ω light from the target that could damage laser components. The initial design intended to shield LEH and plume emissions

by extending the shields ≈ 7.5 mm above and below the LEH. Hydrocode simulations of this large shield design predicted significant solid and molten debris directed towards optics with sufficient size and velocity to damage several layers of NIF optics (see figure 3). For example, solid fragments up to 6.7 mg were identified with velocities of ≈ 2 km/s—sufficient to penetrate more than 18 mm of borosilicate glass (a 3.3 mm DDS is predicted to be penetrated by 6.7 mg fragments at velocities greater than ≈ 250 m/s, or alternatively by fragments at 2 km/s with masses greater than ≈ 150 μ g). In terms of Risk Acceptance, superficial damage to the 3.3 mm disposable debris shields (DDS) may be acceptable, but full penetration and any predicted damage to the 10 mm thick Grated Debris Shields (GDS) or other optics is not.

Replacing the 10.75 mm diameter circular HEIDI aperture with a rectangular 6.5 mm $\times$ 10.75 mm aperture (see figure 4) allowed the shield extension to be reduced to 1.1 mm, above and below the LEH. Simulation of the new configuration predicted near full melt of the shield with little directed towards the optics, thus avoiding the risk of the initial design. As such the residual risks—significant x-ray and debris load on the primary diagnostic and only a nominal debris risk to the laser optics—could be transferred and accepted by the facility:

Post shot inspections from many MatStrTaRT shots have found no optics damage resulting from these shots. The HEIDI diagnostic [3] does collect significant debris and shows cratering of the tungsten alloy aperture as shown in the pre- and post-shot images (figures 4 and 5, respectively) of the nose cap from shot N130923. The strip of gold stuck to the aperture is approximately 7 mm $\times$ 1 mm.

2.2. Mono Angle Crystal Spectrometer (MACS)

The MACS diagnostic has been developed for x-ray Thompson scattering spectroscopy of matter and uses a curved Highly-Oriented Pyrolytic Graphite (HOPG) crystal to focus the x-ray scattering signal towards one strip of a NIF Gated X-ray Detector (GXD) [7]. Although the direct line-of-sight to the detector is blocked (see figure 6), the fragile HOPG crystals could be damaged by ablation or debris without x-ray filtration. X-ray ablation simulations found that monolithic or stacked polycarbonate main filter configurations, constrained by a maximum apparent thickness of ≈ 900 μ m (for acceptable signal attenuation), could suffer spall failures and thus would not remove the risk. The addition of a thin tilted prefilter has been identified as a successful risk avoidance strategy; decoupling the x-ray and debris loads by allowing the blowoff from x-ray ablation of the prefilter to be directed away from subsequent filters [8]. A 25 μ m kapton prefilter was selected (based on predicted ablation depth of 7 μ m). The 700 μ m main filter is sized to provide a total apparent thickness of ≤ 820 μ m (the apparent thickness varies due to the tilting of the shields). The main filter covers a 32 mm $\times$ 17 mm aperture and remains subject to significant debris wind loading, despite x-ray decoupling. Five 1 mm wide support aluminum bars—machined as part of the main filter mount—span the height of the aperture to reduce the unsupported span of the main filter. Shadows cast by the support bars reduce the effective width of the curved HOPG crystal but are aligned parallel to the dispersive direction of the crystals and therefore do not interrupt the measured spectra. During a shot, the prefilter is expected to only move a small distance by the time fast moving plasma from the target reaches it. This may explain the patterns of burned and protected regions on the main filter, visible in some post-shot inspections (see figure 7) These inspections have found that this configuration has performed well. However, reuse of the MACS without replacing the prefilter, e.g. for sequential shots, should be avoided to mitigate the risk this would pose.

3. Conclusions

This paper has described some of the influence debris and shrapnel assessments have on the design of NIF targets and diagnostics. Careful assessment of the risks posed by any new target or diagnostic allows the hazards to be avoided or mitigated while facilitating the scientific goals and limiting the risk transferred to the facility. The risk reduction steps taken in the development of the MatStrTaRT target and MACS spectrometer demonstrate Avoidance, Mitigation and Transference strategies.

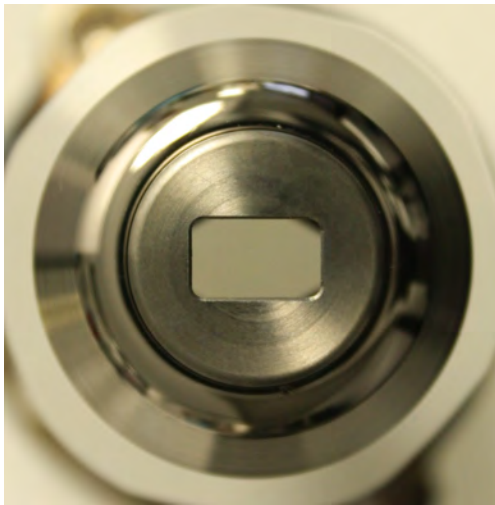


Figure 4: HEIDI nose cap before shot.

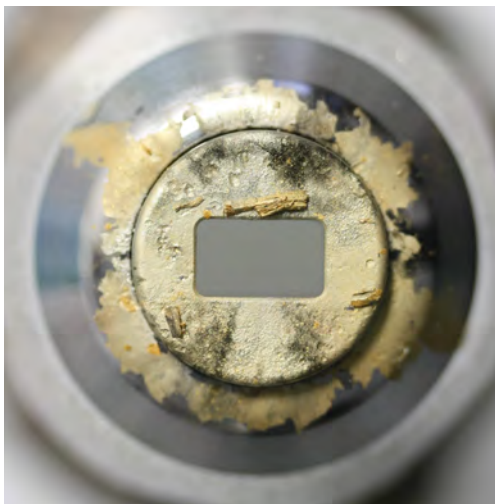


Figure 5: Significant debris deposition following shot, including large gold fragments.

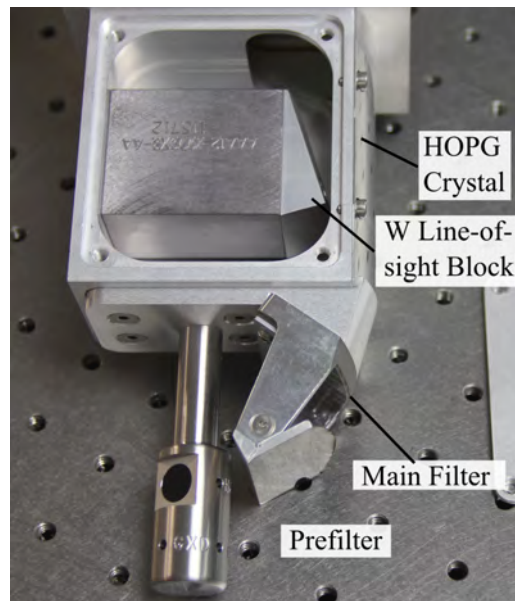


Figure 6: MACS Spectrometer with side panel removed showing line-of-sight block, location of crystals and pre- and main filters.

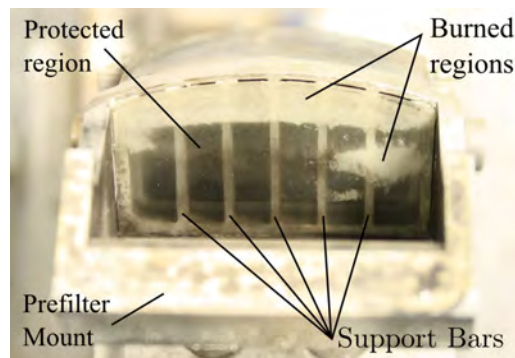


Figure 7: Post-shot inspection of the main filter showing absence of prefilter, main filter support bars and protected and burned regions on the main filter.

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