

# TARDIS-C: A target diagnostic for measuring material structure at high pressure

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**Abstract.** A goal of the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory is to better understand solid matter behavior at extreme conditions. Diagnostic tools such as the Target Diffraction In-Situ (TARDIS) have been designed to record data of solid material compressed to tens of Mbars over short time scales. NIF drive beams ( $\sim 120$  kJ) heat a carefully designed ablator to ramp compress the target to high pressure. A backlighter produces an x-ray source which is diffracted onto image plates through the compressed target. An unimpeded optical path allows Velocity Interferometer System for Any Reflector (VISAR) measurements to be recorded as the compression wave progresses through the target. To reduce the VISAR blast shield's exposure to debris and minimize contamination of the NIF chamber, a transparent barrier has been designed to contain debris within the TARDIS body.

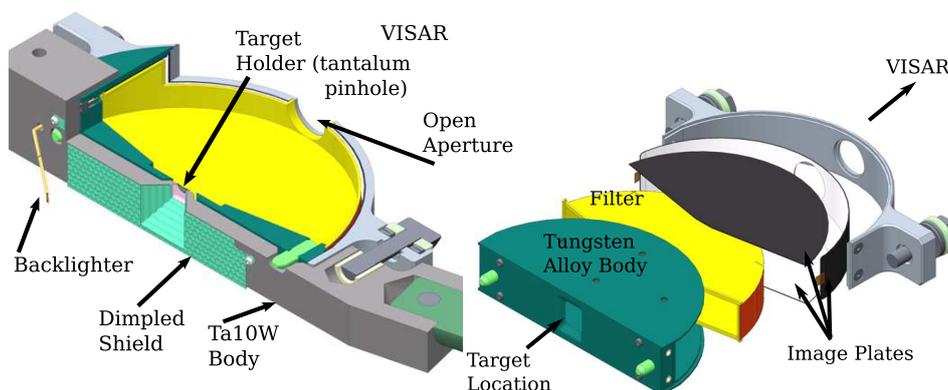
## 1. Introduction

The National Ignition Facility (NIF) is fielding the Target Diffraction In-Situ (TARDIS) diagnostic to understand dynamic phase changes and structural transitions between state of matter at pressures and temperatures comparable to those found in “Super-Earths” (planets twenty times more massive than Earth). Ramp (shock-free) compression of the target material prevents material melting so that a solid matter state is retained while compressed to the extreme densities found in the center of planets. Experiments have been performed which ramp compressed diamond to five terapascals to obtain high pressure equation-of-state (EOS) data [1]. Future experiments include studying the EOS and high pressure melt curves of metals such as iron, and compressing diamond to break and reform atomic bonds from the SC1 state to the BC8 state to determine whether metastable BC8 carbon can exist at ambient conditions [2]. To prevent fast moving debris from these experiments from contaminating the NIF chamber or damaging diagnostics, a transparent barrier has been designed to block the VISAR aperture (Figure 1) while still allowing VISAR to record data, turning TARDIS into TARDIS-C.

## 2. Original TARDIS diagnostic

The TARDIS diagnostic is composed of two distinct components: the target assembly and the diagnostic assembly. Figure 1 contains both a cut-away and blow-out view of the device. The left of Figure 1 labels the components of the target assembly while the right labels the diagnostic assembly. The target assembly holds the target, provides a mount for the backlighter, shields the image plates from x-rays with the tantalum-10-tungsten (Ta10W) body, and is covered by a plastic-coated, aluminum dimpled shield to angularly disperse specular reflections of unconverted  $1$  and  $2\omega$  light to reduce their impact on laser optics. In the diagnostic assembly, the tungsten





**Figure 1.** Two views of the TARDIS assembly, left labels the target assembly while the right labels the diagnostic assembly.

alloy body provides additional x-ray shielding for the reusable phosphorus image plates. Filters help to further reduce background signal from reaching the image plates. The image plates capture the sample's spectrography diffraction lines while the specimen is at peak compression. The backlighter, a thin foil material, emits a quasi-monochromatic He- $\alpha$  x-ray source when it is impinged upon by the lasers. The x-ray signal passes through the compressed sample material and the diffraction lines are then captured on the image plates. The diffraction lines contain information about the target material structure while under compression.

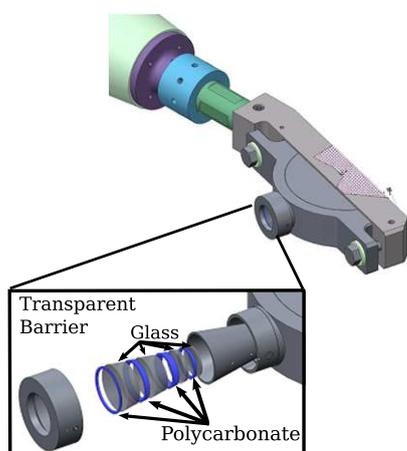
On the side of the diagnostic assembly opposite the target holder, an aperture provides a line of sight for VISAR measurements. VISAR records the target's free surface velocity, allowing the compressed state and drive pressure to be determined. The target material has an unimpeded path from the target holder through the image plate aperture and onto the VISAR blast shield. Further details of the diagnostic design, as well as alignment, operation, and post-shot handling are described in [3].

### 3. Debris threat and transparent barrier design considerations

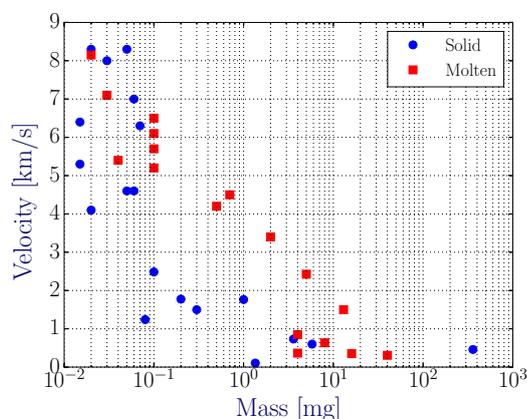
While the NIF drive beams ( $\sim 120$  kJ laser pulse) vaporize or melt most of the ablator and target material, small pieces of unvaporized target debris and the TARDIS tantalum pinhole are driven toward the VISAR debris shield with velocities in the range of several kilometers per second. To prevent damage to the blast shield and to contain debris within the TARDIS body, an optically transparent barrier has been placed in the aperture to VISAR, as shown in Figure 2. To prevent altering the function of TARDIS, design of the barrier was highly constrained. The barrier's size and shape had to maximize the VISAR field of view without shadowing the image plates. External dimensions were limited by beam alignment fixturing. A single pane of protective transparent barrier would not suffice as the shrapnel impact shock would fracture the entire barrier and prevent a visual inspection from assessing whether debris had escaped the diagnostic enclosure. In developing a multi-pane barrier, care had to be taken to ensure the front panes would not cause debris to rebound and reenter the NIF chamber through the target holder entrance. Consideration also had to be given to the failed transparent material to ensure it did not create additional debris which could enter the NIF chamber.

### 4. TARDIS-C: TARDIS modified by a transparent debris "C"atcher

To design the transparent barrier, an estimate of the debris' mass and velocity distribution were obtained from radiation hydrocode (an LLNL code, ARES[4]) simulations of laser interaction



**Figure 2.** Transparent barrier modification to prevent contamination



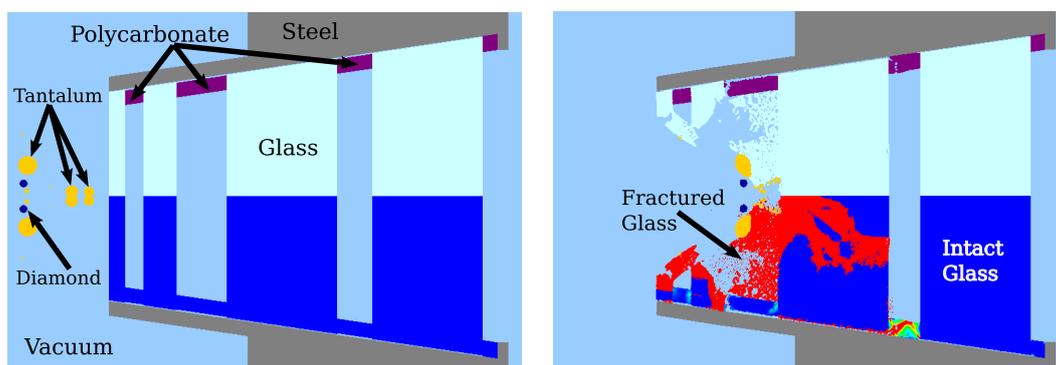
**Figure 3.** Debris field from target and pinhole impacting the transparent barrier

with the target and pinhole. The resulting debris field is shown in Figure 3. The simulations predicted a mass of 468 mg impacting the barrier with a mass averaged velocity of 540 m/s. The debris includes material from both the pinhole and the target package. The molten material is traveling much quicker at 795 m/s but only accounts for 94 mg (20%) while the remaining mass, 374 mg, remains solid and travels with a mass averaged velocity of 475 m/s. A more conservative case, which consisted of all the laser energy being converted to kinetic energy to launch the entire intact pinhole (480 mg at 2,000 m/s) at the barrier, was also considered.

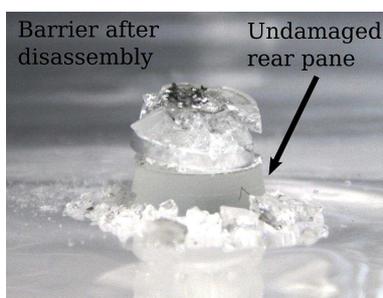
After many design iterations, the final barrier configuration, shown in the left of Figure 4, consisted of four panes of borosilicate float glass. In modeling the barrier, the work of [5, 6] were implemented in a constitutive response which modeled glass subjected to large strains, high strain rates, and high pressures. The constitutive model also accounts for material placement, such as whether the material is in the undamaged bulk, near a surface, or near damaged material. Polycarbonate was also considered for the barrier material, but when used alone as a barrier, it would shock melt and provided inadequate protection due to its relatively low density and melt temperature. When used in combination with borosilicate glass, the polycarbonate would be launched as a flyer plate which then impacted and heavily damaged the other barrier elements. Polycarbonate spacers were used to separate the glass panes, acting to isolate the rear glass panes from the initial debris impact shock and preventing damage of the rear panes. A comparison of the model predictions with experimental observations is shown in Figure 5. The simulations agreed well with the experimentally observed damage; both depict extensive damage to the front two panes, cracking and fracture of the third pane, and an intact, undamaged rear pane.

After much modeling effort, four design considerations which have the largest influence on barrier behavior were observed:

- Thin front glass panes – prevents debris rebounding back through target entrance and allows small, fast moving debris to be captured in the TARDIS body. Debris that does rebound off front glass has significantly reduced velocity
- Large air space between front glass panes – leaves room for debris to spall front panes instead of propagating damage to rear panes
- Thin, compliant spacer rings – minimizes load transmitted between glass panes, protecting rear panes from damage. Polycarbonate spacers minimize shock transmission to the glass
- Dense material is recommended for the barrier as more impact energy is absorbed in accelerating the heavier fragments



**Figure 4.** Transparent barrier, pre and post-impact. Due to design constraints, the barrier had to be less than 26.4 mm in length and have a radius of 11 mm at the VISAR exit and 7.16 mm at the target facing entrance. Top view in each figure shows the material while the bottom view depicts the damage (red→failed material).



**Figure 5.** Transparent barrier recovered post-shot. Front two panes are completely damaged, third pane is in large fragments, while rear pane is undamaged, agreeing with model predictions.

## 5. Summary

A four pane borosilicate barrier is sufficient to prevent debris from contaminating the NIF chamber and damaging the VISAR shield. Thin front panes limit the rebounding of material while thick rear panes prevent material from escaping the barrier and allow a visual assessment to determine whether the barrier failed. Low density materials such as polycarbonate are not recommended for the barrier. If higher shot energies are needed, it may be possible to replace the rear glass panes with a stronger and higher density transparent material, such as sapphire.

## Acknowledgments

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