JSC-66527

International Space Station (ISS) Soyuz Vehicle Descent Module Evaluation of Thermal Protection System (TPS) Penetration Characteristics

Hypervelocity Impact Technology Group

Astromaterials Research and Exploration Science Directorate (KA)

Human Exploration Science Office (KX)

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Engineering and Science Contract Group

February 2013

National Aeronautics and

Space Administration

Lyndon B. Johnson Space Center

Houston, Texas

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Prepared for the

ISS Systems Engineering and Integration Office

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Acronyms and Abbreviations

Al	aluminum
AMg	Aluminum magnesium alloy (Russian)
cm	centimeter
DM	descent module
ESCG	Engineering and Science Contract Group
g	gram
g/cm	gram per centimeter
HVIT	Hypervelocity Impact Technology Group
HVI	Hypervelocity Impact
in.	inch
ISS	International Space Station
JSC	Johnson Space Center
KA	Astromaterials Research and Exploration Science Directorate
KX	Human Exploration Science Office
MLI	multi-layer insulation
mm	millimeter
MMOD	Micrometeoroid Orbital Debris
NASA	National Aeronautics and Space Administration
RHTL	Remote Hypervelocity Test Laboratory
RTV	room temperature vulcanizing
TPS	thermal protection system
VIM	Vacuum insulation material (Russian)
WSTF	White Sands Test Facility

1.0 Introduction

The descent module (DM) of the ISS Soyuz vehicle is covered by thermal protection system (TPS) materials that provide protection from heating conditions experienced during reentry. Damage and penetration of these materials by micrometeoroid and orbital debris (MMOD) impacts could result in loss of vehicle during return phases of the mission. The descent module heat shield has relatively thick TPS and is protected by the instrument-service module. The TPS materials on the conical sides of the descent module (referred to as "backshell" in this test plan) are exposed to more MMOD impacts and are relatively thin compared to the heat shield. This test program provides hypervelocity impact (HVI) data on materials similar in composition and density to the Soyuz TPS on the backshell of the vehicle. Data from this test program was used to update ballistic limit equations used in Soyuz TPS penetration risk assessments. The impact testing was coordinated by the NASA Johnson Space Center (JSC) Hypervelocity Impact Technology (HVIT) Group [1] in Houston, Texas. The HVI testing was conducted at the NASA-JSC White Sands Hypervelocity Impact Test Facility (WSTF) at Las Cruces, New Mexico.

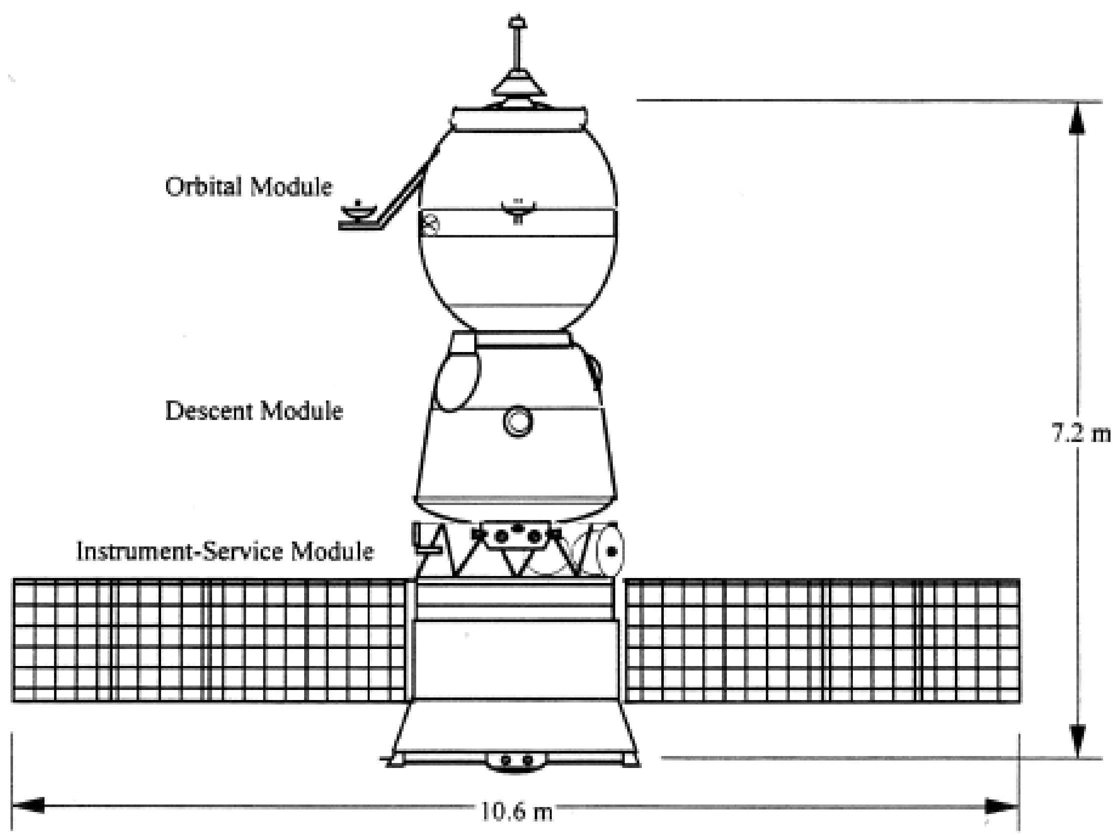


Figure 1 Soyuz vehicle

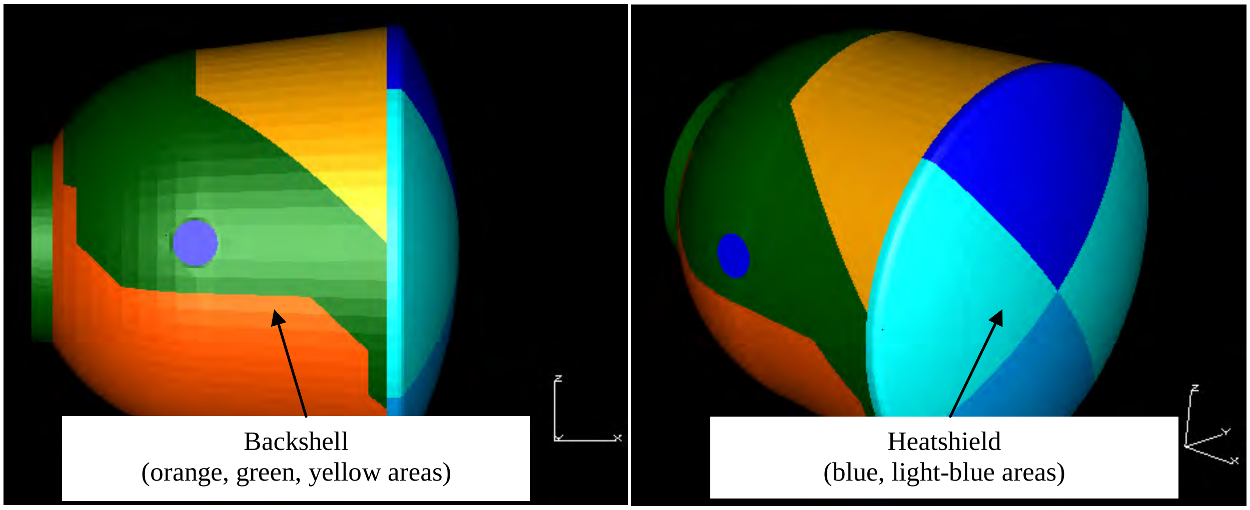


Figure 2 Soyuz Descent Module

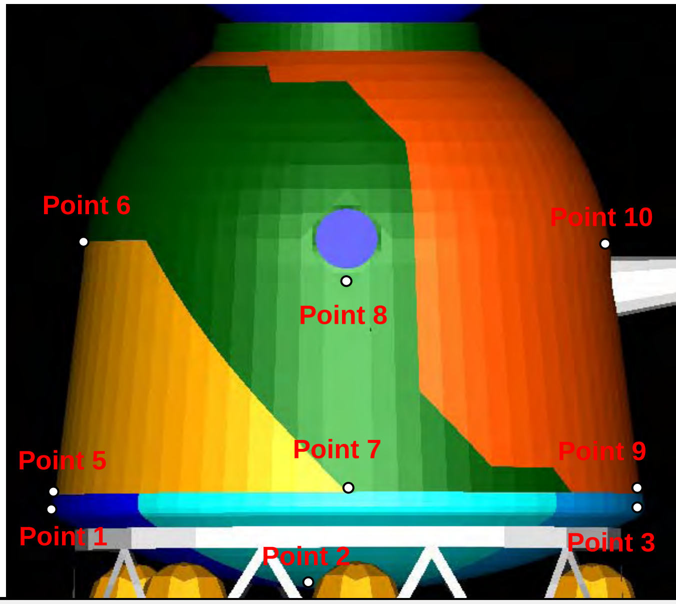
2.0 Objectives

The objective of this hypervelocity impact test program was to determine the projectile size on the threshold of complete penetration of the TPS as a function of projectile density, impact speed and angle. The TPS consisted of an outer ablator material bonded to a fiberglass substrate. Aluminum and 440C stainless steel spherical projectiles were used in the testing. TPS penetration characteristics were evaluated at several impact conditions (velocity and angle combinations).

3.0 Soyuz TPS Description

Figure 3 indicates the type of TPS materials that protect the descent module, and the thickness of these materials. The heat shield materials are represented by points 1-3, whereas the backshell materials correspond to points 5-10. The Soyuz descent module has an offset center of gravity, and the stagnation point during reentry is shifted to one side of the vehicle. That is, one side of vehicle leads during reentry and is the “windward” side of the vehicle, whereas the opposite side trails during reentry and is referred to as the “leeward” side of the vehicle. The windward side of the descent module is exposed to higher heating during reentry, and the TPS materials are therefore thicker on the windward side of the descent module, compared to the leeward side. The backshell TPS is at higher risk of penetration from MMOD impacts, and is the focus of this impact test program. The backshell TPS consists of an ablator (Ftorlon) bonded to a fiberglass substrate. In some places on the backshell (leeward side), no Ftorlon is used. Elsewhere, the Ftorlon thickness varies from 1.0mm to 5.5mm. The backshell substrate is 2.5mm to 4.0mm thick reinforced fiberglass and is attached 41mm to 60mm from the 2.0mm thick aluminum AMG-6 pressure shell (41mm on the windward side, 60mm on the leeward side). There is 28-30mm of VIM (low density silica fibrous insulation) between the backshell substrate and pressure shell (the VIM is attached to the back of the substrate). Although not part of this test plan, the heat shield consists of 21mm to 28mm thick ablator (glass-phenolic composite) which is held by brackets approximately 15mm from the 3.5mm thick aluminum AMg-6 substrate.

VIM low-density silica fibrous insulation (8mm thick) is contained in the gap between the heat shield ablator and aluminum substrate. The 2.0mm thick aluminum AMg-6 pressure shell is approximately 25mm-35mm from the back of the substrate.



Soyuz Descent Module - Thermal Protection Material Thickness (mm)				
Descent Module Point Number	**PKT-11K-FL ПКТ-11К-ФЛ** ρ=1200-1400 kg/m^3, 1.30 g/cm^3 (average)	**Ftorlon (FT)** ρ=1800-1900 kg/m^3, 1.85 g/cm^3 (average)	**TSP-F-N ТСП-Ф-Н** ρ=1600-1650 kg/m^3, 1.625 g/cm^3 (average)	**VIM-2 ВИМ-2** ρ=140-150 kg/m^3, 0.145 g/cm^3 (average)
1	28.0			8.0
2	24.0			8.0
3	21.0			8.0
4 (unused)	-	-	-	-
5		5.5	4.0	28.0
6		4.2	4.0	28.0
7		1.5	3.2	28.8
8		1.0	3.2	28.8
9		1.0	2.5	29.5
10			2.5	29.5

(1) ПКТ-11К-Фл – a laminate plastic (ρ=1,200-1,400 kg/m^3) based on a silicon dioxide/Capron fabric and a phenol/formaldehyde adhesive

(2) ВИМ-2 – a fibrous material (ρ=140-150 kg/m^3) based on super-thin silicon-dioxide fibers and an organosilicon adhesive

(3) ТСП-Ф – volume-reinforced fiberglass (ρ=1,600-1,650 kg/m^3) based on stitched silicon dioxide fabric and a phenol/formaldehyde adhesive, with a sub-layer of ВИМ-2 thermal insulating material

(4) ftorolon (ФТ) – layer of sublimating material (ρ=1,800-1,900 kg/m^3)

Figure 3 Soyuz Descent Module TPS materials

4.0 Test Article Description

The test articles for this test series contain US materials that match as closely as possible the density, composition and mass per unit area of the Soyuz descent module TPS. A majority of the MMOD risk for a TPS penetration is represented by the thinnest areas of the Soyuz descent module backshell (95% of the MMOD risk is represented by the “thin” and “medium” thickness regions of the TPS). Four different test configurations were tested as described below.

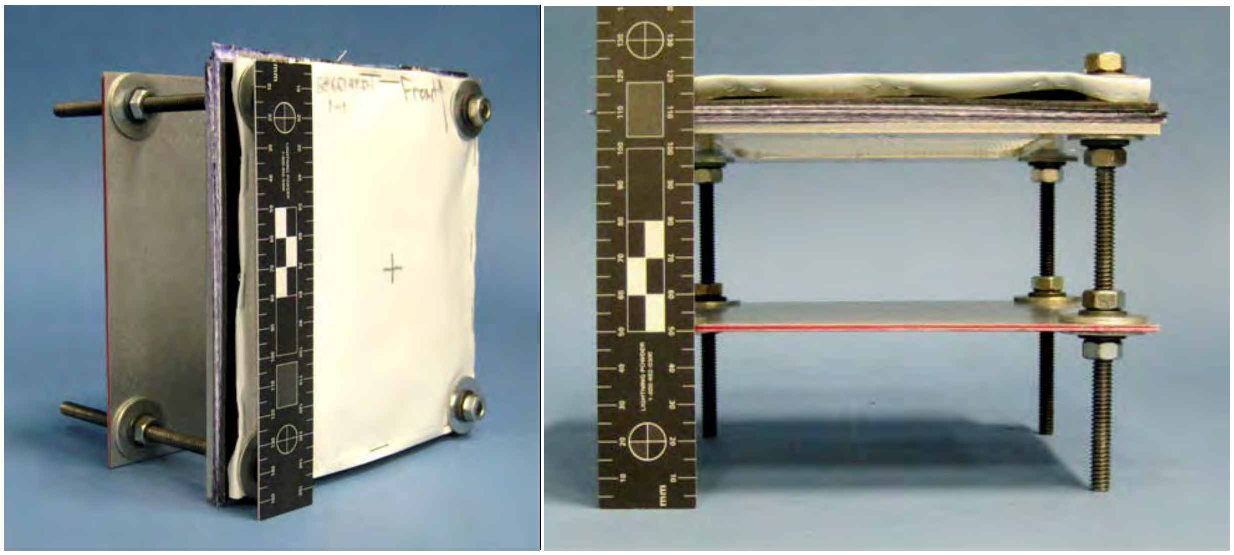


Figure 1 Overall oblique and side view of test article configuration (typical)

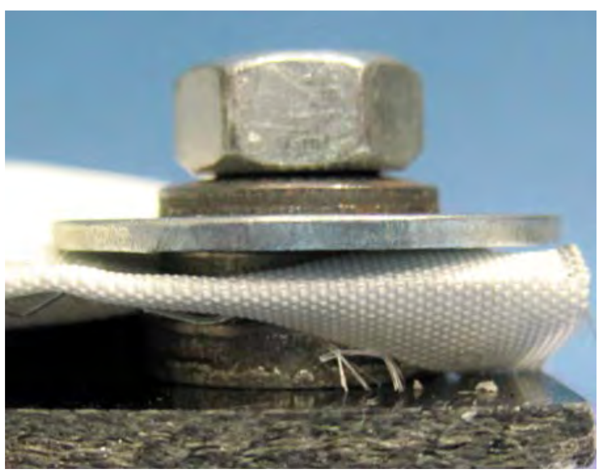


Figure 2 Close-up of method securing MLI to TPS (typical)

Figures 1 and 2 illustrate the typical test article configuration for all configurations. Figure 2 shows how the MLI package is being secured using two 0.125” thick shims (0.25” total) at each corner of the target between the MLI and TPS. This allows the MLI to rest on top of the TPS with minimal compression of the thermal blanket. The test article is secured at each of the four corners by means of all-thread, Belleville spring washers and nuts which maintain the standoff between TPS and rear wall during the testing process.

Type 1 test article represents the thin leeward backshell TPS region, with no Ftorlon. The type 1 test article is described in Figure 3, and compared to the Russian configuration in Figure 4 and Table 1. Table 2 lists the materials used in the targets, as well as the total number of targets of each type in the current test matrix.

The US configuration uses fiberglass NP504 in place of TSP-F fiberglass substrate material. NP504 is a high performance composite manufactured by Norplex-Micarta from a woven glass fabric with high-temperature Phenolic resin system. NP504 offers high temperature resistance, as well as good flexural, compressive, and impact strength at elevated temperatures. In addition, the Phenolic resin system gives the product excellent creep resistance. This thermoset composite does not melt or become soft with heat. NP504 complies with the requirements of MIL-I-24768/18, Type GPG. NP504 has a density of 1.85 g/cm^3, and a tensile strength (0.125" thickness) of 42,000 psi (290 MPa) lengthwise, and 34,000 psi crosswise (234 MPa). The NP504 material is manufactured by a company called Norplex-Micarta (www.norplex-micarta), see Appendix E for property data sheet on this product.

The US configuration uses fiberglass 7725 cloth (14 layers, 54x18 count, 2x2 twill weave) in place of VIM2 insulation. The total fiberglass areal density (mass per unit area) was made similar to the reported VIM2 areal density. Fiberglass cloth is made from silica fibers, whereas VIM2 is a low-density fibrous silica material.

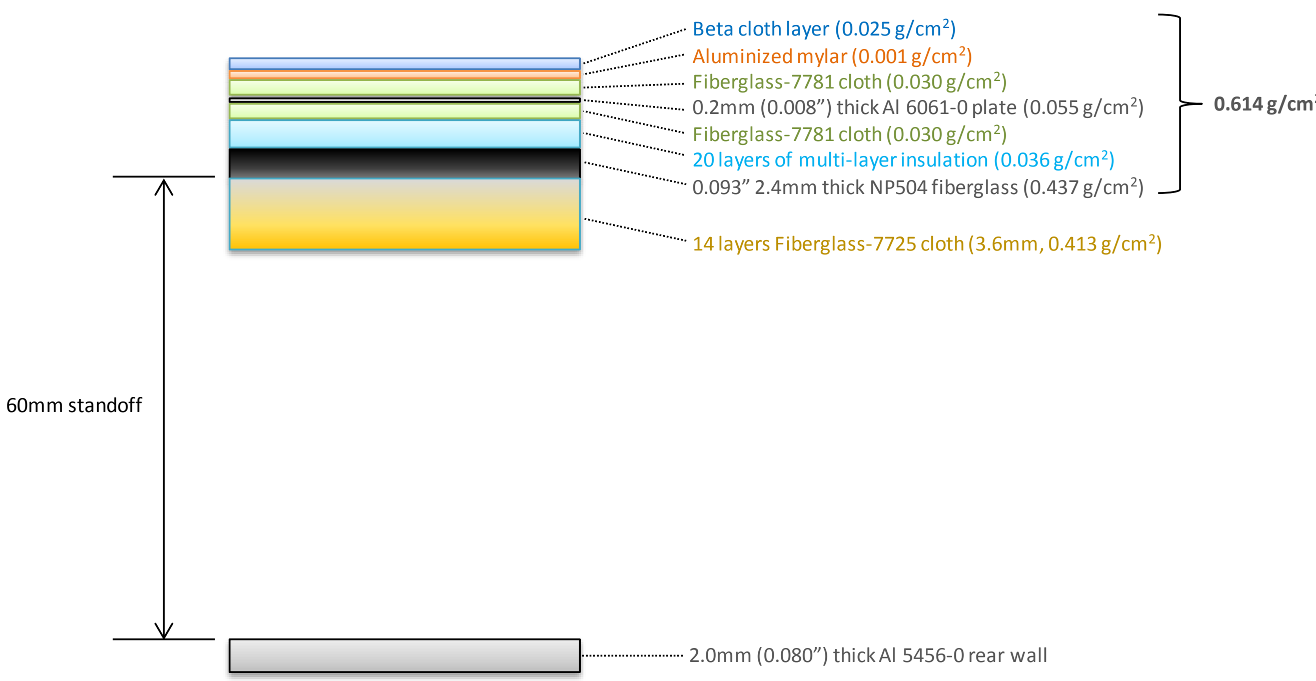


Figure 3 Type 1 test article, representing thin TPS region of the Soyuz DM

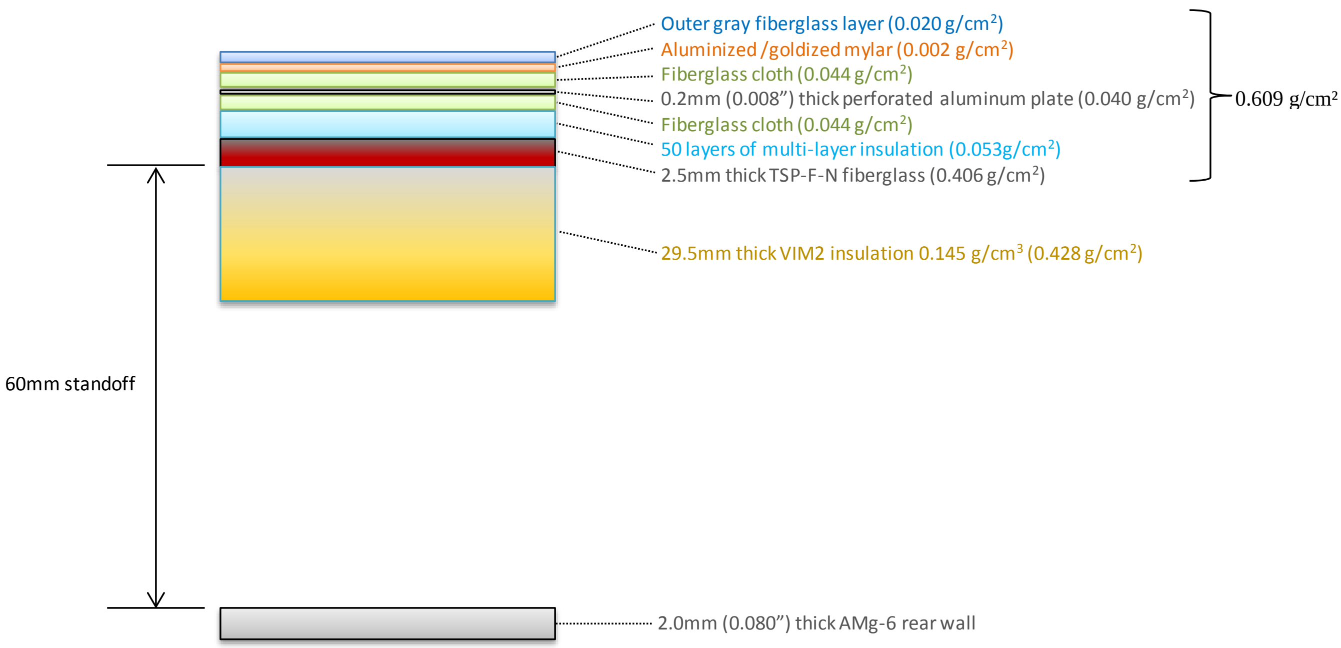


Figure 4 Thin TPS leeward backshell region of Soyuz DM

The multi-layer insulation (MLI) used in the US version contains 20 layers of 0.00025" aluminized kapton with 0.006" thick Dacron scrim between Kapton layers (i.e., the MLI contains 39 layers including scrim).

The 0.2mm (0.008") thick Al 6061-0 plate is bent on the edges to make the insulation thicker. Each edge of the plate is bent 90degrees with a 0.125" (3.2mm) wide bend. Adjacent sides of the plate are bent in opposite directions, leaving two edges bent upward and two edges bent downward. This makes the effective thickness of the 0.008" plate close to 0.25" thick.

Type 2 test article is representative of the medium backshell TPS region (average thickness). Figure 5 illustrates the type 2 test article. Figure 6 and Table 1 provides a comparison to the Russian configuration for this region of the vehicle. The US configuration uses Torlon 5030, in place of Ftorlon. Torlon 5030 is a high-strength, 30% glass-filled polyamide-imide polymer. Typical properties of this material include high stiffness, high strength, good retention of stiffness at high temperatures, and very low creep. The density of this material is 1.61 g/cm^3 and the tensile strength is 29.7 ksi (205 MPa). The Torlon 5030 material in manufactured by a company called Drake Plastics (www.drakeplastics.com), see Appendix E for property data sheet on this product. RTV 560 is used to bond the Torlon 5030 to the NP504 fiberglass plate. The RTV 560 has an application thickness range of 0.004" – 0.007" and an average mass per unit area of 0.015 g/cm².

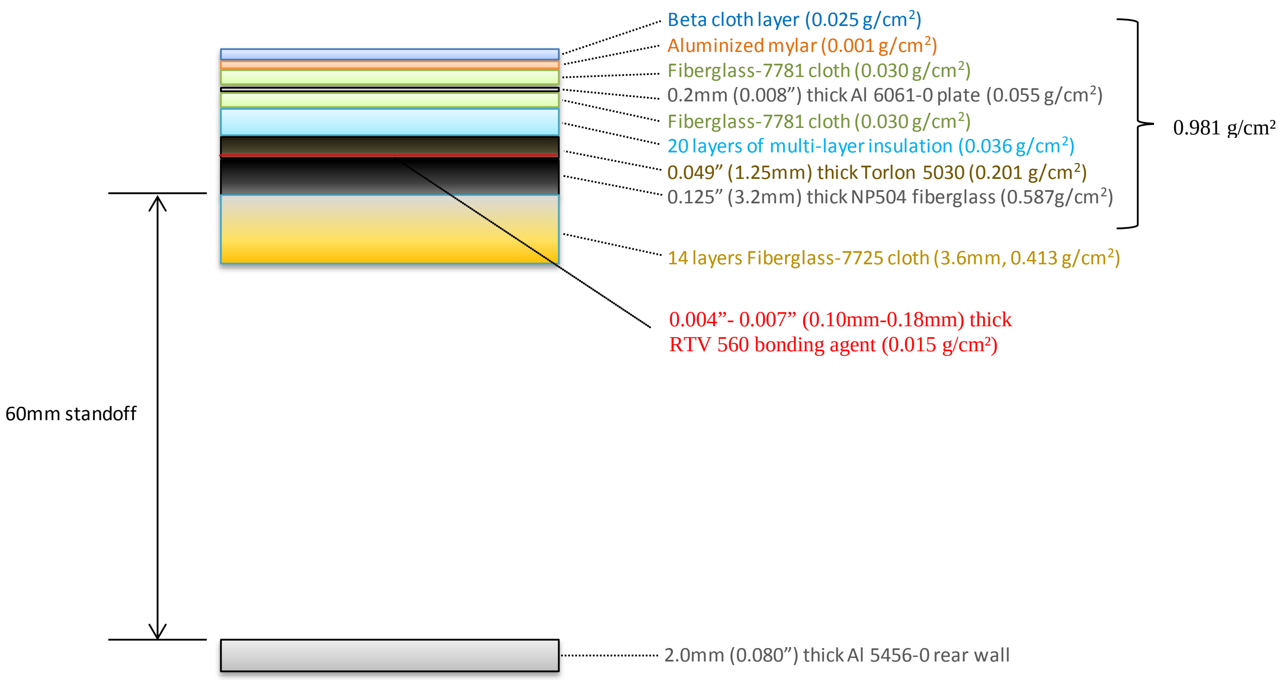


Figure 5 Type 2 test article, representing the average medium thickness TPS region

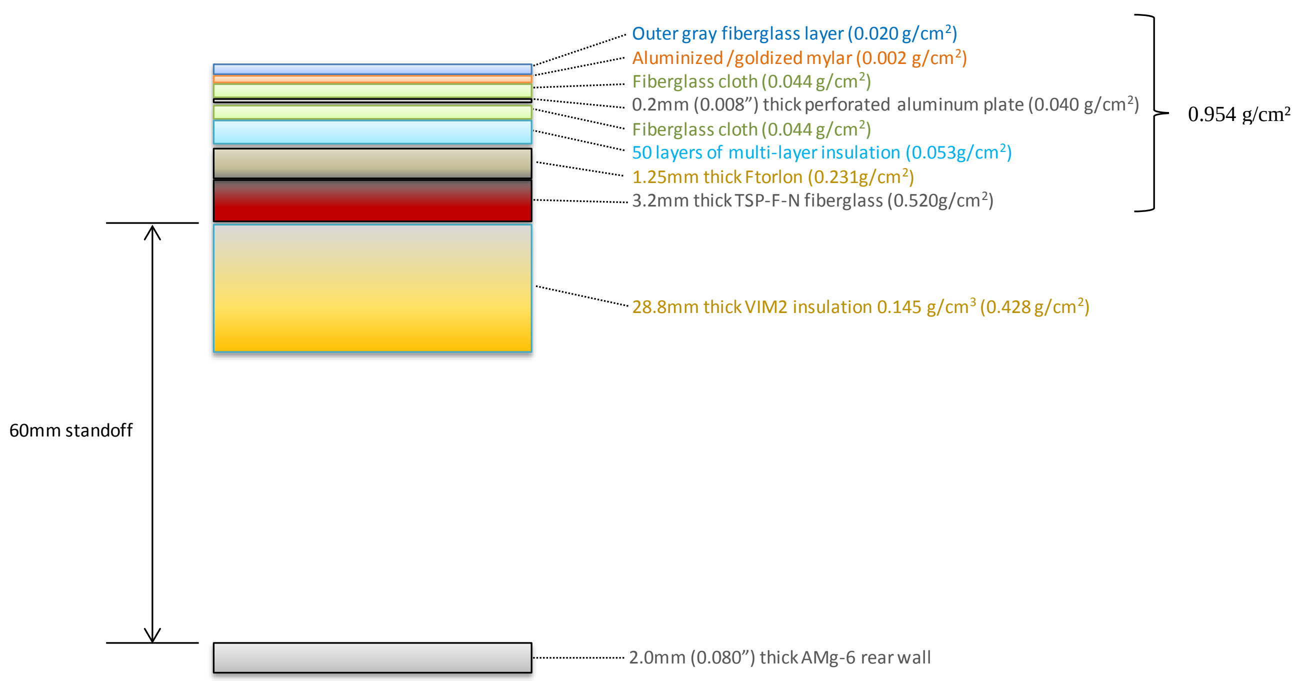


Figure 6 Average medium TPS region of Soyuz DM

Type 3 test article is representative of the thickest backshell TPS region (average thickness), in the windward area of the vehicle's backshell. Figure 7 illustrates the type 3 test article. Figure 8 and Table 1 provides a comparison to the Russian configuration for this region of the vehicle. RTV 560 is used to bond the Torlon 5030 to the NP504 fiberglass plate. The RTV 560 has an application thickness range of 0.004" – 0.007" and an average mass per unit area of 0.015 g/cm².

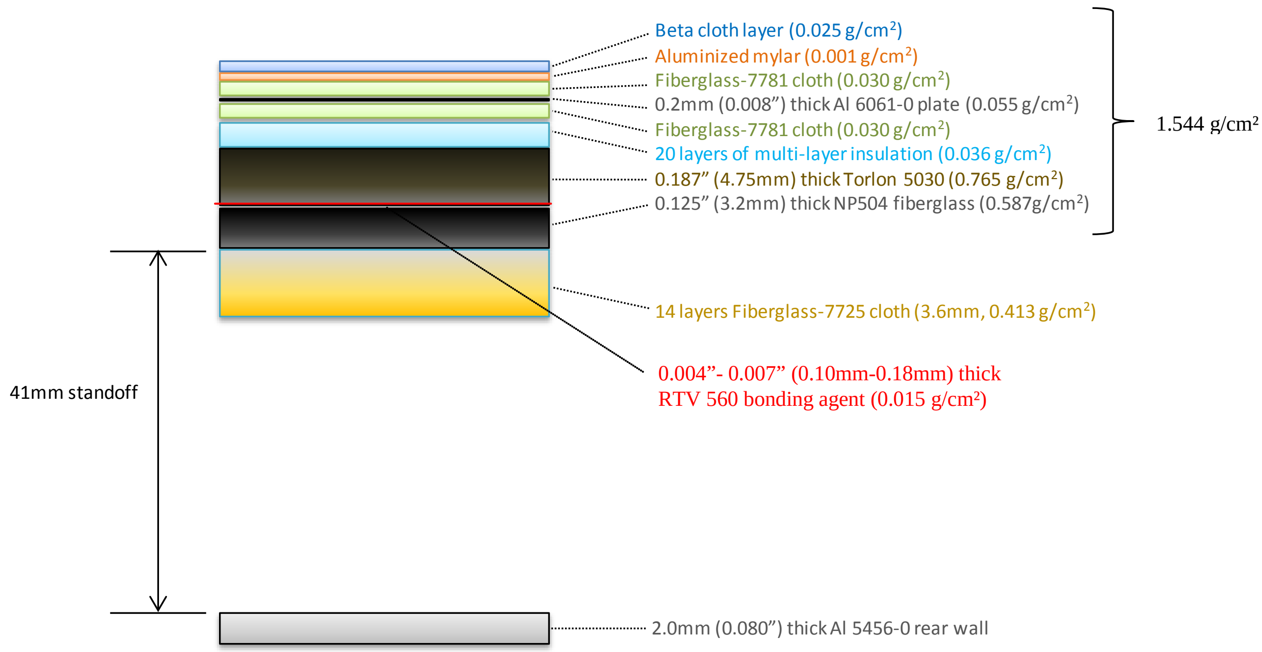


Figure 7 Type 3 test article, representing the average thick area of the TPS

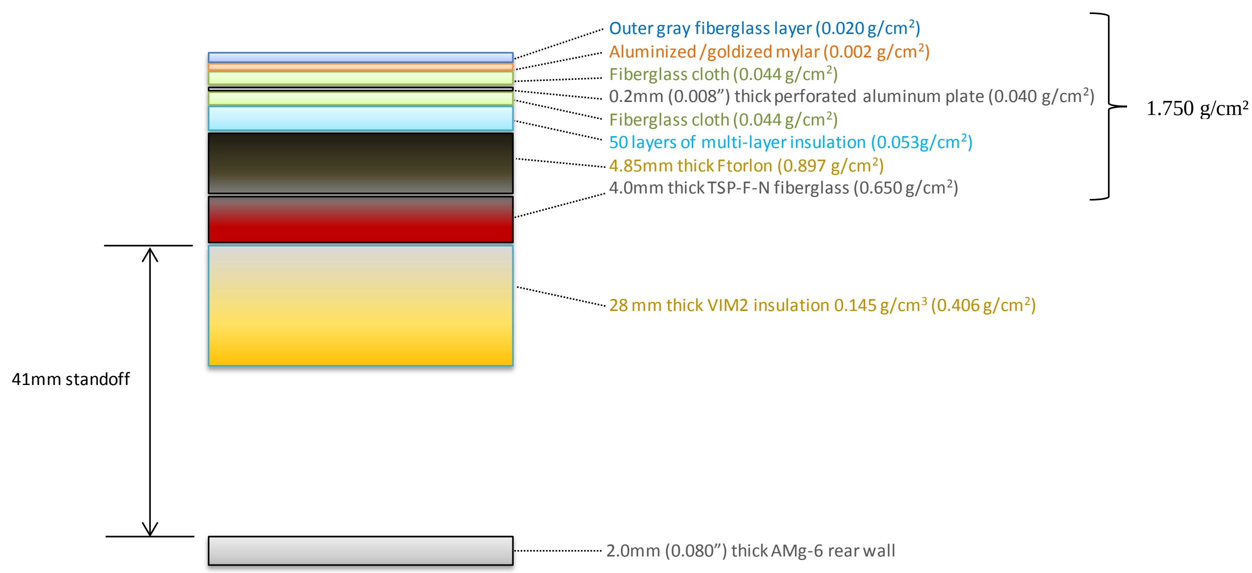


Figure 8 Average thick TPS region of Soyuz DM

Type 4 test article is similar to Type 1 test article, representative of the thin TPS region in the leeward area of the vehicle's backshell, but containing Saffil insulation behind the NP504 fiberglass instead of fiberglass 7725 cloth. This target will be used for assessments of rear wall penetration ballistic limits. Saffil is considered a better material choice to represent the VIM-2 insulation, but was not available for early testing. Figure 9 illustrates the type 4 test article. The Saffil used in this application is Ecoflex E200LB, which is a densified polycrystalline fiber mat (97% alumina and 3% silica). The Saffil is 21mm thick with a density of 0.171 g/cm^3. In addition, a 0.04" (1mm) thick Al 2024-T3 witness plate is included 2" (5.08cm) behind the 2mm thick Al 5456-0 rear wall.

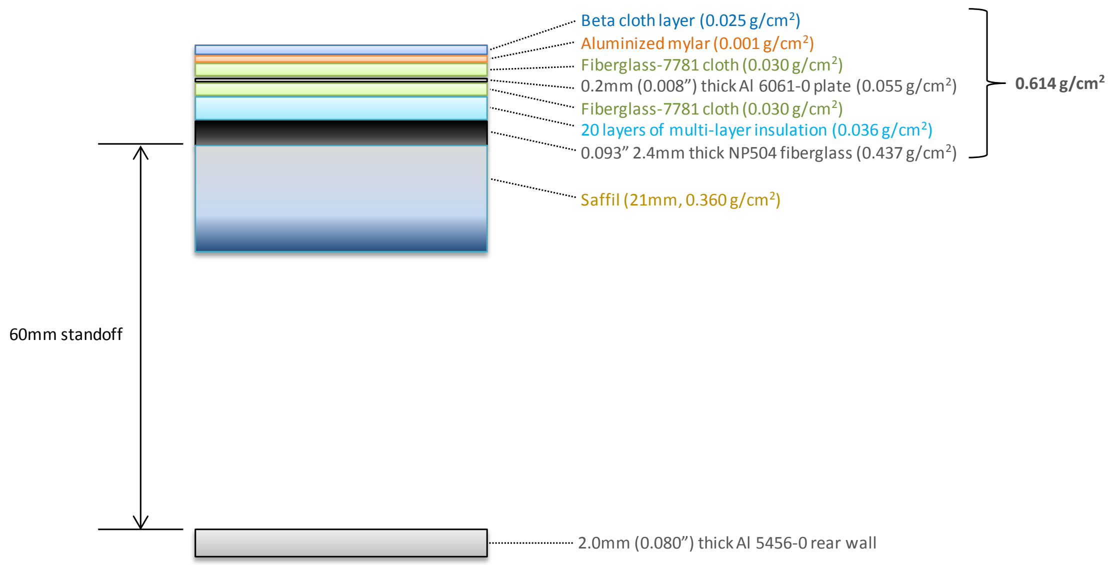


Figure 9 Type 4 test article, thin TPS region of Soyuz DM with Saffil insulation

Table 1 – Summary of Target Areal Densities (mass per unit area) Compared to Similar Soyuz DM Regions

Target type	Areal density thermal blanket + TPS (g/cm^2)		Areal density entire shield including rear wall (g/cm^2)	
	US	Russian	US	Russian
1	0.614	0.609	1.56	1.57
2	0.966	0.954	1.91	1.90
3	1.53	1.75	2.48	2.68
4	0.614	0.609	1.52	1.57

Table 2 – Summary of Materials Contained in Targets

	Target type 1		Target type 2		Target type 3		Target type 4	
Number of targets	26		4		3		2	
Material	**Thickness, mm**	**Mass/Area, g/cm^2**	**Thickness, mm**	**Mass/Area, g/cm^2**	**Thickness, mm**	**Mass/Area, g/cm^2**	**Thickness, mm**	**Mass/Area, g/cm^2**
Beta cloth	0.20	0.025	0.20	0.025	0.20	0.025	0.20	0.025
Mylar	0.0064	0.001	0.0064	0.001	0.0064	0.001	0.0064	0.001
FG 7781	0.23	0.030	0.23	0.030	0.23	0.030	0.23	0.030
0.2mm Al	0.2*	0.055	0.2*	0.055	0.2*	0.055	0.2*	0.055
FG 7781	0.23	0.030	0.23	0.030	0.23	0.030	0.23	0.030
MLI	3.0	0.036	3.0	0.036	3.0	0.036	3.0	0.036
Torlon	0	0	1.25	0.201	4.75	0.765	0	0
*RTV	0	0	0.10 – 0.18	0.015	0.10 – 0.18	0.015	0	0
NP504 FG	2.4	0.437	3.2	0.587	3.2	0.587	2.4	0.437
FG 7725	3.6	0.413	3.6	0.413	3.6	0.413	0	0
Saffil	0	0	0	0	0	0	21	0.360
Al 5456-0	2.0	0.541	2.0	0.541	2.0	0.541	2.0	0.541

*average mass per unit area for RTV derived from bonding summary (see Appendix D)

5.0 Test Facility Diagnostics

WSTF 50-Caliber Non-Hazardous Range [2]

Range Instrumentation

Projectile Velocity
Projectile velocity will be obtained with the following methods:

- Laser stations consisting of two multi-beam lasers, LX1 to LX2.
- Muzzle laser, LX0, paired with LX1 and LX2 laser stations or with target photo diode.
- Photo diode impact flash detectors are located at the stripper plate and target impact point.

WSTF .50-Caliber Gun Velocity Measurement Uncertainty Analysis Summary

.50 Caliber Light Gas Gun

LX0 = Muzzle Laser LX1 = Laser 1 LX2 = Laser 2 EP1 = Stripper Diode EP2 = Target Diode	Recommended Uncertainties Between Velocity Stations (μsec)				
	LX0 to LX1	LX0 to LX2	LX1 to LX2	LX0 to EP1	LX0 to EP2
Random Uncertainty, +/-	0.3%	0.3%	0.4%	0.8%	0.4%
Upper Bound Uncertainty, +/-	0.48%	0.43%	0.96%	1.63%	0.85%

WSTF-IR-1103-001-08.C January 5, 2011

Projectile Integrity
Projectile integrity is obtained using ultra high speed imaging system cameras and/or high speed video cameras to capture projectiles in flight immediately prior to impact. The typical setup captures a shadowgraph of the projectile. Images of the impact can usually be obtained upon request.

Target Tank Pressure
The pressure within the target chamber is maintained at 0.3 psia (14 to 16 torr) Nitrogen during impact. Higher pressures are available upon request. Nitrogen is used in order to minimize the effects of oxygen during impact.

WSTF 17-Caliber Non-Hazardous Range [3]

Range Instrumentation

Projectile Velocity

Projectile velocity is obtained with the following methods:

- Laser station consisting of two multi-beam lasers, LX1 to LX2.
- Muzzle laser is paired with either laser station or with either photo diode to obtain velocity.
- Photo diode impact flash detectors are located at the stripper plate and target impact point

WSTF 17-Caliber Velocity Measurement Uncertainty Analyses Summary

.17-caliber Light Gas Gun					
Measurement System	Laser LX1 to LX2	Muzzle Laser to LX1	Muzzle Laser to LX2	Muzzle Laser to Sabot Stripper	Muzzle Laser to Target
Random Uncertainty, ±	1.1%	0.5%	0.4%	0.8%	0.9%
Upper Bound Uncertainty,±	1.8%	0.9%	0.6%	1.4%	1.2%

WSTF-IR-1086-001-07

Projectile Integrity

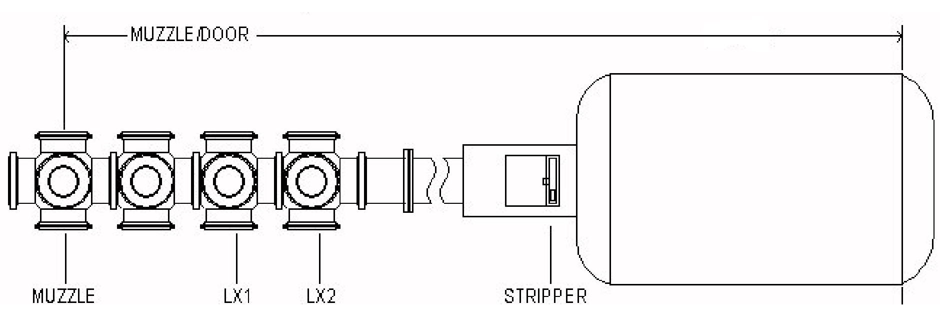
Projectile integrity is obtained on projectiles larger than 0.4mm using ultra high speed imaging system cameras to capture projectiles in flight immediately prior to impact. The typical setup captures a shadowgraph of the projectile. Images of the impact can usually be obtained upon request.

Target Tank Pressure

The pressure within the target chamber is maintained below 2.5 torr (~0.05 psia) Nitrogen during impact. Higher pressures are available upon request. Nitrogen is used in order to minimize the effects of oxygen during impact.

Typical Range Diagnostics Configuration Schematic

Note: The door is considered the primary point of reference from which to measure back to the impact face of the installed test article.



6.0 Projectile Verification Summary

The table below provides a summary of projectile verification for each test conducted in this test program. For projectile verification, we determine if the projectile is intact and round (spherical) prior to impact. There were two different high-speed cameras used to capture the projectile prior to impacting the target, Specialized Imaging SIMX-8 (capable of 200 million frames per second) and Phantom v711 (capable of 1.4 million frames per second). The SIMX-8 camera is primarily used to capture a side view of the projectile approaching the target and the Phantom v711 is oriented to capture the projectile from a front oblique view of the target.

Table 3 – Projectile Verification Summary

Test Number / HITF Number	*Projectile Verification		**Secondary Debris		Is Data Usable (yes or no)	Comments
	SIMX-8 (yes or no)	Phantom v711 (yes or no)	SIMX-8 (yes or no)	Phantom v711 (yes or no)		
#1 HITF12283	yes	no	no	no	yes	Projectile too blurry on phantom to verify roundness of projectile
#2 HITF12284	yes	no	no	no	yes	Projectile too blurry on phantom to verify roundness of projectile
#3 HITF12285	no	no	no	no	yes	Projectile impact found near desired impact point, cameras triggered early not capturing projectile prior to impact
#4 HITF12286	yes	yes	no	no	yes	Good data collected on both cameras, data used
#5 HITF12287	yes	no	no	no	yes	Secondary debris impacts present not captured via camera, considered to have no influence on test
#6 HITF12288	yes	yes	yes	yes	yes	Piece of sabot came down range with projectile and impacted target, but far enough away from impact to not influence test
#7 HITF12289	yes	yes	no	no	yes	Good data collected on both cameras, data used
#8 HITF12290	yes	yes	no	no	yes	Good data collected on both cameras, data used
#9 HITF12291	yes	yes	no	no	yes	Good data collected on both cameras, data used

Table 3 – Projectile Verification Summary						
Test Number / HITF Number	*Projectile Verification		**Secondary Debris		Is Data Usable (yes or no)	Comments
	SIMX-8 (yes or no)	Phantom v711 (yes or no)	SIMX-8 (yes or no)	Phantom v711 (yes or no)		
#10 HITF12292	yes	yes	no	no	yes	Good data collected on both cameras, data used
#11 HITF12293	yes	yes	no	no	yes	Good data collected on both cameras, data used
#12 HITF12294	yes	no	no	no	yes	Projectile to blurry on phantom to verify roundness of projectile. There's a secondary hole above the entry damage of the projectile, which was debris deflecting out through the front surface of MLI
#13 HITF12295	yes	yes	no	no	yes	Good data collected on both cameras, data used
#14 HITF12296	yes	yes	no	no	yes	Re-tested conditions on test #14-B, velocity was low. Data was collected for this velocity
#14-B HITF12296-B	yes	yes	no	no	yes	There's a secondary hole above the entry damage of the projectile, which was debris deflecting out through the front surface of MLI
#15 HITF12297	yes	yes	no	yes	yes	Secondary debris impacted, but far enough away to not influence test
#16 HITF12298	yes	yes	no	no	yes	There's a secondary hole above the entry damage of the projectile, which was debris deflecting out through the front surface of MLI
#17 HITF12299	yes	yes	no	yes	yes	Secondary impact above projectile impact, possibly influenced test results
#18 HITF12300	yes	yes	no	no	yes	Good data collected on both cameras, data used
#19 HITF12301	yes	yes	no	no	yes	Good data collected on both cameras, data used

Table 3 – Projectile Verification Summary

Test Number / HITF Number	*Projectile Verification		**Secondary Debris		Is Data Usable (yes or no)	Comments
	SIMX-8 (yes or no)	Phantom v711 (yes or no)	SIMX-8 (yes or no)	Phantom v711 (yes or no)		
#20 HITF12302	yes	yes	no	no	yes	Good data collected on both cameras, data used
#21 HITF12303	no	no	no	no	yes	Camera's triggered late, not capturing projectile prior to impact. The projectile did impact the desired location and velocity was obtained, entry damage was reflective of a projectile impact, so therefore data was used
#22 HITF12304	yes	yes	yes	yes	yes	Secondary debris impacted, but far enough away to not influence test
23 HITF12305	yes	no	yes	yes	yes	Projectile to blurry on phantom to verify roundness of projectile. Secondary impacts present and also followed directly behind the projectile, this test passed even with the influence of the secondary debris, which told us we were still a bit conservative on projectile size (still useful data)
24 HITF12306	yes	yes	no	no	yes	Good data collected on both cameras, data used
25 HITF12307	yes	yes	no	no	yes	Good data collected on both cameras, data used
26 HITF12308	yes	yes	yes	yes	yes	Re-tested conditions on test #26-B, velocity was low and secondary debris was present. Data was collected for this velocity and secondary debris impacted far enough away to not influence test
26-B HITF12308-B	yes	yes	no	no	yes	There's a secondary hole above the entry damage of the projectile, which was debris deflecting out through the front surface of MLI
27 HITF12309	no	yes	no	no	yes	Projectile partially visible via SIMX-8

Table 3 – Projectile Verification Summary						
Test Number / HITF Number	*Projectile Verification		**Secondary Debris		Data Usable (yes or no)	Comments
	SIMX-8 (yes or no)	Phantom v711 (yes or no)	SIMX-8 (yes or no)	Phantom v711 (yes or no)		
28 HITF12310	yes	yes	no	no	yes	Good data collected on both cameras, data used
29 HITF12311	no	yes	no	no	no	Projectile not verified via SIMX-8 camera. Projectile out of round, said by gun technician that projectile glanced off of the stripping tube and deflected onto the target. Re-tested condition within test #29-B
29-B HITF12311-B	yes	yes	no	no	yes	Good data collected on both cameras, data used
30 HITF12312	yes	yes	no	no	yes	Good data collected on both cameras, data used
31 HITF12313	yes	yes	no	no	yes	Good data collected on both cameras, data used
32 HITF12314	yes	yes	no	no	yes	Good data collected on both cameras, data used

*Verify projectile is intact and spherical prior to impact.
**secondary debris impacts observed via camera.

7.0 Test Results Summary

The following table and images document results from the impact tests on the Soyuz DM TPS test articles. A brief description is provided of the Torlon 5030 (T) and NP504 fiberglass (FG) damage resulting from the impact test. Damage to the Saffil and Al 5456-0 rear wall (RW) is also reported if it occurs. Two dimensions are typically provided for hole measurements, where the first measurement is along the flight direction of the projectile and the second dimension is measured orthogonal to the first. Projectiles are 440C stainless steel or Al 2017-T4 spheres, with a projectile density of 7.667 g/cm^3 and 2.796 g/cm^3, respectively. Actual projectile diameters are calculated from the measured projectile mass.

Table 4 – I SS Soyuz Vehicle Descent Module TPS Test Results Summary

Test Number / HITF Number	Target Type	Projectile Material	Actual Projectile Diameter (mm)	Actual Projectile Mass (g)	Actual Impact Velocity (km/s)	Impact Angle (deg)	Damage Results (mm)
1 HITF12283	Type 1 Average thin	Steel 440C	0.89	0.00281	6.86	30	**NP 504 Substrate = Pass / Pressure Shell = Pass** **Beta cloth entry damage** = 1.0 x 1.2 perforation **MLI exit damage** = perforations present on back side of MLI blanket within a 9.6 x 8.8 area with the largest being 7.5 x 5.6 **NP 504 entry damage** = impacts present within 11.7 x 9.5 area with exposed severed ply's present within 6.4 x 4.1 area, no perforation present (light tight) **NP 504 exit damage** = 13.4 x 12.7 bump present on back side that has a maximum height of 0.2, there is a 0.3 x 0.1 detached spall area on top of bump, no perforation present (light tight) **FG 7725 damage** = no damage present **Rear wall damage** = none present
2 HITF12284	Type 1 Average thin	Steel 440C	1.00	0.00400	7.16	45	**NP 504 Substrate = Pass / Pressure Shell = Pass** **Beta cloth entry damage** = 1.7 x 1.3 perforation **MLI exit damage** = 17.5 x 9.7 perforation **NP 504 entry damage** = impacts present within 16.5 x 14.4 area with exposed severed ply's present within 6.3 x 7.2 area, no perforation present (light tight) **NP 504 exit damage** = 14.9 x 12.6 bump present on back side that has a maximum height of 0.3, there is a 1.9 x 1.0 detached spall area on top of bump, no perforation present (light tight) **FG 7725 damage** = 3.3 x 2.4 area with few severed fibers present on back side of 1st layer, no perforation **Rear wall damage** = none present
3 HITF12285	Type 1 Average thin	Steel 440C	1.00	0.00400	5.04	30	**NP 504 Substrate = Pass / Pressure Shell = Pass** **Beta cloth entry damage** = 2.3 x 1.9 perforation **MLI exit damage** = 11.0 x 8.4 petalled perforation with ripping propagating away from the perforation with the largest rip being 28.9 tip to tip **NP 504 entry damage** = impacts present within 34.9 x 22.6 area with exposed severed ply's present within 5.8 x 4.9 area, no perforation present (light tight) **NP 504 exit damage** = 16.7 x 15.1 bump present on back side that has a maximum height of 0.7, there is a 5.3 x 2.9 detached spall area on top of bump, no perforation present (light tight) **FG 7725 damage** = 1.6 x 1.5 darkened area on back side of 2nd layer, no perforation present **Rear wall damage** = none present

Table 4 – ISS Soyuz Vehicle Descent Module TPS Test Results Summary (continued)							
Test Number / HITF Number	**Target Type**	**Projectile Material**	**Actual Projectile Diameter (mm)**	**Actual Projectile Mass (g)**	**Actual Impact Velocity (km/s)**	**Impact Angle (deg)**	**Damage Results (mm)**
4 HITF12286	Type 2 Average medium	Steel 440C	1.19	0.00681	6.94	30	**NP 504 Substrate = Pass / Pressure Shell = Pass** **Beta cloth entry damage** = 1.6 x 1.4 perforation **MLI exit damage** = 14.6 diameter petalled perforation with ripping propagating away from the perforation with the largest rip being 41.1 tip to tip **Torlon damage** = impact residue and impacts present on front face of plate within 6.1 x 7.1 area, within this area is a 4.0 x 3.1 area of exposed substrate (irregular shaped) **NP 504 damage** = 25.4 x 22.4 bump present on back side that has a maximum height of 1.1, there is detached spall within a 6.7 x 4.5 area on top of bump, no perforation present (light tight) **FG 7725 damage** = 4.1 x 6.2 area with stretched fibers and strands present on back side of 1st layer, no perforation **Rear wall damage** = none present
5 HITF12287	Type 1 Average thin	Steel 440C	1.72	0.02050	7.20	60	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = multiple secondary impacts, primary impact was identified as 4.5 x 2.4 perforation **MLI exit damage** = 18.5 x 10.6 petalled perforation with significant ripping propagating away from the perforation with the largest rip being 151.4 tip to tip **NP 504 entry damage** = delamination and severed fiberglass ply's present within a 17.6 x 10.4 area, within this area is a 6.3 x 3.2 perforation **NP 504 exit damage** = 6.3 x 3.2 perforation **FG 7725 damage** = 10.9 x 8.9 perforation present on last layer **Rear wall damage** = impact residue and surface pitting present within a 60.7 x 57.3 area with the largest pit being 0.3 x 0.2 that has a maximum depth of 0.02, no perforations present on back side of plate
6 HITF12288	Type 1 Average thin	Steel 440C	1.39	0.01078	2.91	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 1.7 x 1.4 perforation (secondary impact present above projectile impact) **MLI exit damage** = projectile impact induced perforations present on back side of MLI blanket within a 11.7 x 7.1 area with the largest being 5.4 x 4.3 (large perforation above created by secondary impact) **NP 504 entry damage** = delamination and severed fiberglass ply's present within a 7.6 x 5.3 area, within this area is a 2.5 x 1.8 perforation **NP 504 exit damage** = 2.5 x 1.8 perforation **FG 7725 damage** = 5.5 x 4.4 perforation present on last layer **Rear wall damage** = impact residue and surface cratering present within a 35.4 x 33.2 area with the largest pit being 1.0 x 0.6 that has a maximum depth of 0.3, no perforations present on back side of plate

Table 4 – ISS Soyuz Vehicle Descent Module TPS Test Results Summary (continued)							
Test Number / HITF Number	**Target Type**	**Projectile Material**	**Actual Projectile Diameter (mm)**	**Actual Projectile Mass (g)**	**Actual Impact Velocity (km/s)**	**Impact Angle (deg)**	**Damage Results (mm)**
7 HITF12289	Type 1 Average thin	Steel 440C	1.29	0.00859	6.93	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 1.9 x 1.7 perforation **MLI exit damage** = 11.0 x 8.5 petalled perforation with ripping propagating away from the perforation with the largest rip being 21.4 tip to tip **NP 504 entry damage** = impacts present within 28.6 x 24.2 area with exposed severed ply's present within 9.3 x 8.1 area with 3.2 x 1.7 perforation **NP 504 exit damage** = 3.2 x 1.7 perforation **FG 7725 damage** = 8.7 x 5.0 perforation present on last layer **Rear wall damage** = very subtle impact residue present within a 11.2 x 9.8 area, no pitting or cratering present
8 HITF12290	Type 1 Average thin	Steel 440C	1.00	0.00400	7.14	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 1.5 x 1.4 perforation **MLI exit damage** = 7.9 x 6.8 petalled perforation with ripping propagating away from the perforation with the largest rip being 26.0 tip to tip **NP 504 entry damage** = impacts present within 12.2 x 15.0 area with exposed severed ply's present within 6.8 x 8.7 area with 1.1 x 1.1 perforation **NP 504 exit damage** = 1.1 x 1.1 perforation **FG 7725 damage** = 3.3 x 2.7 area with frayed fibers and strands present on back side of 7th layer, no perforation **Rear wall damage** = none present
9 HITF12291	Type 1 Average thin	Steel 440C	1.19	0.00680	6.89	45	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 1.8 x 1.4 perforation **MLI exit damage** = 15.7 x 8.4 petalled perforation **NP 504 entry damage** = impacts present within 18.4 x 20.1 area with exposed severed ply's present within 8.2 x 7.9 area with 0.8 x 1.5 perforation **NP 504 exit damage** = 0.8 x 1.5 perforation **FG 7725 damage** = 5.2 x 6.4 area with frayed fibers and strands present on back side of 8th layer, no perforation **Rear wall damage** = none present
10 HITF12292	Type 1 Average thin	Steel 440C	1.19	0.00681	5.06	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 1.5 x 1.3 perforation **MLI exit damage** = 7.0 x 6.8 petalled perforation with ripping propagating away from the perforation with the largest rip being 13.9 tip to tip **NP 504 entry damage** = impacts present within 11.1 x 14.9 area with exposed severed ply's present within 6.1 x 6.9 area with 2.7 x 2.2 perforation **NP 504 exit damage** = 2.7 x 2.2 perforation **FG 7725 damage** = darkened area and minor fraying of fibers present within a 3.1 x 2.8 area on back side of last layer, no perforation **Rear wall damage** = none present

Table 4 – ISS Soyuz Vehicle Descent Module TPS Test Results Summary (continued)							
Test Number / HITF Number	**Target Type**	**Projectile Material**	**Actual Projectile Diameter (mm)**	**Actual Projectile Mass (g)**	**Actual Impact Velocity (km/s)**	**Impact Angle (deg)**	**Damage Results (mm)**
11 HITF12293	Type 2 Average medium	Steel 440C	1.39	0.01080	6.90	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 2.0 x 1.7 perforation **MLI exit damage** = 11.5 x 10.8 petalled perforation with ripping propagating away from the perforation with the largest rip being 27.3 tip to tip **Torlon damage** = impact residue and impacts present on front face of plate within 21.1 x 17.7 area, within this area is a 1.8 x 2.6 perforation **NP 504 damage** = 1.8 x 2.6 perforation **FG 7725 damage** = darkened area and minor fraying of fibers present within a 1.9 x 2.1 area on back side of 9th layer, no perforation **Rear wall damage** = none present
12 HITF12294	Type 1 Average thin	Steel 440C	1.29	0.00862	6.99	60	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 2.9 x 1.6 perforation **MLI exit damage** = 13.9 x 14.5 petalled perforation with ripping propagating away from the perforation with the largest rip being 36.3 tip to tip **NP 504 entry damage** = impacts present within 27.2 x 32.0 area with exposed severed ply's present within 14.0 x 5.2 area with 2.5 x 1.1 perforation **NP 504 exit damage** = 2.5 x 1.1 perforation **FG 7725 damage** = darkened area and minor fraying of fibers present within a 6.7 x 7.3 area on back side of 9th layer, no perforation **Rear wall damage** = none present
13 HITF12295	Type 1 Average thin	Steel 440C	1.19	0.00679	2.94	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 1.5 x 1.2 perforation **MLI exit damage** = 4.0 x 3.7 petalled perforation with ripping propagating away from the perforation with the largest rip being 7.3 tip to tip **NP 504 entry damage** = impacts present within 6.8 x 8.2 area with exposed severed ply's present within 5.2 x 6.0 area with 1.5 x 1.4 perforation **NP 504 exit damage** = 1.5 x 1.4 perforation **FG 7725 damage** = darkened area and minor fraying of fibers present within a 3.3 x 2.9 area on back side of last layer, no perforation **Rear wall damage** = none present
14 HITF12296	Type 1 Average thin	Steel 440C	1.72	0.02042	6.08	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 2.3 x 1.7 perforation **MLI exit damage** = 15.7 x 12.5 petalled perforation with ripping propagating away from the perforation with the largest rip being 67.6 tip to tip **NP 504 entry damage** = impacts present within 38.1 x 32.7 area with exposed severed ply's present within 15.4 x 10.9 area with 5.4 x 4.4 perforation **NP 504 exit damage** = 5.4 x 4.4 perforation **FG 7725 damage** = 18.8 x 18.8 perforation **Rear wall damage** = minor pitting, deposits and cratering present on front of plate within a 68.2 x 72.8, with the largest crater being 0.5 x 0.4 that has a maximum depth of 0.1, no damage present on back side of plate

Table 4 – ISS Soyuz Vehicle Descent Module TPS Test Results Summary (continued)							
Test Number / HITF Number	**Target Type**	**Projectile Material**	**Actual Projectile Diameter (mm)**	**Actual Projectile Mass (g)**	**Actual Impact Velocity (km/s)**	**Impact Angle (deg)**	**Damage Results (mm)**
14-B HITF12296-B	Type 1 Average thin	Steel 440C	2.00	0.03155	7.00	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 2.7 x 1.9 perforation **MLI exit damage** = 22.9 x 17.6 petalled perforation with ripping propagating away from the perforation with the largest rip being 39.2 tip to tip **NP 504 entry damage** = impacts present within 46.4 x 28.9 area with exposed severed ply's present within 15.7 x 14.6 area with 7.7 x 7.3 perforation **NP 504 exit damage** = 7.7 x 7.3 perforation **FG 7725 damage** = 19.2 x 18.8 perforation **Rear wall damage** = minor pitting, deposits and cratering present on front of plate within a 97.3 x 102.3, with the largest crater being 0.9 x 0.5 that has a maximum depth of 0.2, no damage present on back side of plate
15 HITF12297	Type 1 Average thin	Al 2017-T4	1.40	0.00404	5.69	30	**NP 504 Substrate = Pass / Pressure Shell = Pass** **Beta cloth entry damage** = 2.2 x 1.8 perforation **MLI exit damage** = 11.0 x 12.3 petalled perforation with ripping propagating away from the perforation with the largest rip being 22.8 tip to tip **NP 504 entry damage** = impacts present within 29.8 x 32.6 area with exposed severed ply's present within 5.1 x 4.5 area, no perforation present (light tight) **NP 504 exit damage** = very subtle 10.7 x 7.5 bump on back side of plate with maximum height of 0.02, no detached spall or perforation present **FG 7725 damage** = no damage present **Rear wall damage** = none
16 HITF12298	Type 1 Average thin	Al 2017-T4	1.60	0.00599	7.19	45	**NP 504 Substrate = Pass / Pressure Shell = Pass** **Beta cloth entry damage** = 3.5 x 1.8 perforation **MLI exit damage** = 25.6 x 17.9 perforation **NP 504 entry damage** = impacts present within 28.9 x 33.7 area with exposed severed ply's present within 7.8 x 8.9 area, no perforation present (light tight) **NP 504 exit damage** = 13.7 x 12.5 bump present on back side that has a maximum height of 0.3, there is detached spall within a 3.0 x 2.8 area on top of bump, no perforation present (light tight) **FG 7725 damage** = no damage present **Rear wall damage** = none
17 HITF12299	Type 1 Average thin	Al 2017-T4	1.72	0.00740	5.08	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 2.9 x 2.7 perforation **MLI exit damage** = 14.5 x 10.1 petalled perforation with ripping propagating away from the perforation with the largest rip being 48.7 tip to tip **NP 504 entry damage** = impacts present within 50.8 x 64.2 area with exposed severed ply's present within 10.4 x 8.9 area with 0.6 x 0.7 perforation present **NP 504 exit damage** = 0.6 x 0.7 perforation **FG 7725 damage** = 1.7 x 0.9 darkened area on back side of 2nd layer, no perforation present **Rear wall damage** = no damage present

Table 4 – ISS Soyuz Vehicle Descent Module TPS Test Results Summary (continued)							
Test Number / HITF Number	**Target Type**	**Projectile Material**	**Actual Projectile Diameter (mm)**	**Actual Projectile Mass (g)**	**Actual Impact Velocity (km/s)**	**Impact Angle (deg)**	**Damage Results (mm)**
18 HITF12300	Type 2 Average medium	Al 2017-T4	1.99	0.01156	7.22	30	**NP 504 Substrate = Pass / Pressure Shell = Pass** **Beta cloth entry damage** = 2.8 x 2.5 perforation **MLI exit damage** = 11.8 x 9.8 petalled perforation with ripping propagating away from the perforation with the largest rip being 24.1 tip to tip **Torlon damage** = impact residue and impacts present on front face of plate within 28.1 x 21.4 area, within this area is a 4.7 x 4.5 area of exposed substrate (irregular shaped) **NP 504 damage** = 25.9 x 32.6 bump present on back side that has a maximum height of 0.4, there is detached spall within a 1.7 x 3.2 area on top of bump, no perforation present (light tight) **FG 7725 damage** = 2.9 x 4.3 darkened and fiber fraying area on back side of 1st layer, no perforation present **Rear wall damage** = no damage present
19 HITF12301	Type 1 Average thin	Al 2017-T4	1.99	0.01156	6.88	60	**NP 504 Substrate = Pass / Pressure Shell = Pass** **Beta cloth entry damage** = 9.9 x 4.4 perforation **MLI exit damage** = 25.3 x 16.9 petalled perforation with ripping propagating away from the perforation with the largest rip being 43.8 tip to tip **NP 504 entry damage** = impact present within 70.1 x 56.0 area with exposed severed ply's present within 20.9 x 8.6 area, no perforation present (light tight) **NP 504 exit damage** = no damage present **FG 7725 damage** = no damage present **Rear wall damage** = none present
20 HITF12302	Type 1 Average thin	Al 2017-T4	3.40	0.05776	3.03	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 4.2 x 3.6 perforation **MLI exit damage** = 11.6 x 12.1 petalled perforation with ripping propagating away from the perforation with the largest rip being 28.8 tip to tip **NP 504 entry damage** = delamination and severed fiberglass ply's present within a 22.6 x 13.9 area, within this area is a 6.8 x 4.8 perforation **NP 504 exit damage** = 6.8 x 4.8 perforation **FG 7725 damage** = 15.5 x 14.6 perforation **Rear wall damage** = impact residue and surface pitting present within a 68.4 x 43.3 area with the largest pit being 1.0 x 0.7 that has a maximum depth of 0.03, no perforations present on back side of plate
21 HITF12303	Type 1 Average thin	Al 2017-T4	2.59	0.02555	7.08	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 6.4 x 3.9 perforation **MLI exit damage** = 22.2 x 19.8 petalled perforation with ripping propagating away from the perforation with the largest rip being 54.3 tip to tip **NP 504 entry damage** = delamination and severed fiberglass ply's present within a 21.6 x 24.0 area, within this area is a 5.2 x 5.6 perforation **NP 504 exit damage** = 5.2 x 5.6 perforation **FG 7725 damage** = 18.7 x 14.7 perforation **Rear wall damage** = impact residue and surface pitting present within a 51.4 x 45.7 area with the largest pit being 0.3 x 0.3 that has a maximum depth of 0.01, no perforations present on back side of plate

Table 4 – ISS Soyuz Vehicle Descent Module TPS Test Results Summary (continued)							
Test Number / HITF Number	**Target Type**	**Projectile Material**	**Actual Projectile Diameter (mm)**	**Actual Projectile Mass (g)**	**Actual Impact Velocity (km/s)**	**Impact Angle (deg)**	**Damage Results (mm)**
22 HITF12304	Type 1 Average thin	Al 2017-T4	1.72	0.00750	7.26	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 2.5 x 2.1 perforation **MLI exit damage** = 10.1 x 9.1 petalled perforation with ripping propagating away from the perforation with the largest rip being 24.3 tip to tip **NP 504 entry damage** = delamination and severed fiberglass ply's present within a 11.9 x 9.7 area, within this area is a 0.9 x 0.6 perforation **NP 504 exit damage** = 0.9 x 0.6 perforation **FG 7725 damage** = 5.7 x 5.3 area with few severed fibers present on back side of 7th layer, no perforation **Rear wall damage** = no damage present
23 HITF12305	Type 1 Average thin	Al 2017-T4	1.92	0.01034	7.19	45	**NP 504 Substrate = Pass / Pressure Shell = Pass** **Beta cloth entry damage** = 4.0 x 2.9 perforation (estimated) **MLI exit damage** = 33.9 x 30.8 petalled perforation with ripping propagating away from the perforation with the largest rip being 112.9 tip to tip **NP 504 entry damage** = impacts present within 50.4 x 73.1 area with exposed severed ply's present within 14.4 x 8.9 area, no perforation present (light tight) **NP 504 exit damage** = 30.6 x 24.6 bump present on back side that has a maximum height of 1.0, there is detached spall within a 4.6 x 3.8 area on top of bump, no perforation present (light tight) **FG 7725 damage** = 5.9 x 5.5 area with few severed fibers present on back side of 2nd layer, no perforation **Rear wall damage** = no damage present
24 HITF12306	Type 1 Average thin	Al 2017-T4	3.97	0.09147	6.96	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 16.7 x 15.1 perforation with ripping migrating away from the perforation wit h the largest rip being 72.4 tip to tip **MLI exit damage** = completely destroyed **NP 504 entry damage** = impacts present within 85.7 x 95.6 area with exposed severed ply's present within 19.1 x 21.8 area with 11.1 x 10.8 perforation **NP 504 exit damage** = 11.1 x 10.8 perforation **FG 7725 damage** = 30.7 x 34.2 perforation **Rear wall damage** = impact residue and surface pitting present within a 122.4 x 139.8 area with largest visible pit being 1.8 x 1.4 that has a maximum depth of 0.2 (largest impact damage is masked by deposits on front surface of plate, very subtle bumps present on back side of plate within a 40.4 x 38.5 area that had a maximum height of 0.5
25 HITF12307	Type 2 Average medium	Al 2017-T4	2.38	0.01975	7.04	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 4.3 x 3.0 perforation **MLI exit damage** = 16.4 x 14.6 petalled perforation with ripping propagating away from the perforation with the largest rip being 34.0 tip to tip **Torlon damage** = impact residue and impacts present on front face of plate within 32.1 x 27.6 area, within this area is a 2.5 x 2.0 perforation **NP 504 damage** = 2.5 x 2.0 perforation **FG 7725 damage** = 3.9 x 4.4 darkened and fiber fraying area on back side of 8th layer, no perforation **Rear wall damage** = none present

Table 4 – ISS Soyuz Vehicle Descent Module TPS Test Results Summary (continued)

Test Number / HITF Number	Target Type	Projectile Material	Actual Projectile Diameter (mm)	Actual Projectile Mass (g)	Actual Impact Velocity (km/s)	Impact Angle (deg)	Damage Results (mm)
26 HITF12308	Type 1 Average thin	Al 2017-T4	2.38	0.01975	5.49	60	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 5.8 x 4.7 perforation **MLI exit damage** = 26.4 x 19.7 petalled perforation with ripping propagating away from the perforation with the largest rip being 44.6 tip to tip **NP 504 entry damage** = impacts present within 70.3 x 71.5 area with exposed severed ply's present within 15.6 x 10.6 area with 2.4 x 1.4 perforation present **NP 504 exit damage** = 2.4 x 1.4 perforation **FG 7725 damage** = 4.8 x 4.3 area with few severed fibers present on back side of 4th layer, no perforation **Rear wall damage** = no damage present
26-B HITF12308-B	Type 1 Average thin	Al 2017-T4	2.38	0.01976	7.13	60	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 6.1 x 3.8 perforation **MLI exit damage** = 20.9 x 26.1 petalled perforation with ripping propagating away from the perforation with the largest rip being 52.1 tip to tip **NP 504 entry damage** = impacts present within 71.8 x 55.6 area with exposed severed ply's present within 16.9 x 13.2 area with 1.9 x 0.8 perforation **NP 504 exit damage** = 0.9 x 0.6 perforation **FG 7725 damage** = 3.9 x 4.5 area with few severed fibers present on back side of 7th layer, no perforation **Rear wall damage** = no damage present
27 HITF12309	Type 1 Average thin	Al 2017-T4	2.38	0.01977	2.95	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 2.8 x 2.1 perforation **MLI exit damage** = 8.3 x 7.5 petalled perforation with ripping propagating away from the perforation with the largest rip being 13.7 tip to tip **NP 504 entry damage** = delamination and severed fiberglass ply's present within a 14.3 x 13.1 area, within this area is a 3.3 x 2.4 perforation **NP 504 exit damage** = 3.3 x 2.4 perforation **FG 7725 damage** = 0.9 x 1.7 darkened area on back side of 10th layer, no perforation present **Rear wall damage** = no damage present
28 HITF12310	Type 1 Average thin	Al 2017-T4	3.18	0.04695	6.95	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 52.4 x 36.1 ripped perforation **MLI exit damage** = 32.2 x 25.8 petalled perforation with ripping propagating away from the perforation with the largest rip being 49.9 tip to tip **NP 504 entry damage** = impacts present within 62.6 x 58.4 area with exposed severed ply's present within 19.4 x 17.8 area with 11.3 x 8.7 perforation present **NP 504 exit damage** = 11.3 x 8.7 perforation **FG 7725 damage** = 24.2 x 22.2 perforation present on last layer **Rear wall damage** = impact residue and surface pitting and cratering present within a 97.5 x 82.7 area with the largest crater being 2.9 x 2.4 that has a maximum depth of 0.1, two very subtle bumps present on back side of plate with the largest being 3.9 diameter that has a maximum height of 0.06

Table 4 – ISS Soyuz Vehicle Descent Module TPS Test Results Summary (continued)							
Test Number / HITF Number	**Target Type**	**Projectile Material**	**Actual Projectile Diameter (mm)**	**Actual Projectile Mass (g)**	**Actual Impact Velocity (km/s)**	**Impact Angle (deg)**	**Damage Results (mm)**
29 HITF12311	Type 3 Average thick	Steel 440C	1.59	0.01619	7.05	30	**NP 504 Substrate = Pass / Pressure Shell = Pass** **Beta cloth entry damage** = 1.9 x 1.7 perforation (high-speed video indicated the projectile was out of round, testing group indicated the projectile impacted the stripping mechanism prior to impacting the target) **MLI exit damage** = 11.4 x 8.0 petalled perforation with ripping propagating away from the perforation with the largest rip being 23.2 tip to tip **Torlon damage** = impact residue and impacts present on front face of plate within 12.1 x 15.2 area, within this area is a 3.1 x 2.4 crater that has a maximum depth of 3.4 (no RTV visibly present at bottom of crater) **NP 504 damage** = 28.5 x 33.7 bump present on back side that has a maximum height of 1.2, there is detached spall within a 5.7 x 5.6 area on top of bump, no perforation present (light tight) **FG 7725 damage** = 8.1 x 9.5 area with few severed fibers present on back side of 4th layer, no perforation **Rear wall damage** = no damage present
29-B HITF12311-B	Type 3 Average thick	Steel 440C	1.59	0.01616	6.97	30	**NP 504 Substrate = Pass / Pressure Shell = Pass** **Beta cloth entry damage** = 2.1 x 2.0 perforation **MLI exit damage** = 10.3 x 9.6 petalled perforation with ripping propagating away from the perforation with the largest rip being 32.5 tip to tip **Torlon damage** = Torlon plate completely delaminated from NP 504 substrate, impact residue and impacts present on front face of plate within 18.9 x 21.1 area, within this area an irregular shaped perforation is present within a 2.6 x 2.2 area **NP 504 damage** = 41.1 x 56.3 bump present on back side that has a maximum height of 3.1, there is detached spall within a 10.4 x 12.2 area on top of bump, no perforation present (light tight) **FG 7725 damage** = 6.8 x 8.4 area with few severed fibers present on back side of 5th layer, no perforation **Rear wall damage** = no damage present
30 HITF12312	Type 3 Average thick	Steel 440C	1.79	0.02307	6.82	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 89.5 x 107.3 ripped perforation **MLI exit damage** = measurement unobtainable due to blanket destruction during test **Torlon damage** = Torlon plate completely delaminated from NP 504 substrate and fractured into three pieces, with pieces put back together a 20.4 x 18.9 perforation is present **NP 504 damage** = 23.7 x 18.3 perforation **FG 7725 damage** = 39.5 x 37.9 perforation **Rear wall damage** = multiple impacts and craters present on front face of plate within a 112.8 x 102.6 area, with the largest being 2.9 x 2.2 that has a maximum depth of 0.7. All of the impacts created a significant bulge on the back side of the plate that deformed the plate 17.4 off of surface plane, multiple dimples present on top of bulge, no perforation present

Table 4 – ISS Soyuz Vehicle Descent Module TPS Test Results Summary (continued)							
Test Number / HITF Number	**Target Type**	**Projectile Material**	**Actual Projectile Diameter (mm)**	**Actual Projectile Mass (g)**	**Actual Impact Velocity (km/s)**	**Impact Angle (deg)**	**Damage Results (mm)**
31 HITF12313	Type 4 Thin w/Saffil	Al 2017-T4	3.40	0.05777	7.01	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 67.3 x 45.5 ripped perforation **MLI exit damage** = 44.7 x 33.3 petalled perforation with ripping propagating away from the perforation with the largest rip being 97.8 tip to tip **NP 504 entry damage** = impact residue and impacts present within 78.8 x 72.1 within this area is a 10.6 x 9.8 perforation present **NP 504 exit damage** = 10.6 x 9.8 perforation present **Saffil damage** = 41.5 x 37.4 perforation present on back side of Saffil layer **Rear wall damage** = impact residue and minor surface pitting present within a 96.6 x 96.3 area with the largest pit being 0.16 x 0.25 that has a maximum depth of 0.02, no perforation present and no damage present on back side of plate **Witness plate damage** = no damage present
32 HITF12314	Type 4 Thin w/Saffil	Al 2017-T4	3.97	0.09151	6.97	30	**NP 504 Substrate = Fail / Pressure Shell = Pass** **Beta cloth entry damage** = 68.8 x 56.6 ripped perforation **MLI exit damage** = 15.6 x 14.5 petalled perforation with ripping propagating away from the perforation with the largest rip being 28.5 tip to tip **NP 504 entry damage** = impact residue and impacts present within 32.6 x 39.0 within this area is a 12.9 x 12.3 perforation present **NP 504 exit damage** = 12.9 x 12.3 perforation **Saffil damage** = 50.3 x 47.9 perforation present on back side of Saffil layer **Rear wall damage** = impact residue and minor surface pitting present within a 105.8 x 99.5 area with the largest pit being 0.28 x 0.32 that has a maximum depth of 0.06, no perforation present and no damage present on back side of plate **Witness plate damage** = no damage present

HITF12283 / Test #1

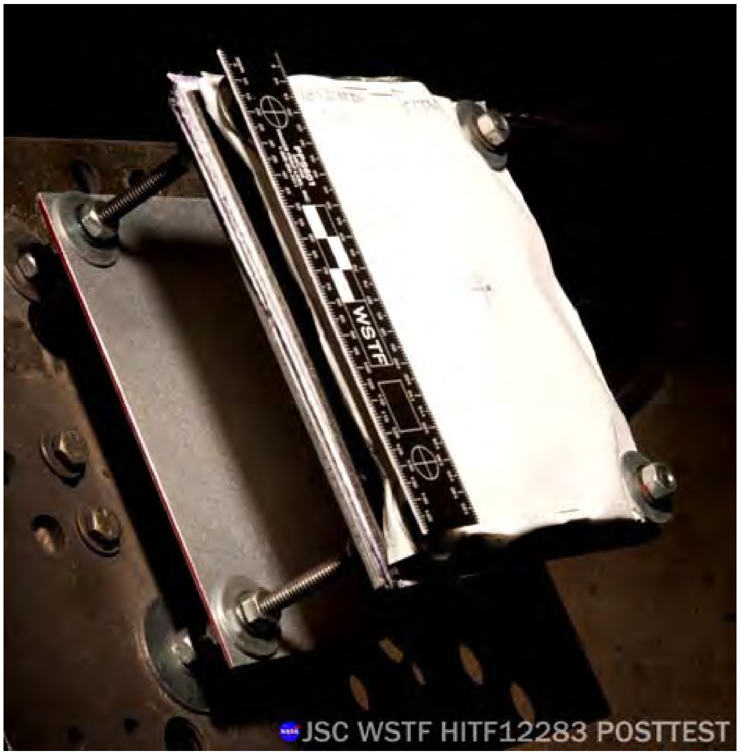


Figure 8 Overall View of Sample in the Target Tank (post-test)

Figure 9 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12283 / Test #1 (continued)

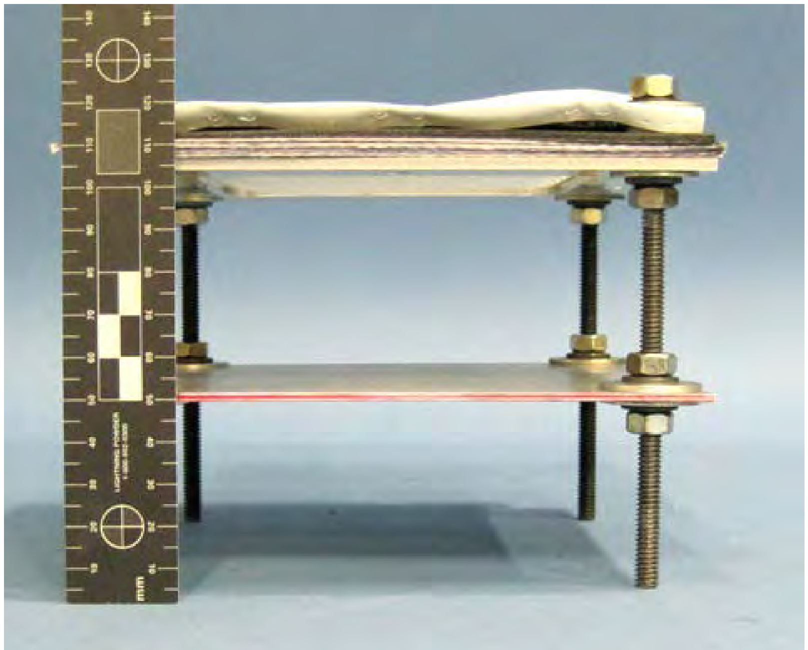


Figure 10 Overall Side View of Sample (scale in 5mm increments)

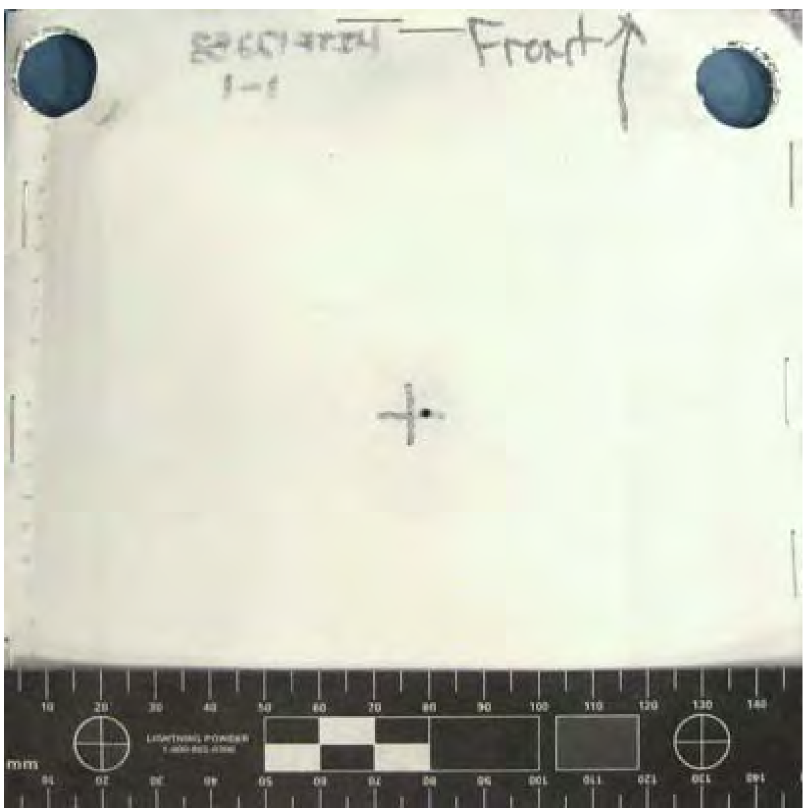


Figure 11 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12283 / Test #1 (continued)

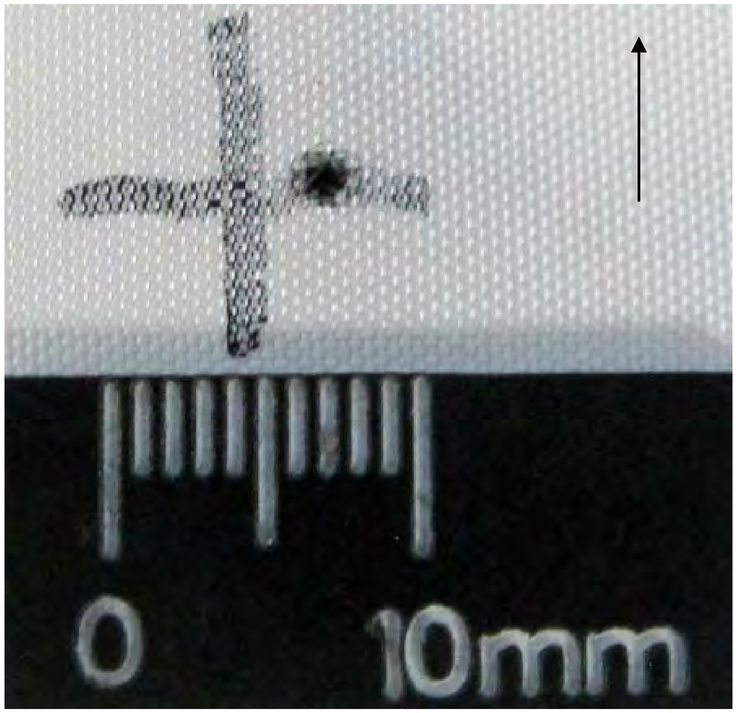


Figure 12 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

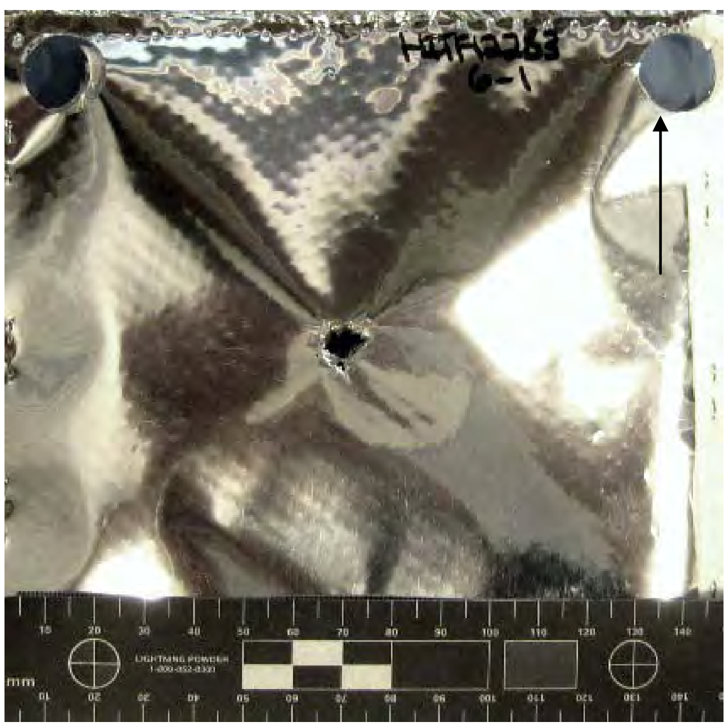


Figure 13 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12283 / Test #1 (continued)

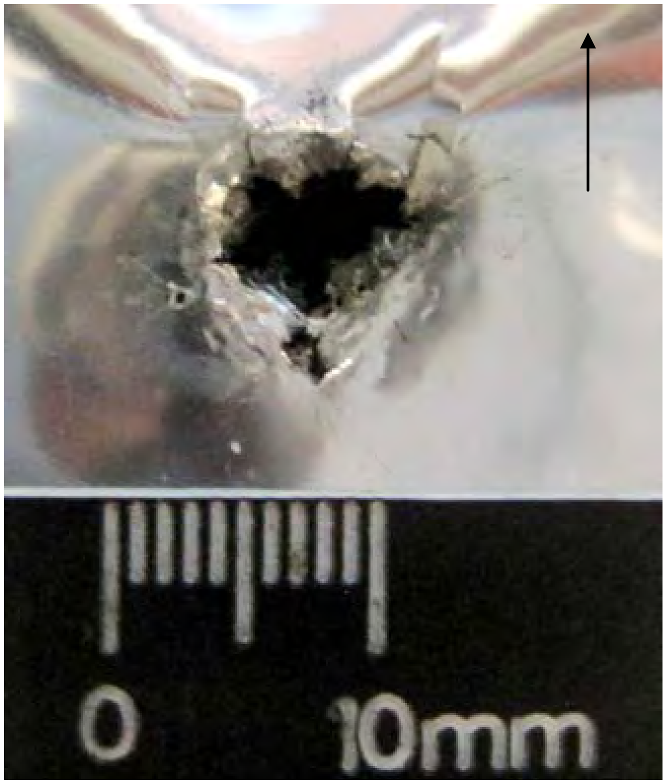


Figure 14 Close-up View of Damage to Back Side of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

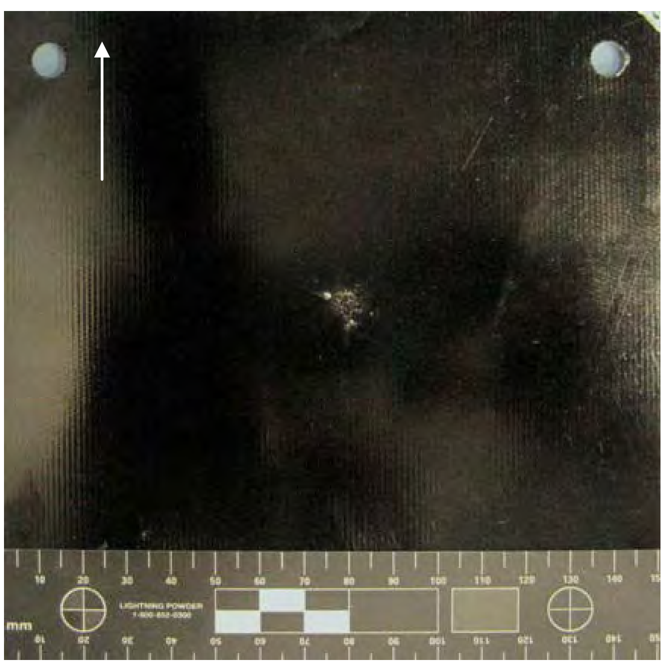


Figure 15 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12283 / Test #1 (continued)

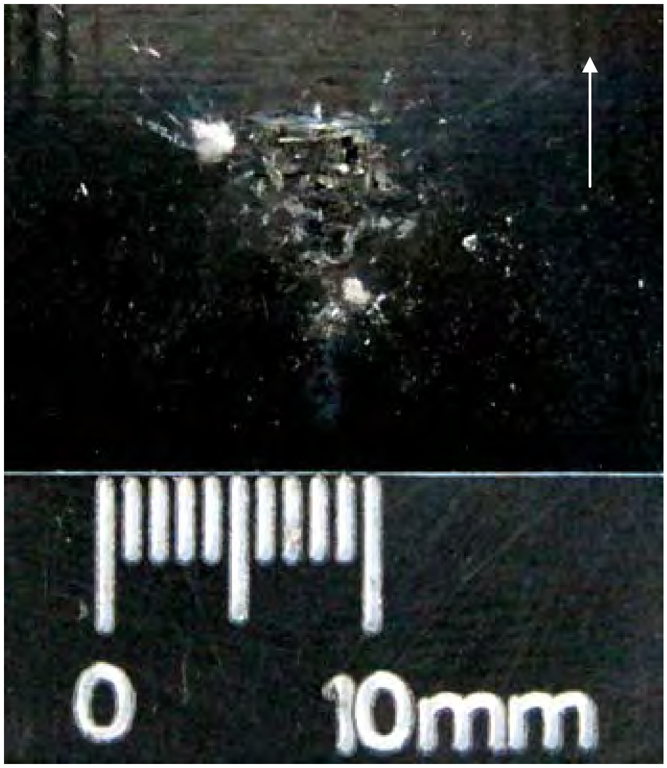


Figure 16 Close-up View of Damage to Front of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

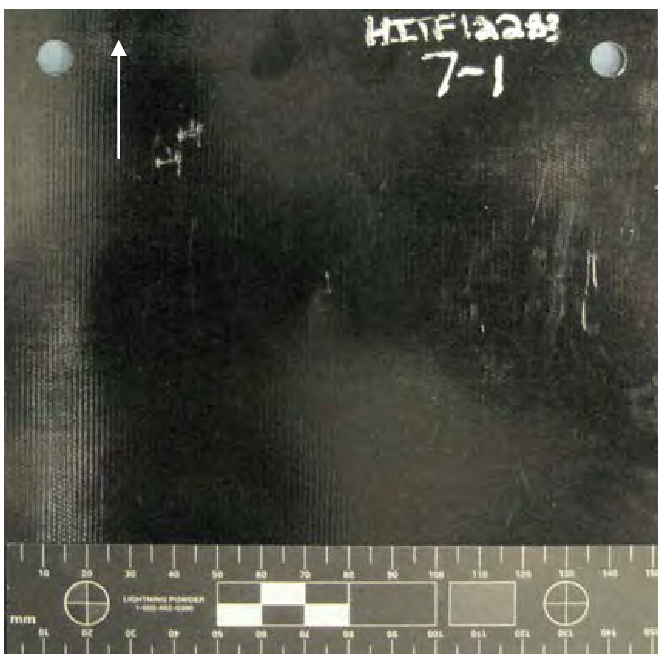


Figure 17 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12283 / Test #1 (continued)

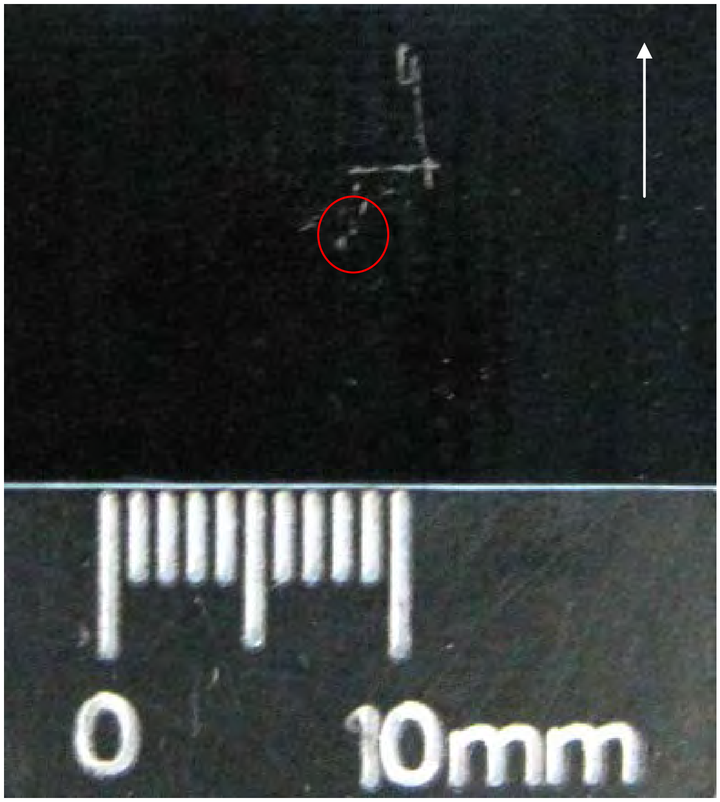


Figure 18 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

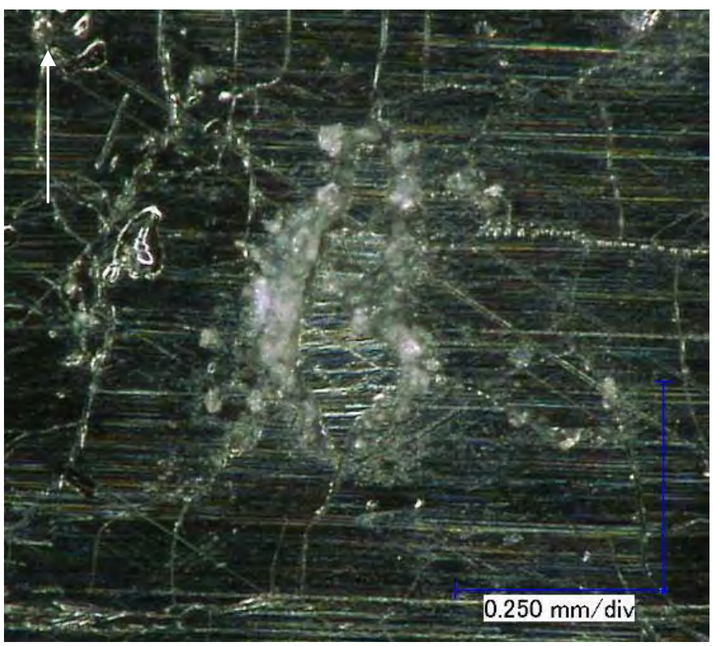


Figure 19 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (white arrow indicates flight path of projectile / damage within red circle in Figure 18)

HITF12283 / Test #1 (continued)

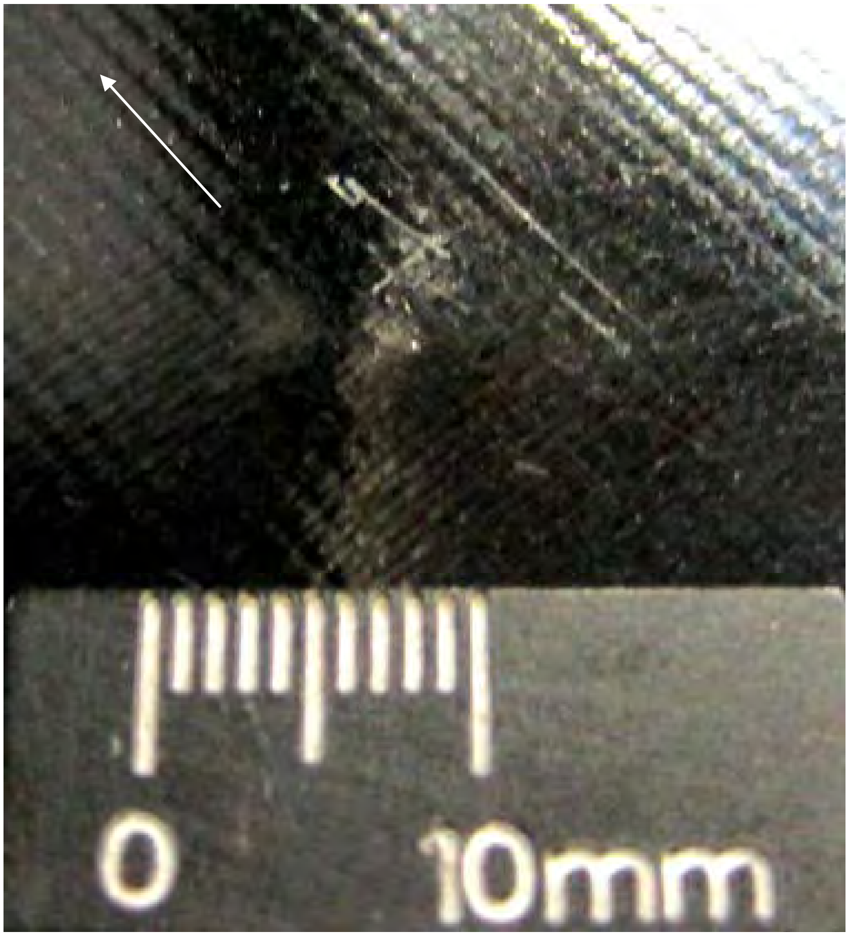


Figure 20 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

HITF12284 / Test #2

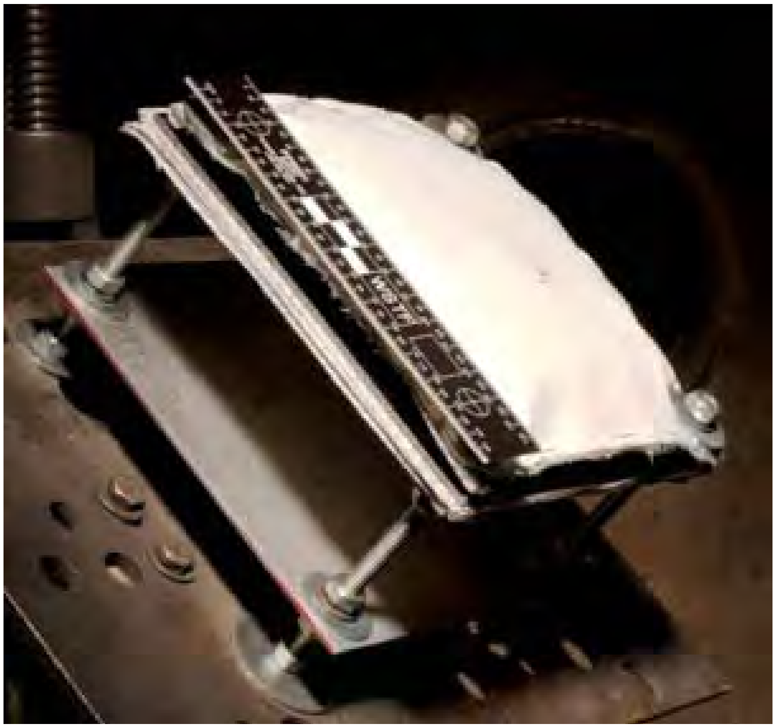


Figure 21 Overall View of Sample in the Target Tank (post-test)

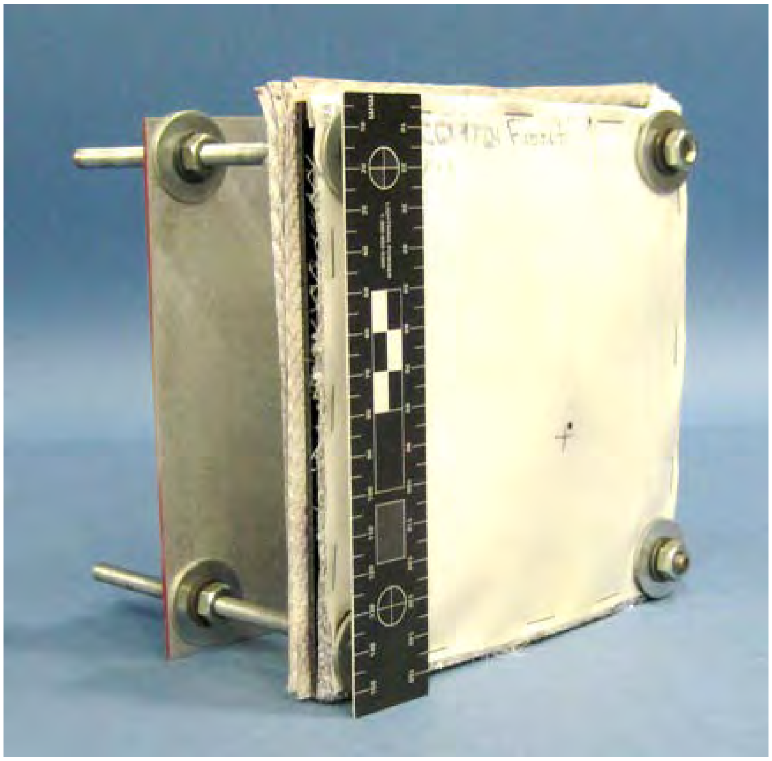


Figure 22 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12284 / Test #2 (continued)

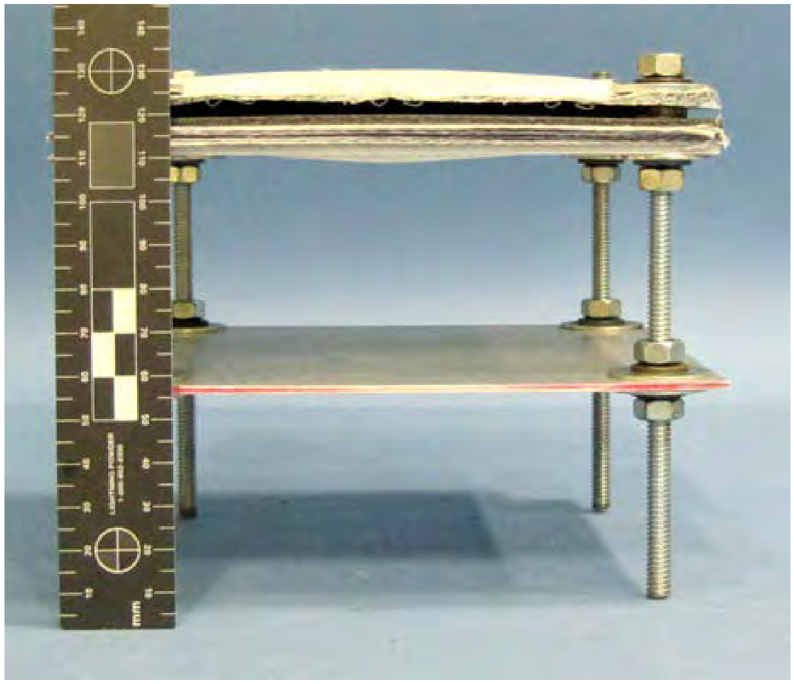


Figure 23 Overall Side View of Sample (scale in 5mm increments)

Figure 24 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12284 / Test #2 (continued)

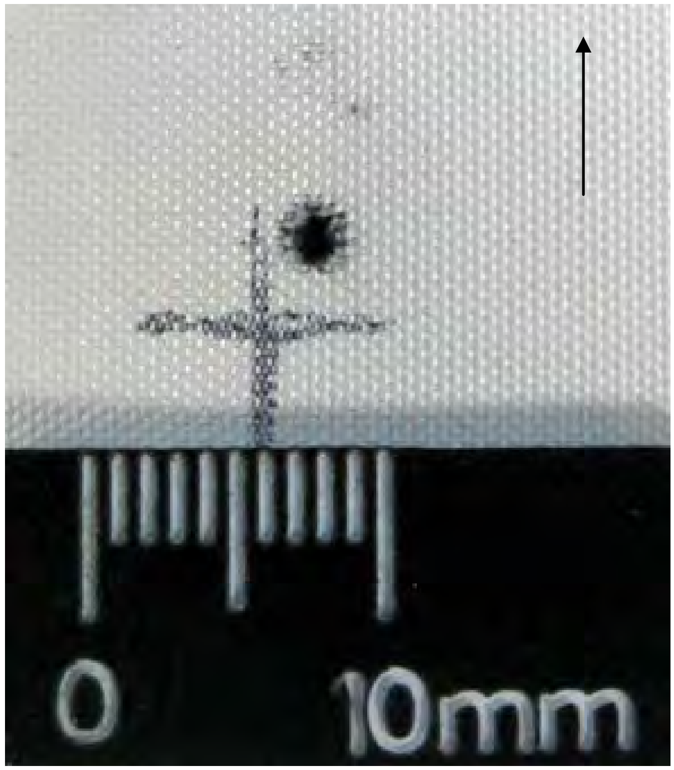


Figure 25 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

Figure 26 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12284 / Test #2 (continued)

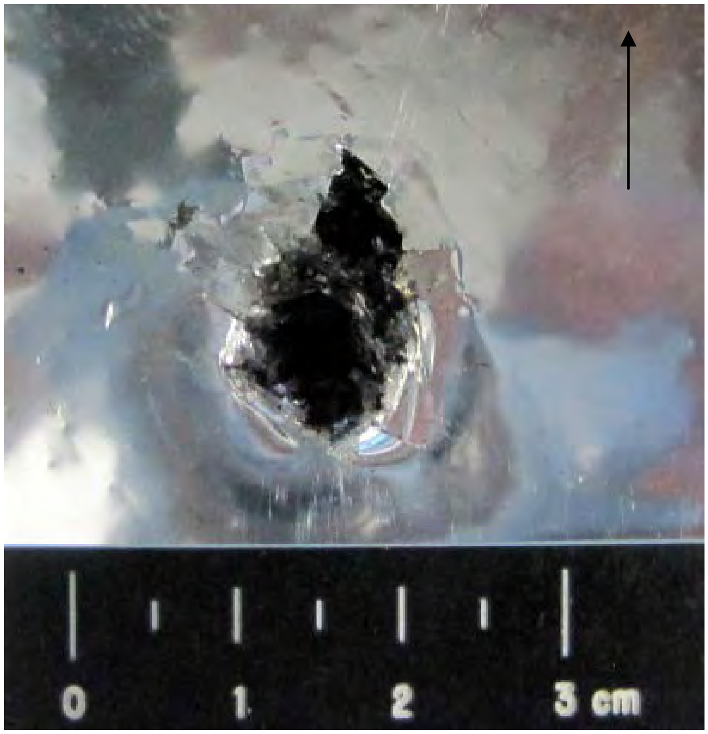


Figure 27 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

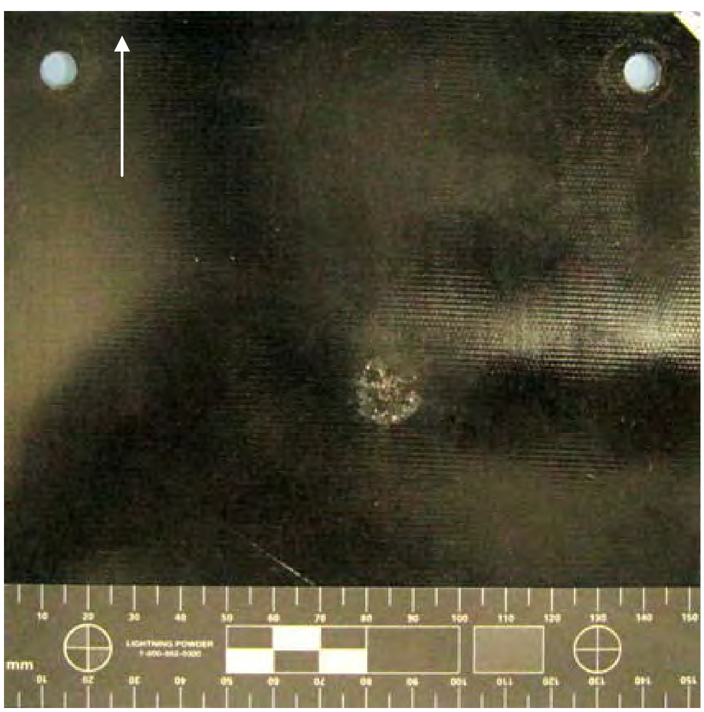


Figure 28 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12284 / Test #2 (continued)

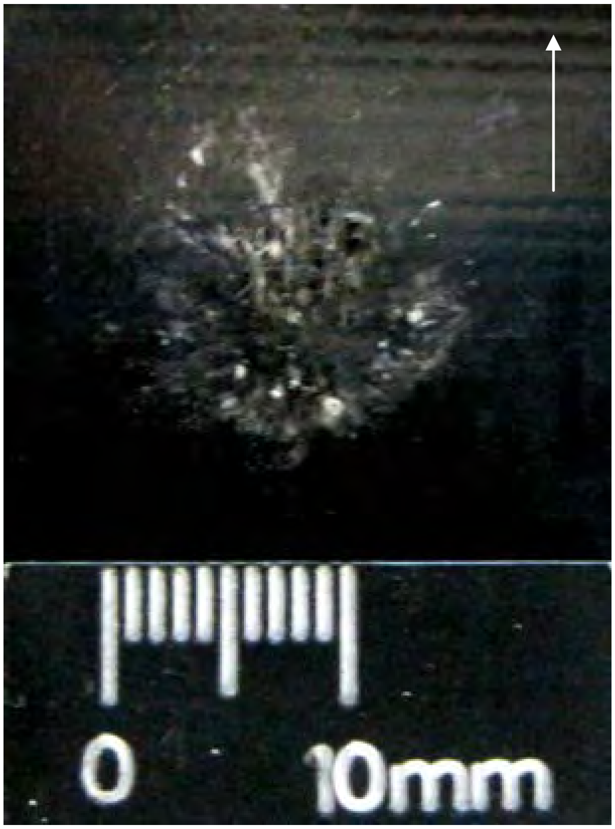


Figure 29 Close-up View of Damage to Front of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

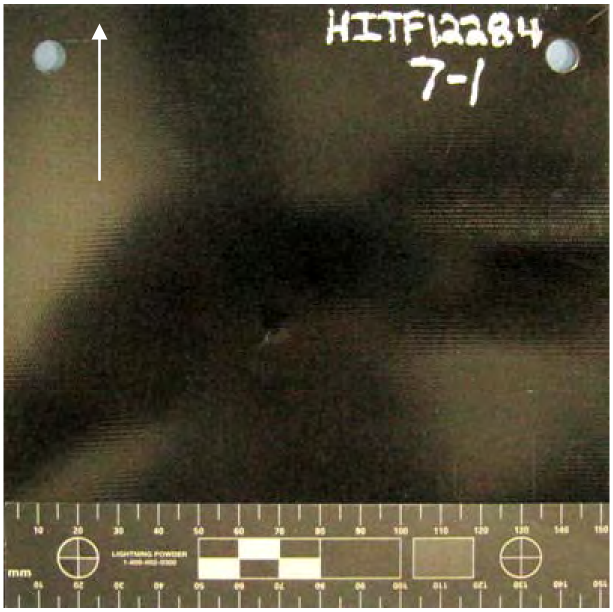


Figure 30 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12284 / Test #2 (continued)

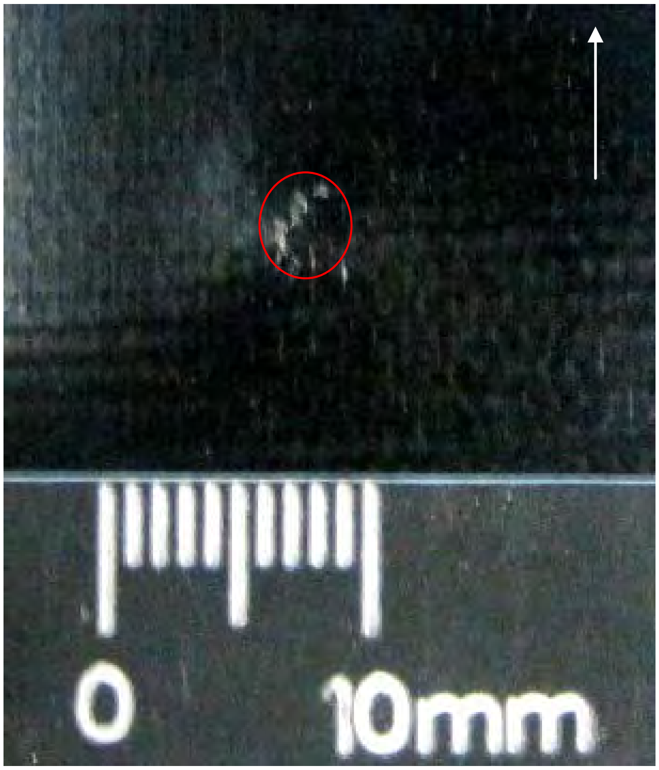


Figure 31 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

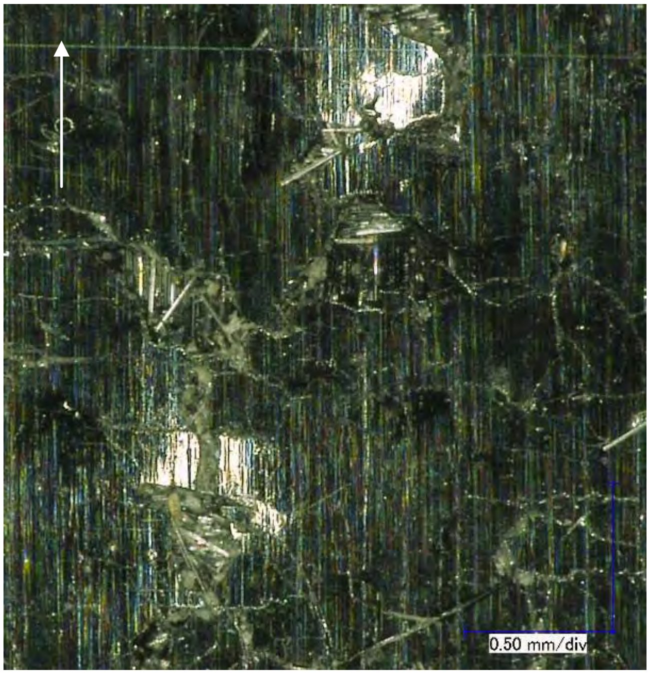


Figure 32 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (white arrow indicates flight path of projectile / damage within red circle in Figure 31)

HITF12284 / Test #2 (continued)

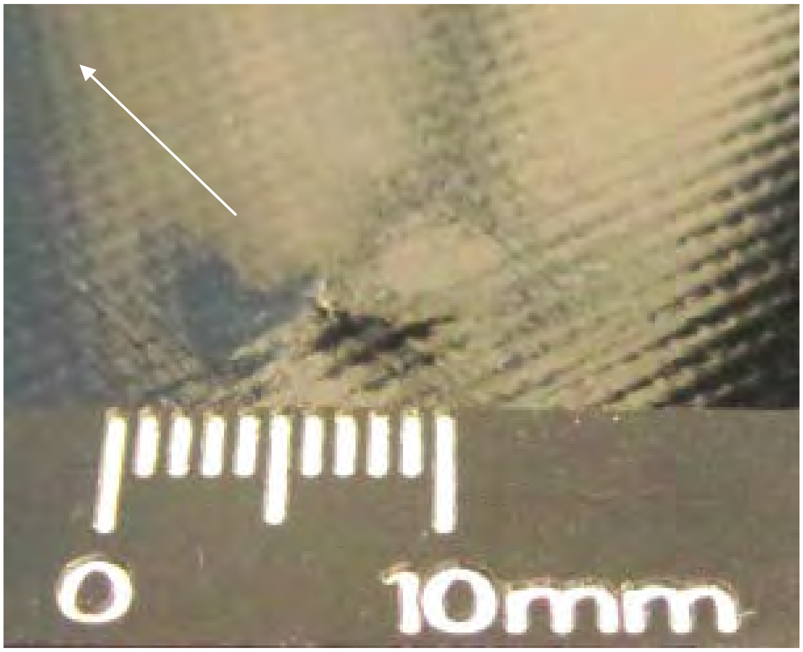


Figure 33 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

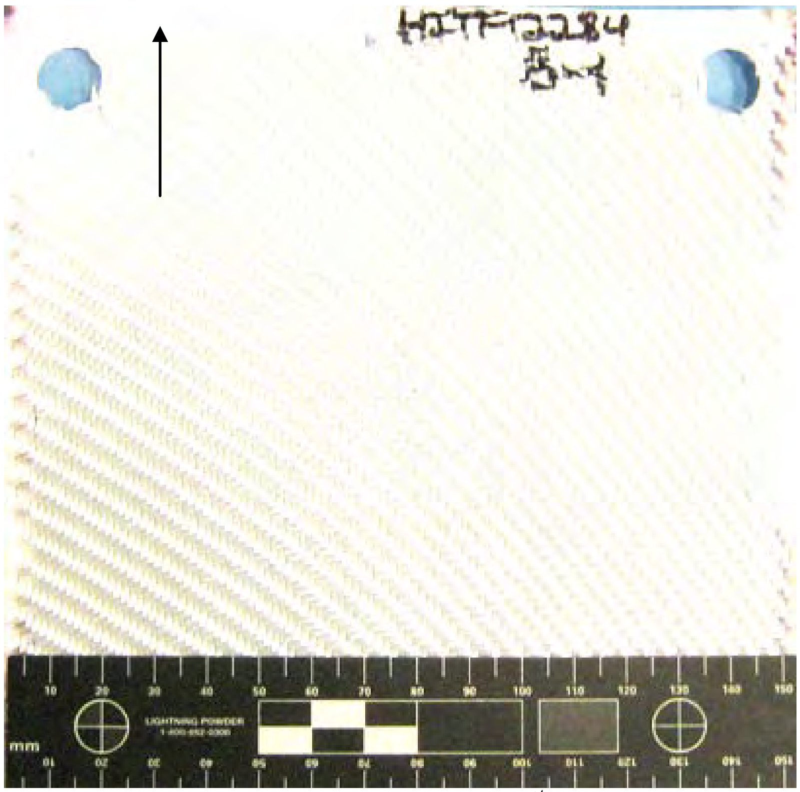


Figure 34 Overall View of Damage to Back Side of 1st Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12284 / Test #2 (continued)

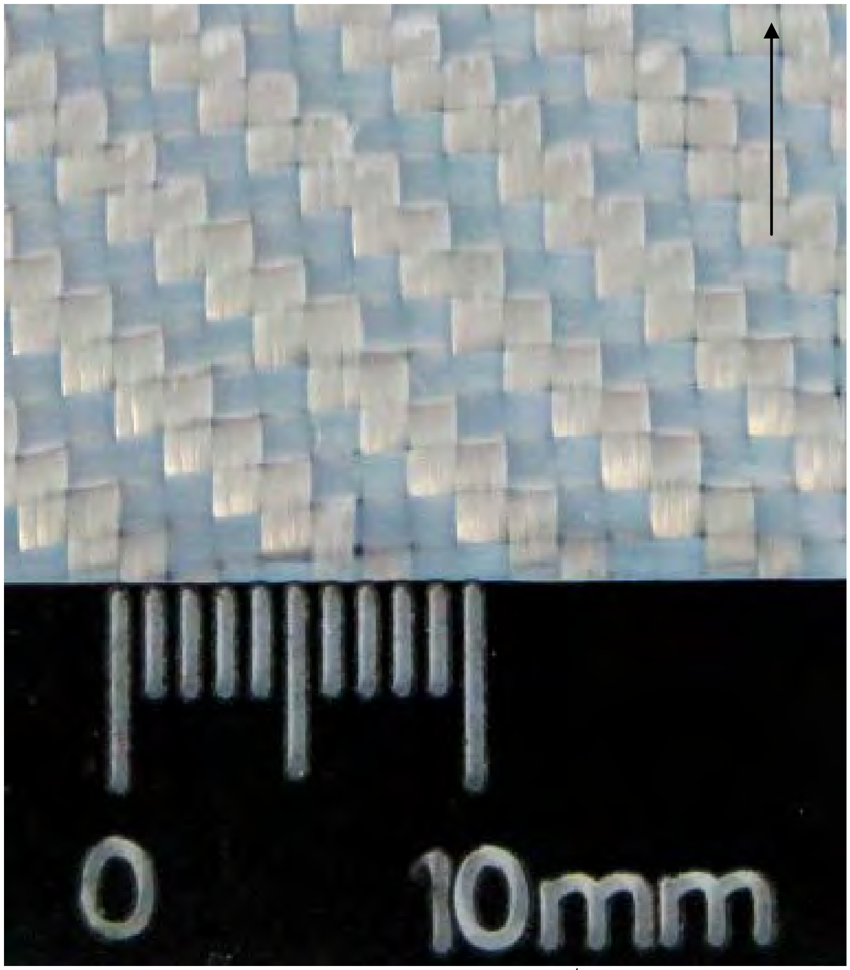


Figure 35 Close-up View of Damage to Back Side of 1st Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12285 / Test #3

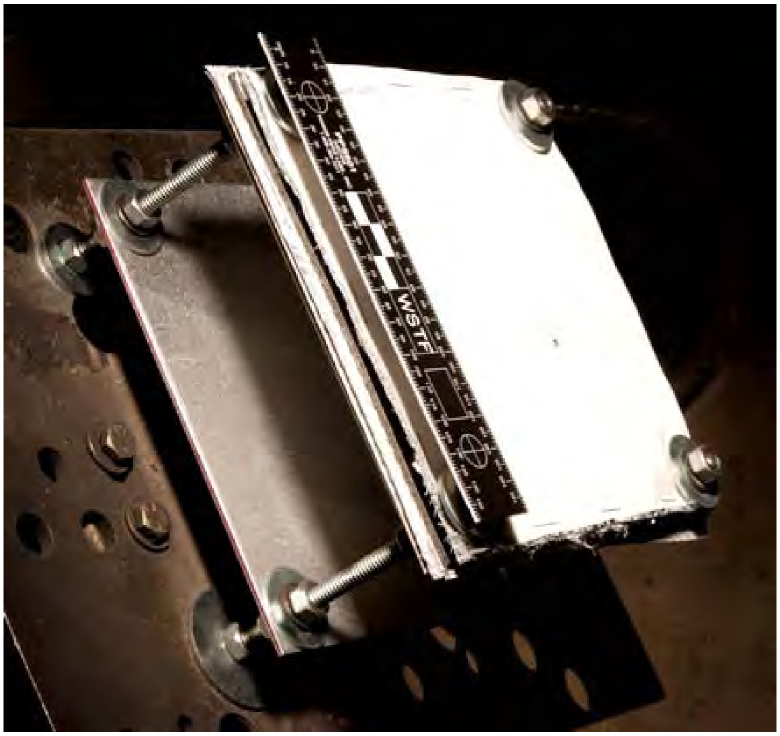


Figure 36 Overall View of Sample in the Target Tank (post-test)

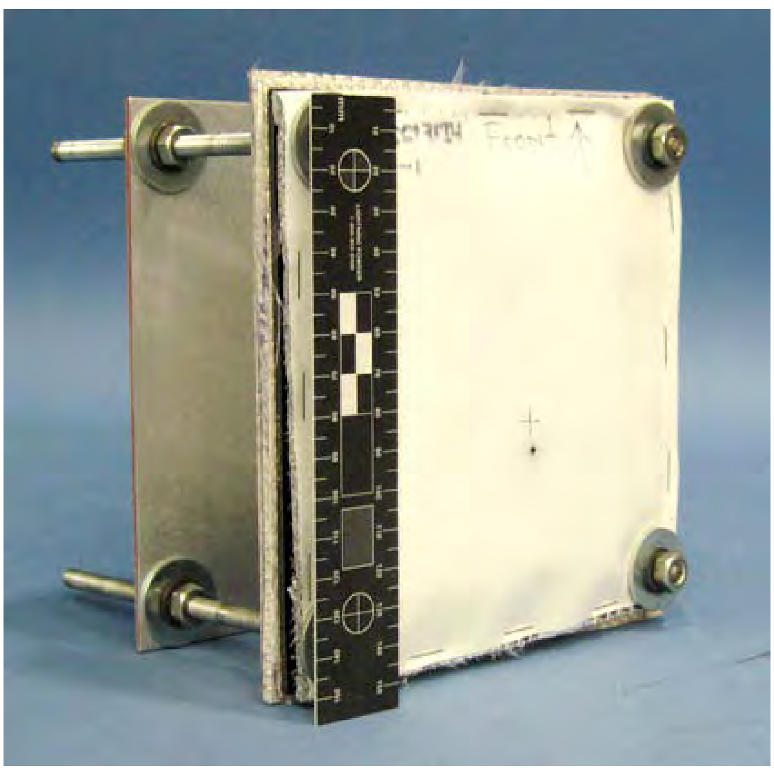


Figure 37 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12285 / Test #3 (continued)

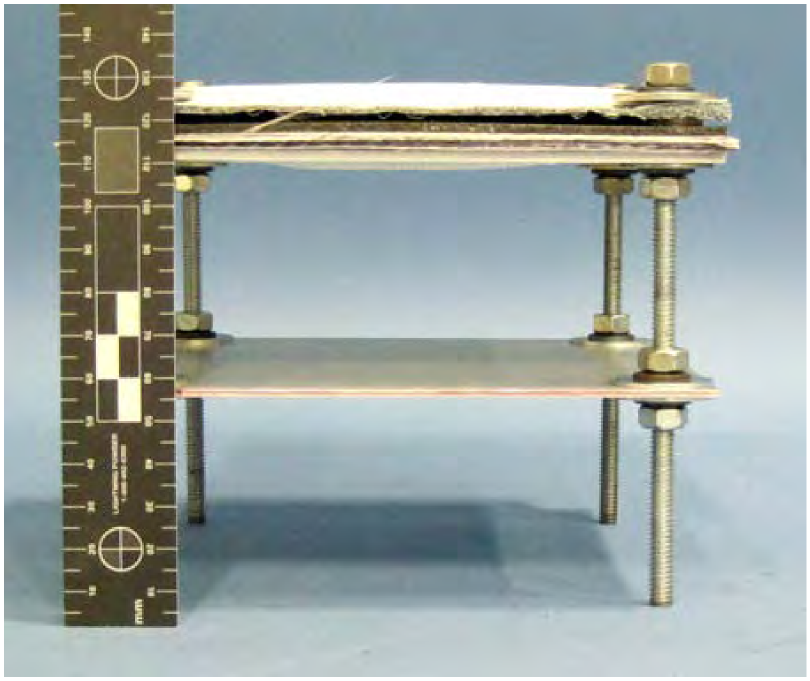


Figure 38 Overall Side View of Sample (scale in 5mm increments)

Figure 39 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12285 / Test #3 (continued)

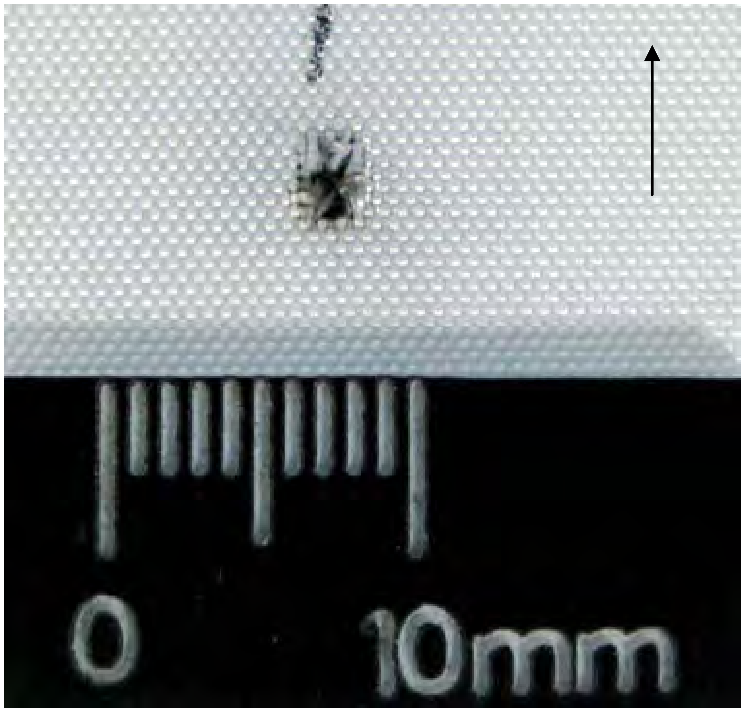


Figure 40 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

Figure 41 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12285 / Test #3 (continued)

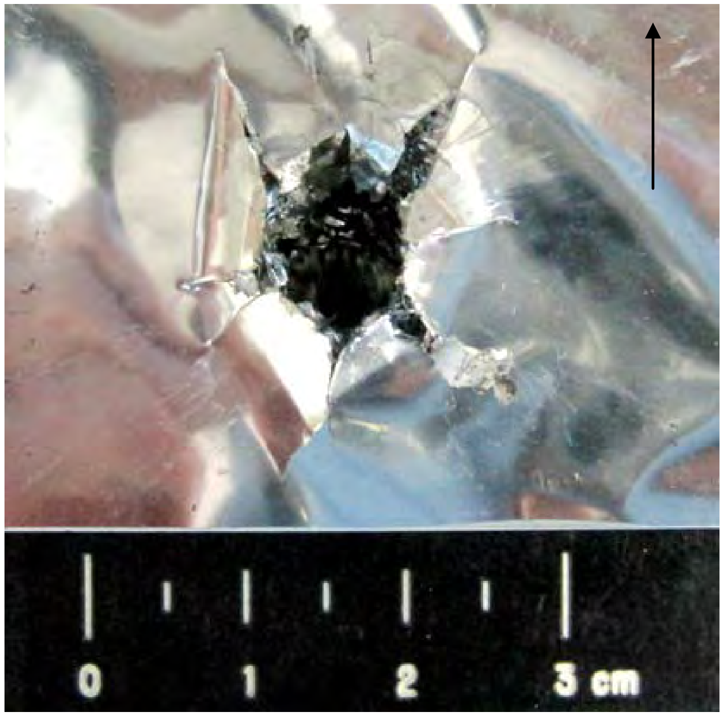


Figure 42 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

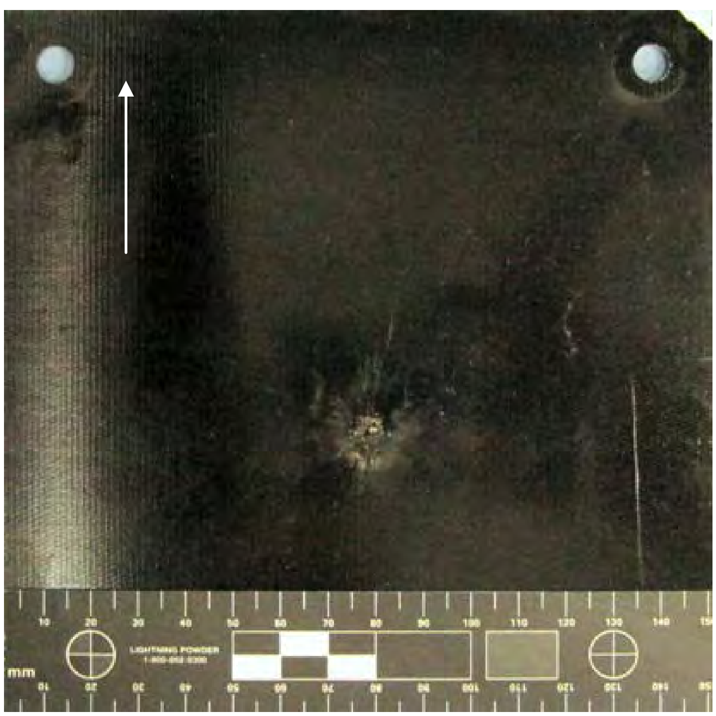


Figure 43 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12285 / Test #3 (continued)

Figure 44 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

Figure 45 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12285 / Test #3 (continued)

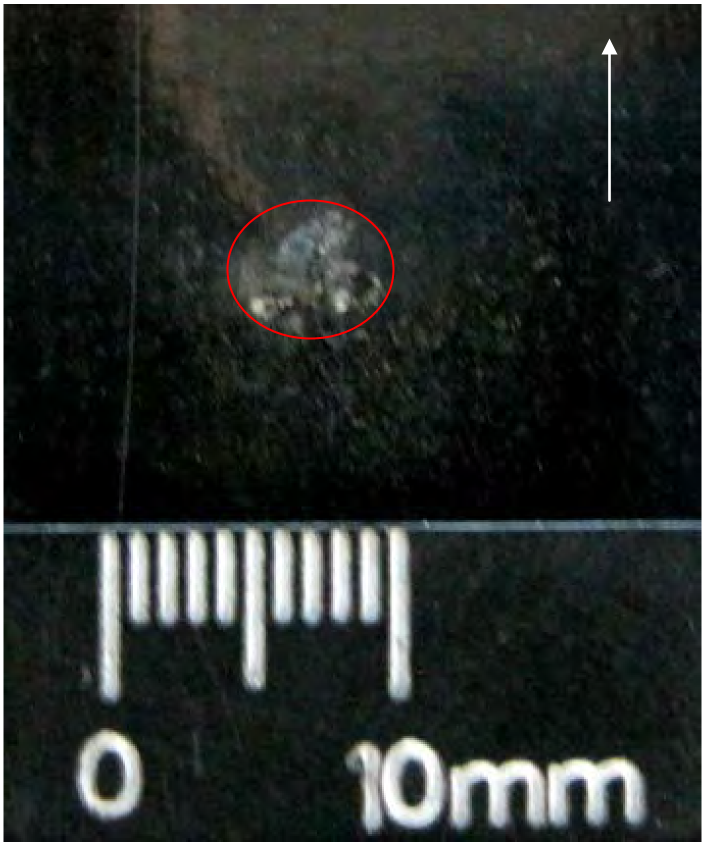


Figure 46 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

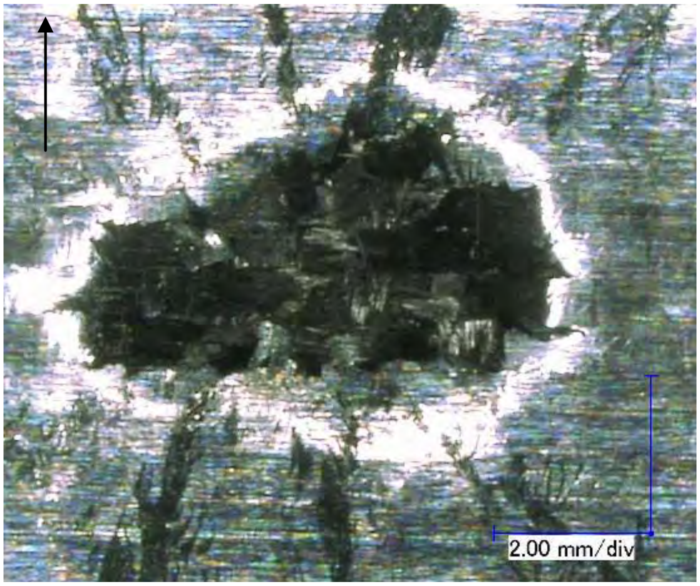


Figure 47 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 46)

HITF12285 / Test #3 (continued)

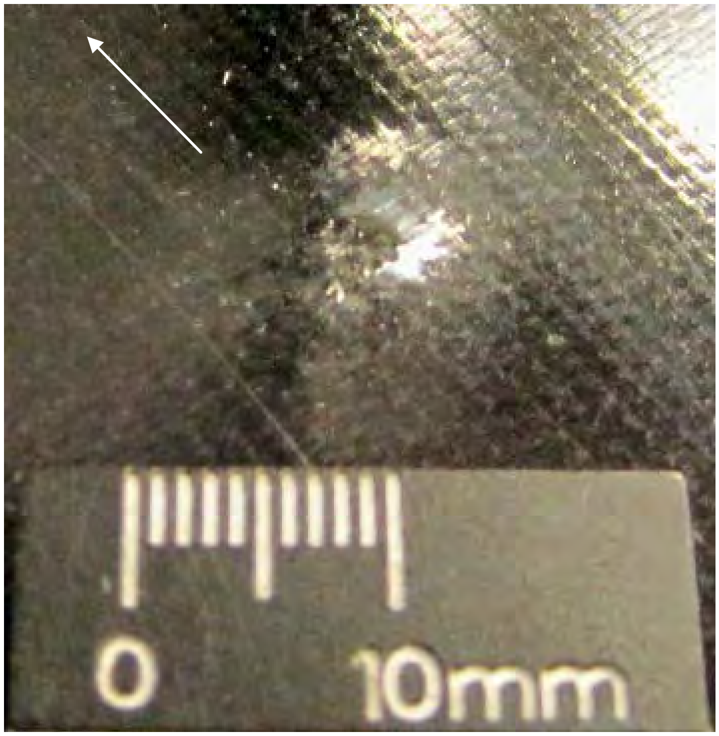


Figure 48 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

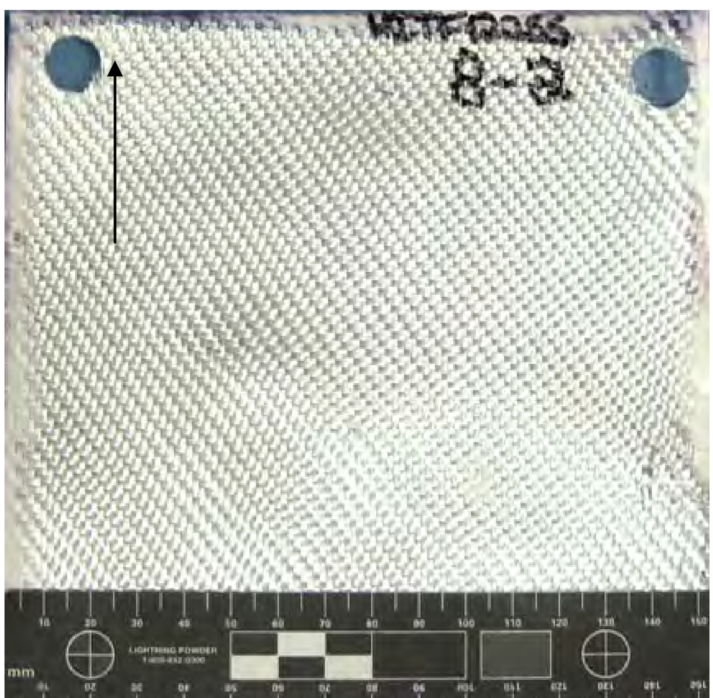


Figure 49 Overall View of Damage to Back Side of 2nd Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12285 / Test #3 (continued)

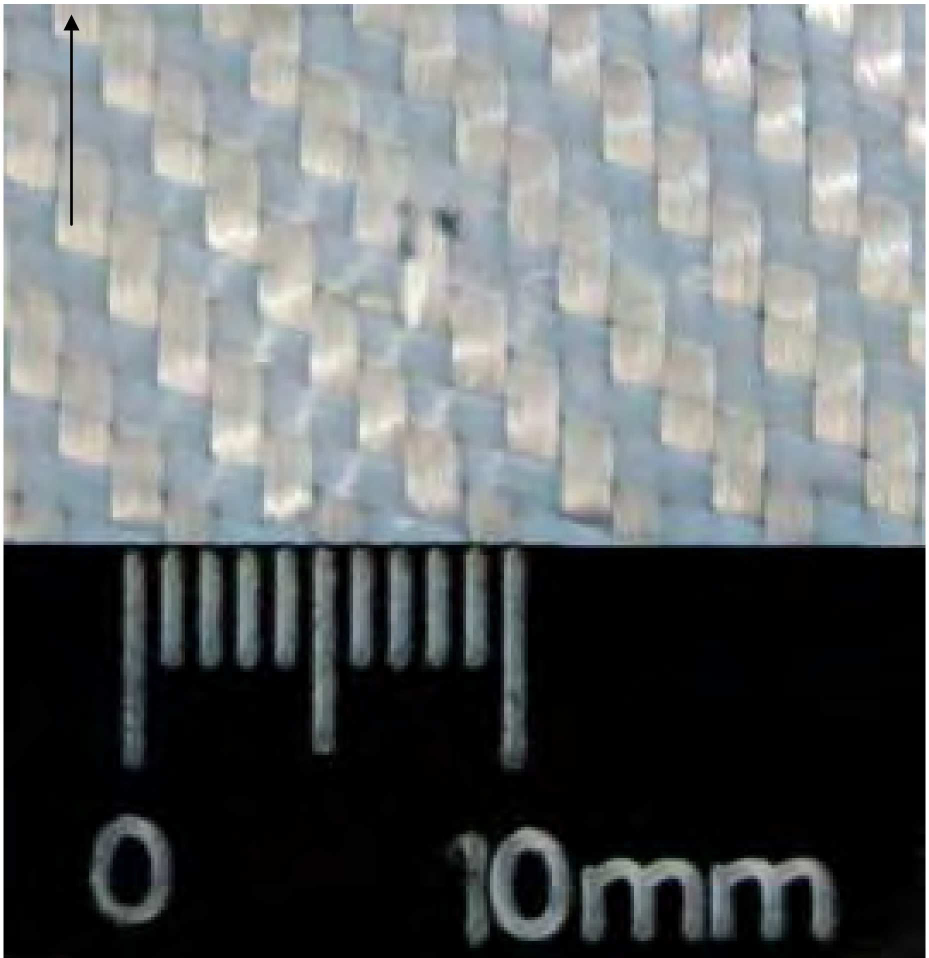


Figure 50 Close-up View of Damage to Back Side of 2nd Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12286 / Test #4

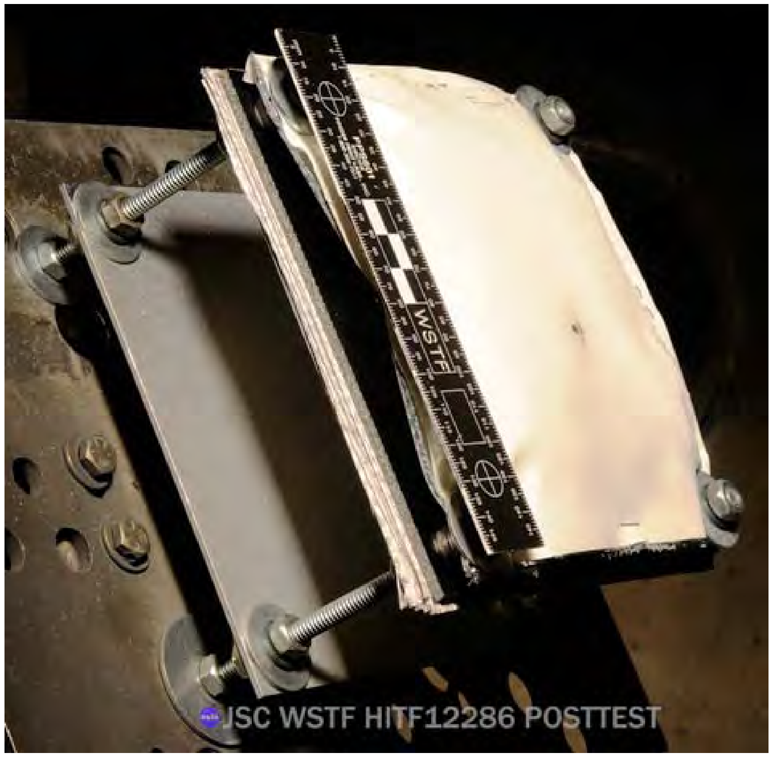


Figure 51 Overall View of Sample in the Target Tank (post-test)


Figure 52 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12286 / Test #4 (continued)

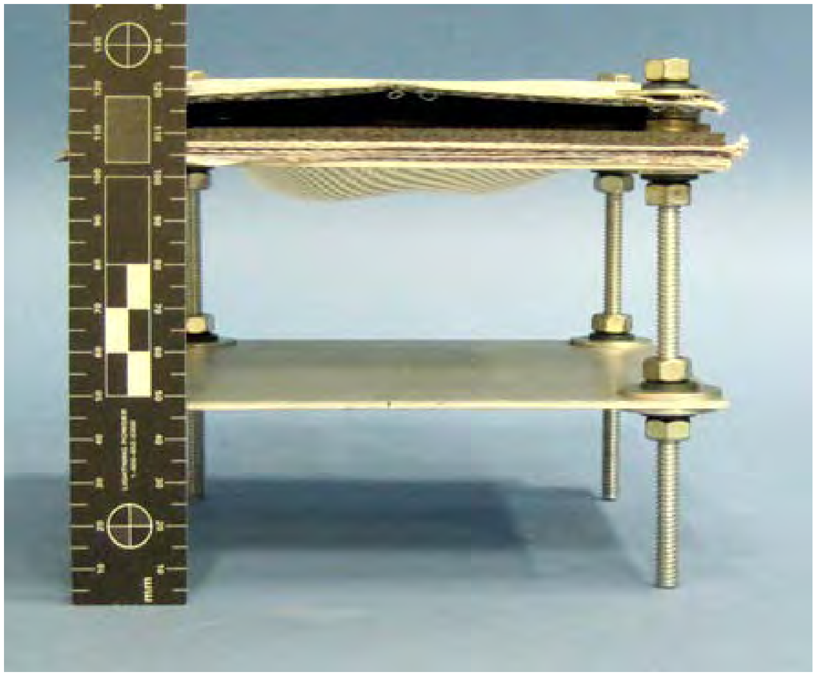


Figure 53 Overall Side View of Sample (scale in 5mm increments)

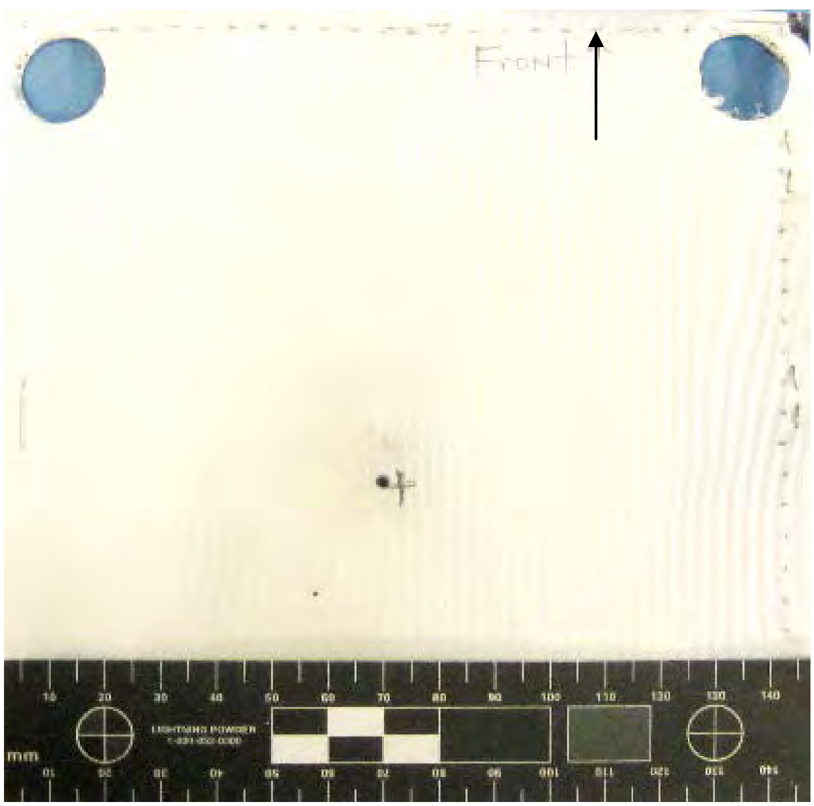


Figure 54 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12286 / Test #4 (continued)

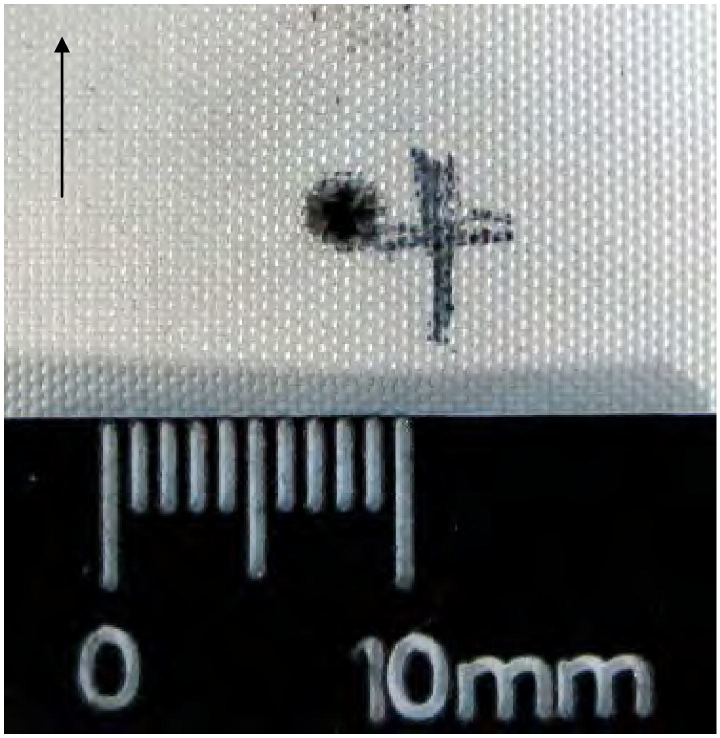


Figure 55 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

Figure 56 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12286 / Test #4 (continued)

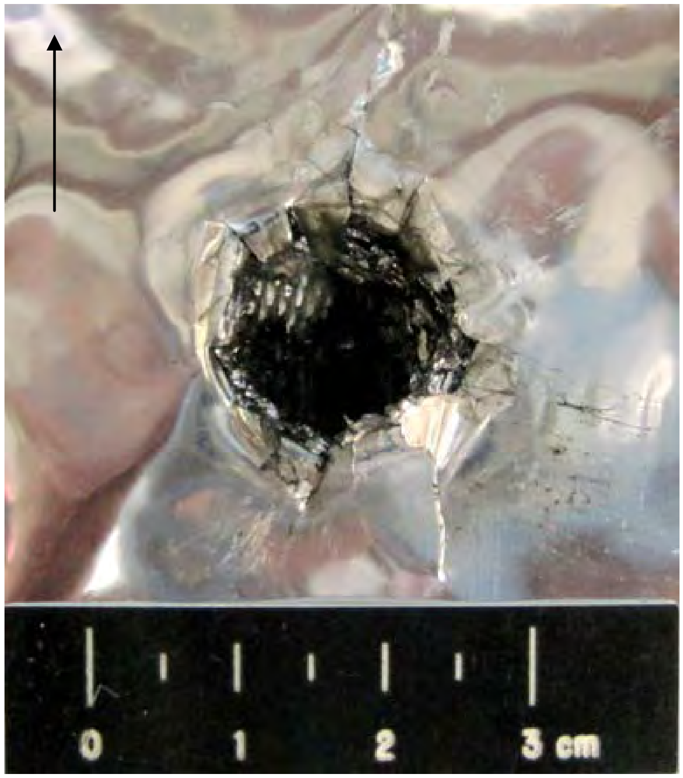


Figure 57 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

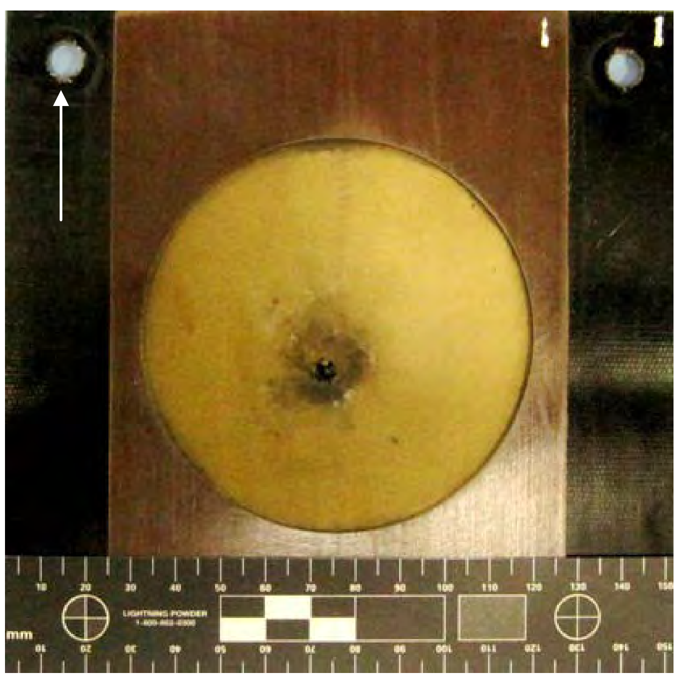


Figure 58 Overall View of Damage to Front of TORLON 5030 (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12286 / Test #4 (continued)

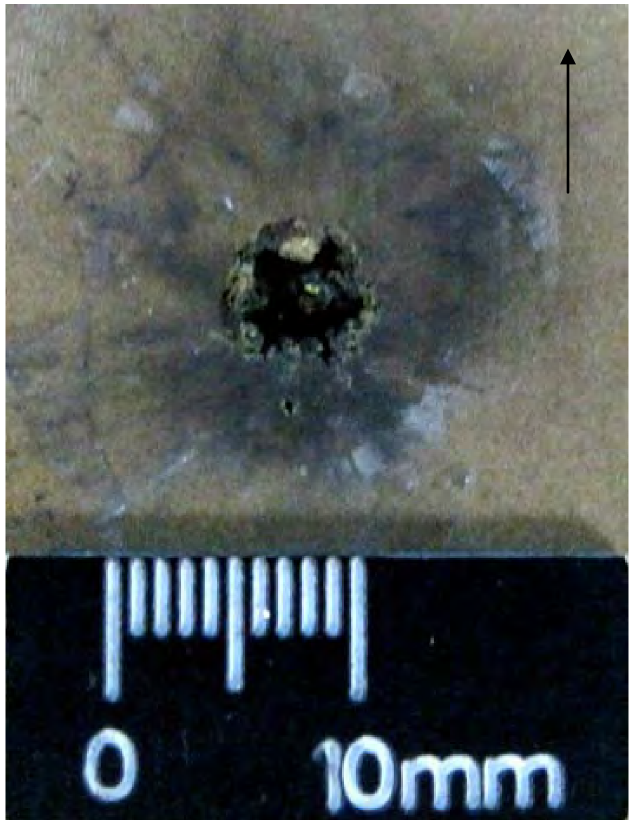


Figure 59 Close-up View of Damage to Front of TORLON 5030 (scale in 1mm increments / black arrow indicates flight path of projectile)

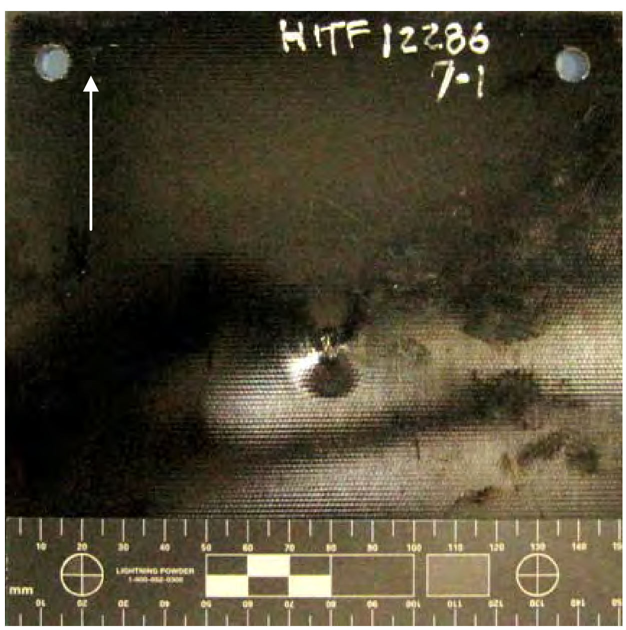


Figure 60 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12286 / Test #4 (continued)

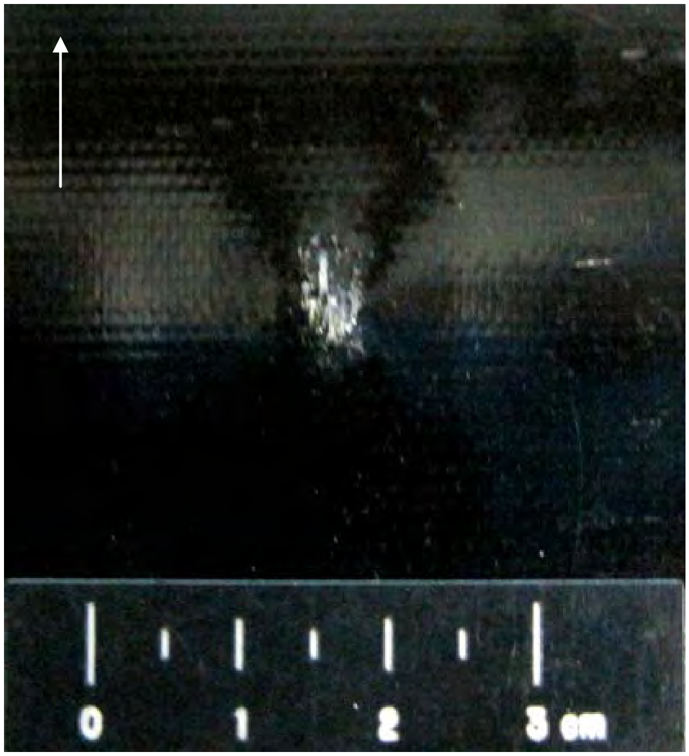


Figure 61 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

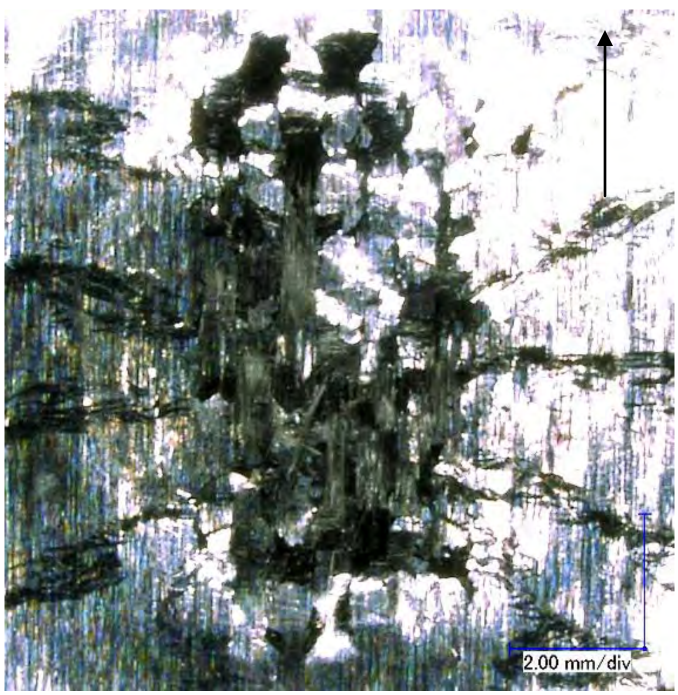


Figure 62 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 61)

HITF12286 / Test #4 (continued)

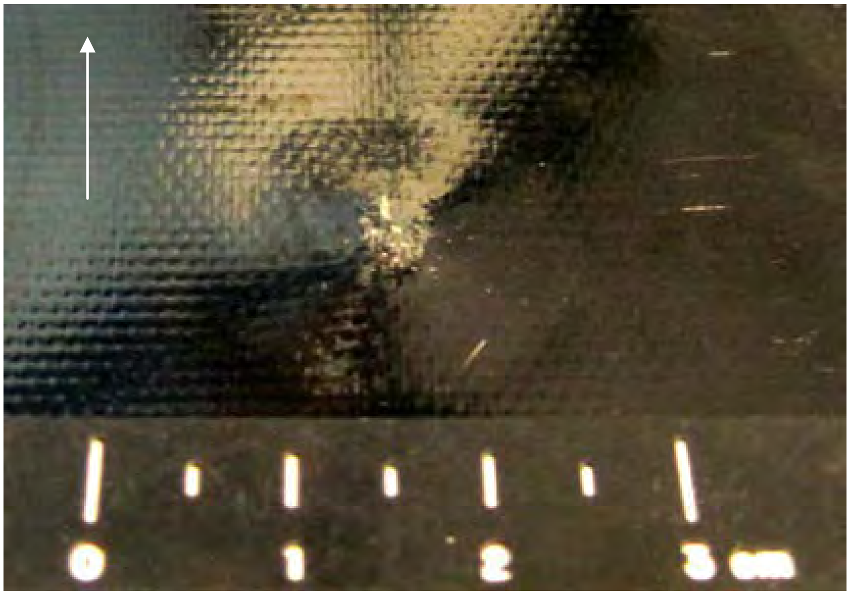


Figure 63 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

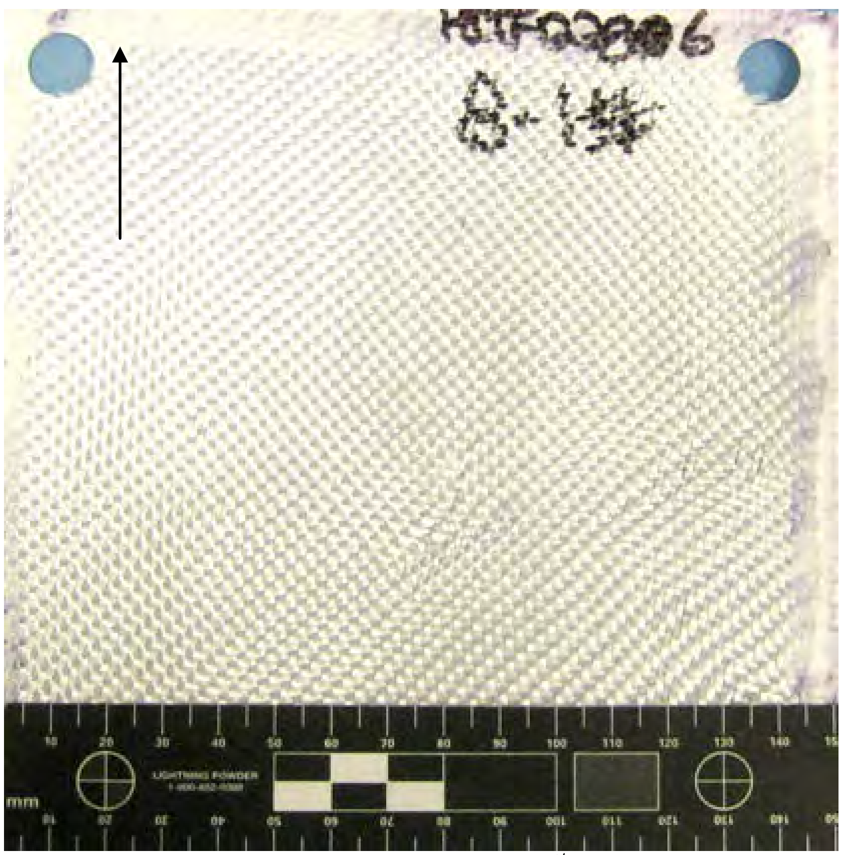


Figure 64 Overall View of Damage to Back Side of 1st Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

<u>HITF12286 / Test #4 (continued)</u>

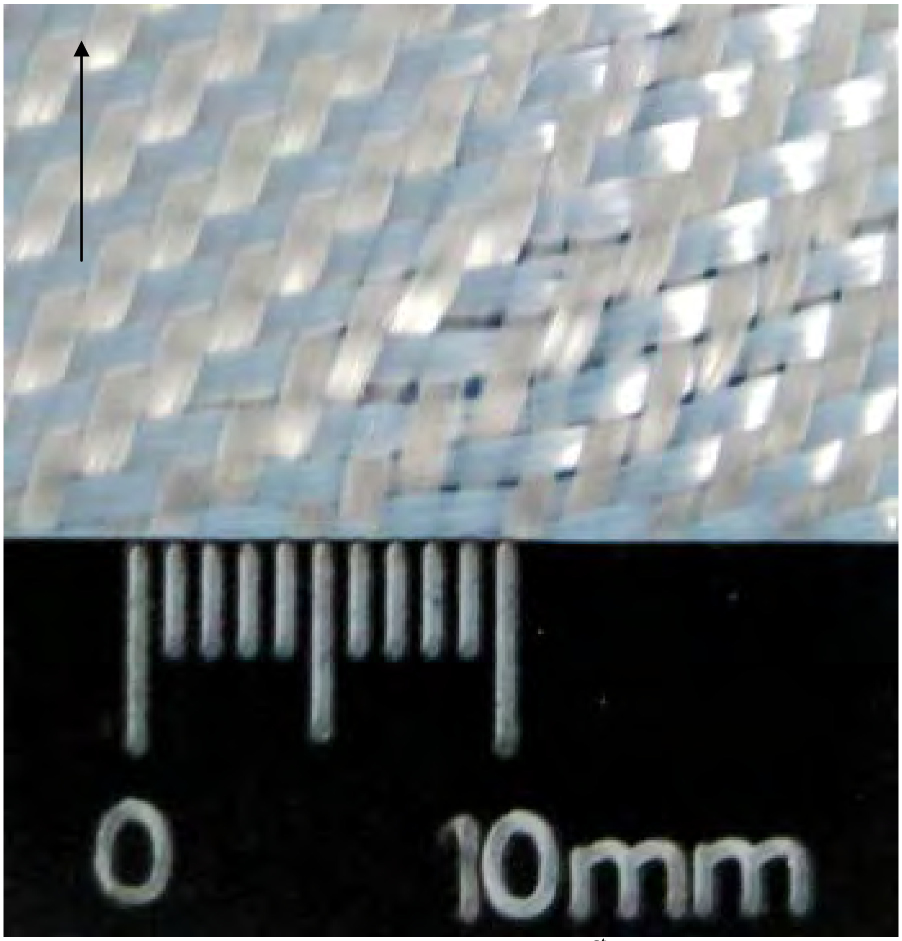


Figure 65 Close-up View of Damage to Back Side of 1st Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12287 / Test #5

Figure 66 Overall View of Sample in the Target Tank (post-test)

Figure 67 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12287 / Test #5 (continued)

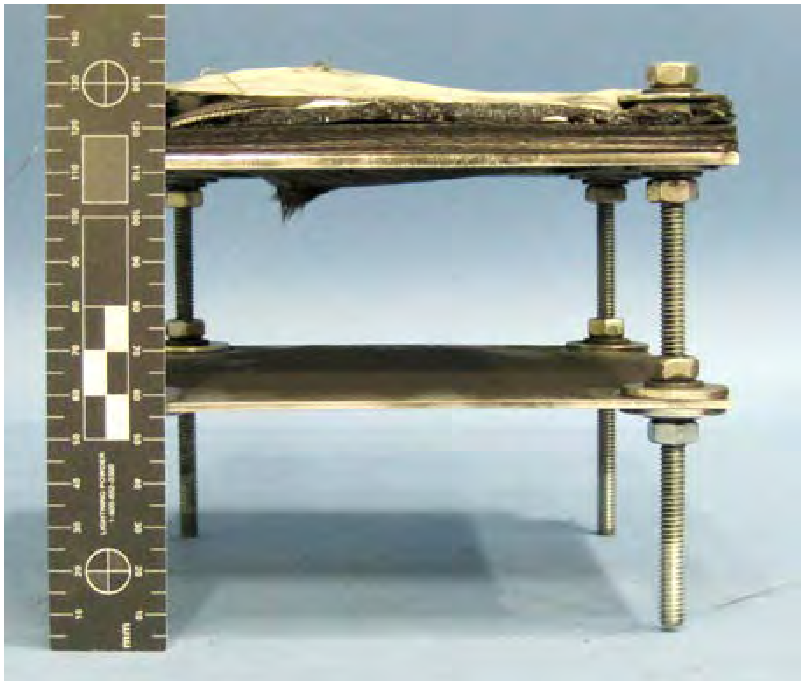


Figure 68 Overall Side View of Sample (scale in 5mm increments)

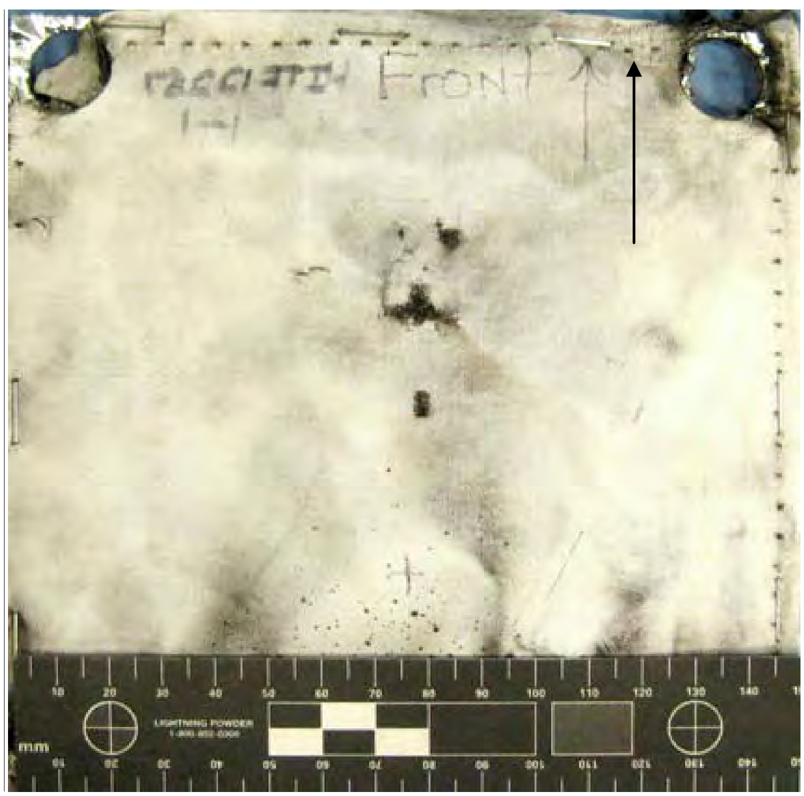


Figure 69 Overall View of Damage to Front of MLI (black arrow indicates flight path of projectile / scale in 5mm increments)

HITF12287 / Test #5 (continued)

Figure 70 Close-up View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile / projectile impacted within red circle)

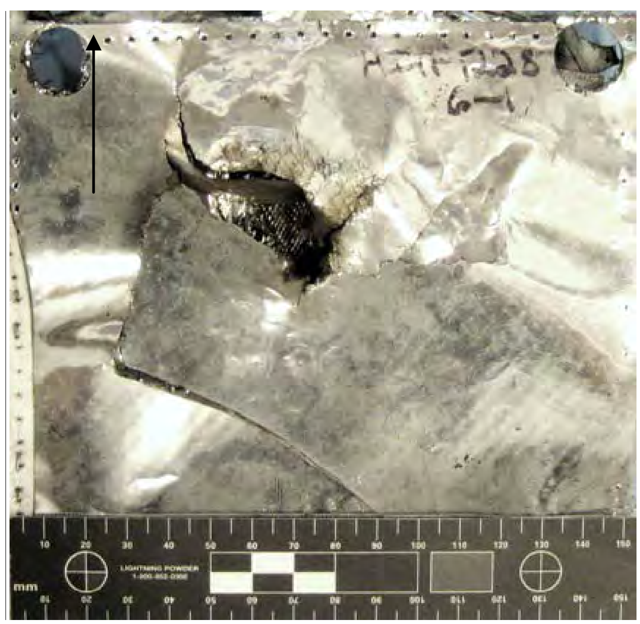


Figure 71 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12287 / Test #5 (continued)

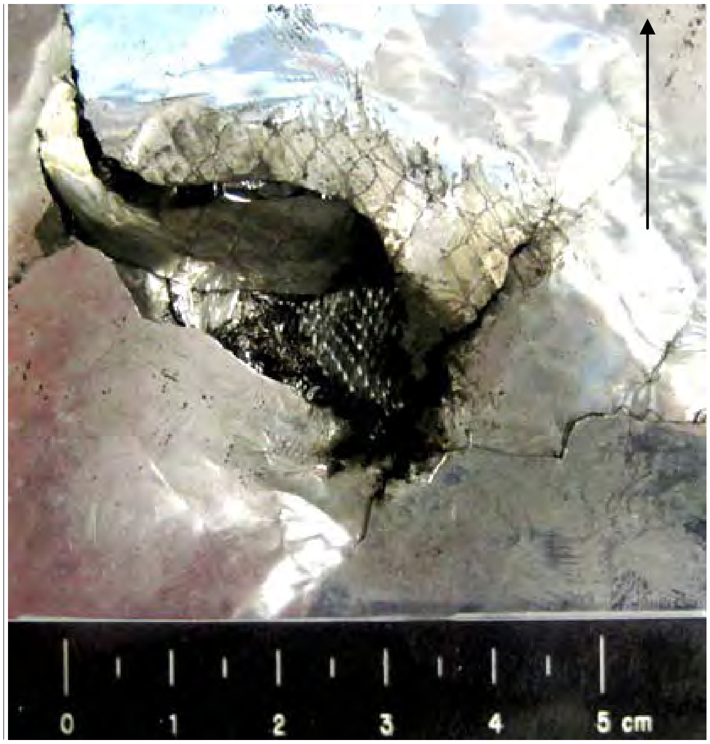


Figure 72 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

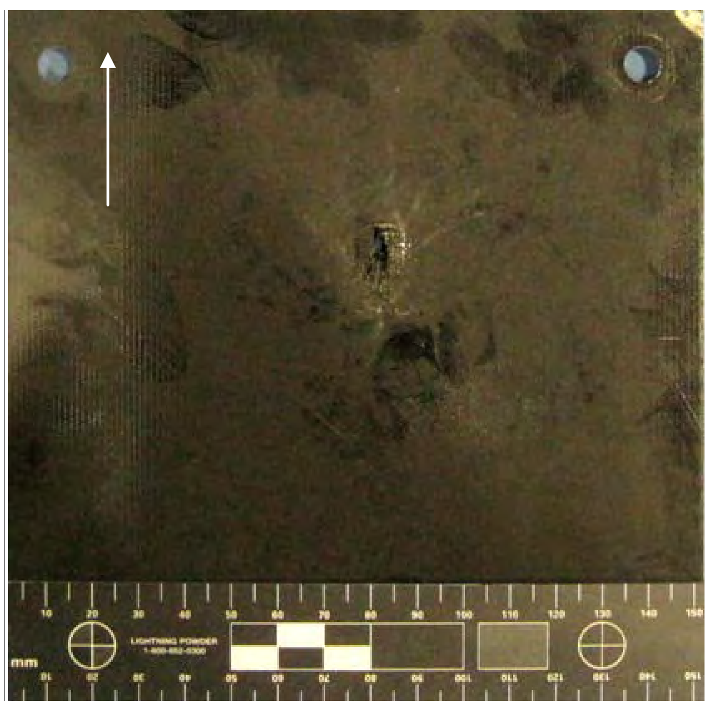


Figure 73 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12287 / Test #5 (continued)

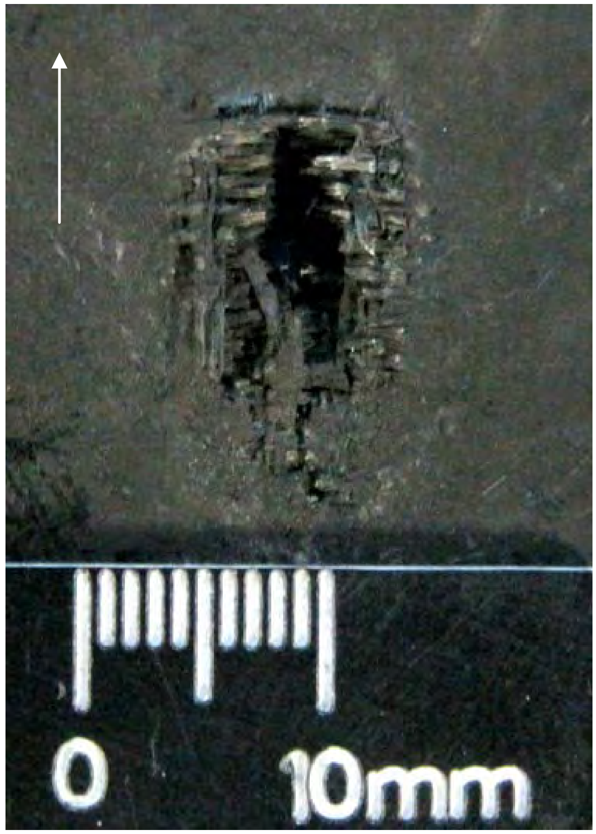


Figure 74 Close-up View of Damage to Front of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

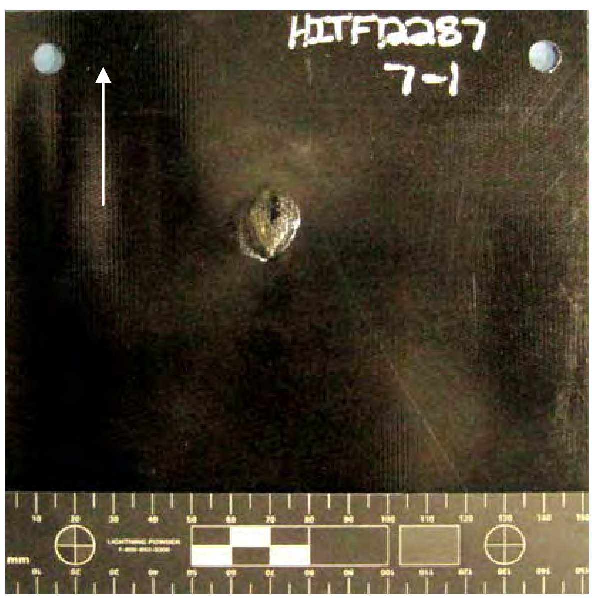


Figure 75 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12287 / Test #5 (continued)

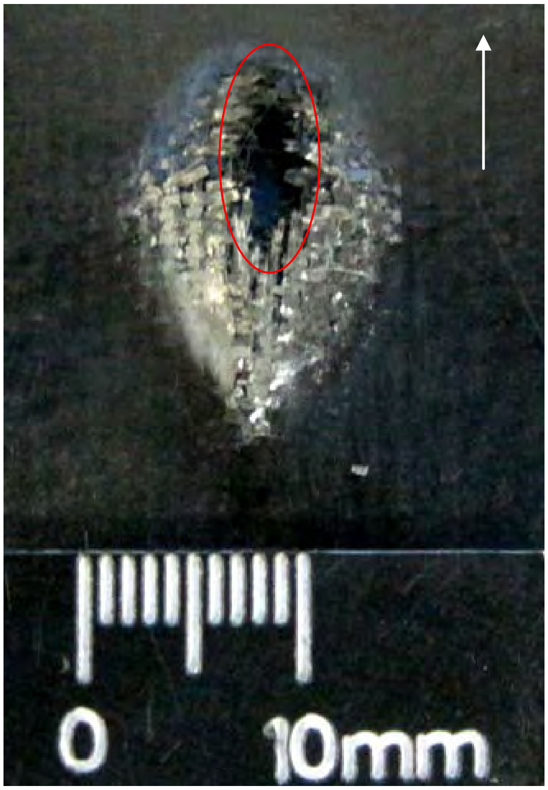


Figure 76 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

Figure 77 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 76)

HITF12287 / Test #5 (continued)

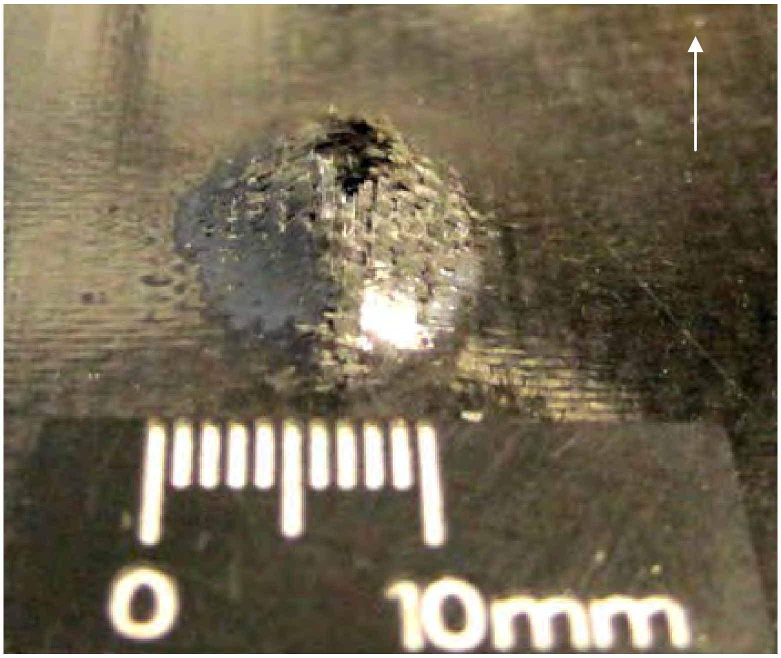


Figure 78 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

Figure 79 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12287 / Test #5 (continued)

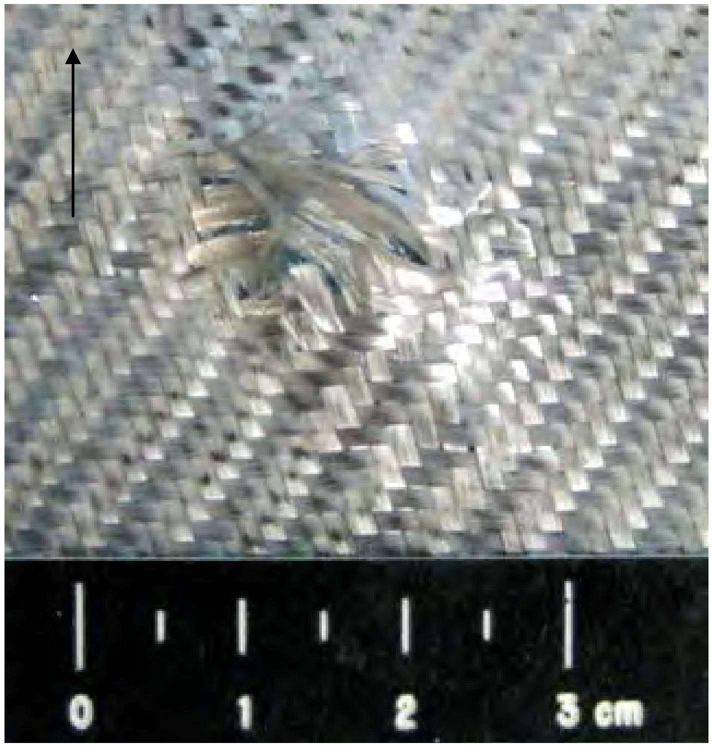


Figure 80 Close-up View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

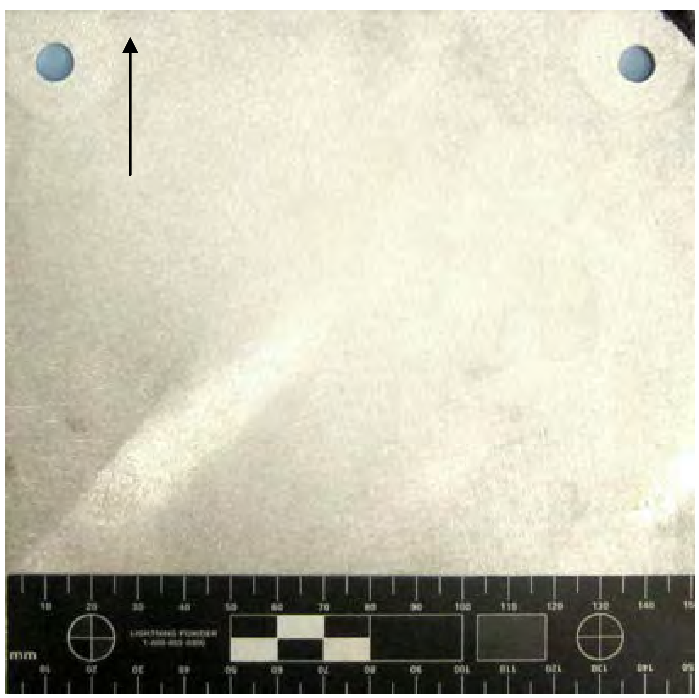


Figure 81 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12287 / Test #5 (continued)

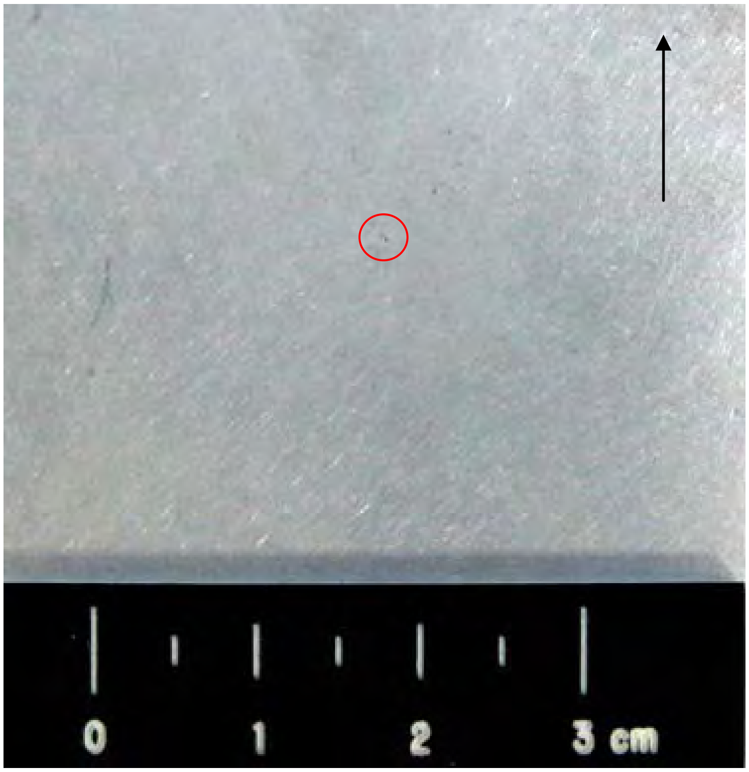


Figure 82 Close-up View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

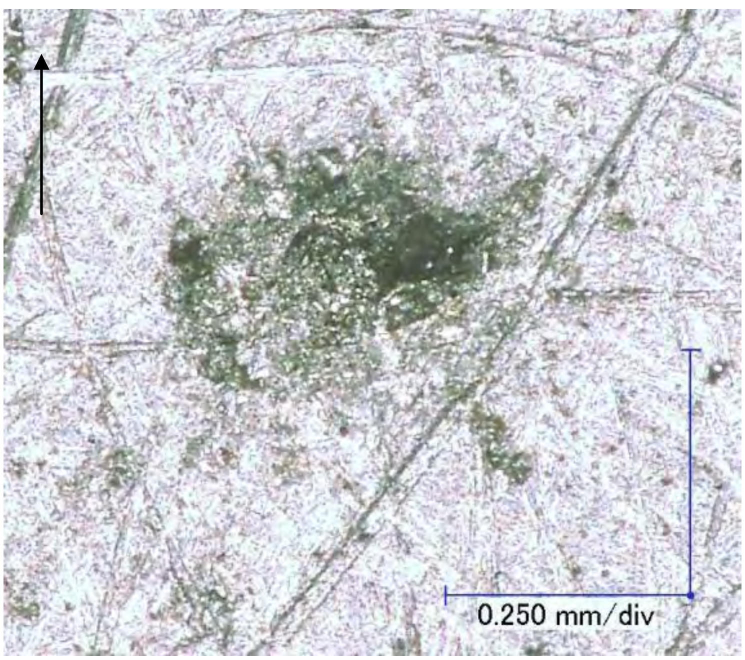


Figure 83 Close-up View of Most Significant Damage to Front of Rear Wall (black arrow indicates flight path of projectile / damage within red circle in Figure 82)

HITF12287 / Test #5 (continued)

Figure 84 Overall View of Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12288 / Test #6

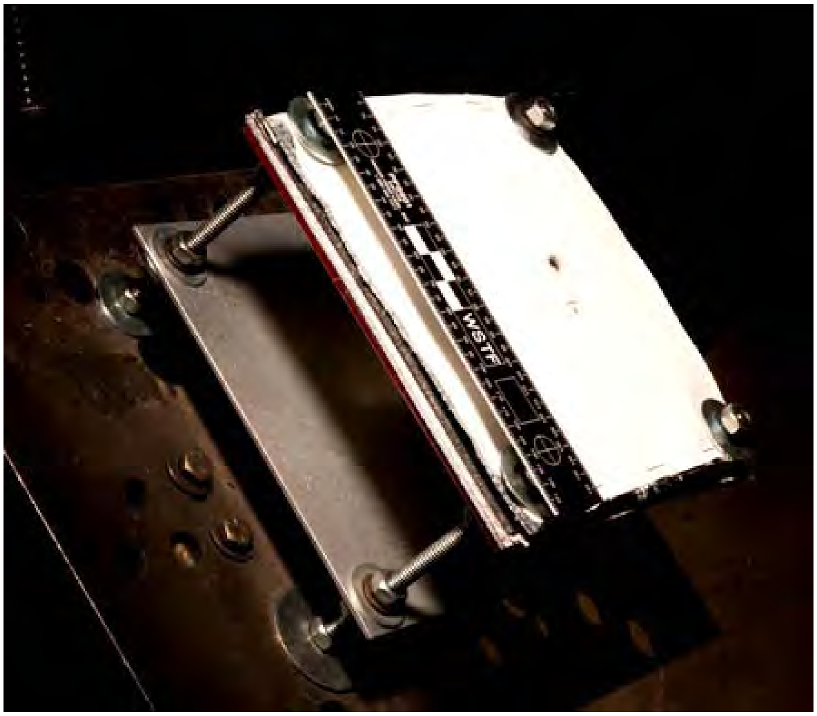


Figure 85 Overall View of Sample in the Target Tank (post-test)

Figure 86 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12288 / Test #6 (continued)

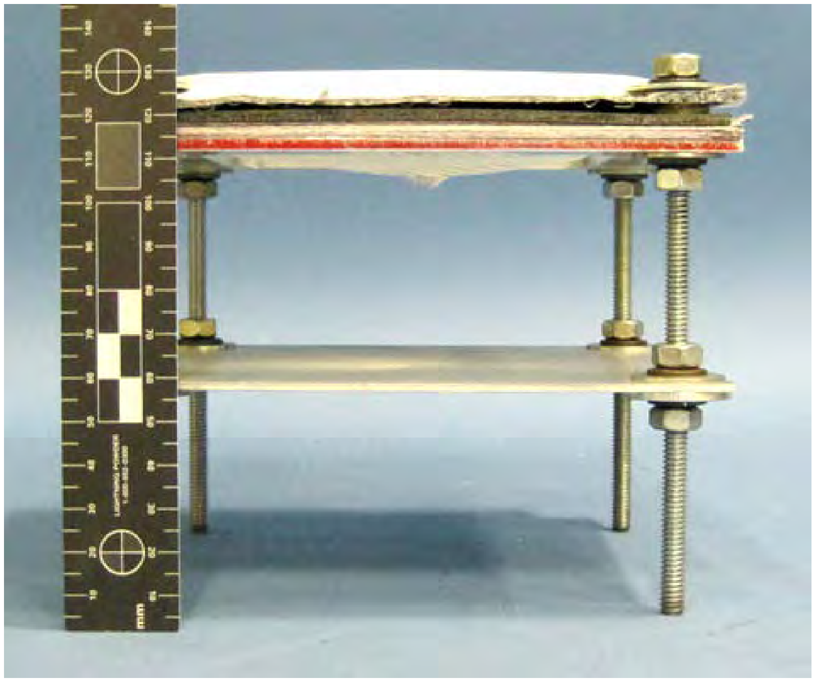


Figure 87 Overall Side View of Sample (scale in 5mm increments)

Figure 88 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12288 / Test #6 (continued)

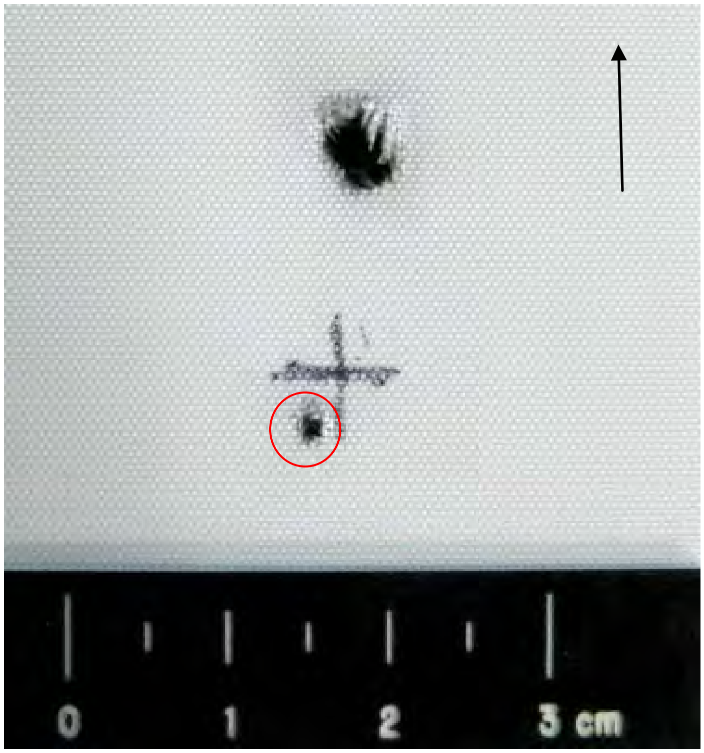


Figure 89 Close-up View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile / projectile impacted within red circle)

Figure 90 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12288 / Test #6 (continued)

Figure 91 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

Figure 92 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12288 / Test #6 (continued)

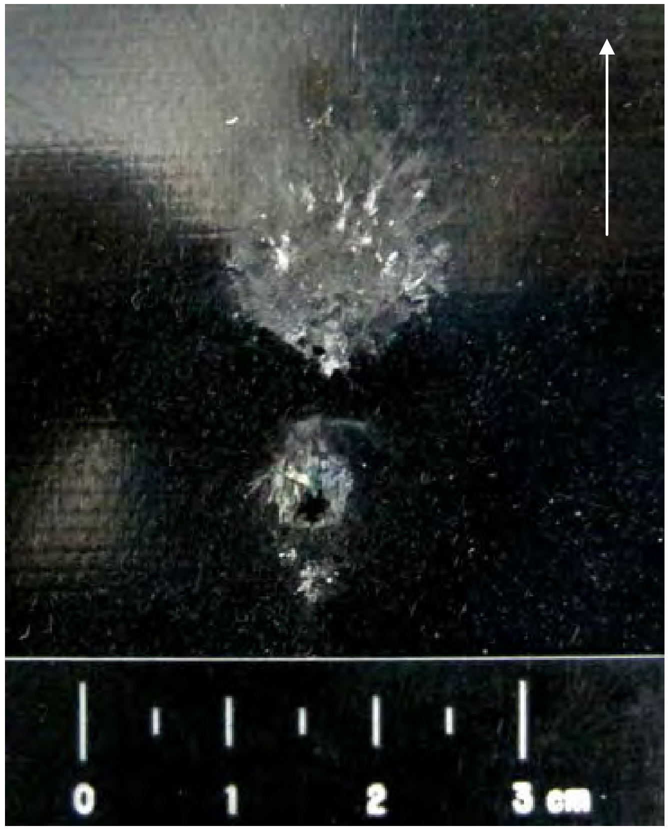


Figure 93 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

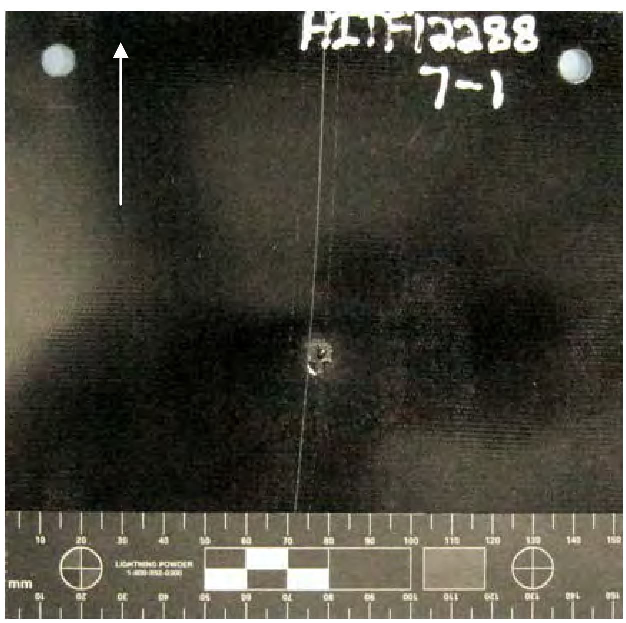


Figure 94 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12288 / Test #6 (continued)

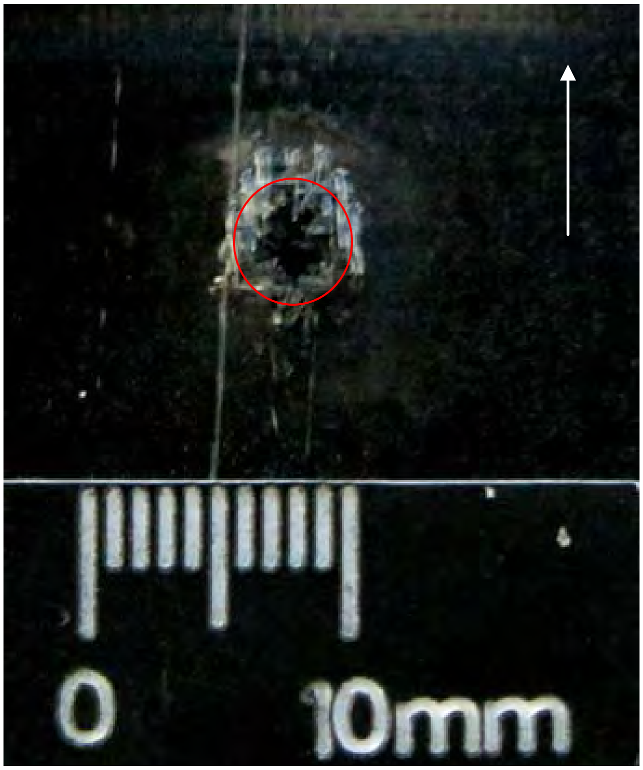


Figure 95 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

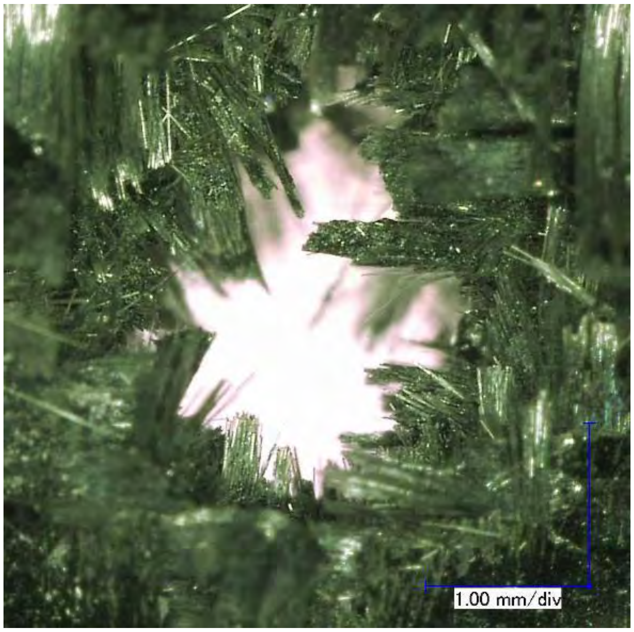


Figure 96 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 95)

HITF12288 / Test #6 (continued)

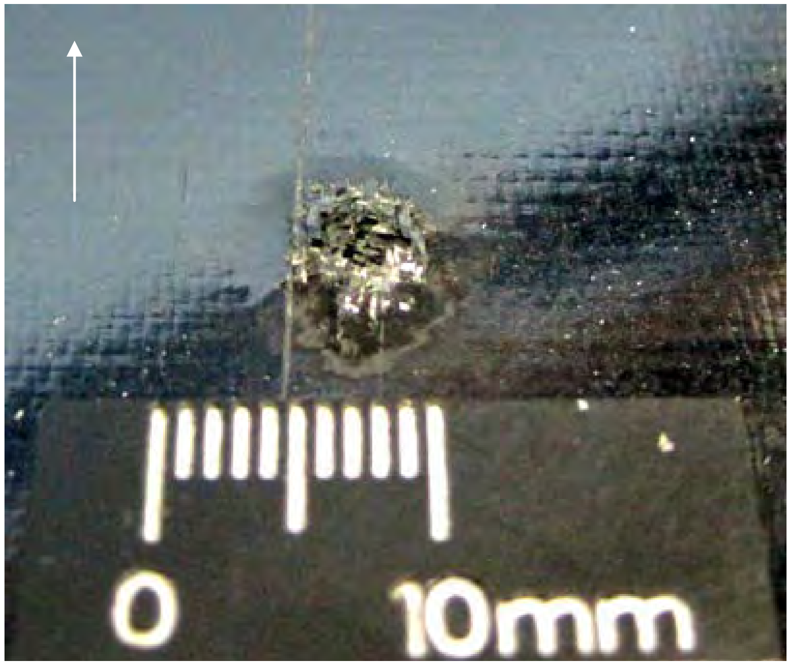


Figure 97 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

Figure 98 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12288 / Test #6 (continued)

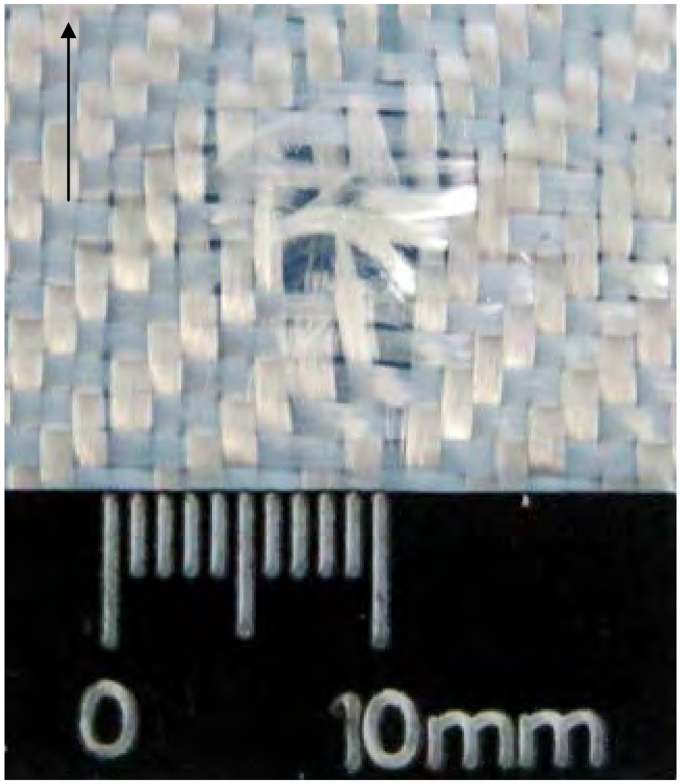


Figure 99 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

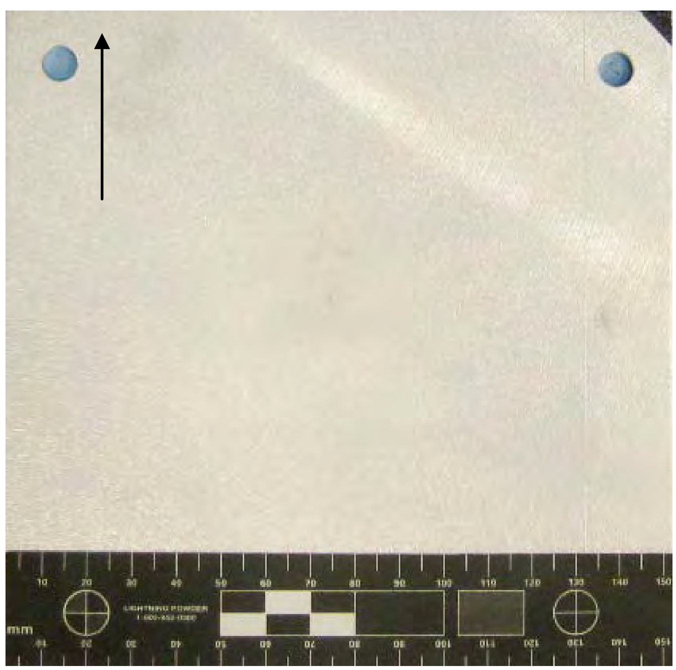


Figure 100 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12288 / Test #6 (continued)

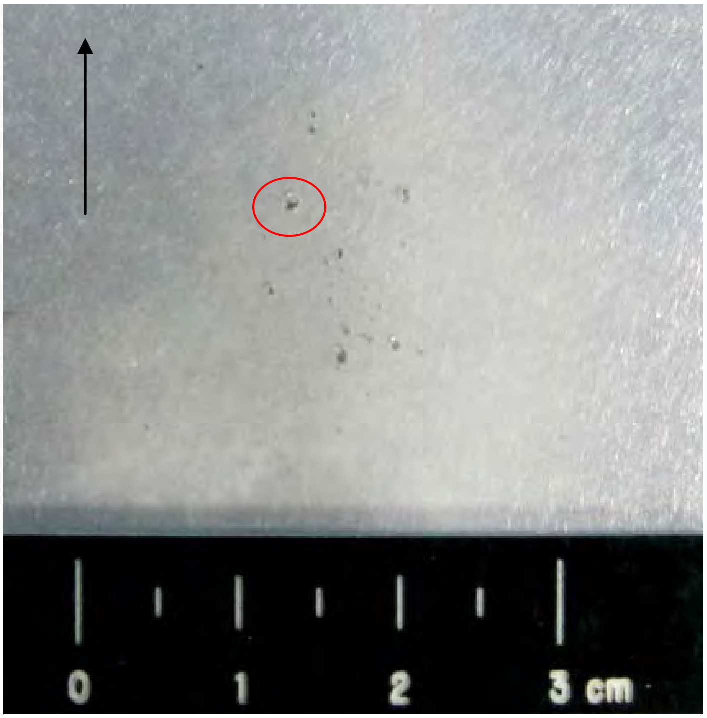


Figure 101 Close-up View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

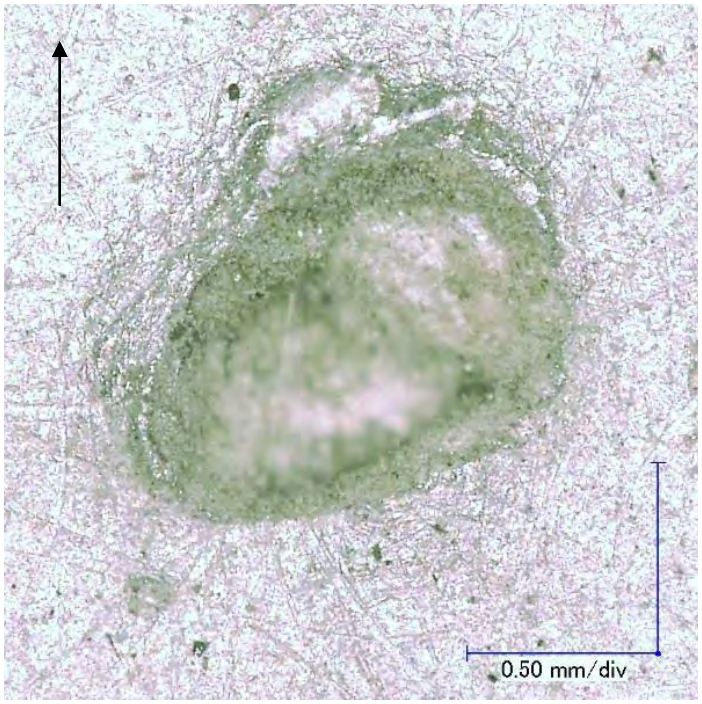


Figure 102 Close-up View of Most Significant Damage to Front of Rear Wall (black arrow indicates flight path of projectile / damage within red circle in Figure 101)

HITF12288 / Test #6 (continued)

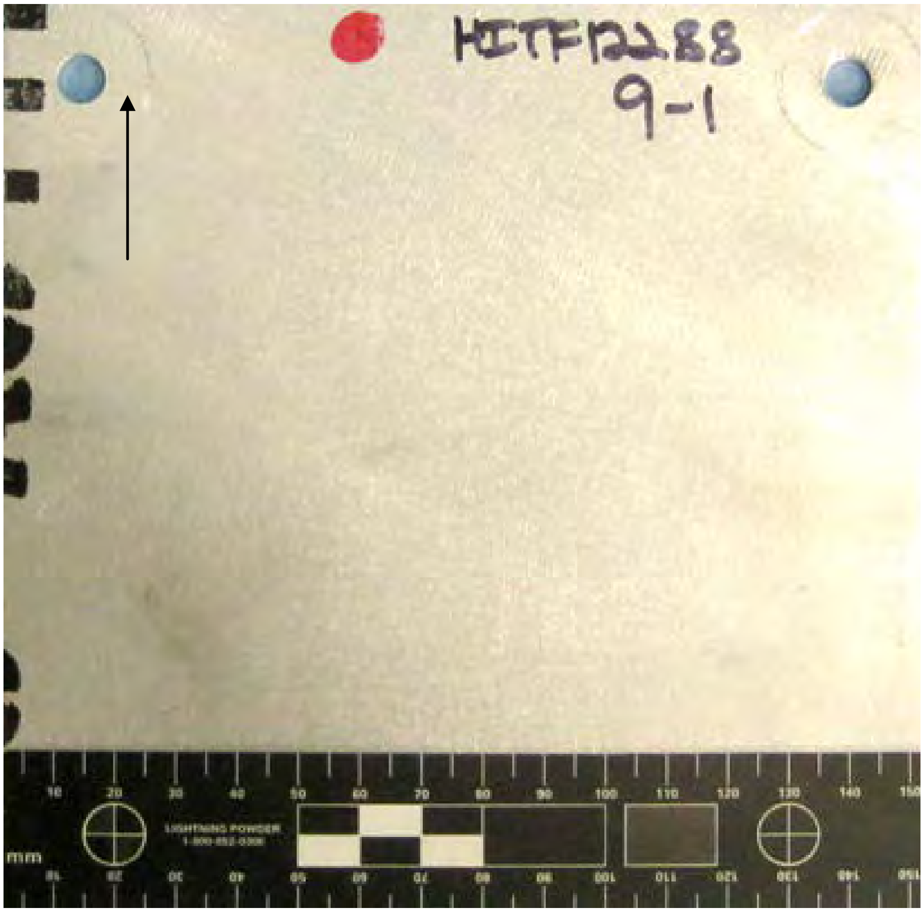


Figure 103 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12289 / Test #7

Figure 104 Overall View of Sample in the Target Tank (post-test)

Figure 105 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12289 / Test #7 (continued)

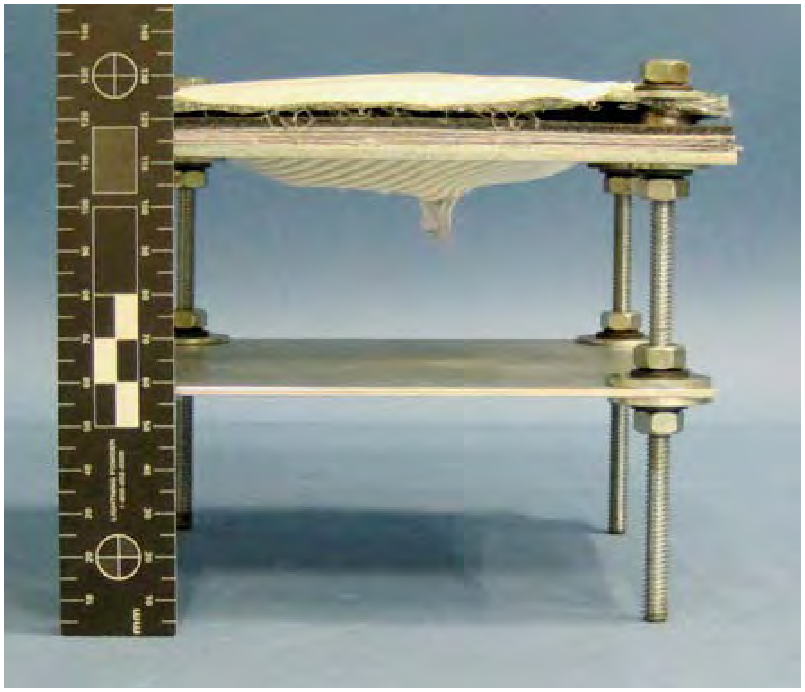


Figure 106 Overall Side View of Sample (scale in 5mm increments)

Figure 107 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12289 / Test #7 (continued)

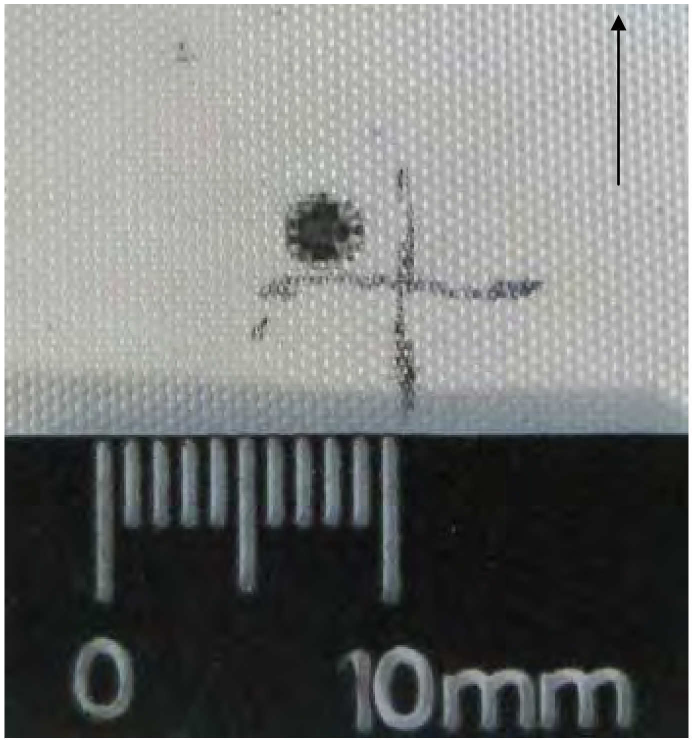


Figure 108 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

Figure 109 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12289 / Test #7 (continued)

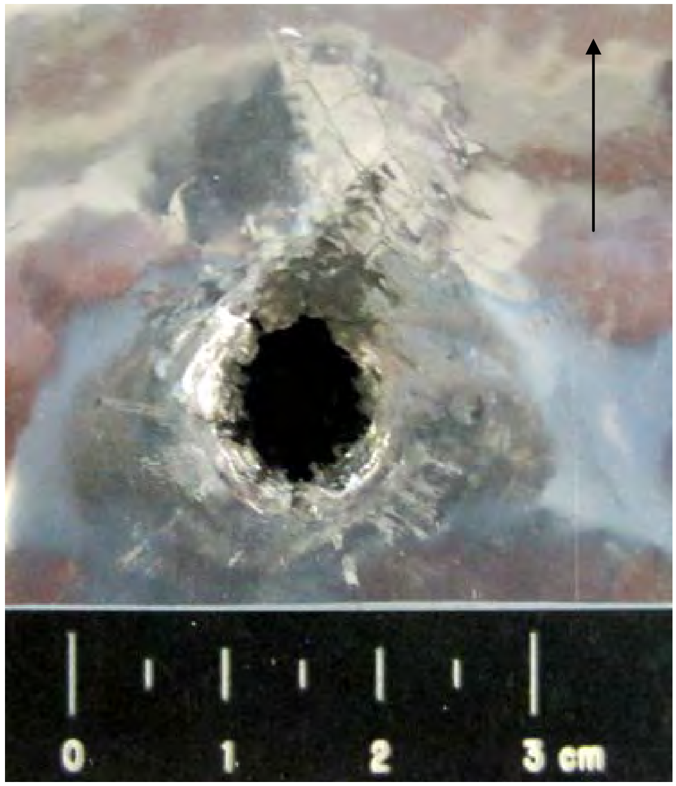


Figure 110 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

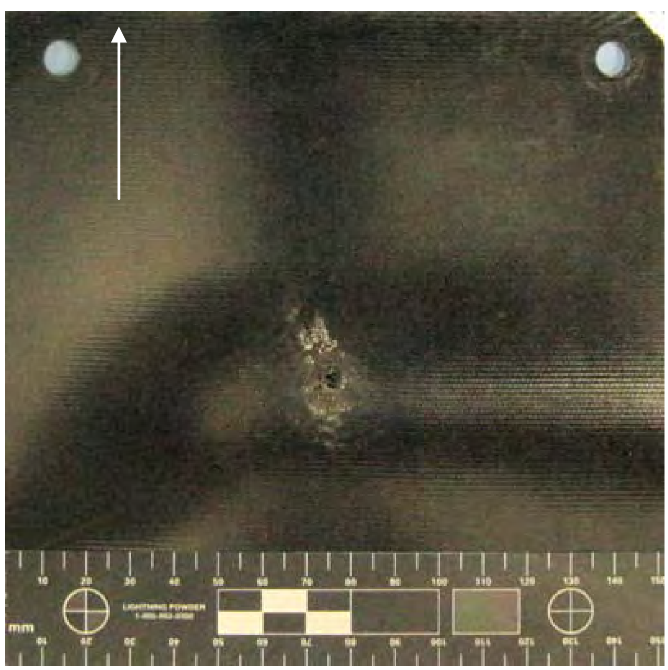


Figure 111 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12289 / Test #7 (continued)

Figure 112 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

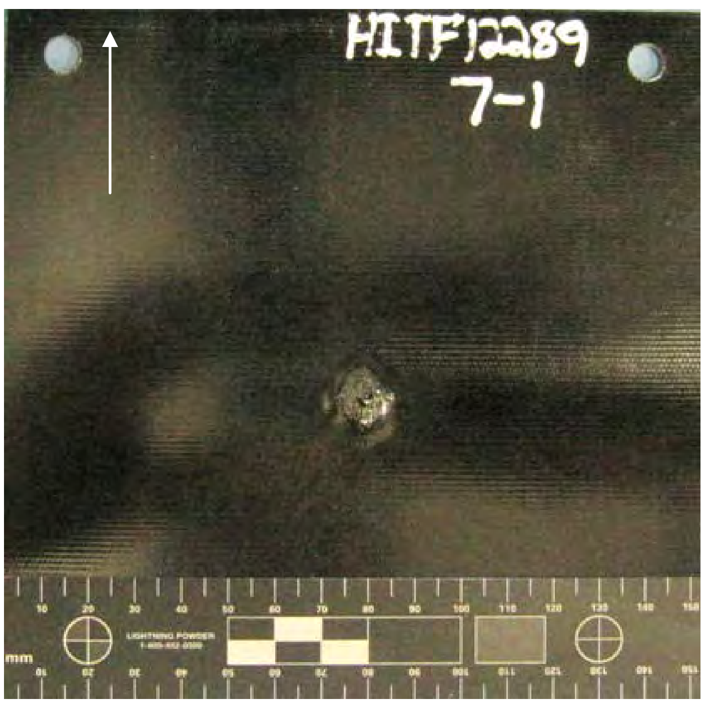


Figure 113 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12289 / Test #7 (continued)

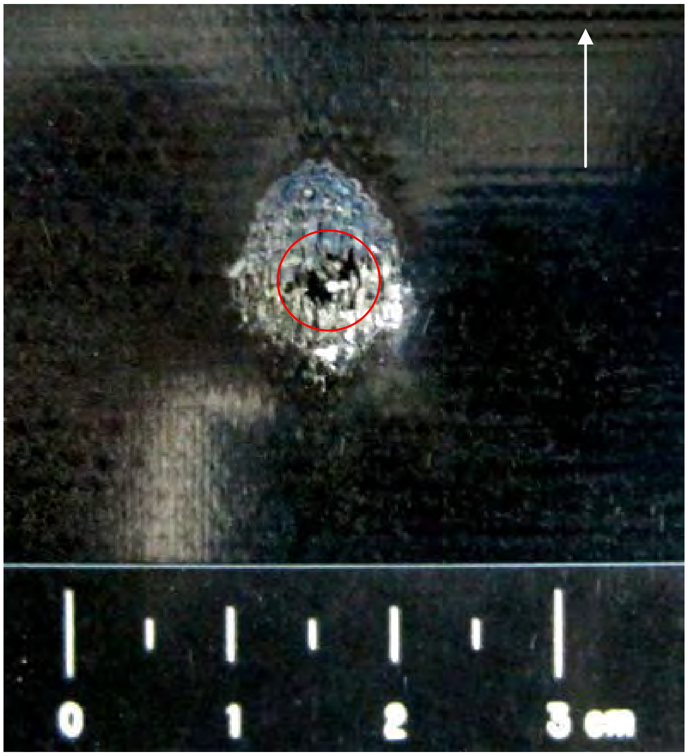


Figure 114 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

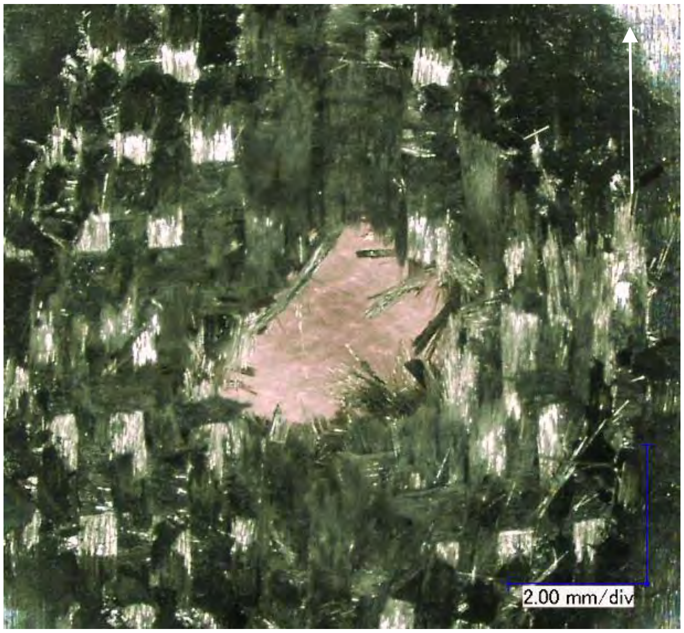


Figure 115 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (white arrow indicates flight path of projectile / damage within red circle in Figure 114)

HITF12289 / Test #7 (continued)

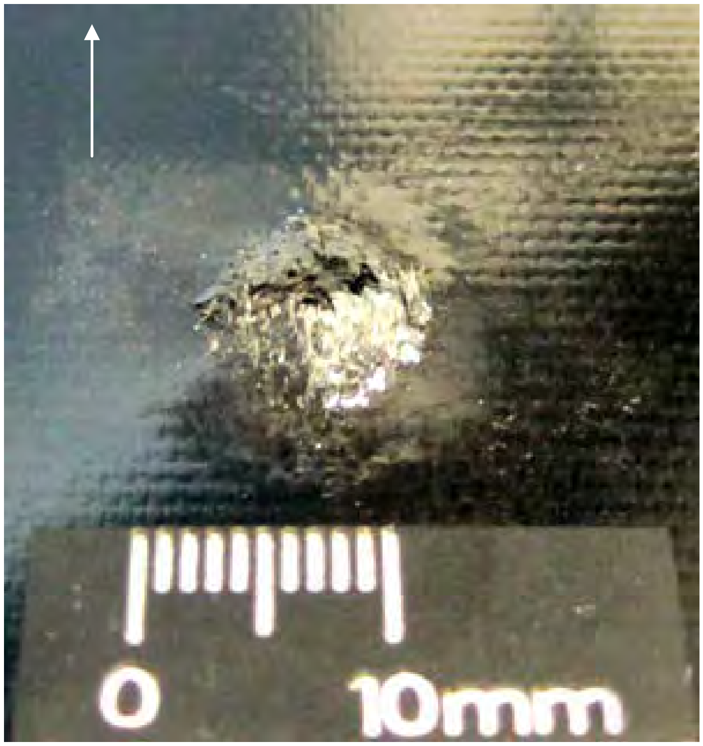


Figure 116 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

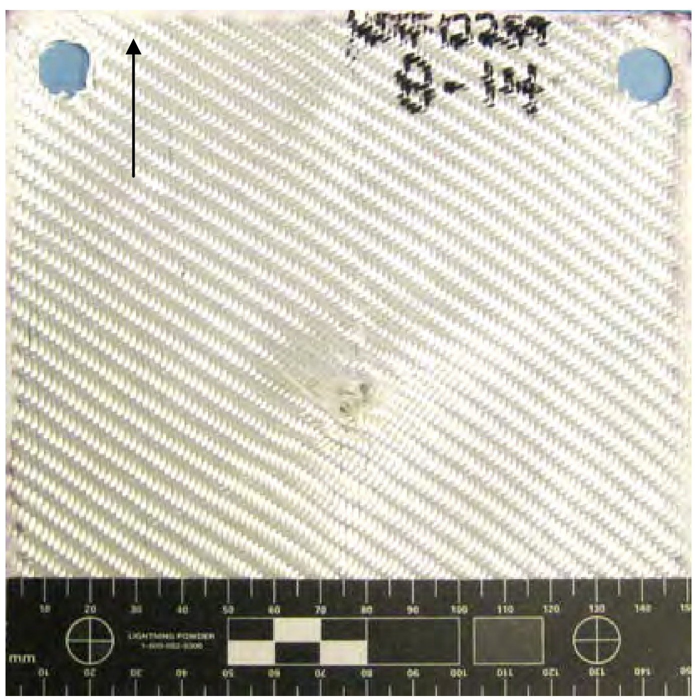


Figure 117 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12289 / Test #7 (continued)

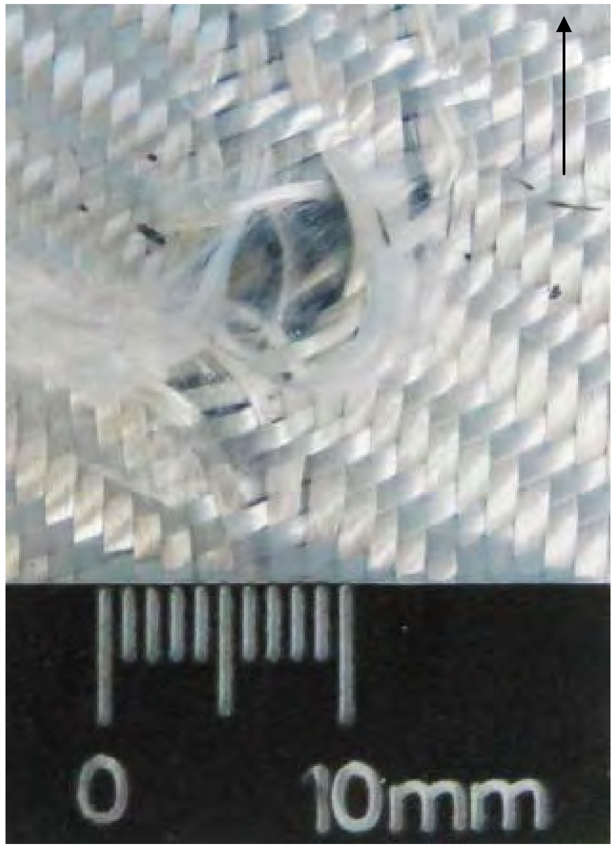


Figure 118 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

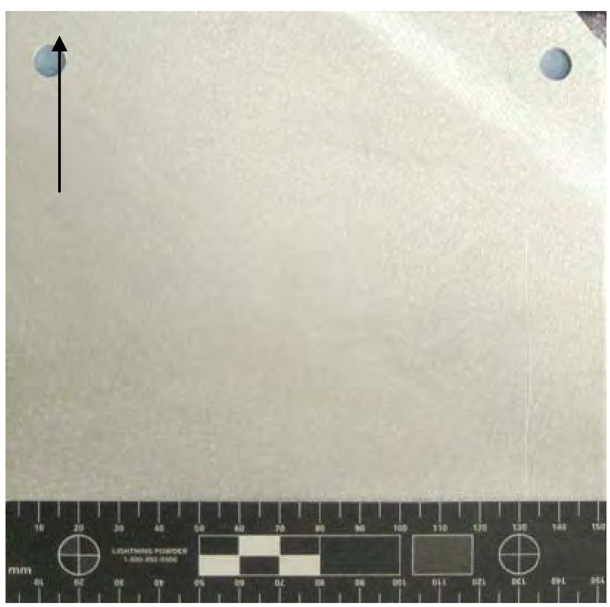


Figure 119 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12289 / Test #7 (continued)

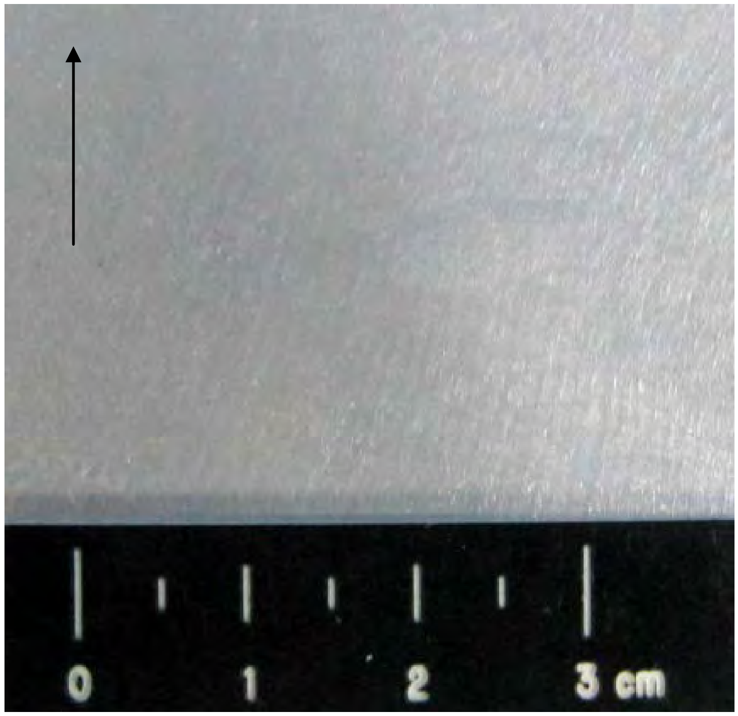


Figure 120 Close-up View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

Figure 121 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12290 / Test #8

Figure 122 Overall View of Sample in the Target Tank (post-test)

Figure 123 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12290 / Test #8 (continued)

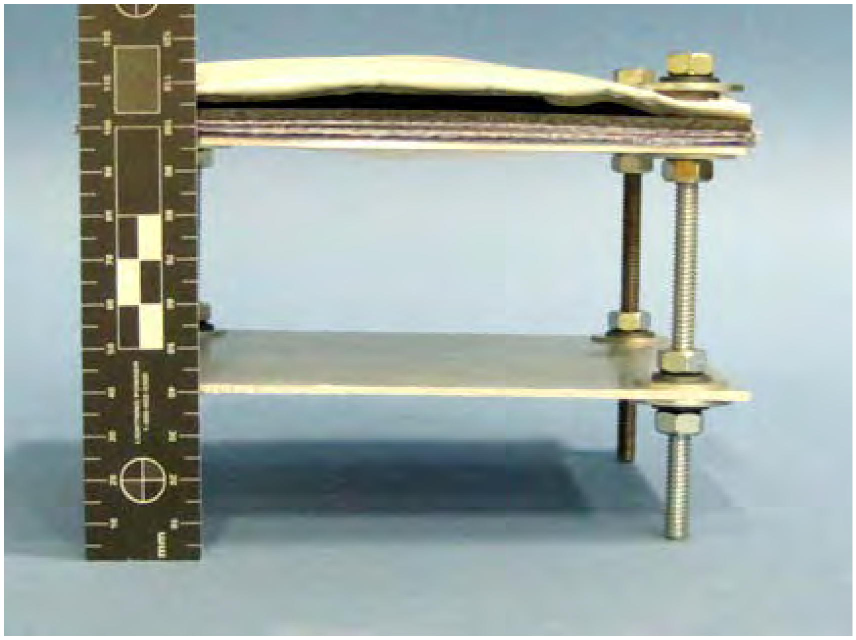


Figure 124 Overall Side View of Sample (scale in 5mm increments)

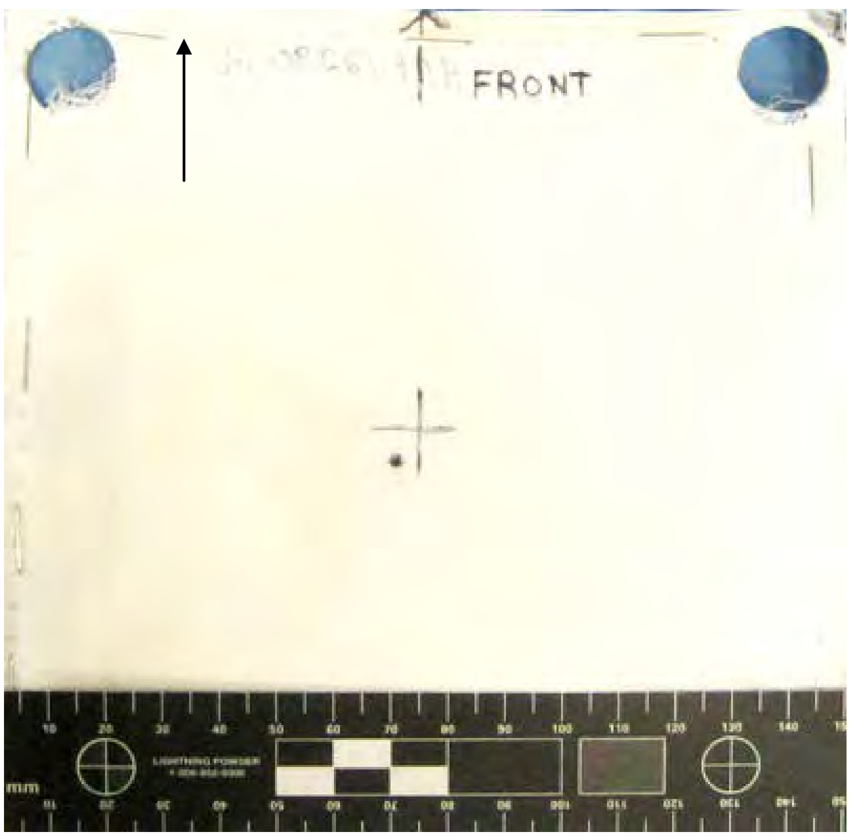


Figure 125 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12290 / Test #8 (continued)

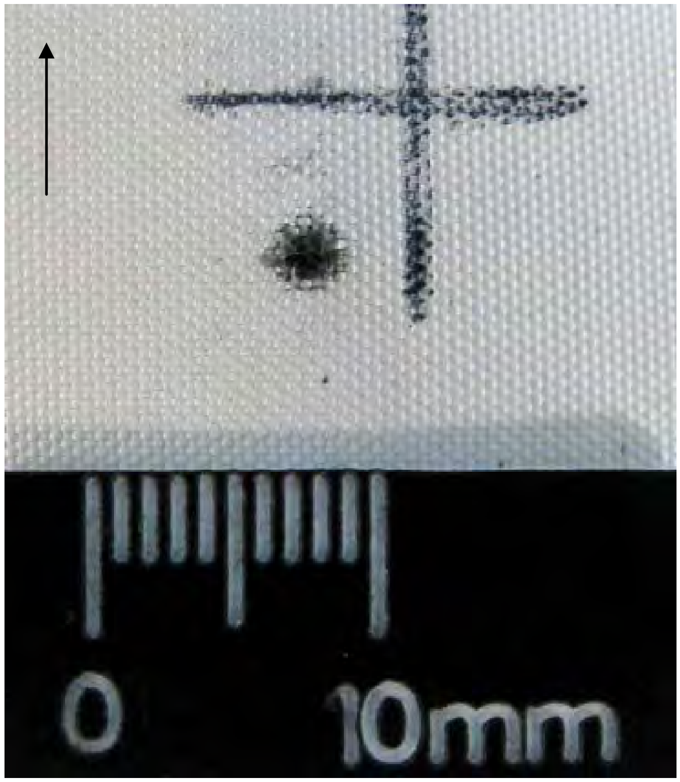


Figure 126 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

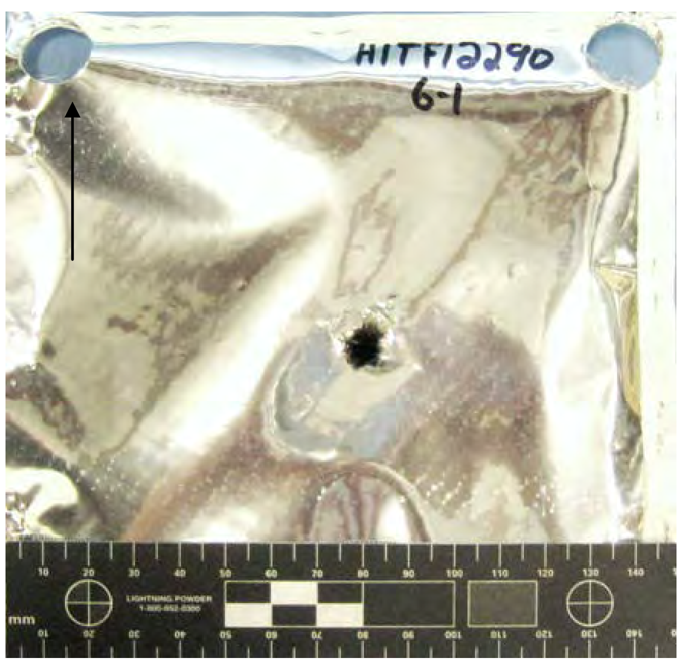


Figure 127 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12290 / Test #8 (continued)

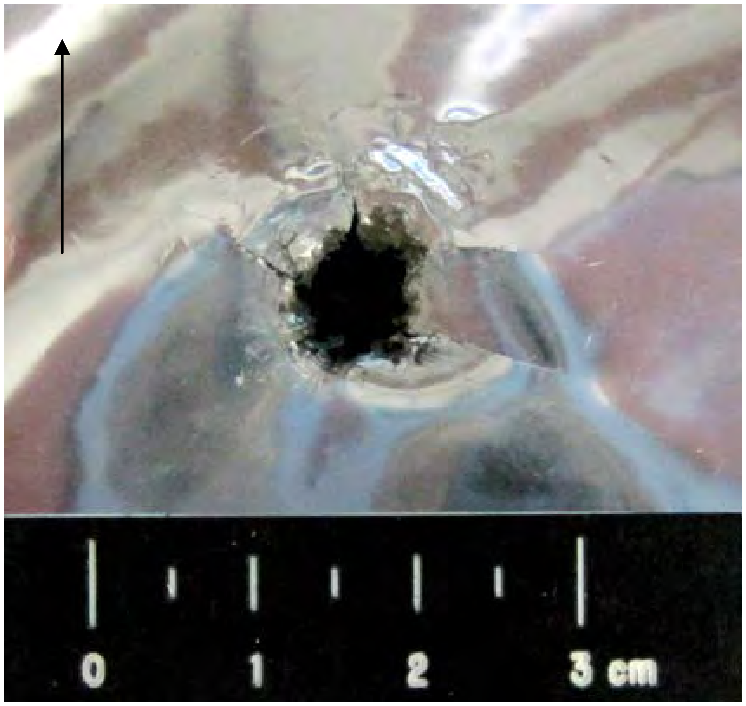


Figure 128 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

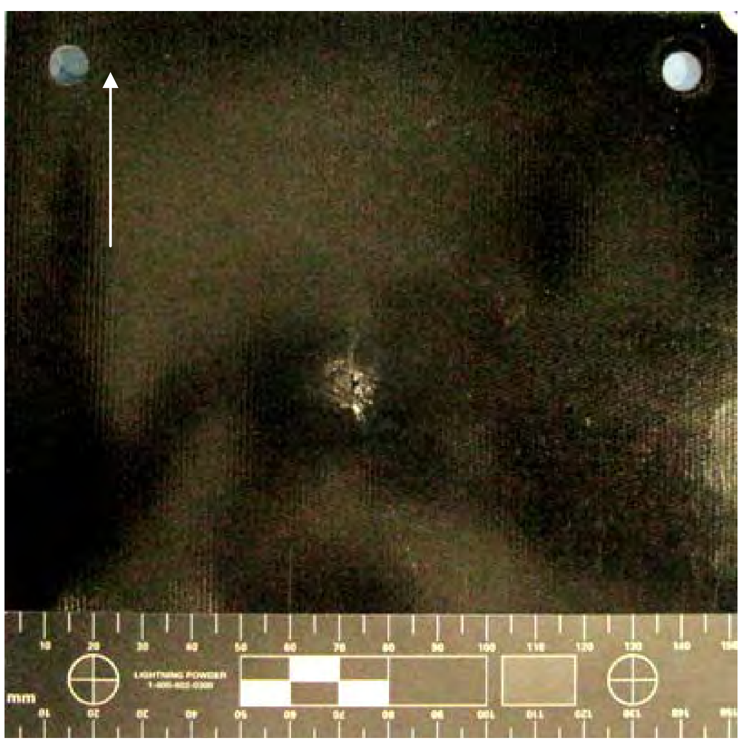


Figure 129 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12290 / Test #8 (continued)

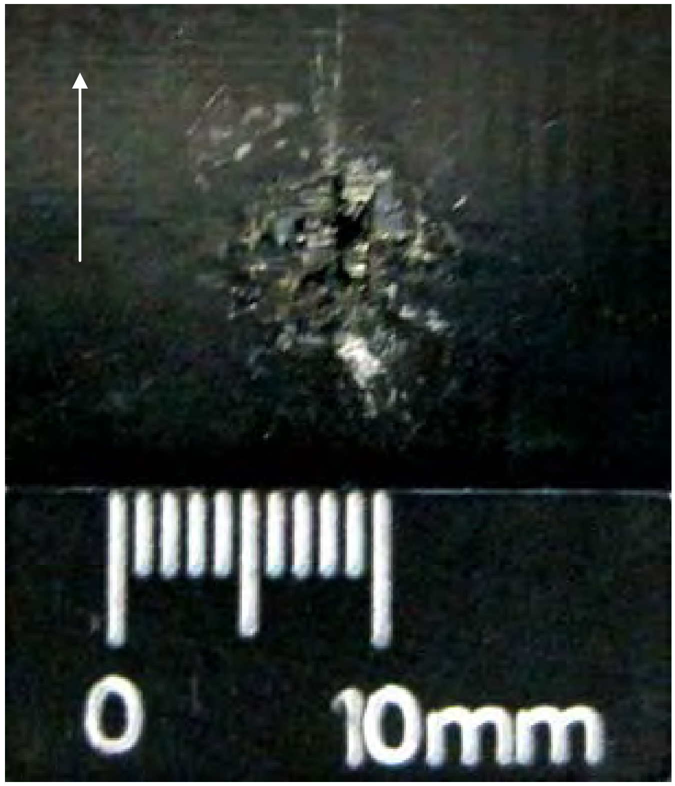


Figure 130 Close-up View of Damage to Front of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

Figure 131 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12290 / Test #8 (continued)

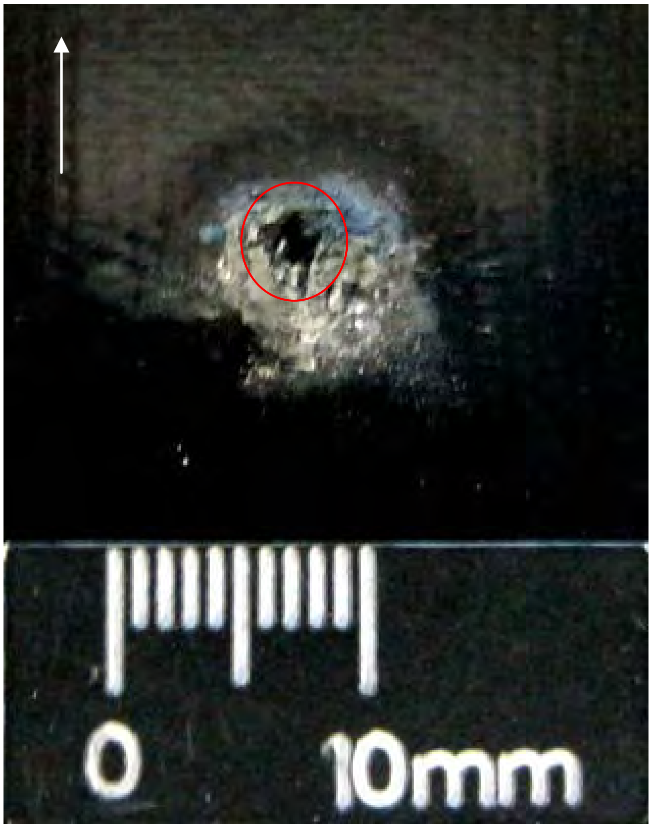


Figure 132 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

Figure 133 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (white arrow indicates flight path of projectile / damage within red circle in Figure 132)

HITF12290 / Test #8 (continued)

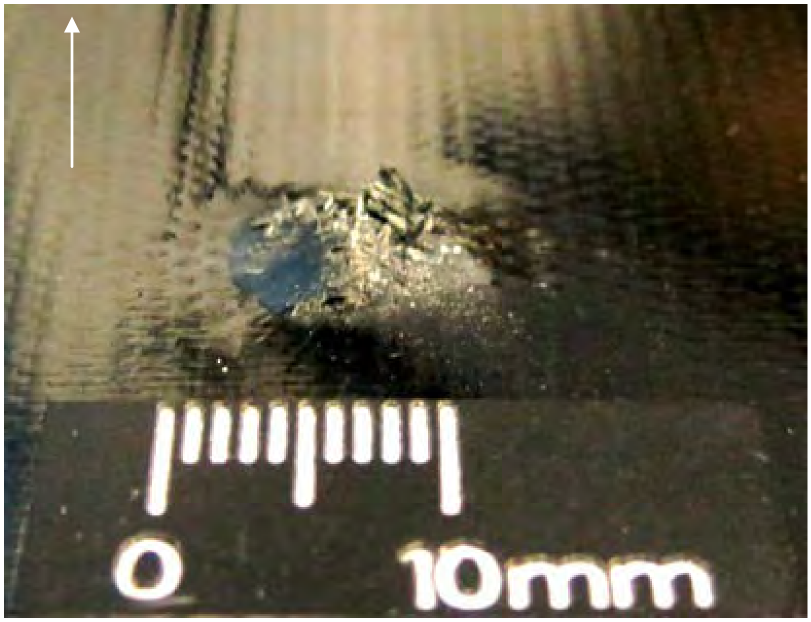


Figure 134 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

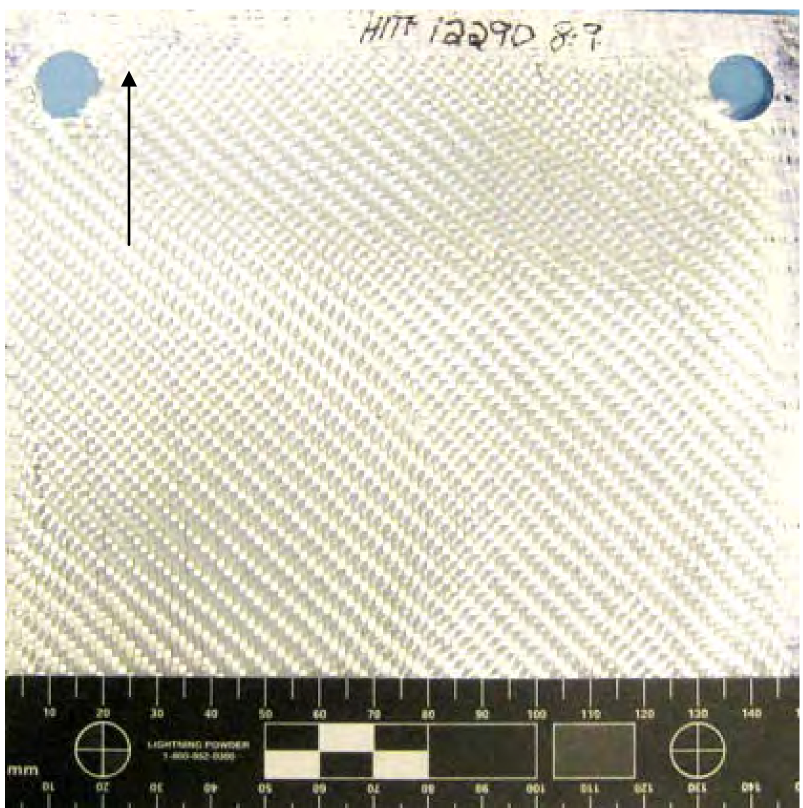


Figure 135 Overall View of Damage to Back Side of 7th Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12290 / Test #8 (continued)

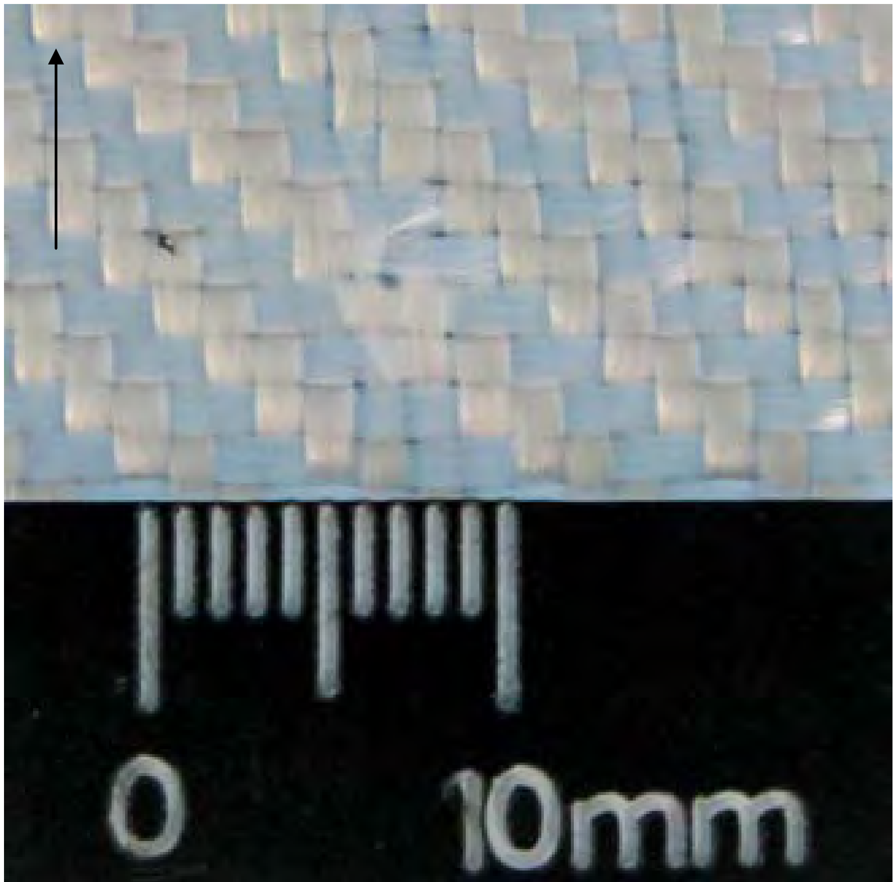


Figure 136 Close-up View of Damage to Back Side of 7^{th} Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12291 / Test #9

Figure 137 Overall View of Sample in the Target Tank (post-test)

Figure 138 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12291 / Test #9 (continued)

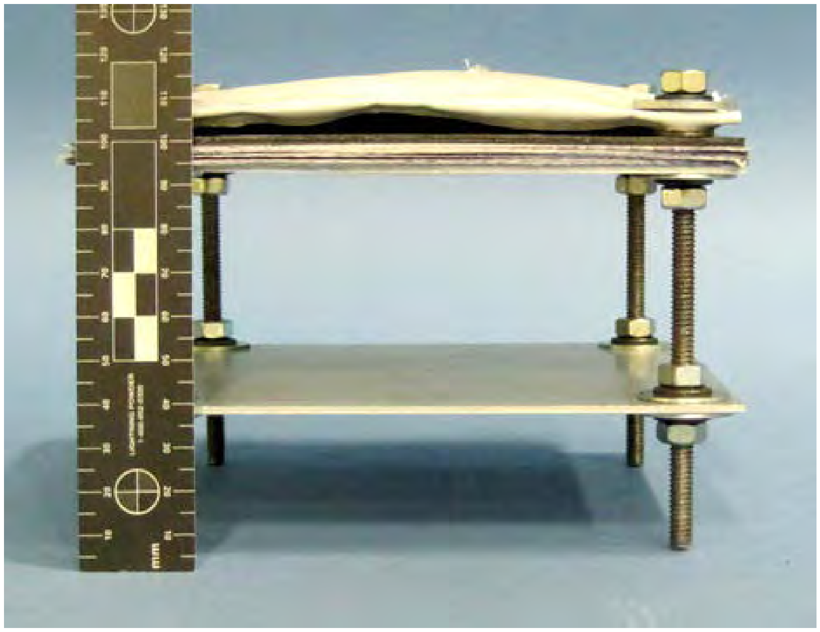


Figure 139 Overall Side View of Sample (scale in 5mm increments)

Figure 140 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

<u>HITF12291 / Test #9 (continued)</u>

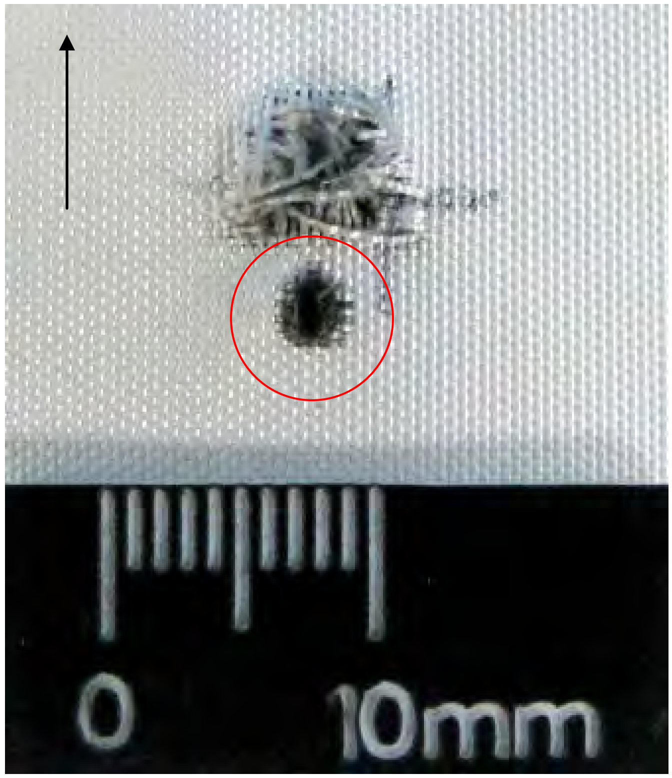


Figure 141 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile / projectile impacted within red circle)

Figure 142 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12291 / Test #9 (continued)

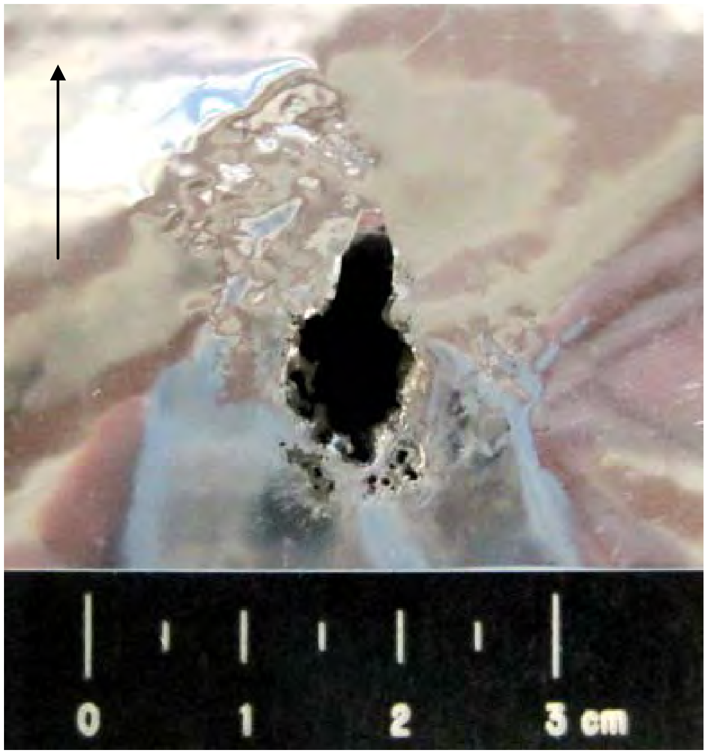


Figure 143 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

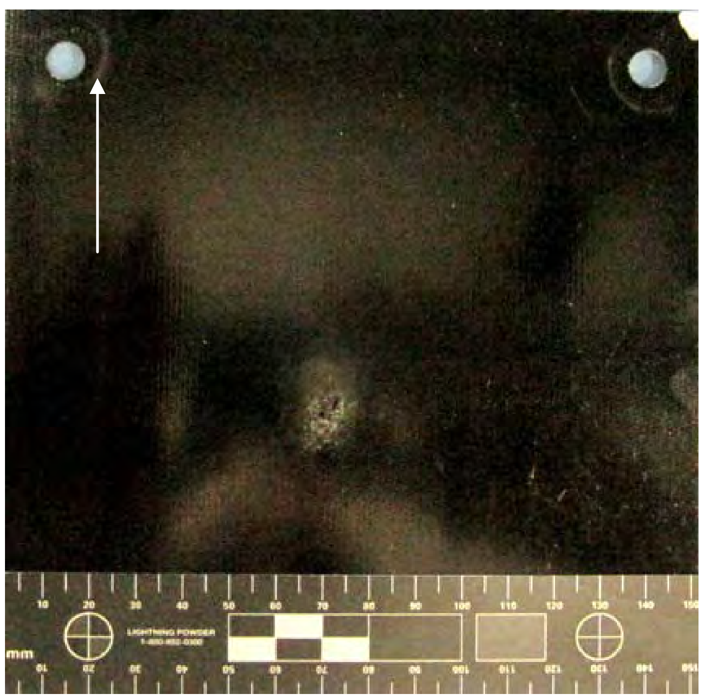


Figure 144 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12291 / Test #9 (continued)

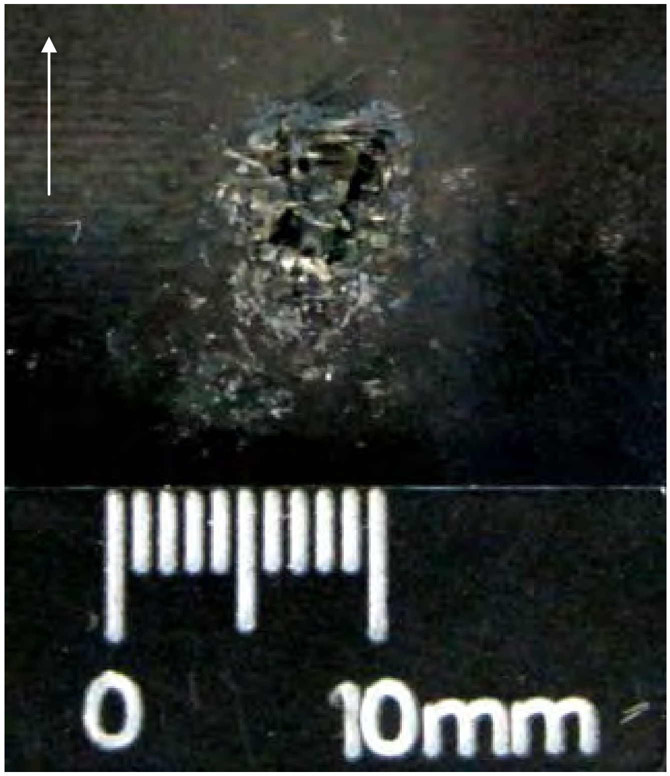


Figure 145 Close-up View of Damage to Front of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

Figure 146 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12291 / Test #9 (continued)

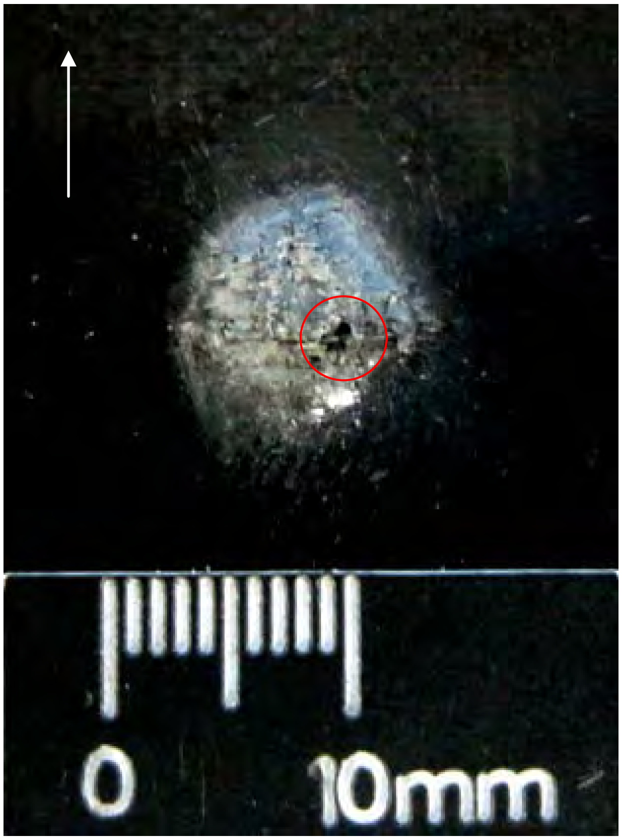


Figure 147 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

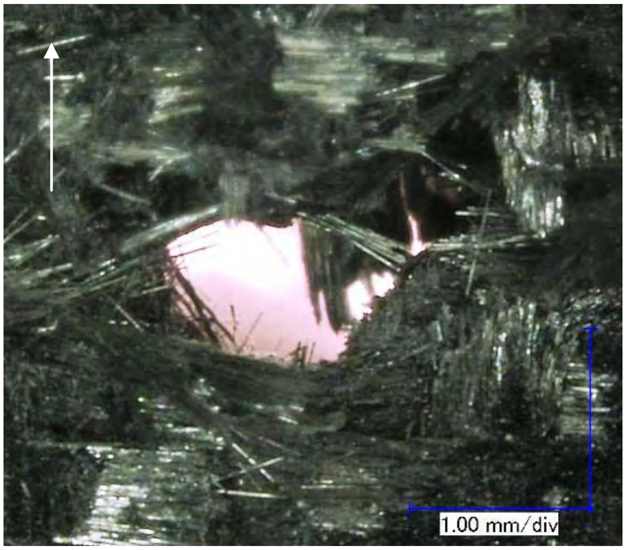


Figure 148 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 155)

HITF12291 / Test #9 (continued)

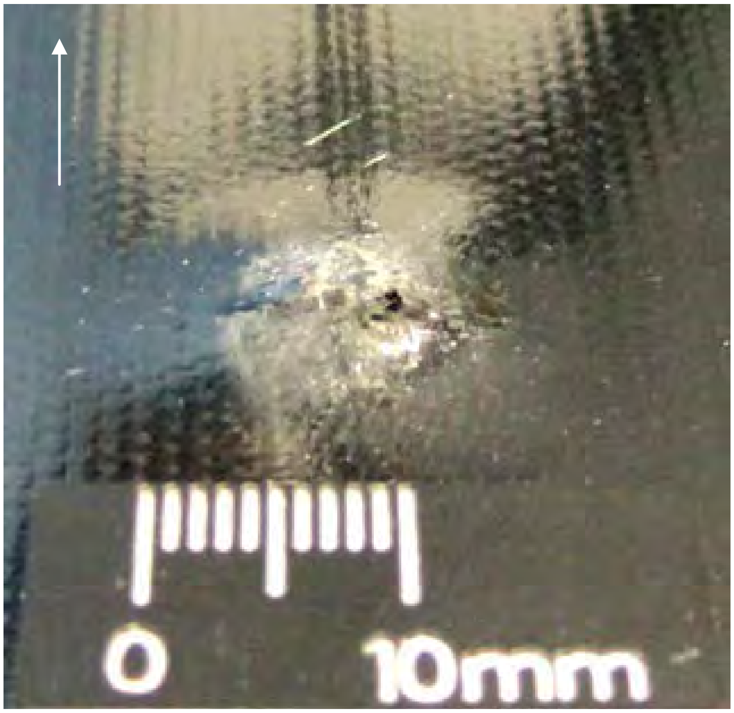


Figure 149 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

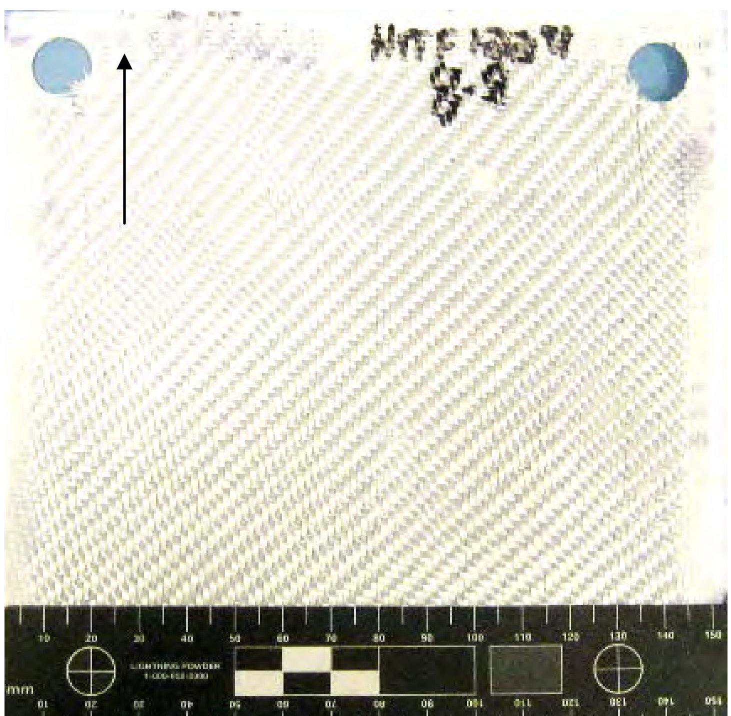


Figure 150 Overall View of Damage to Back Side of 8th Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12291 / Test #9 (continued)

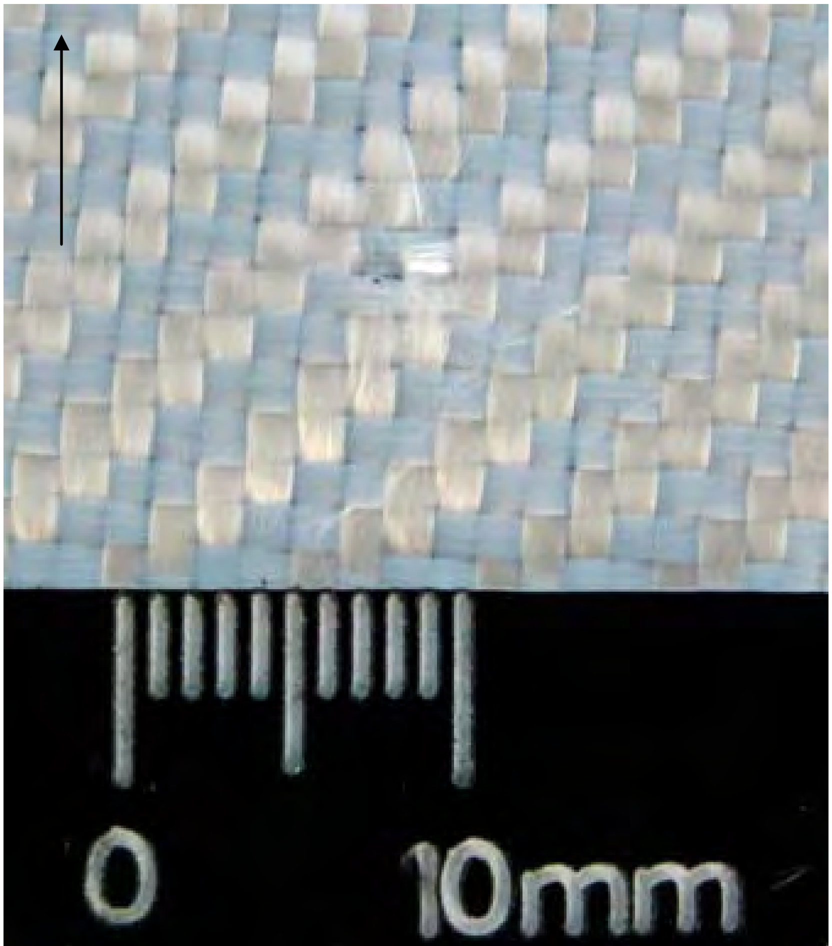


Figure 151 Close-up View of Damage to Back Side of 8th Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12292 / Test #10

Figure 152 Overall View of Sample in the Target Tank (post-test)

Figure 153 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12292 / Test #10 (continued)

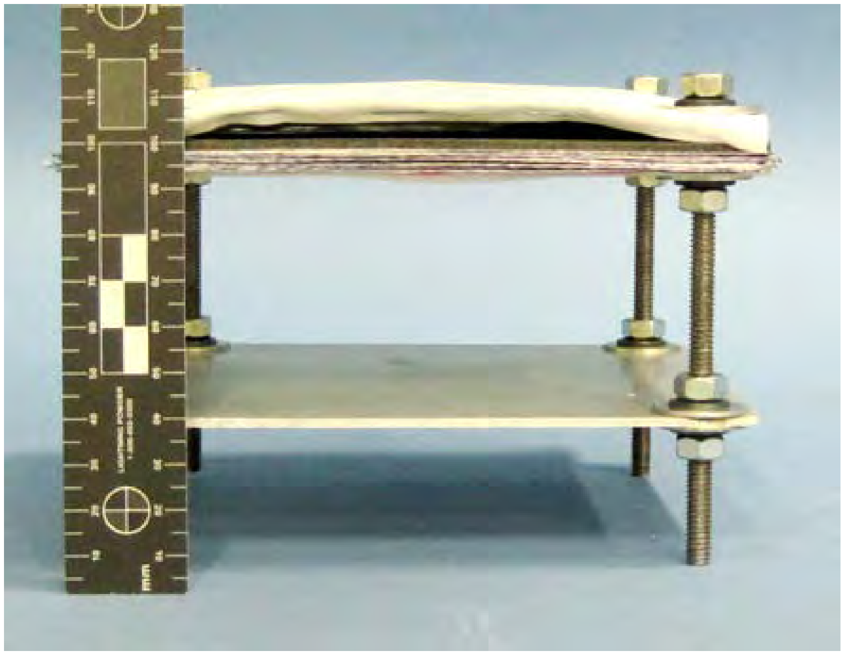


Figure 154 Overall Side View of Sample (scale in 5mm increments)

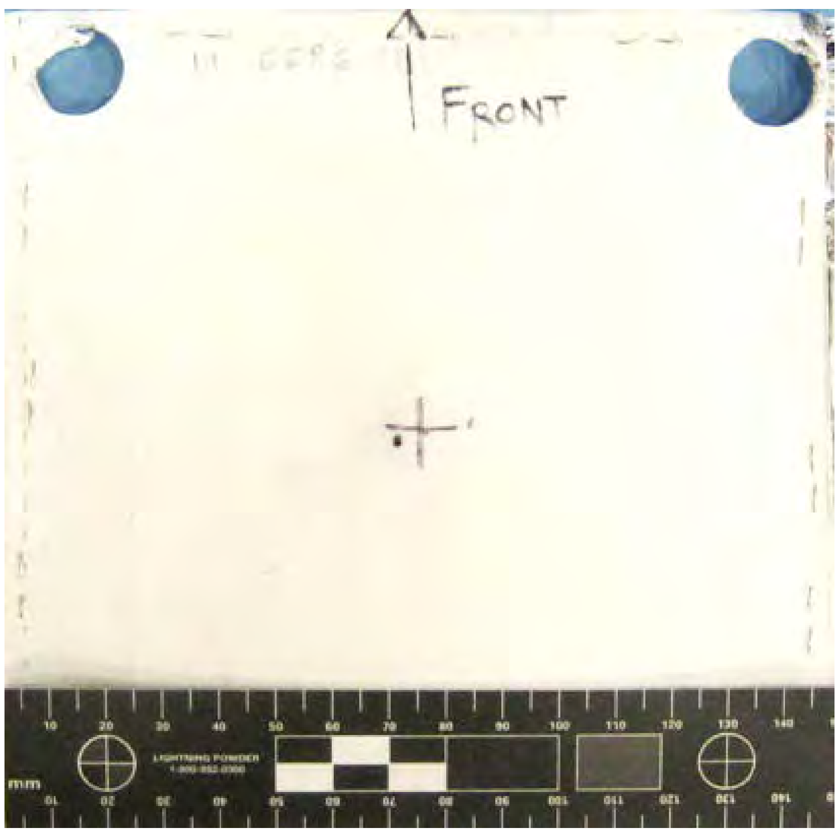


Figure 155 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12292 / Test #10 (continued)

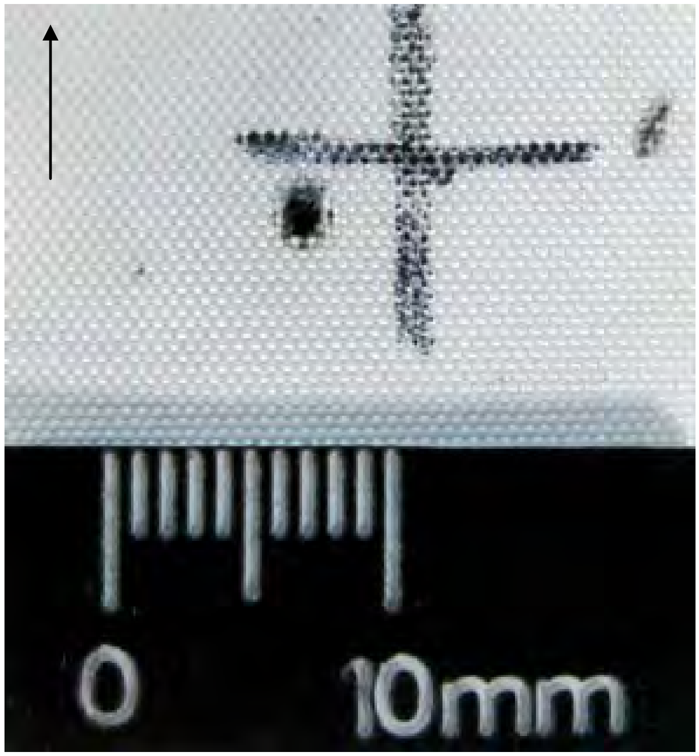


Figure 156 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

Figure 157 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12292 / Test #10 (continued)

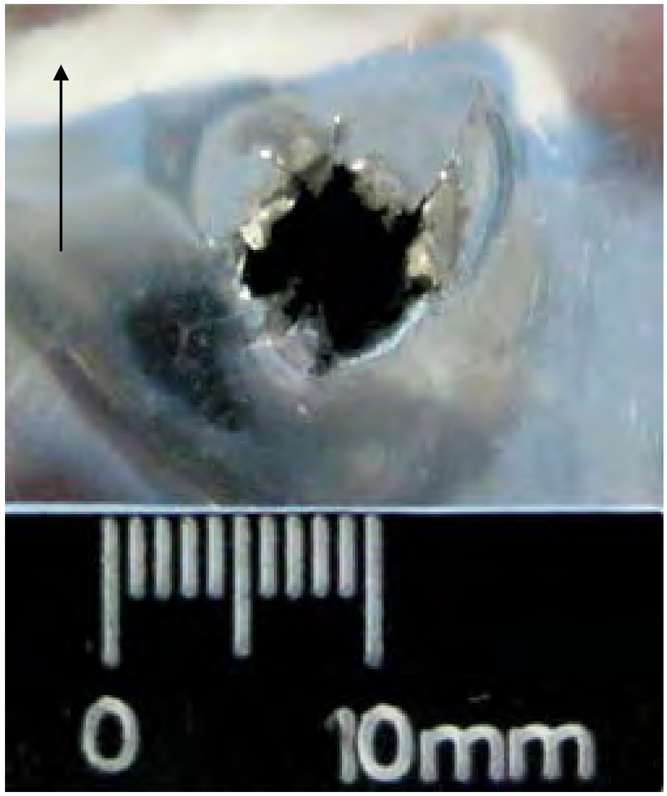


Figure 158 Close-up View of Damage to Back Side of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

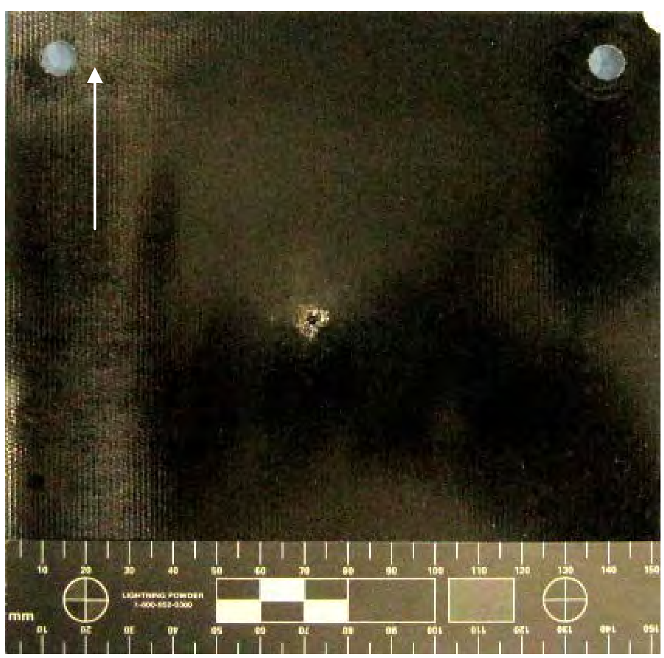


Figure 159 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12292 / Test #10 (continued)

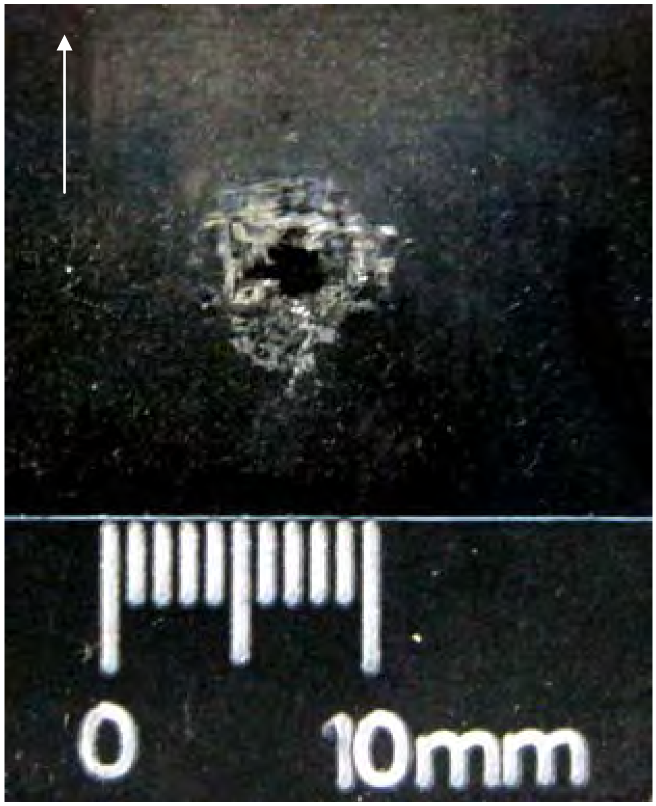


Figure 160 Close-up View of Damage to Front of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

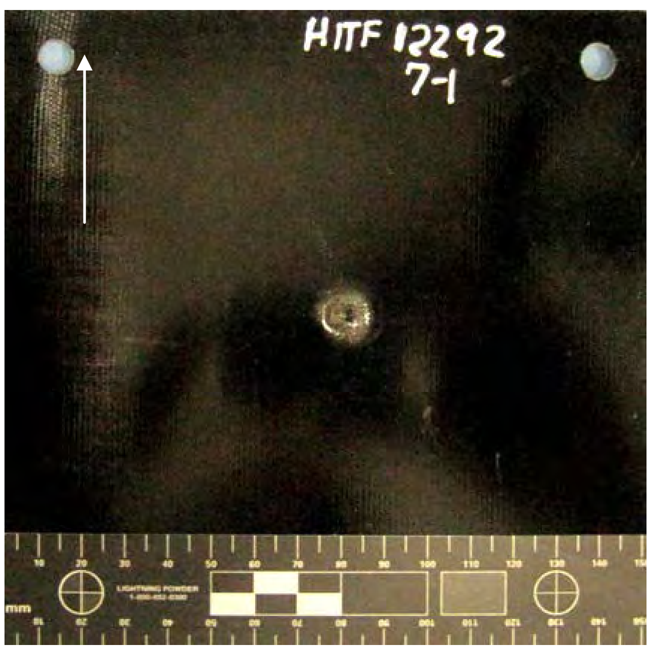


Figure 161 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12292 / Test #10 (continued)

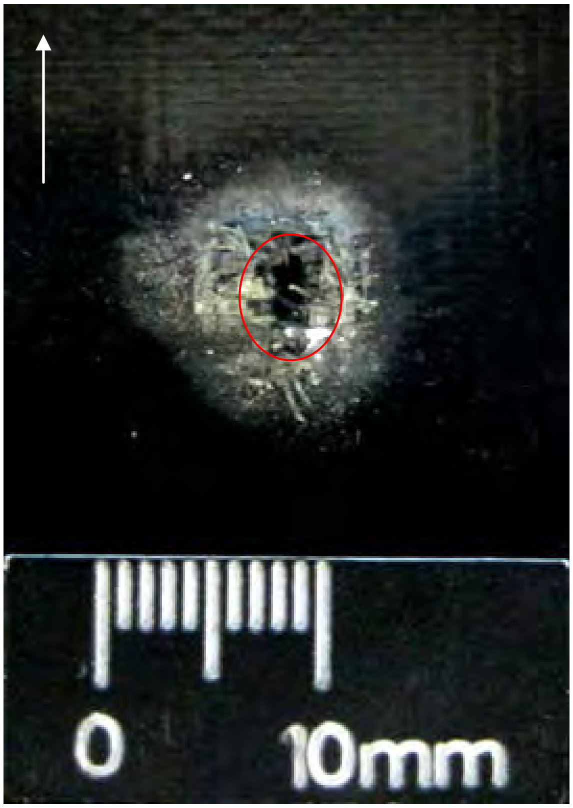


Figure 162 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

Figure 163 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (white arrow indicates flight path of projectile / damage within red circle in Figure 162)

HITF12292 / Test #10 (continued)

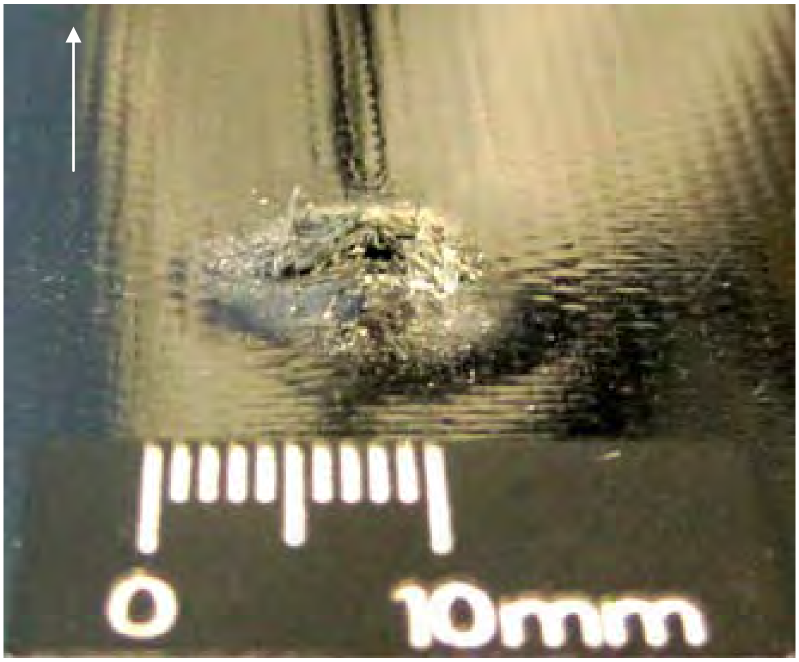


Figure 164 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

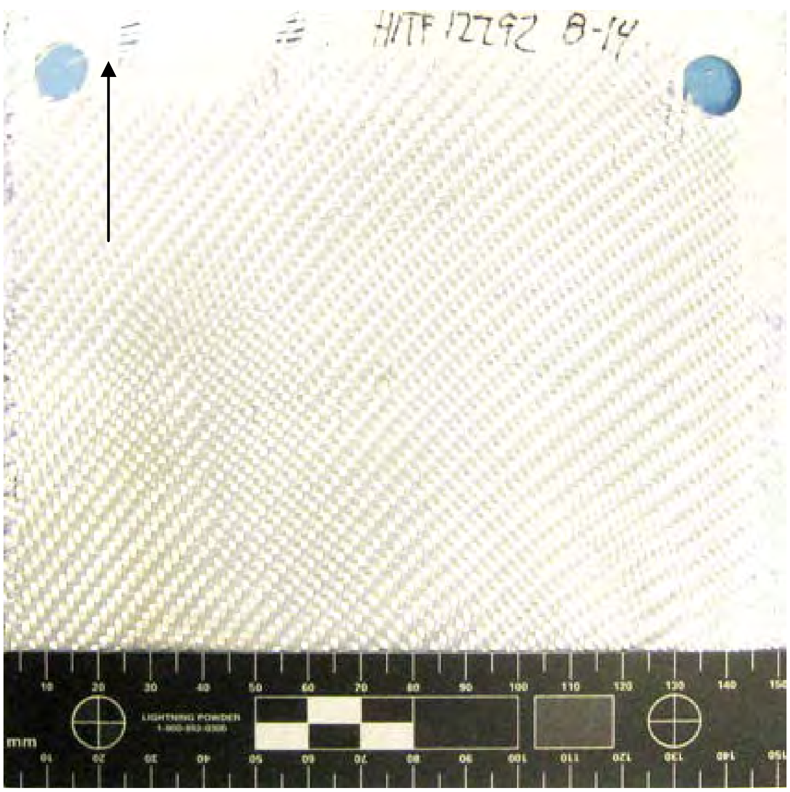


Figure 165 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12292 / Test #10 (continued)

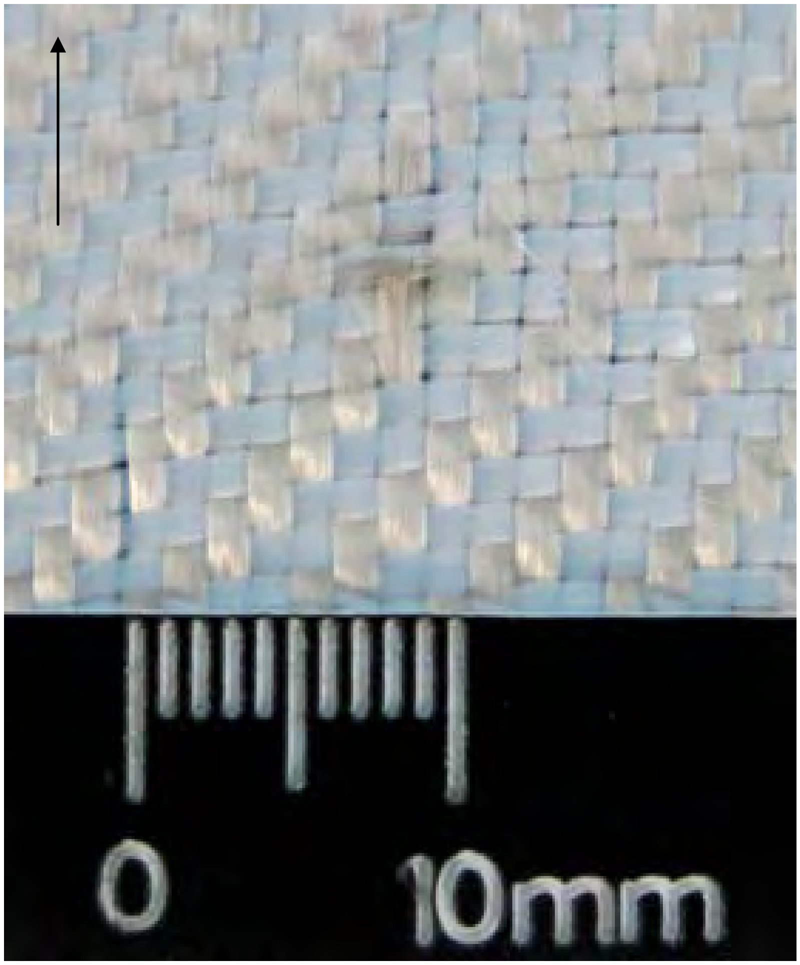


Figure 166 Close-up View of Damage to Back Side of Last Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12293 / Test #11

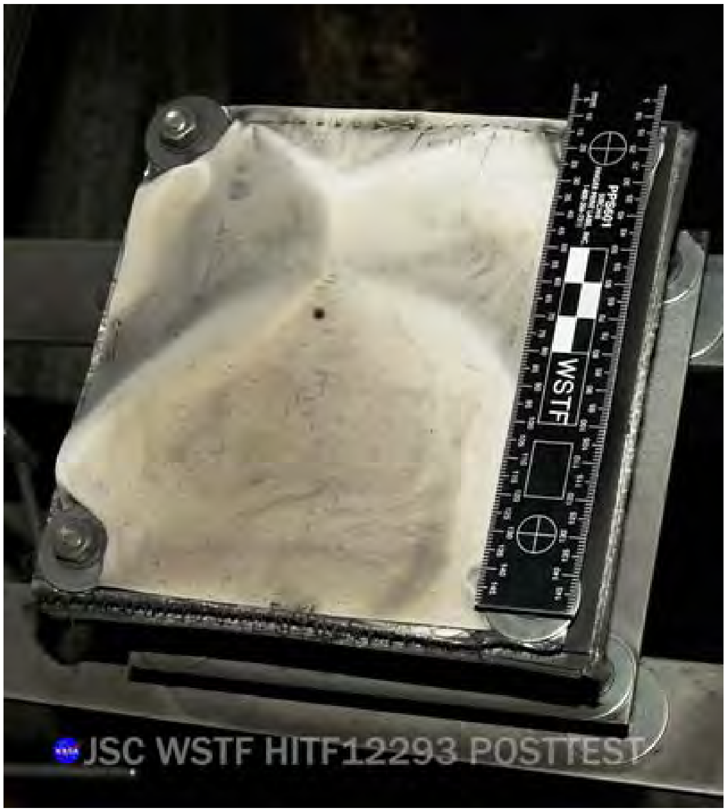


Figure 167 Overall View of Sample in the Target Tank (post-test)

Figure 168 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12293 / Test #11 (continued)

Figure 169 Overall Side View of Sample (scale in 5mm increments)

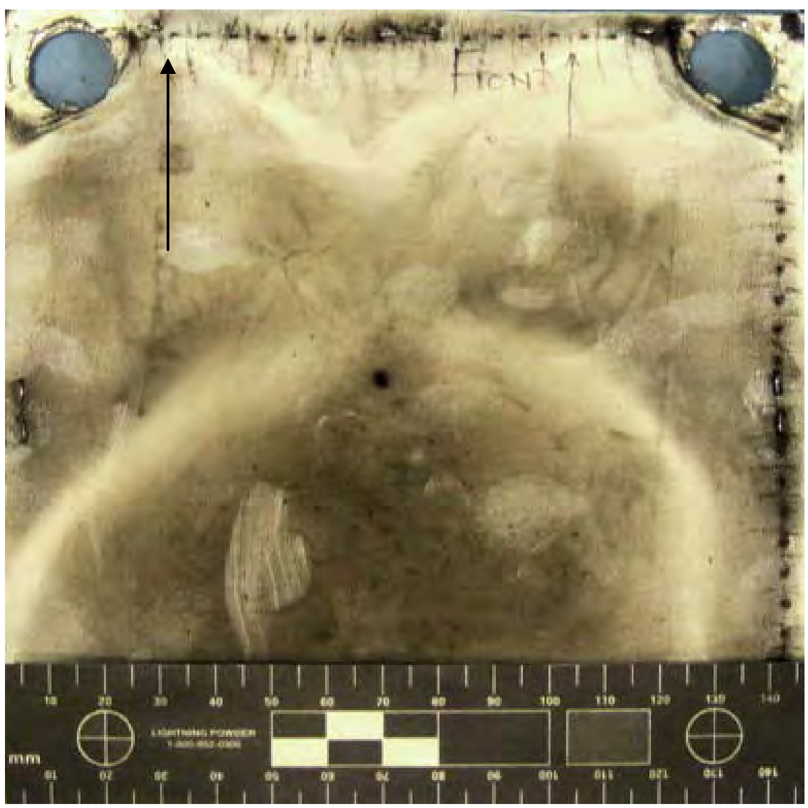


Figure 170 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12293 / Test #11 (continued)

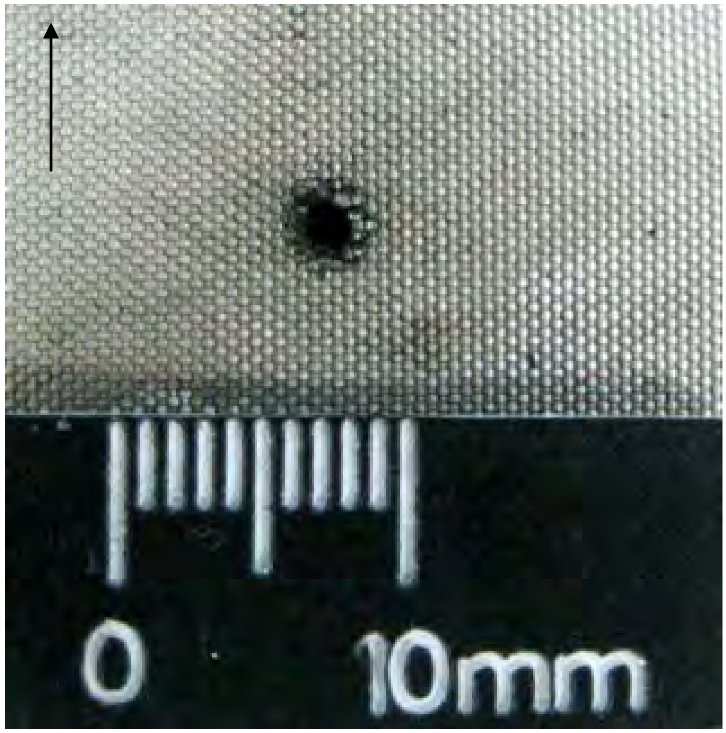


Figure 171 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile / projectile impacted within red circle)

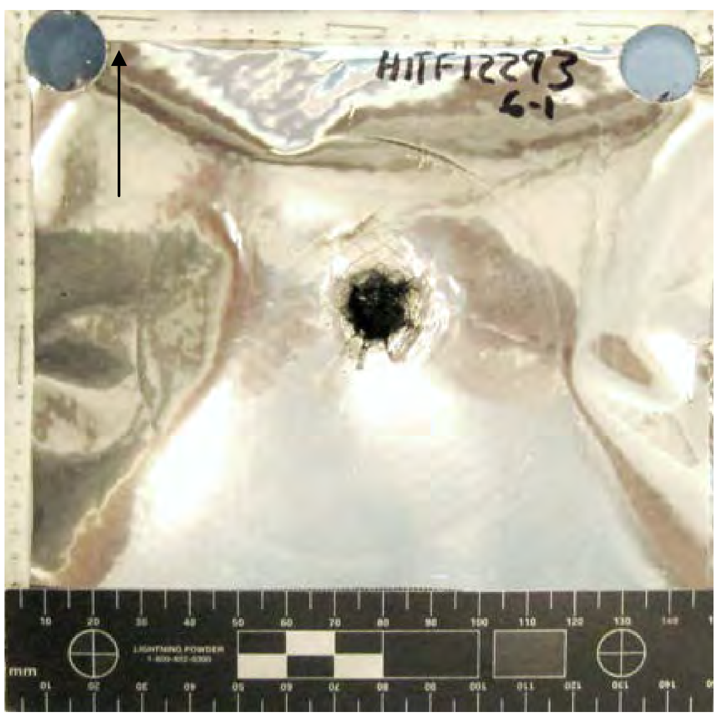


Figure 172 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12293 / Test #11 (continued)

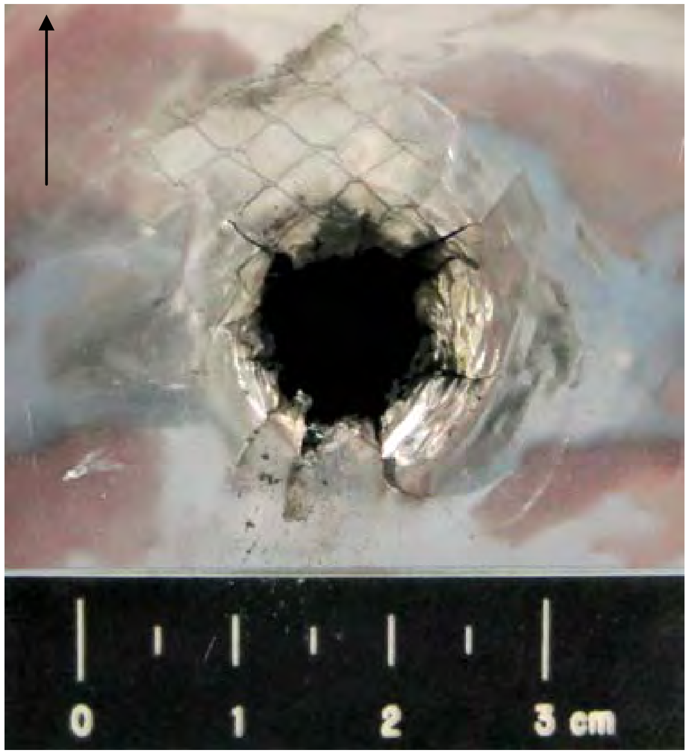


Figure 173 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

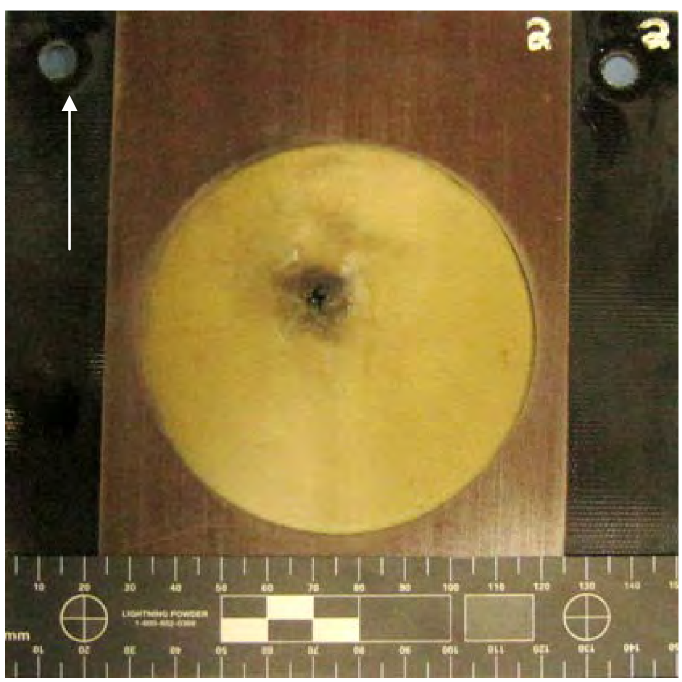


Figure 174 Overall View of Damage to Front of TORLON 5030 (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12293 / Test #11 (continued)

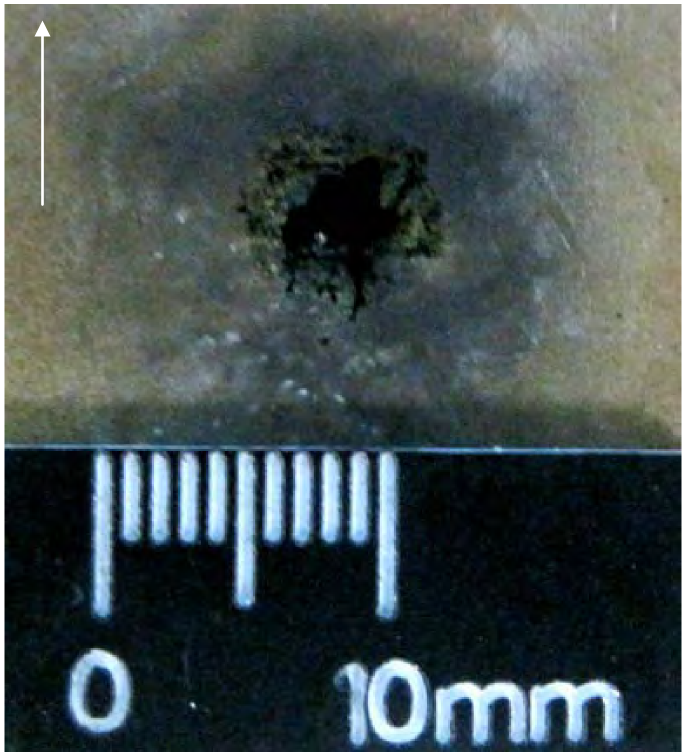


Figure 175 Close-up View of Damage to Front of TORLON 5030 (scale in 1mm increments / white arrow indicates flight path of projectile)

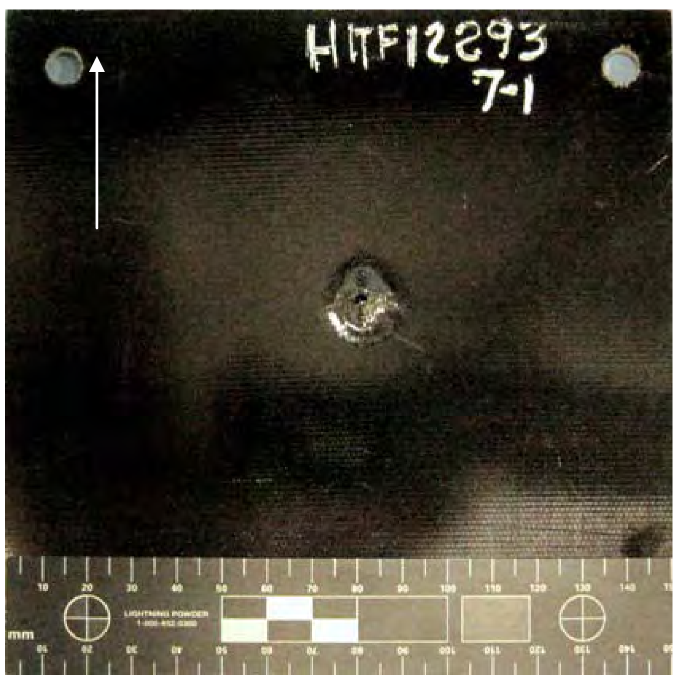


Figure 176 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12293 / Test #11 (continued)

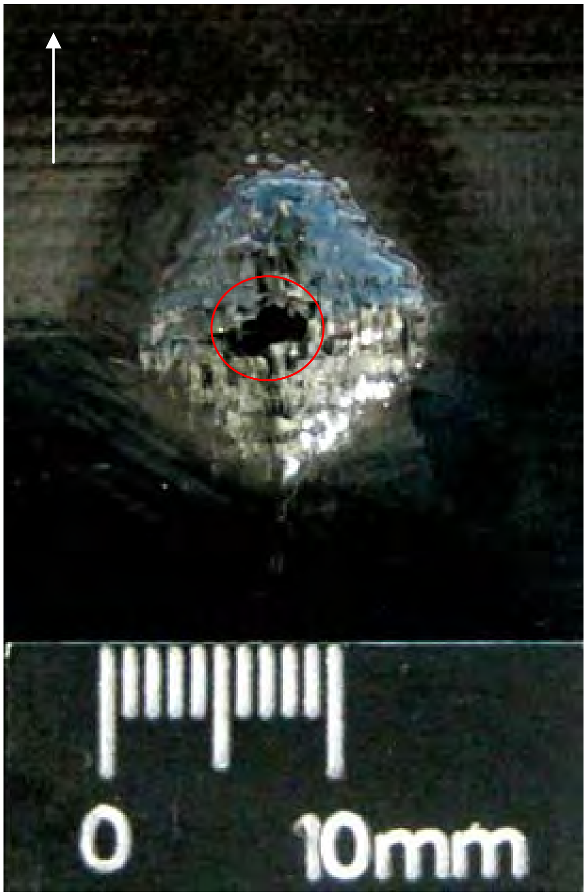


Figure 177 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

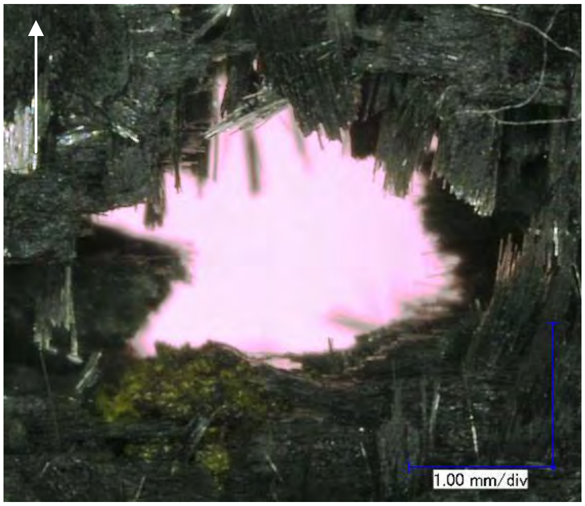


Figure 178 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (white arrow indicates flight path of projectile / damage within red circle in Figure 187)

HITF12293 / Test #11 (continued)

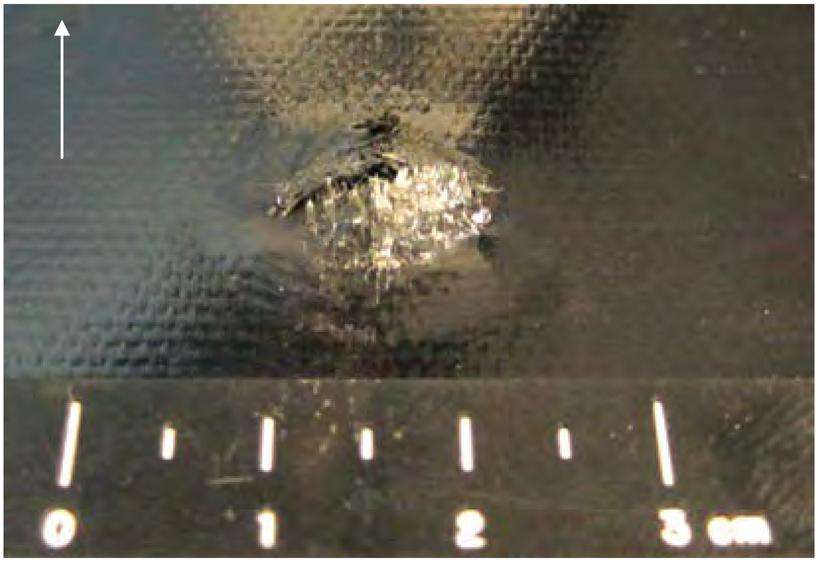


Figure 179 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

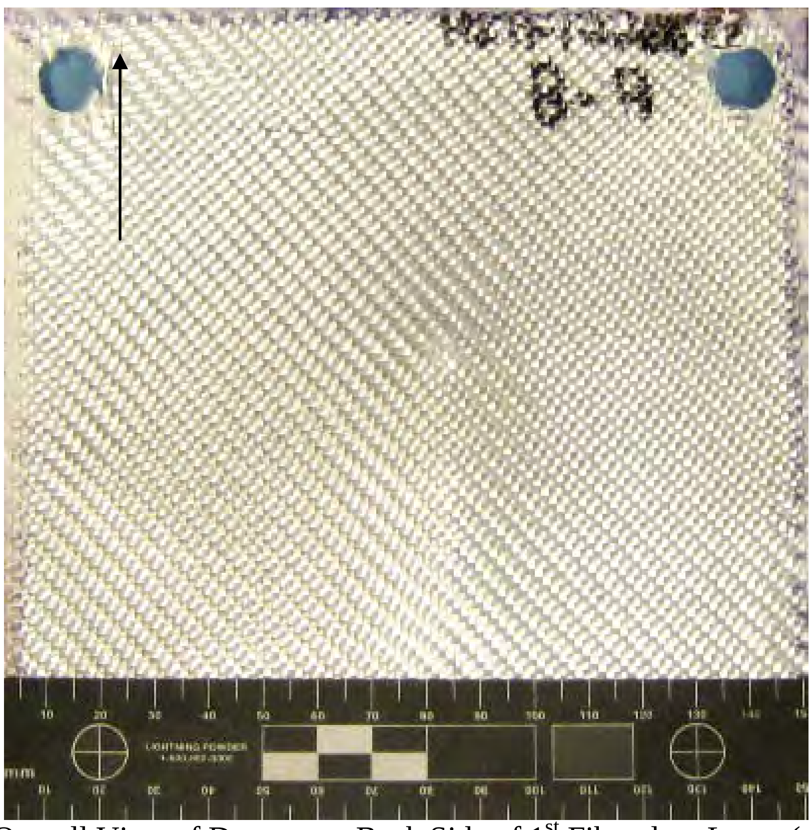


Figure 180 Overall View of Damage to Back Side of 1st Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12293 / Test #11 (continued)

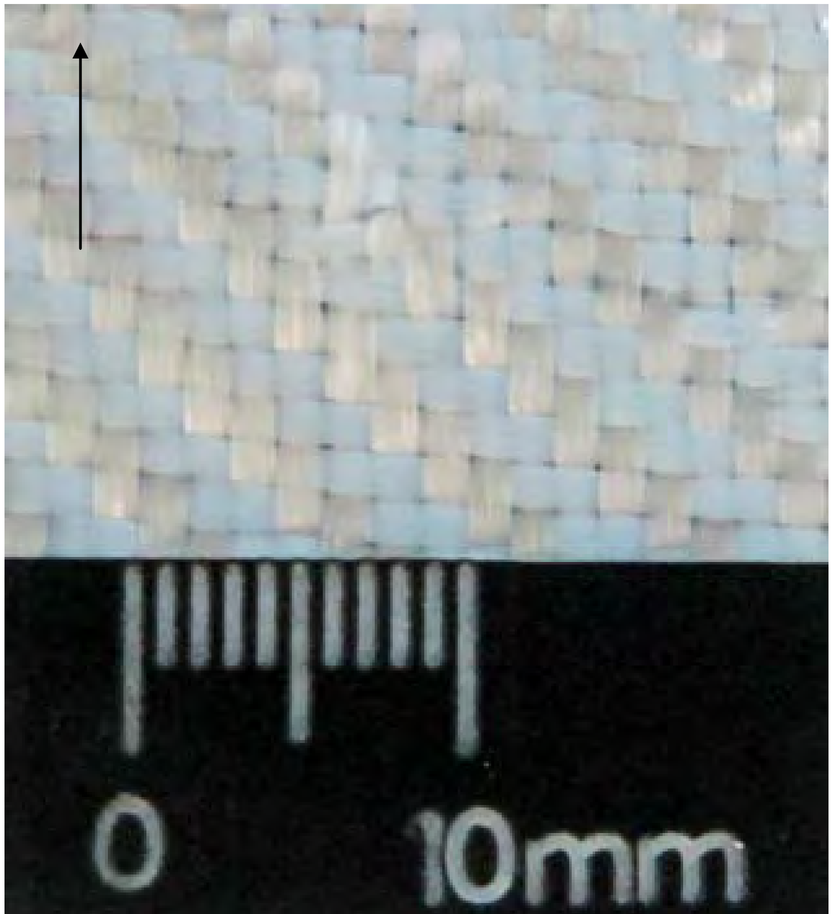


Figure 181 Close-up View of Damage to Back Side of 9th Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12294 / Test #12

Figure 182 Overall View of Sample in the Target Tank (post-test)

Figure 183 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12294 / Test #12 (continued)

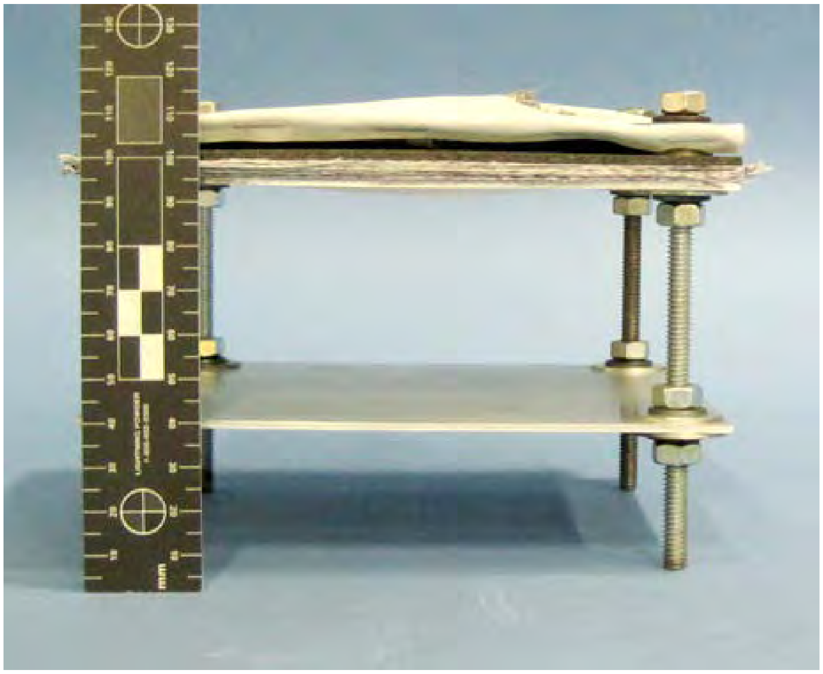


Figure 184 Overall Side View of Sample (scale in 5mm increments)

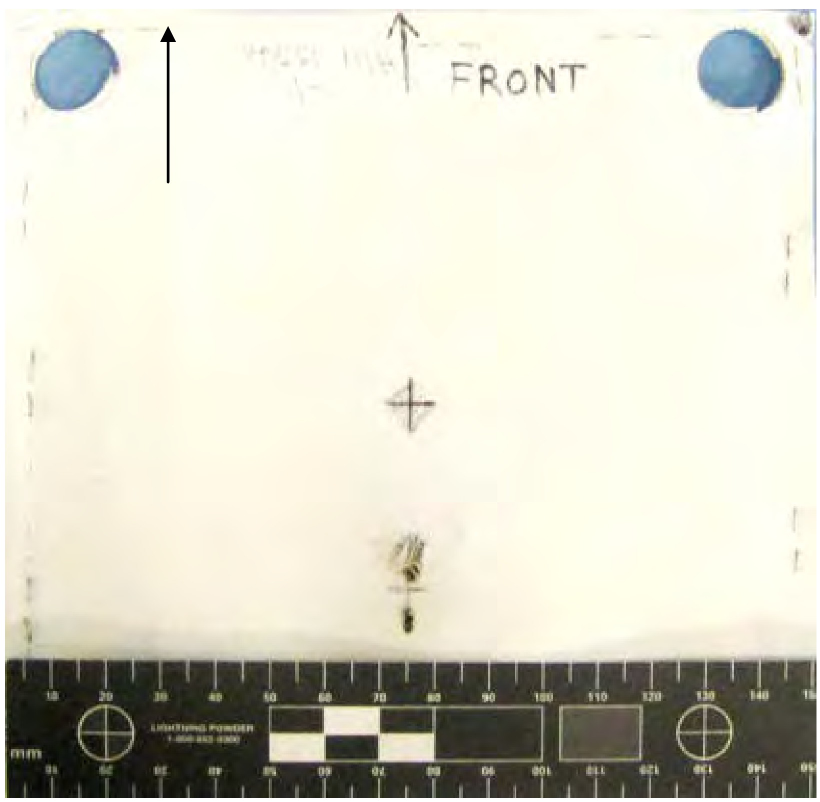


Figure 185 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12294 / Test #12 (continued)

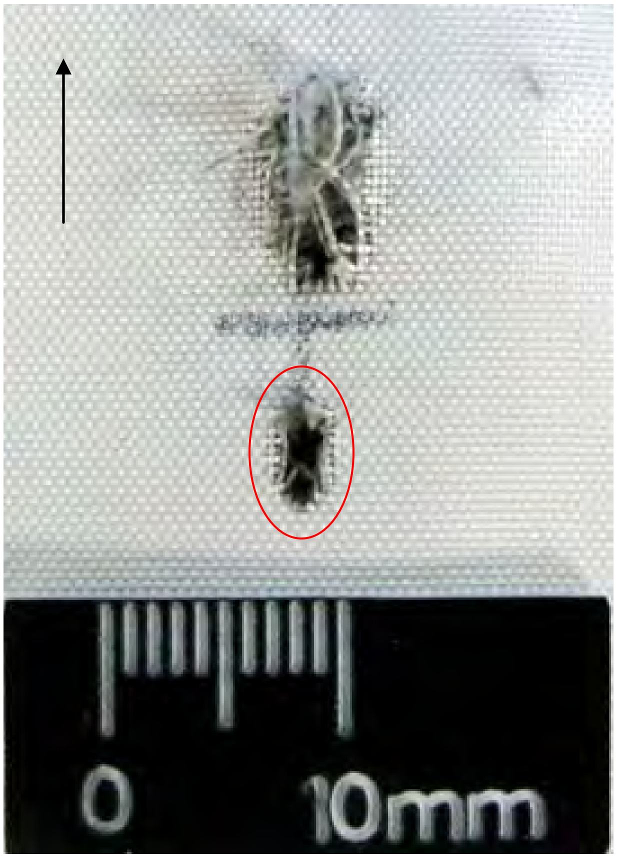


Figure 186 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile / projectile impacted within red circle)

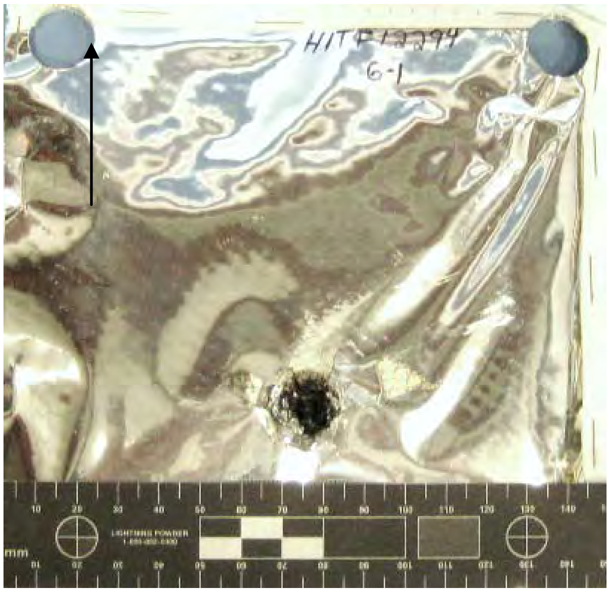


Figure 187 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12294 / Test #12 (continued)

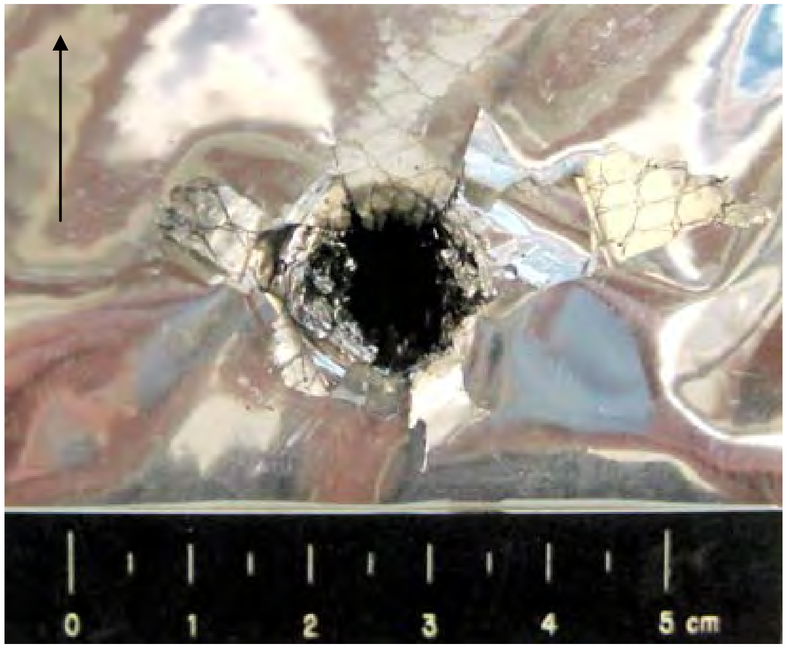


Figure 188 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

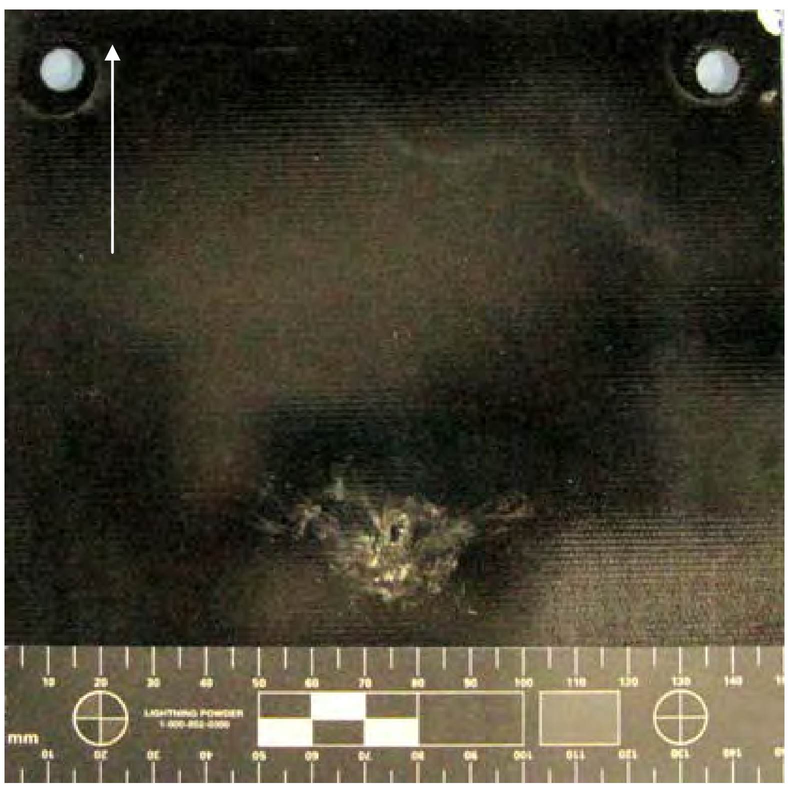


Figure 189 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12294 / Test #12 (continued)

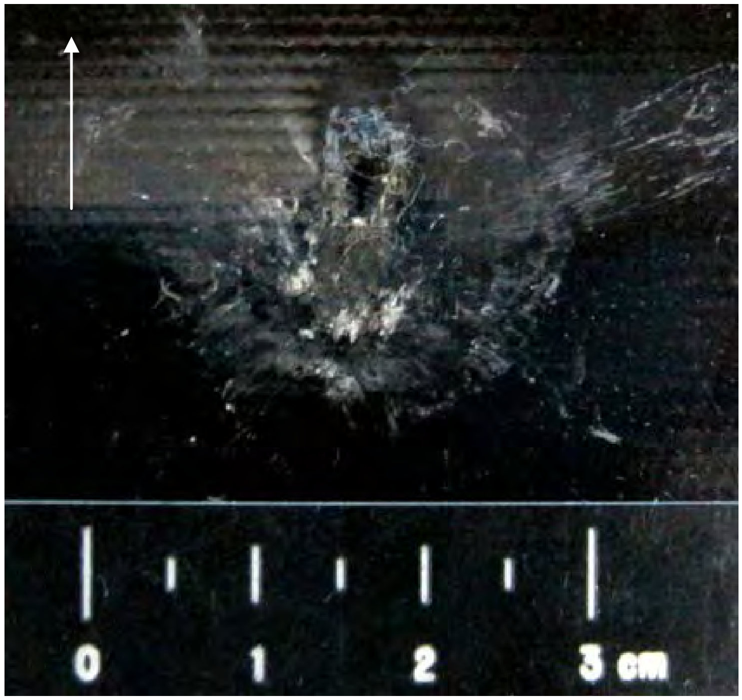


Figure 190 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

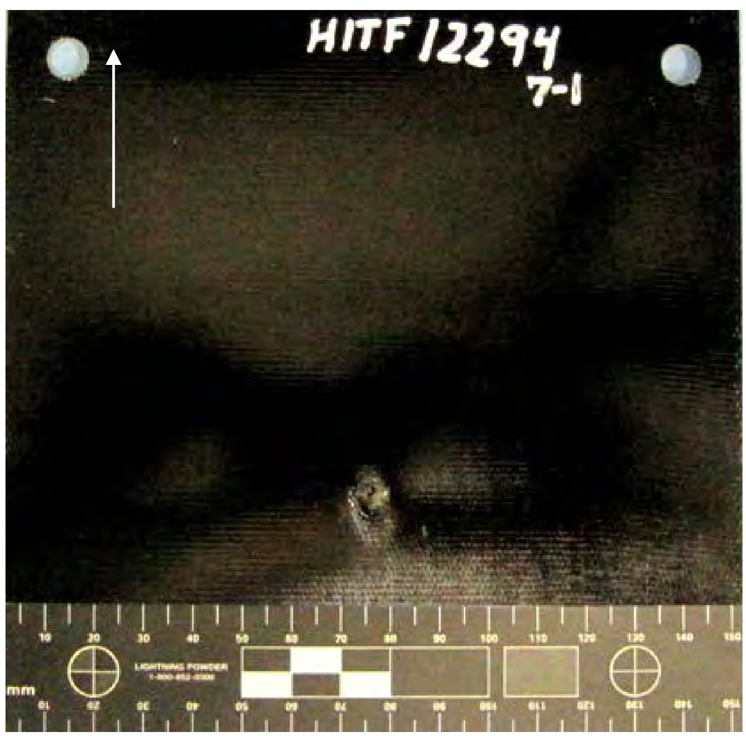


Figure 191 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12294 / Test #12 (continued)

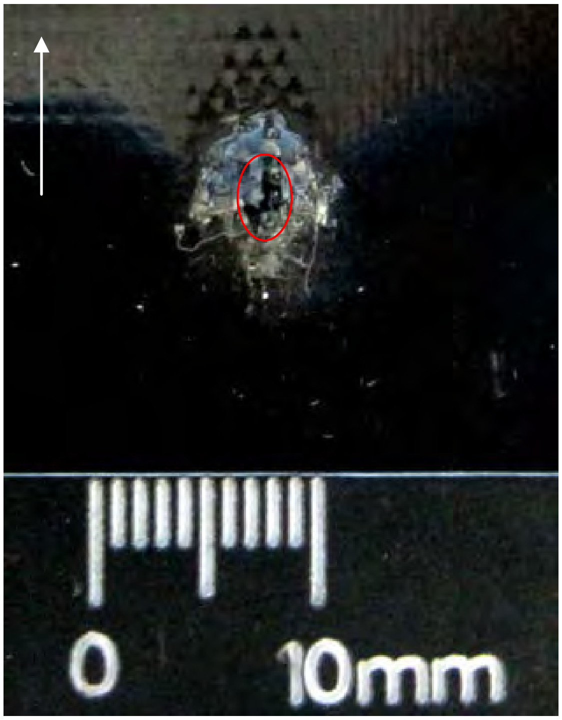


Figure 192 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

Figure 193 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (white arrow indicates flight path of projectile / damage within red circle in Figure 192)

HITF12294 / Test #12 (continued)

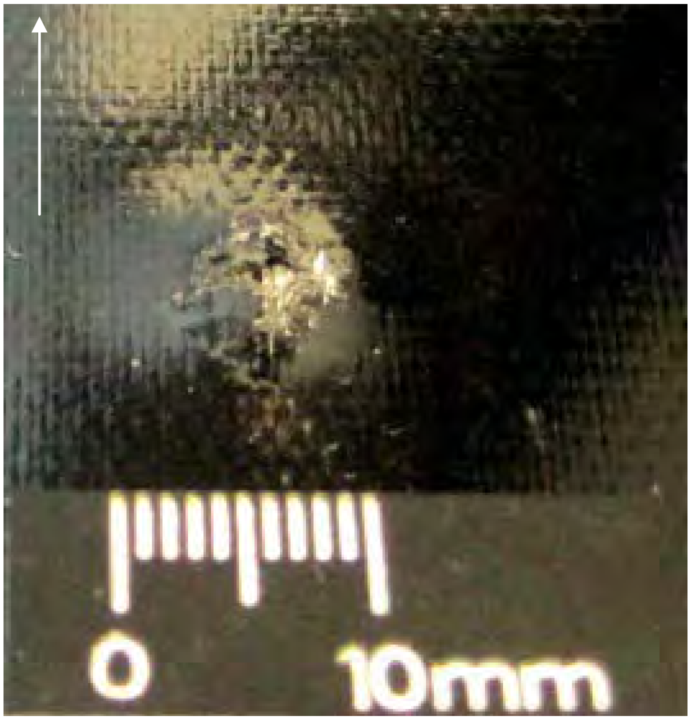


Figure 194 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

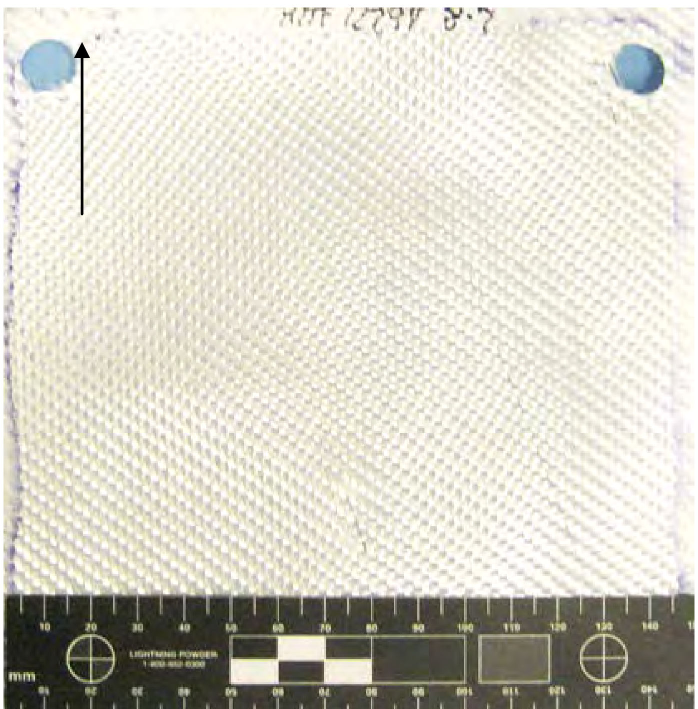


Figure 195 Overall View of Damage to Back Side of 7th Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12294 / Test #12 (continued)

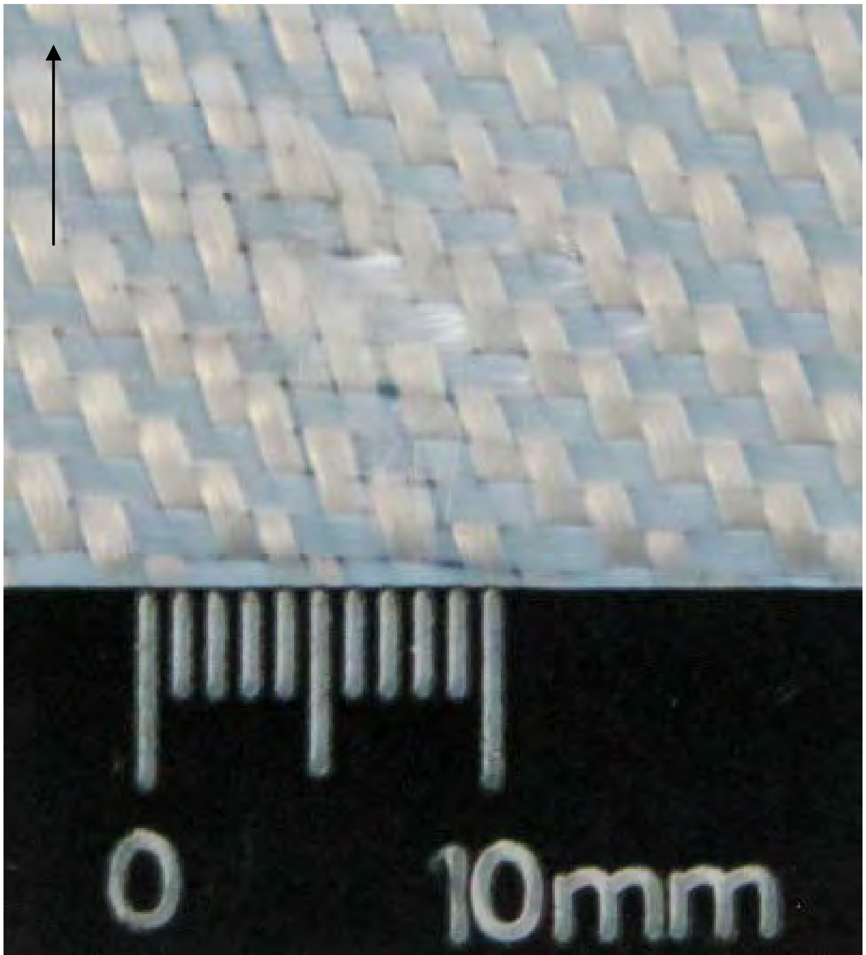


Figure 196 Close-up View of Damage to Back Side of 7th Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12295 / Test #13

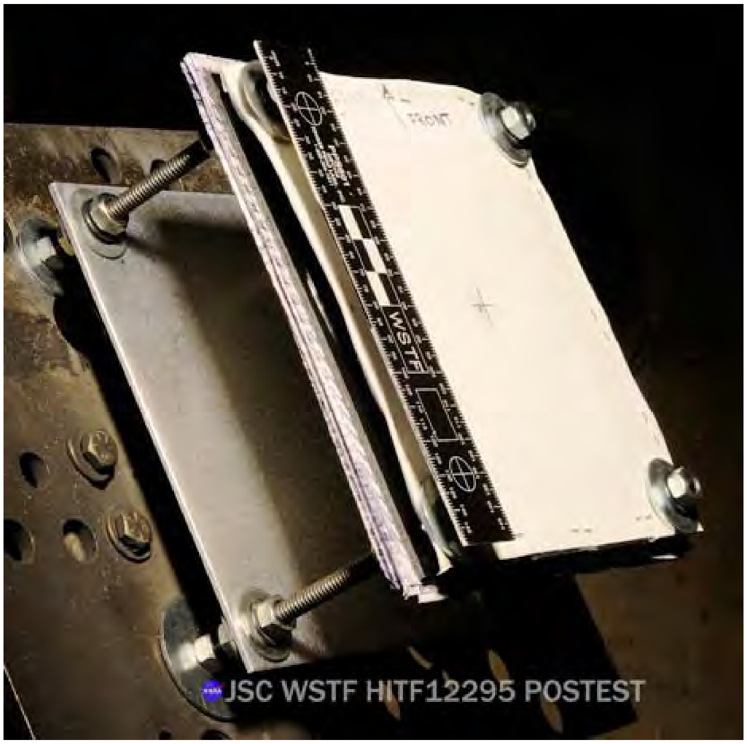


Figure 197 Overall View of Sample in the Target Tank (post-test)

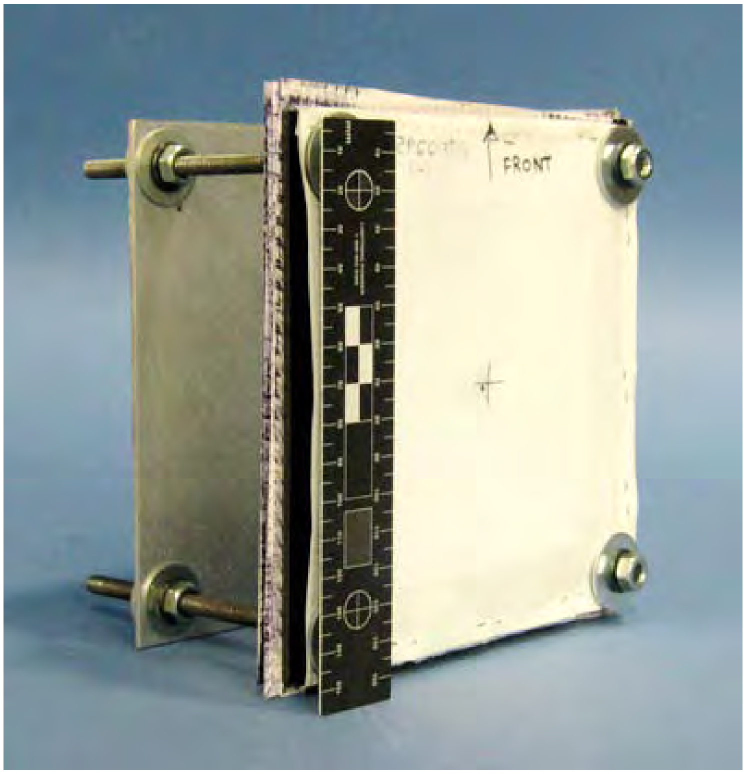


Figure 198 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12295 / Test #13 (continued)

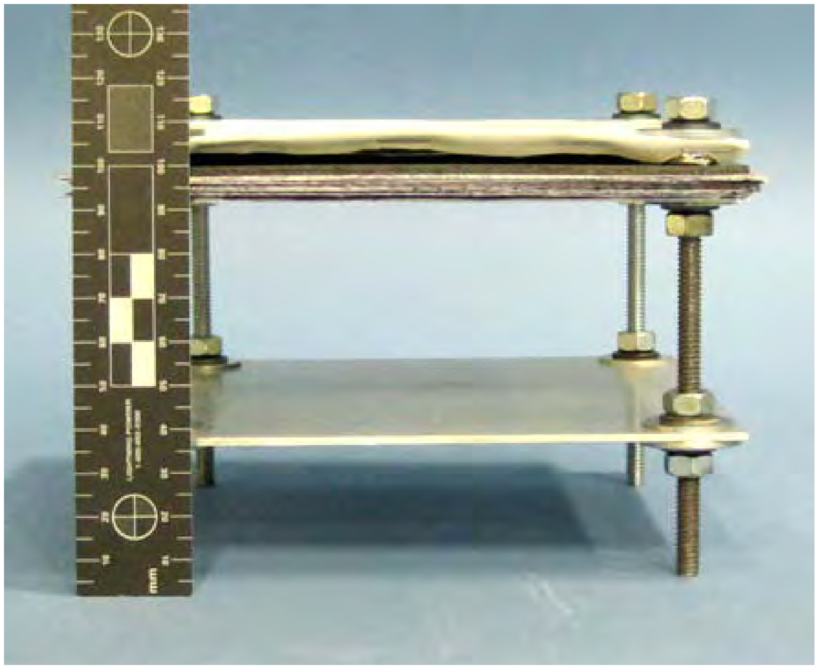


Figure 199 Overall Side View of Sample (scale in 5mm increments)

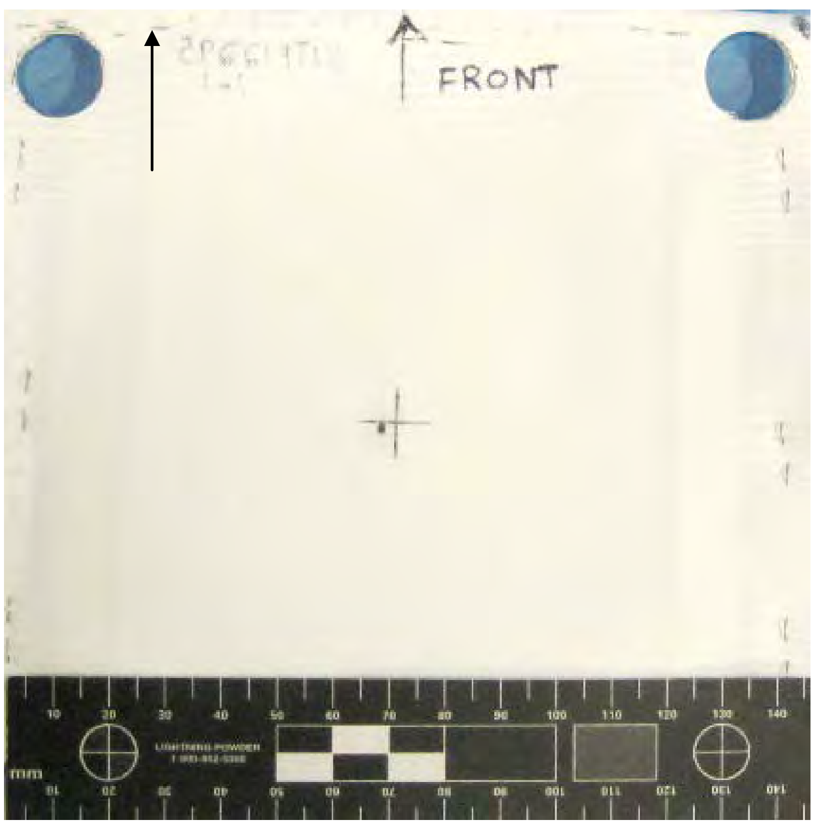


Figure 200 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12295 / Test #13 (continued)

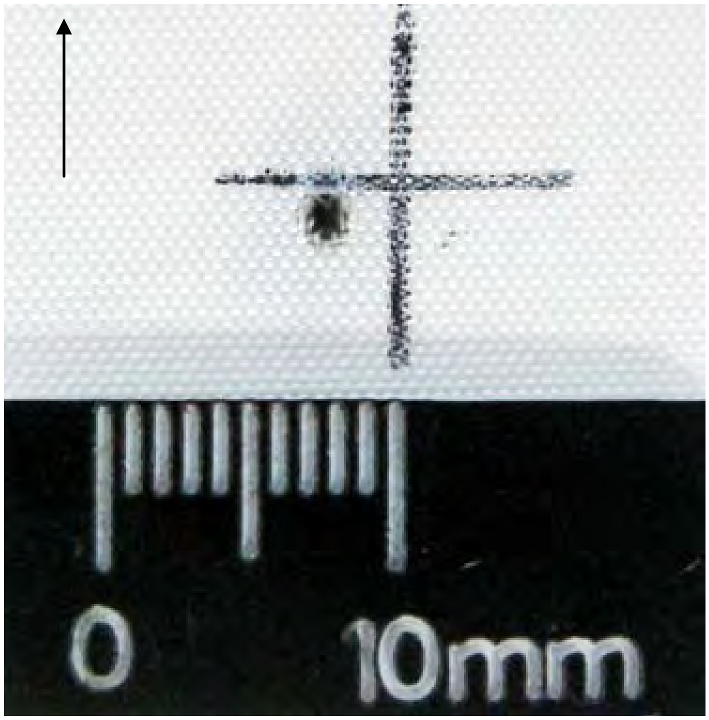


Figure 201 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

Figure 202 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

<u>HITF12295 / Test #13 (continued)</u>

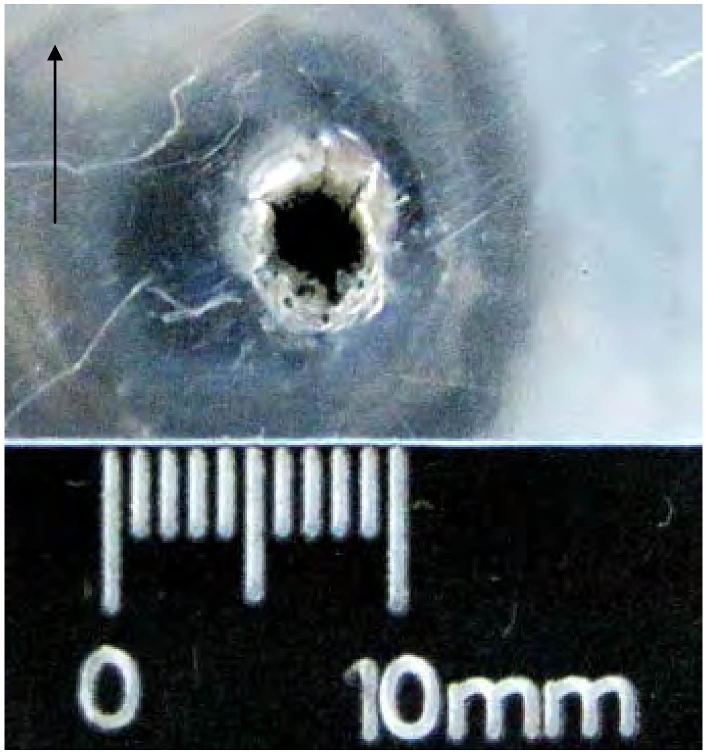


Figure 203 Close-up View of Damage to Back Side of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

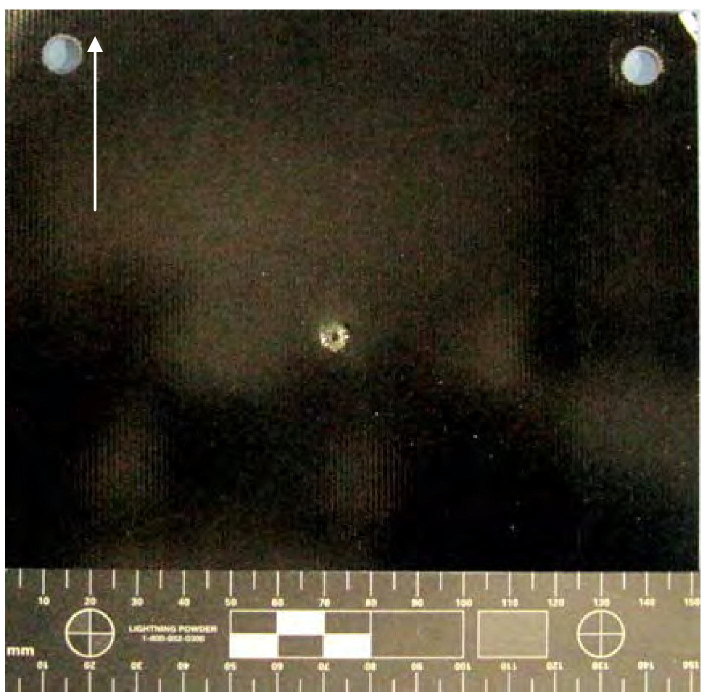


Figure 204 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12295 / Test #13 (continued)

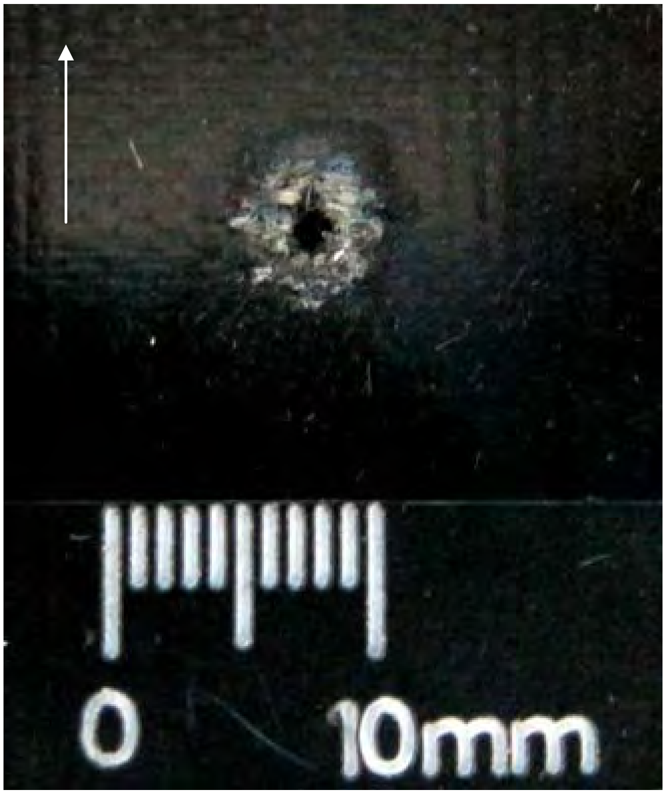


Figure 205 Close-up View of Damage to Front of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

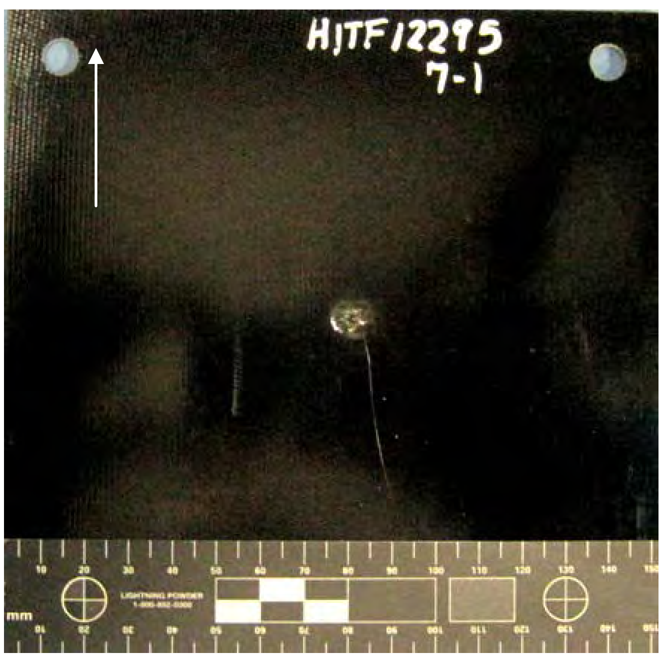


Figure 206 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12295 / Test #13 (continued)

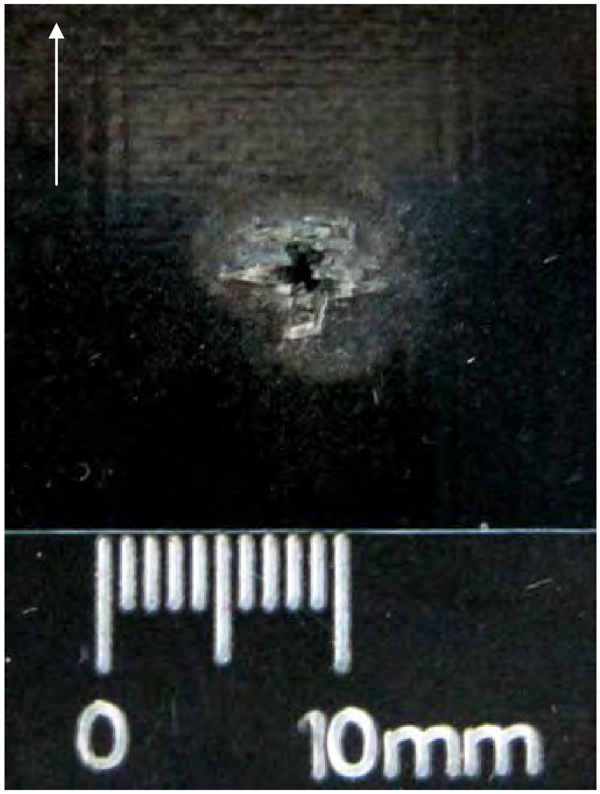


Figure 207 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

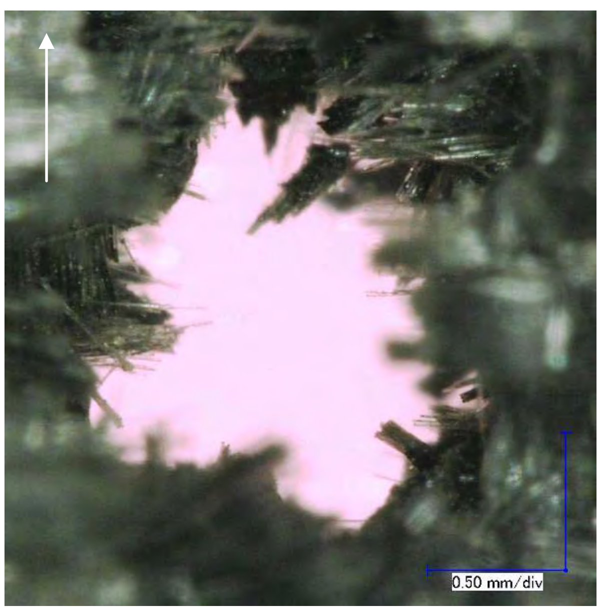


Figure 208 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (white arrow indicates flight path of projectile / damage within red circle in Figure 207)

HITF12295 / Test #13 (continued)

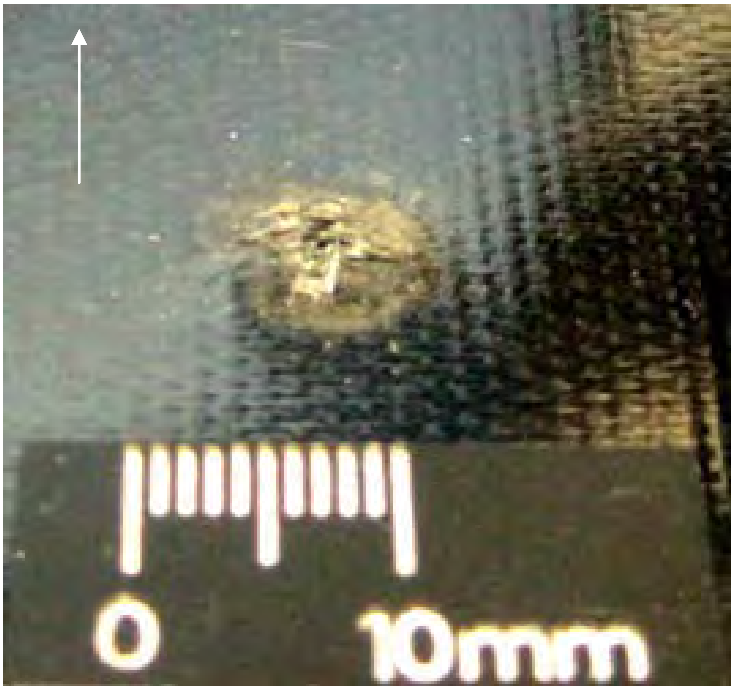


Figure 209 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

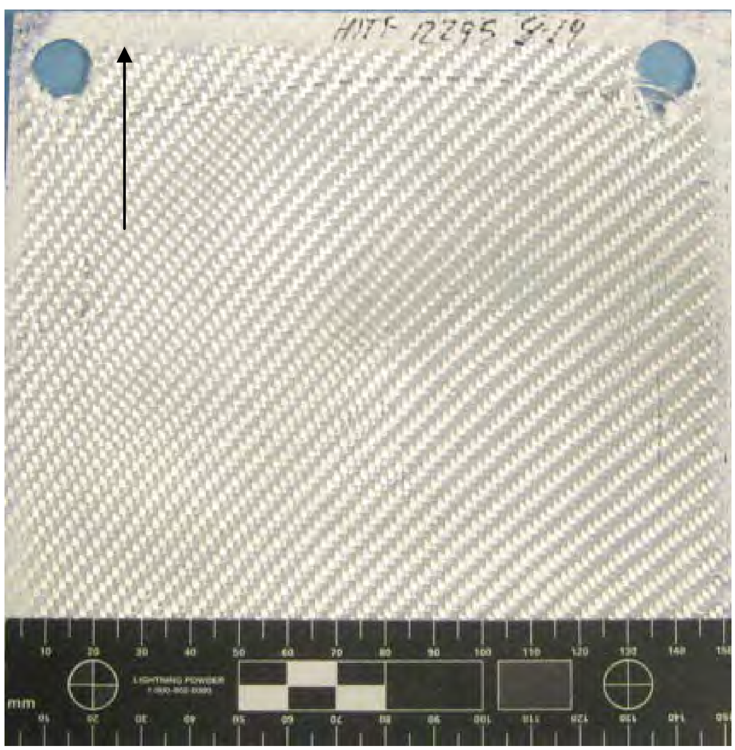


Figure 210 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12295 / Test #13 (continued)

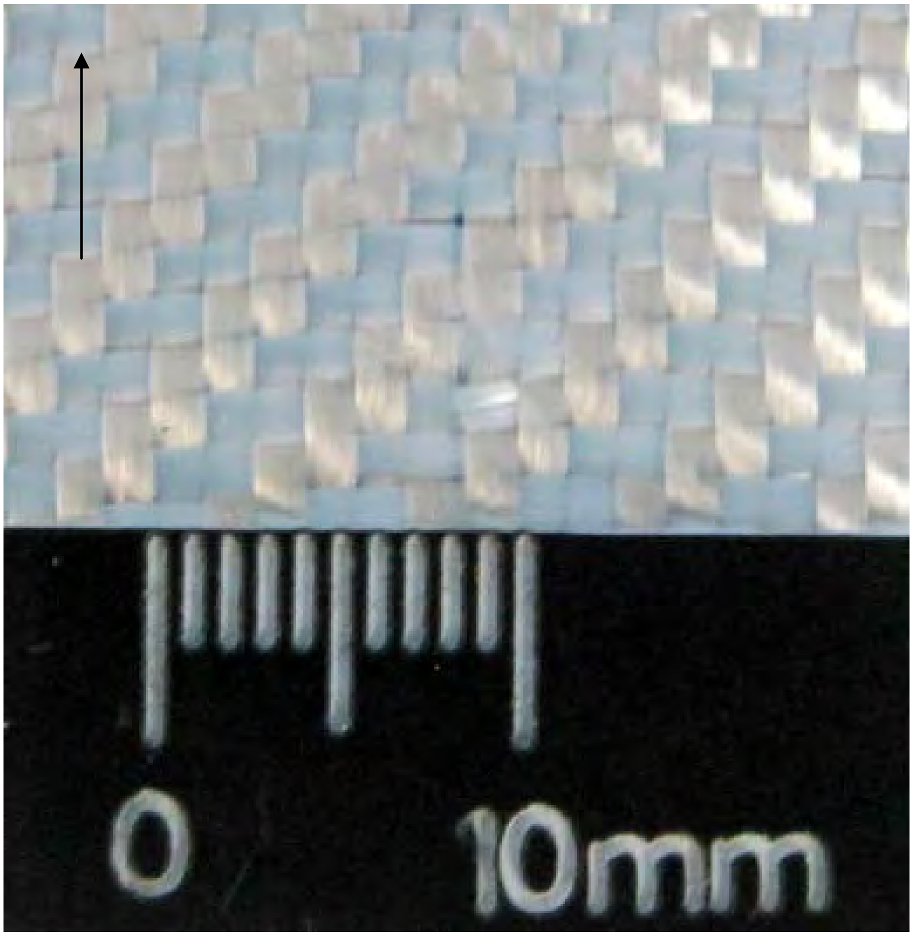


Figure 211 Close-up View of Damage to Back Side of Last Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12296 / Test #14

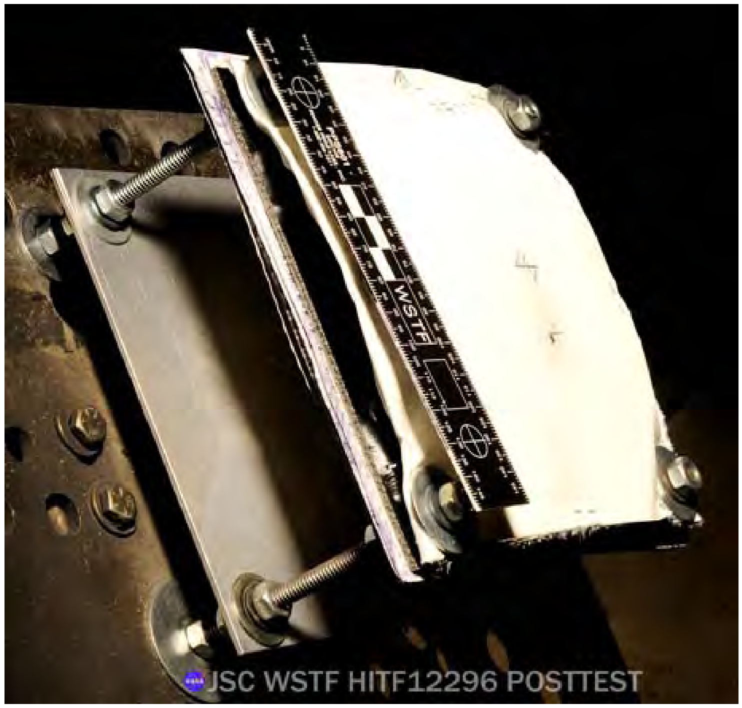


Figure 212 Overall View of Sample in the Target Tank (post-test)

Figure 213 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12296 / Test #14 (continued)

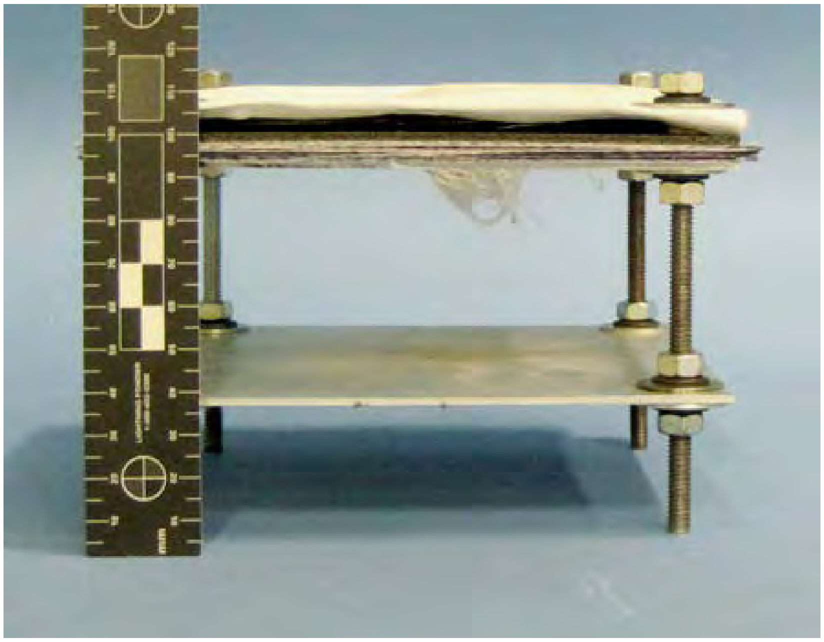


Figure 214 Overall Side View of Sample (scale in 5mm increments)

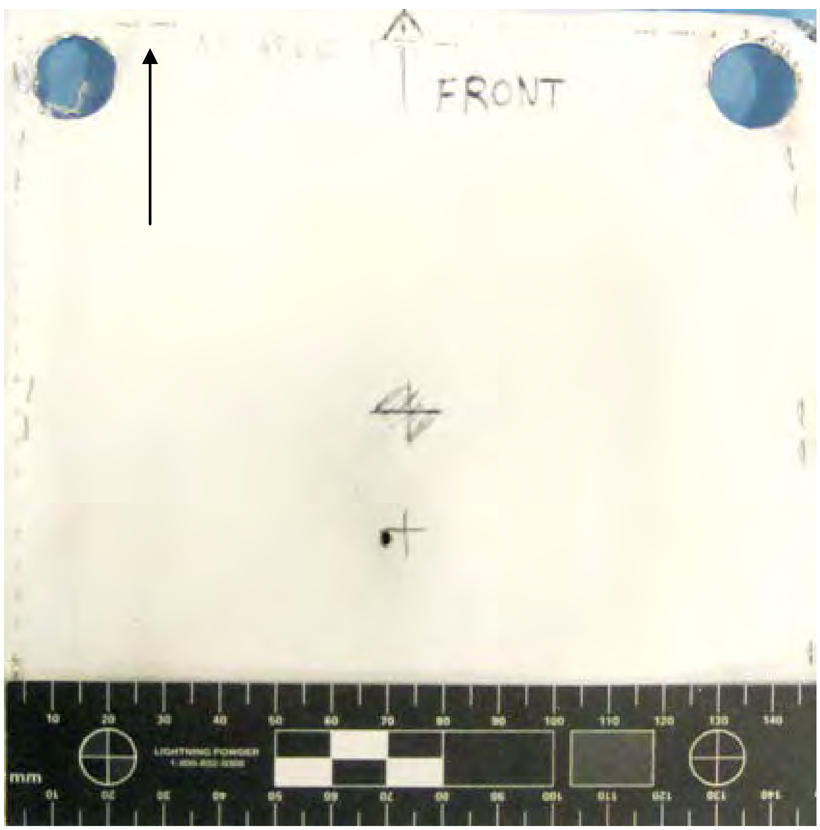


Figure 215 Overall View of Damage to Front of MLI (black arrow indicates flight path of projectile / scale in 5mm increments)

HITF12296 / Test #14 (continued)

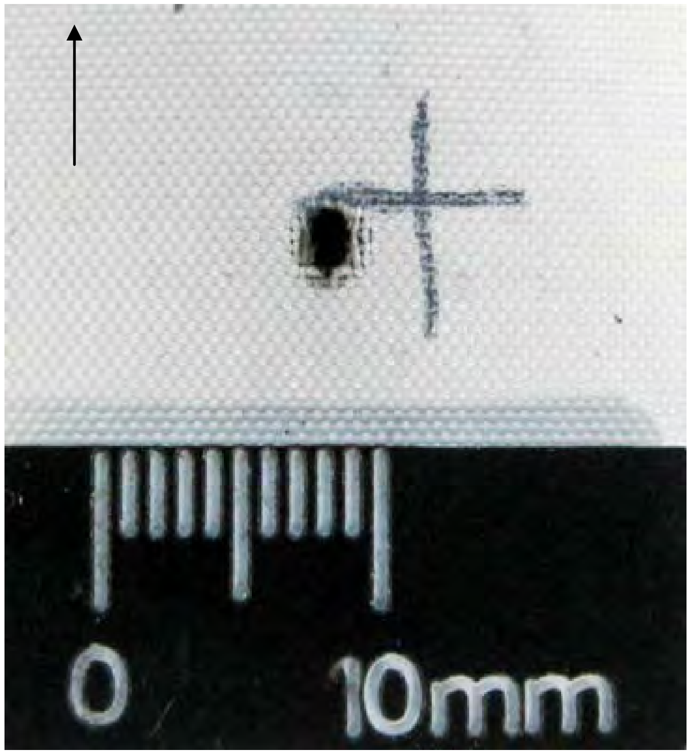


Figure 216 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

Figure 217 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12296 / Test #14 (continued)

Figure 218 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

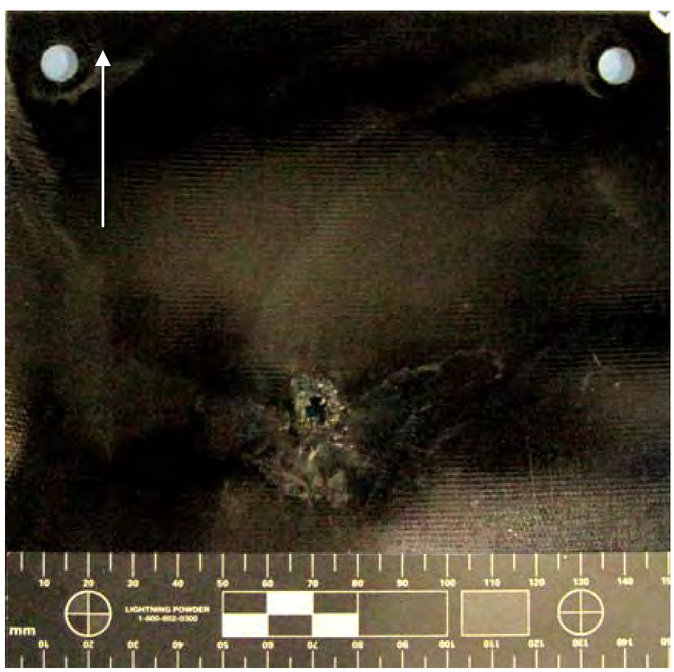


Figure 219 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12296 / Test #14 (continued)

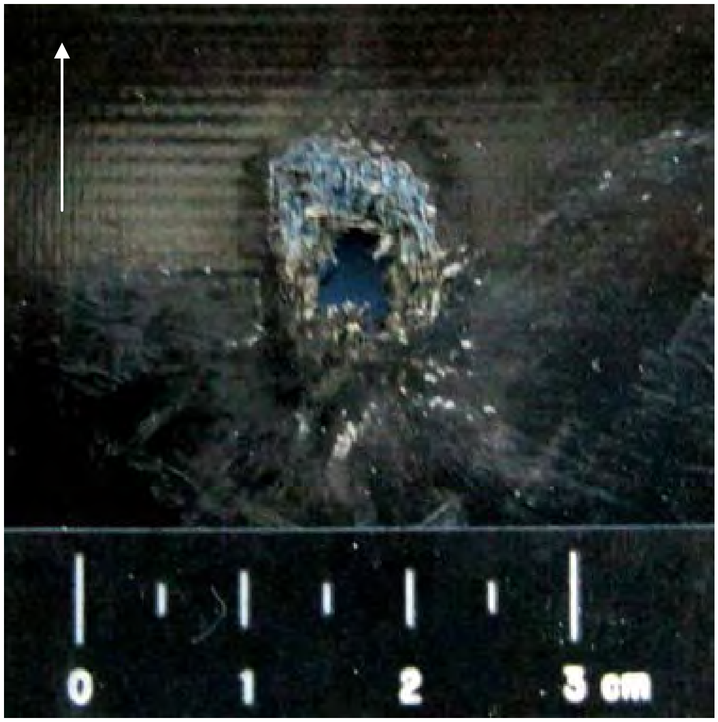


Figure 220 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

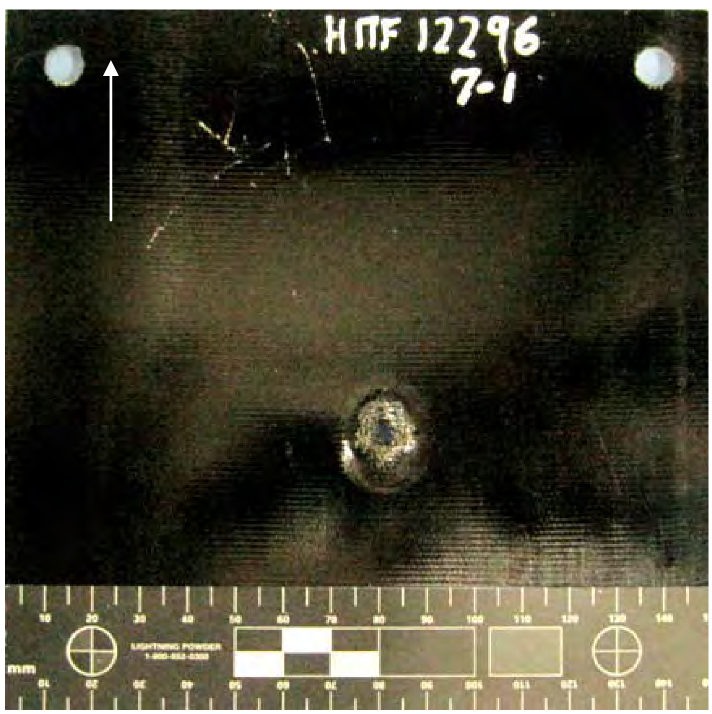


Figure 221 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12296 / Test #14 (continued)

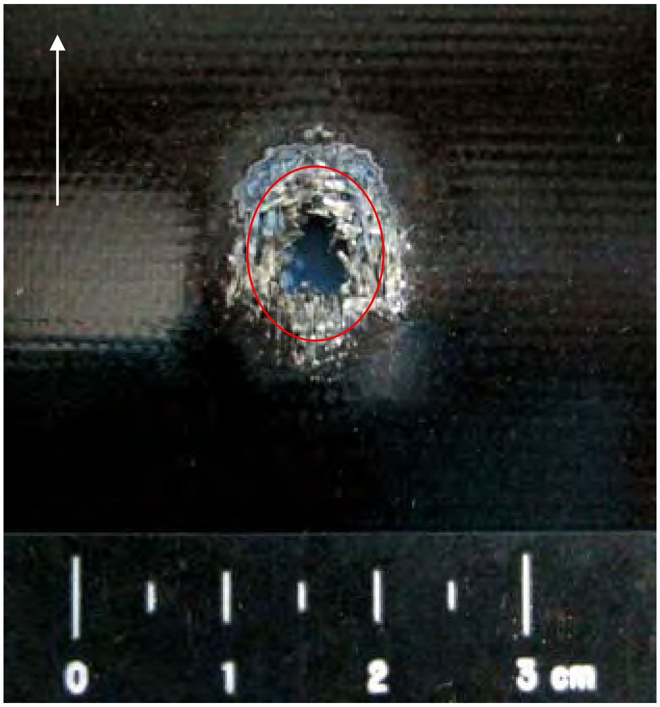


Figure 222 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

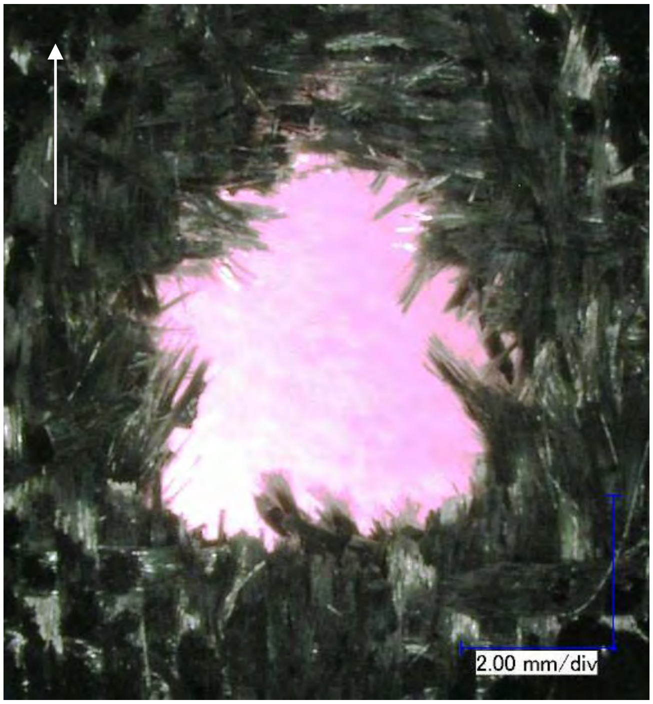


Figure 223 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 222)

HITF12296 / Test #14 (continued)

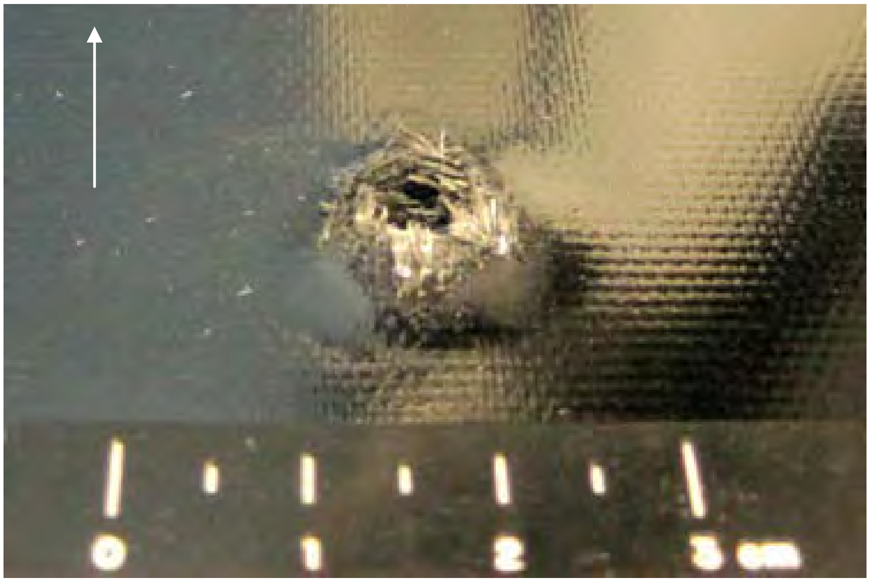


Figure 224 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

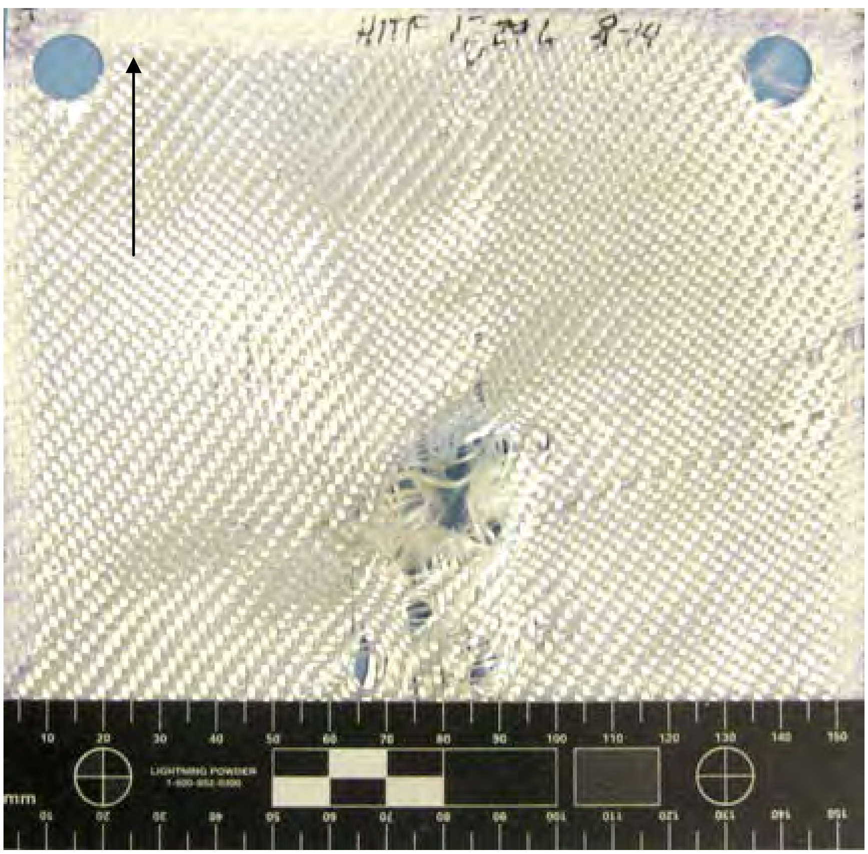


Figure 225 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12296 / Test #14 (continued)

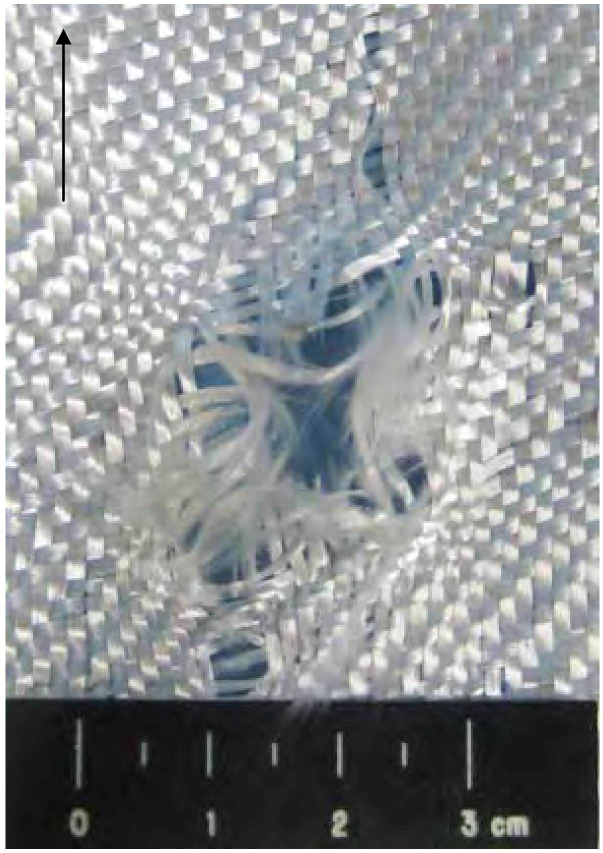


Figure 226 Close-up View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

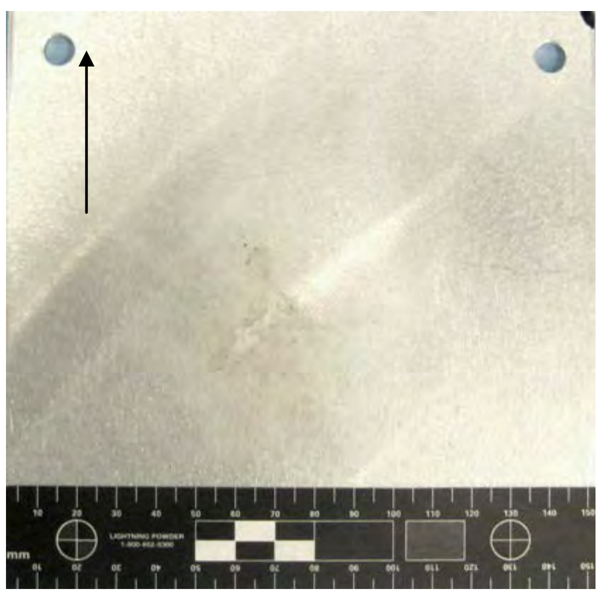


Figure 227 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12296 / Test #14 (continued)

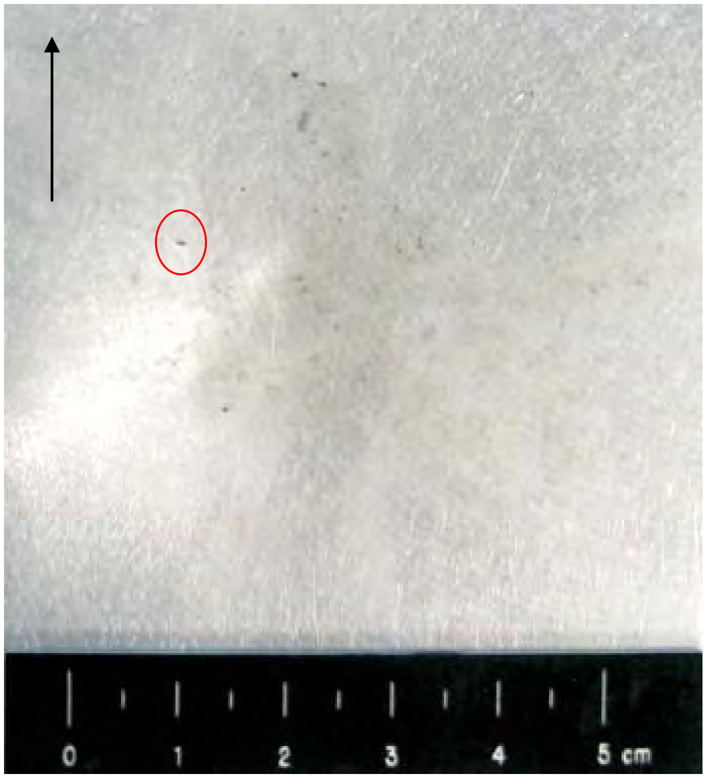


Figure 228 Close-up View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

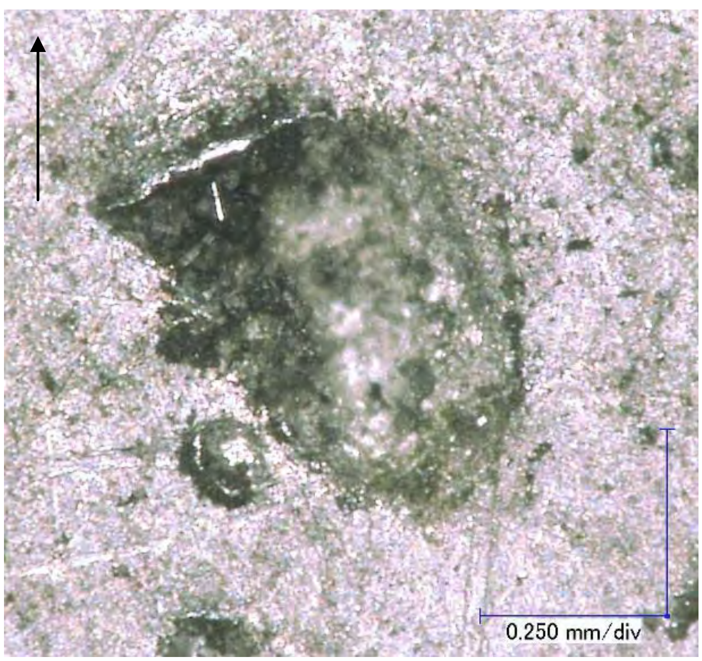


Figure 229 Close-up View of Most Significant Damage to Front of Rear Wall (black arrow indicates flight path of projectile / damage within red circle in Figure 241)

HITF12296 / Test #14 (continued)

Figure 230 Overall View of Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12296-B / Test #14-B

Figure 231 Overall View of Sample in the Target Tank (post-test)


Figure 232 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12296-B / Test #14-B (continued)

Figure 233 Overall Side View of Sample (scale in 5mm increments)

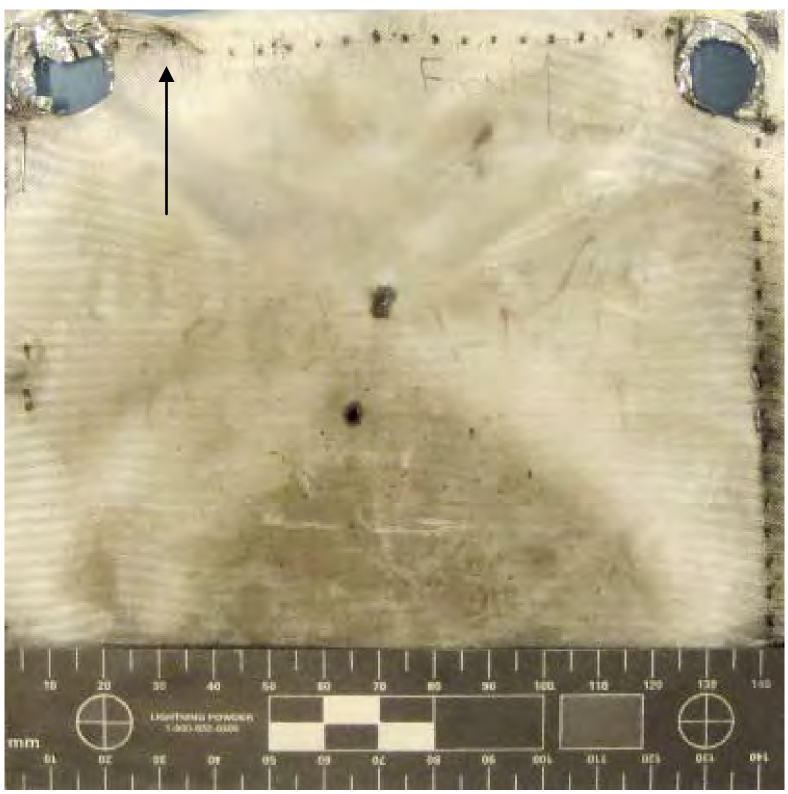


Figure 234 Overall View of Damage to Front of MLI (black arrow indicates flight path of projectile / scale in 5mm increments)

HITF12296-B / Test #14-B (continued)

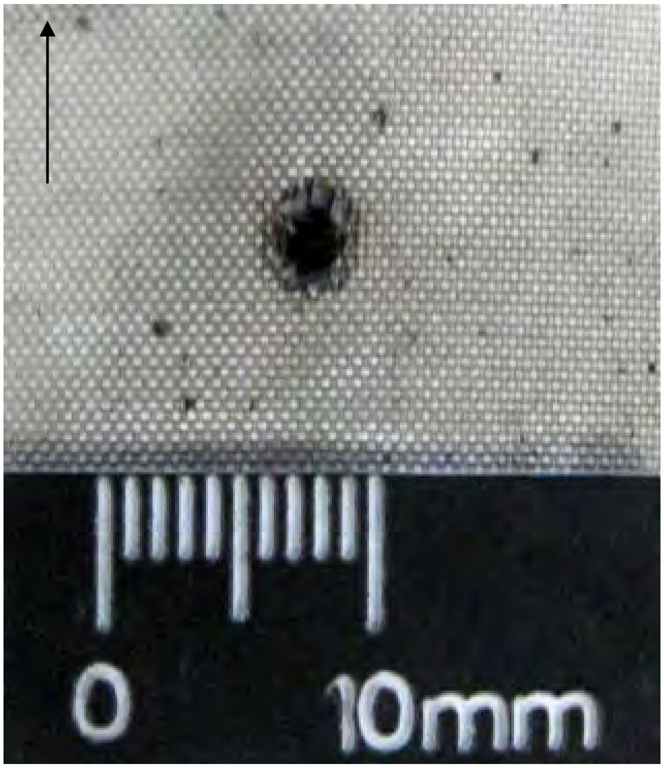


Figure 235 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

Figure 236 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12296-B / Test #14-B (continued)

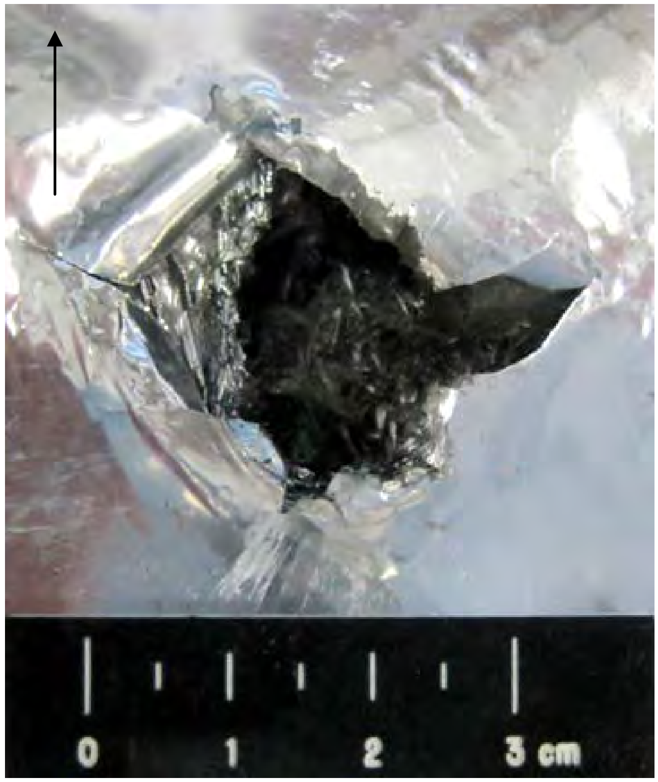


Figure 237 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

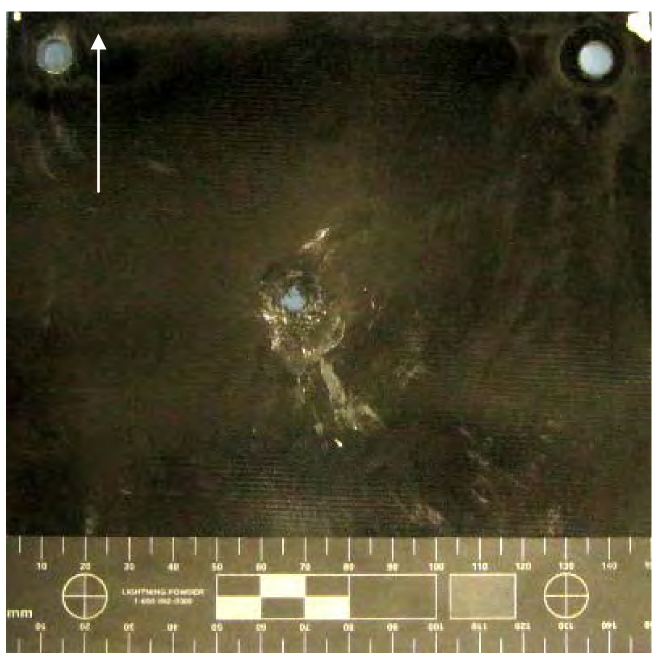


Figure 238 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12296-B / Test #14-B (continued)

Figure 239 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

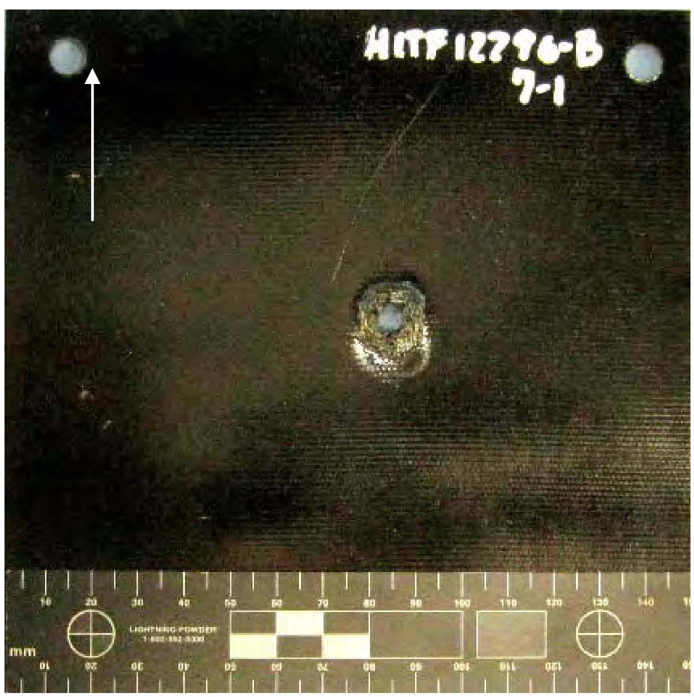


Figure 240 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12296-B / Test #14-B (continued)

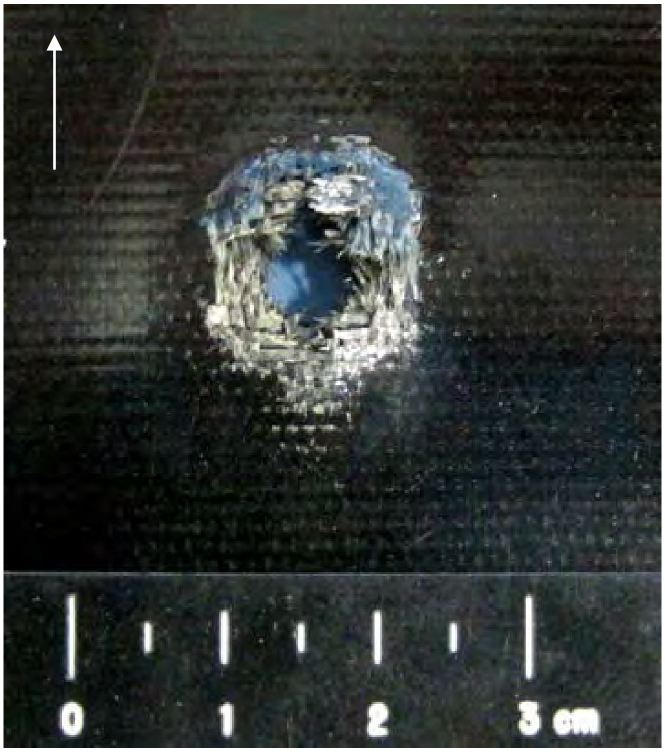


Figure 241 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

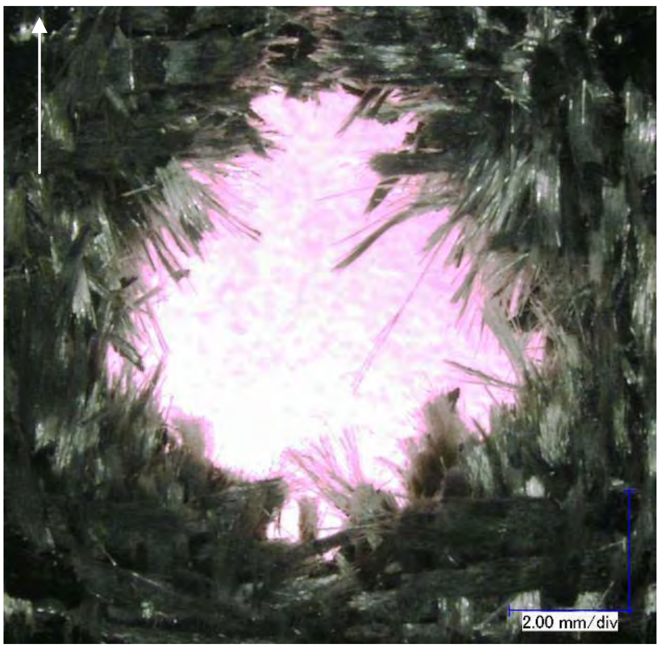


Figure 242 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 241)

HITF12296-B / Test #14-B (continued)

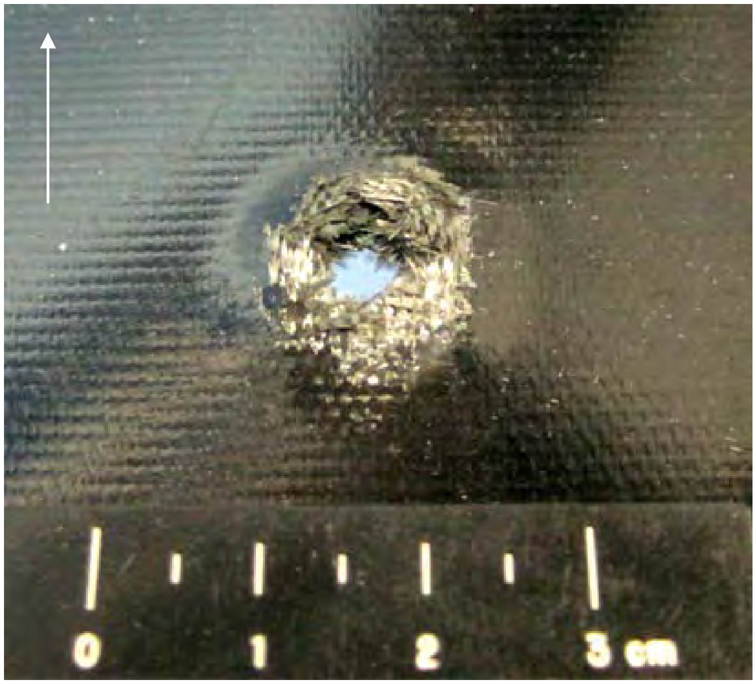


Figure 243 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

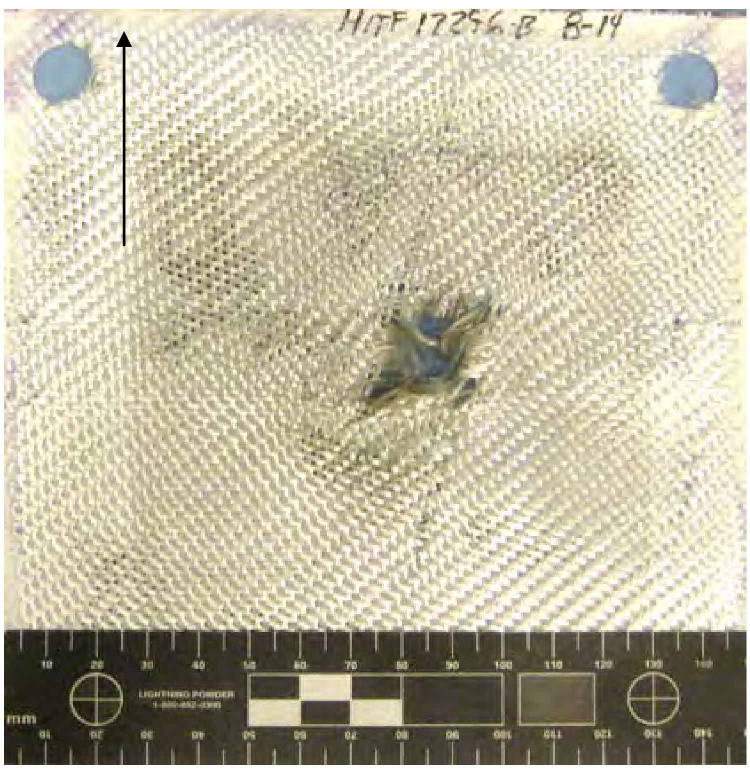


Figure 244 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12296-B / Test #14-B (continued)

Figure 245 Close-up View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

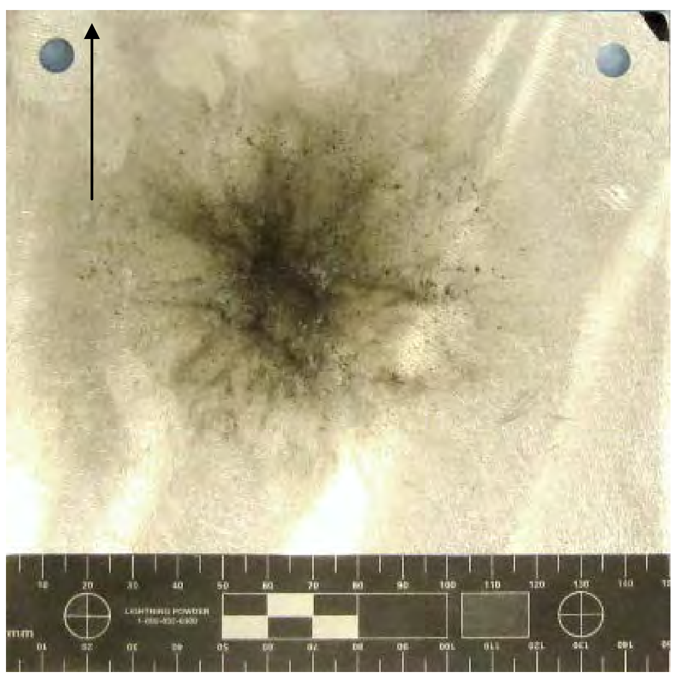


Figure 246 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile / uncleaned)

HITF12296-B / Test #14-B (continued)

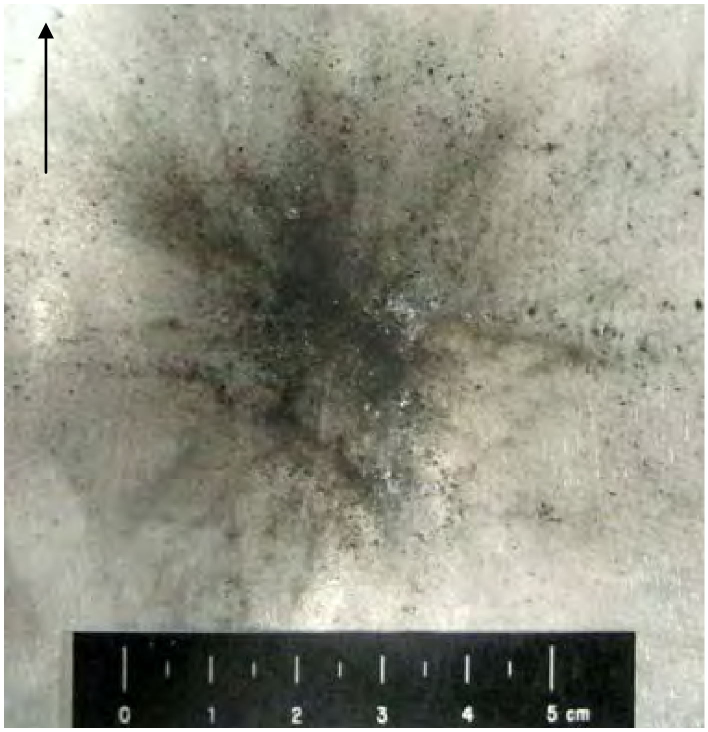


Figure 247 Close-up View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile / uncleaned)

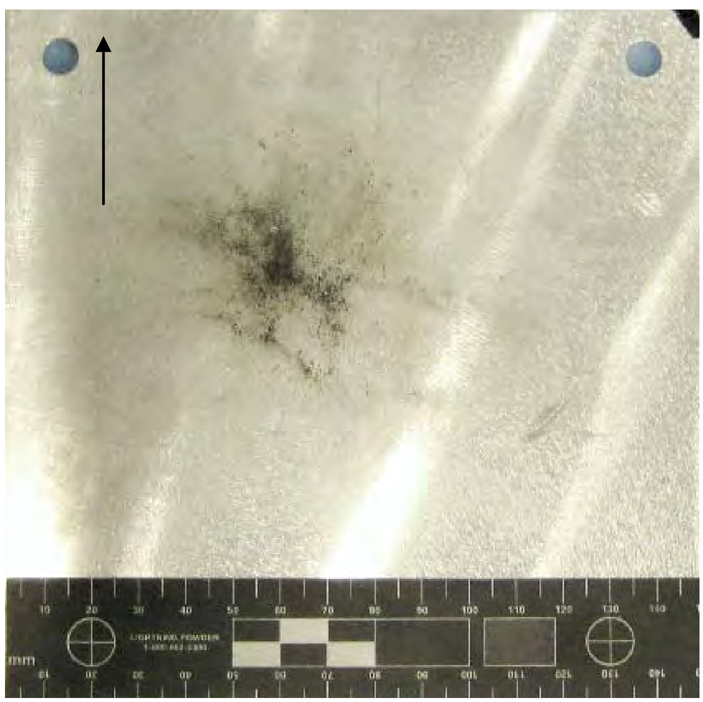


Figure 248 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile / cleaned)

HITF12296-B / Test #14-B (continued)

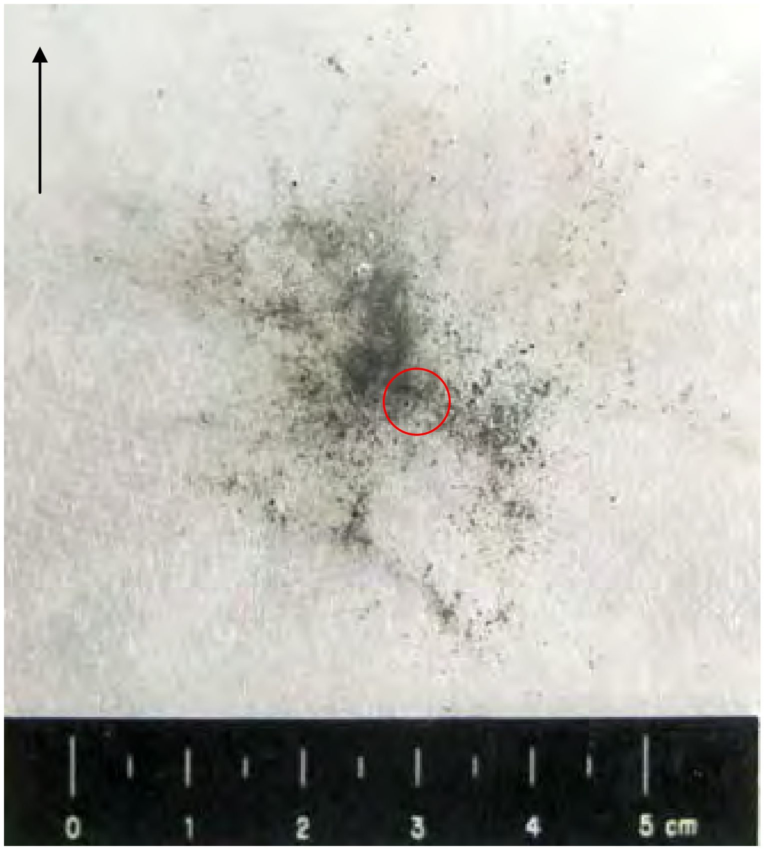


Figure 249 Close-up View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile / cleaned)

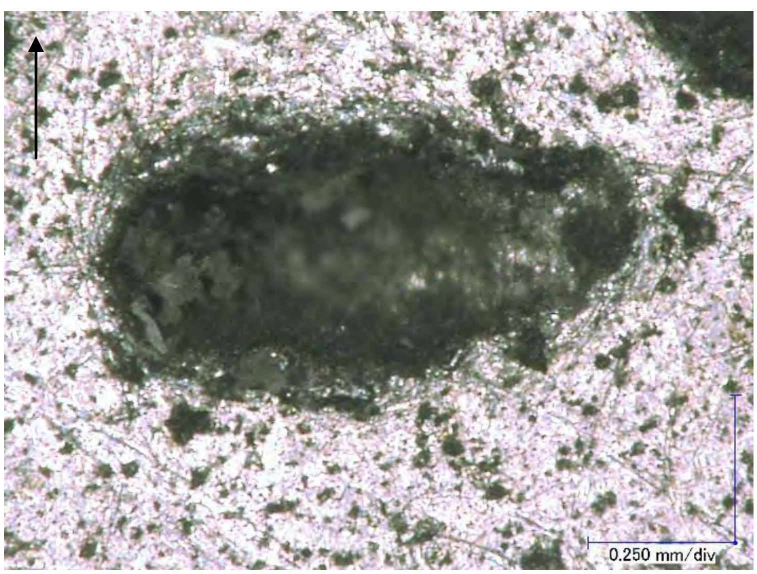


Figure 250 Close-up View of Most Significant Damage to Front of Rear Wall (black arrow indicates flight path of projectile / damage within red circle in Figure 249)

<u>HITF12296-B / Test #14-B (continued)</u>

Figure 251 Overall View of Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12297 / Test #15

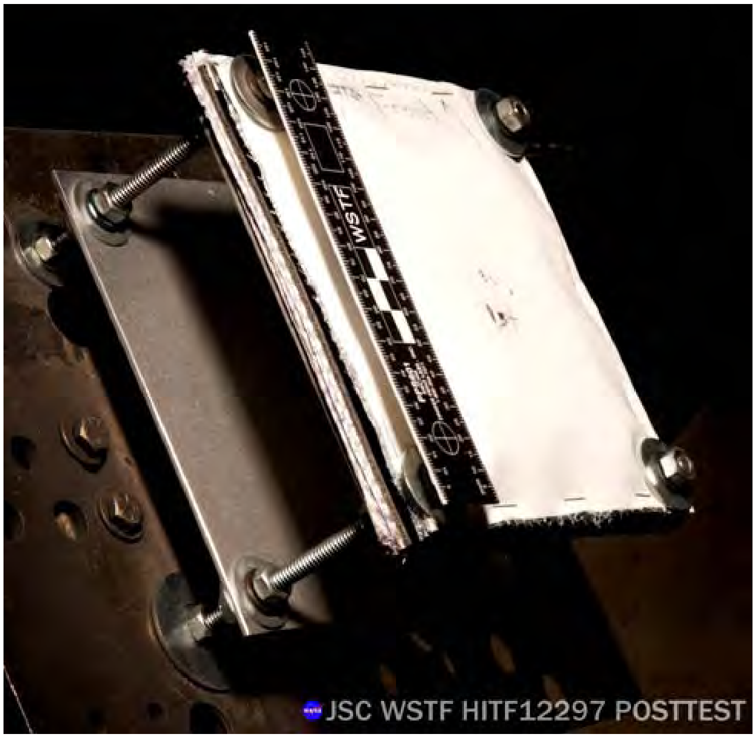


Figure 252 Overall View of Sample in the Target Tank (post-test)

Figure 253 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12297 / Test #15 (continued)

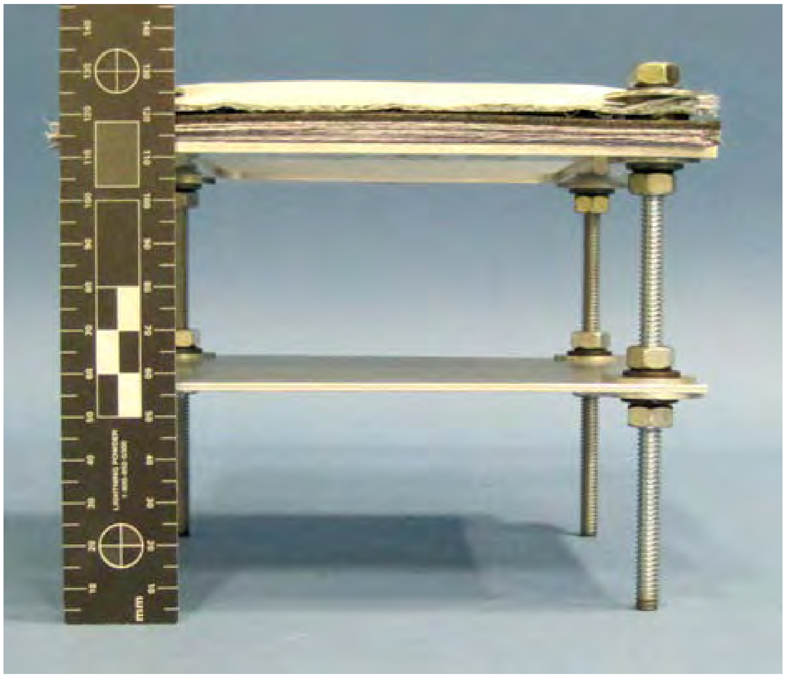


Figure 254 Overall Side View of Sample (scale in 5mm increments)

Figure 255 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12297 / Test #15 (continued)

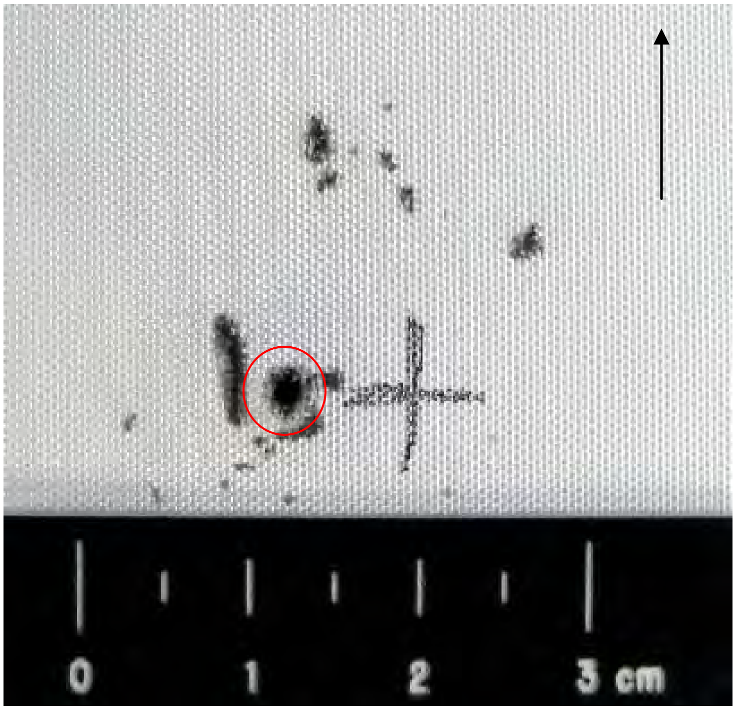


Figure 256 Close-up View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile / projectile impacted within red circle)

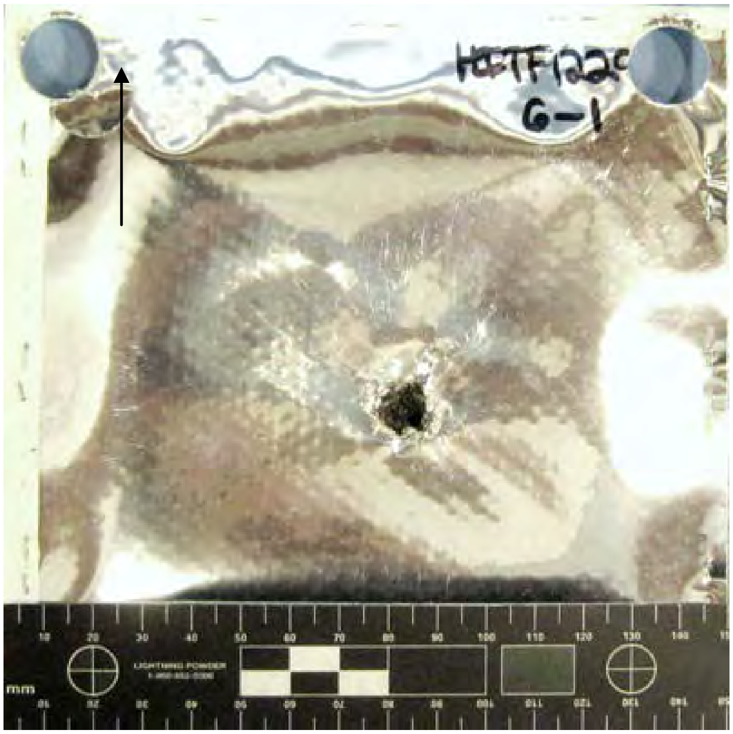


Figure 257 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12297 / Test #15 (continued)

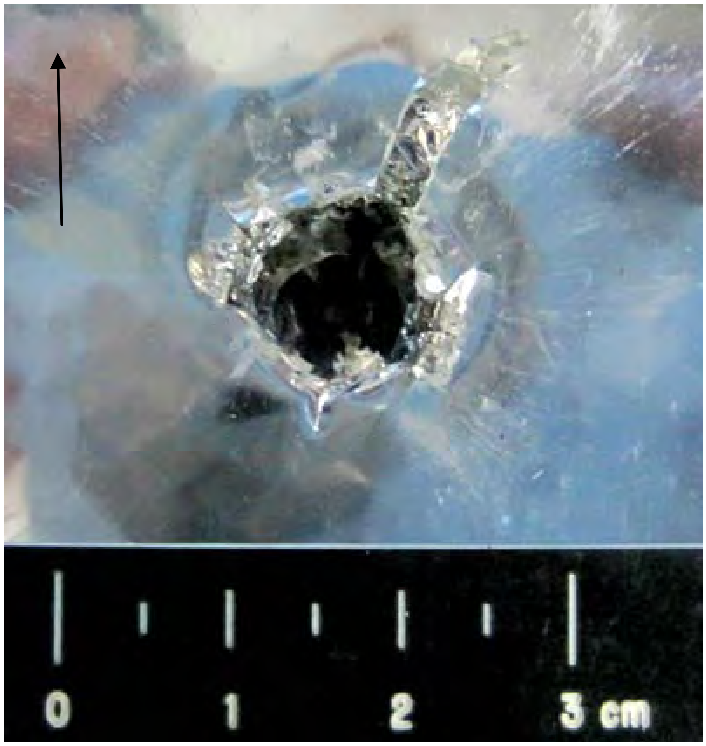


Figure 258 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

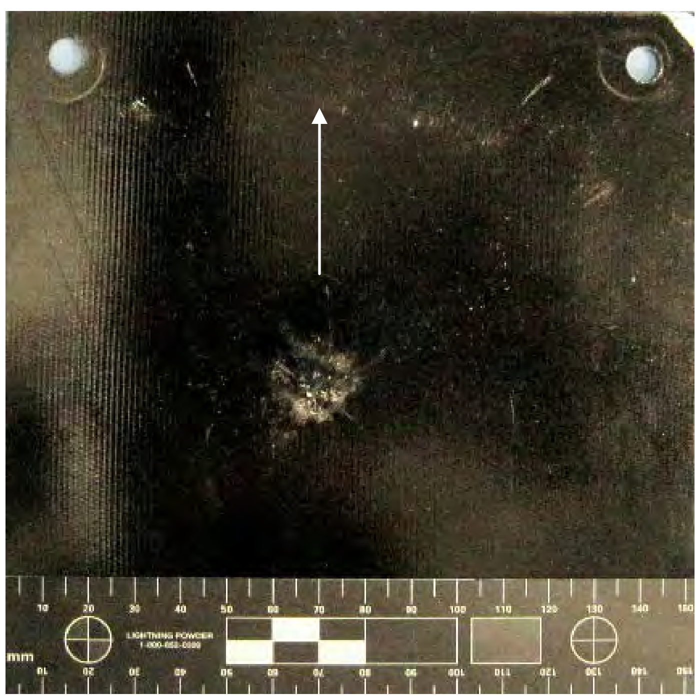


Figure 259 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12297 / Test #15 (continued)

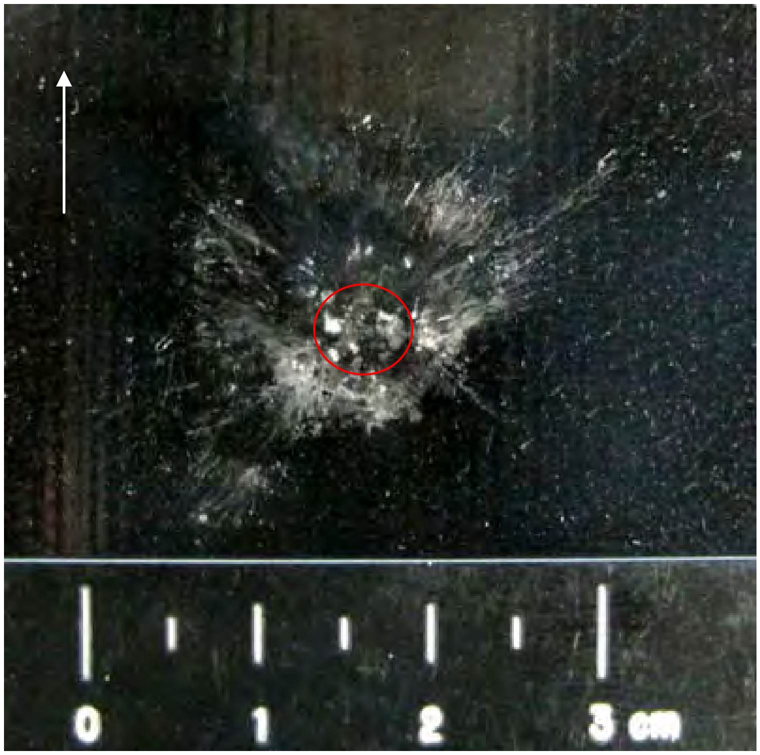


Figure 260 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

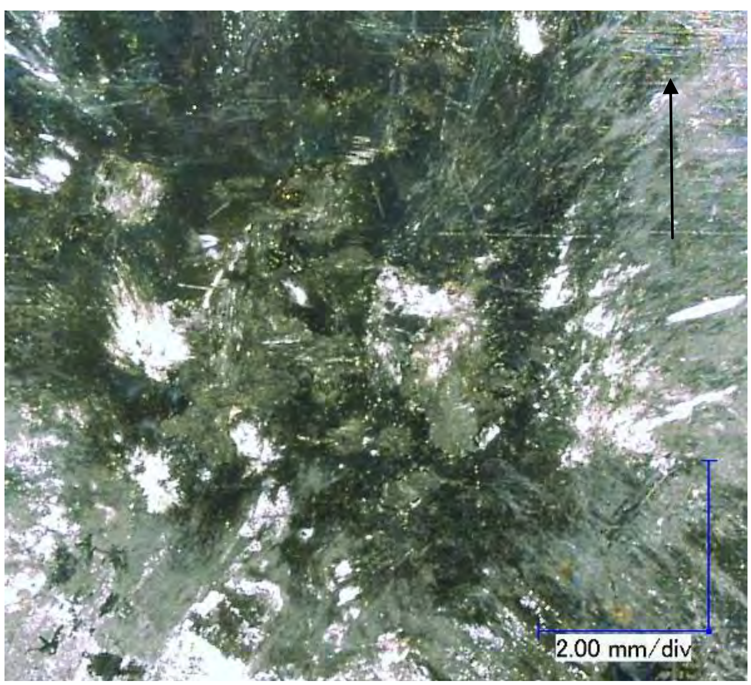


Figure 261 Close-up View of Most Significant Damage to Front of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 260)

HITF12297 / Test #15 (continued)

Figure 262 Overall View of Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12298 / Test #16

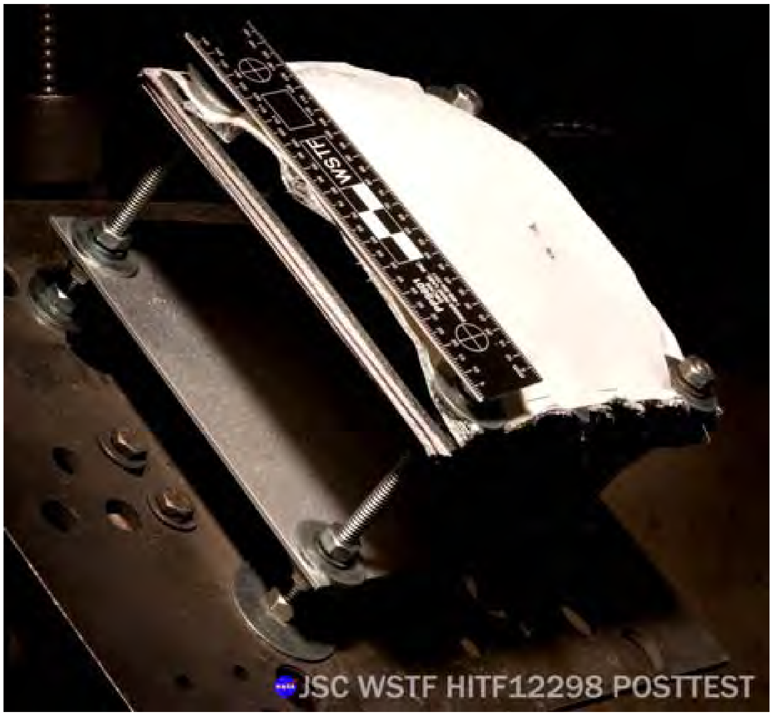


Figure 263 Overall View of Sample in the Target Tank (post-test)

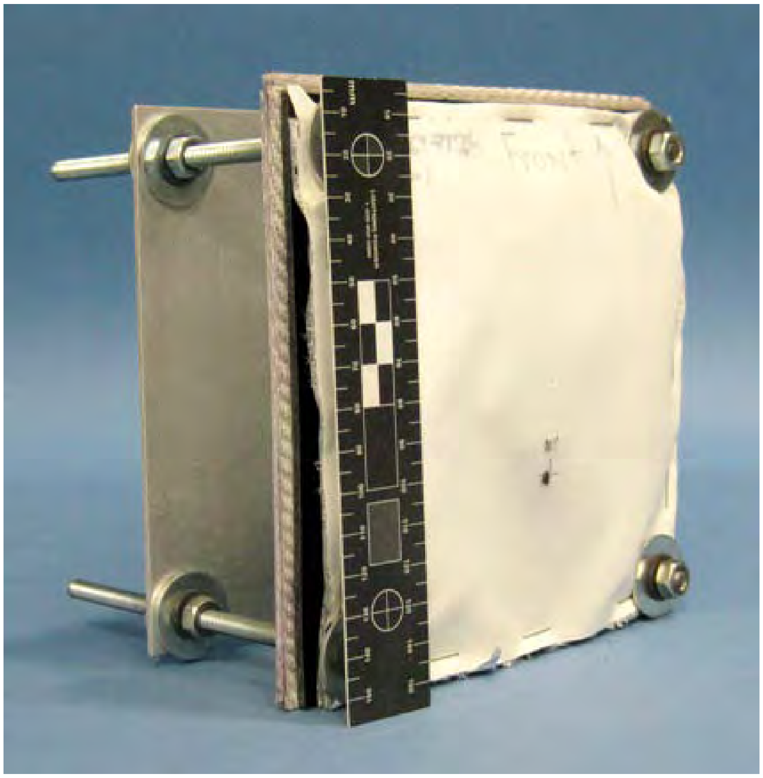


Figure 264 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12298 / Test #16 (continued)

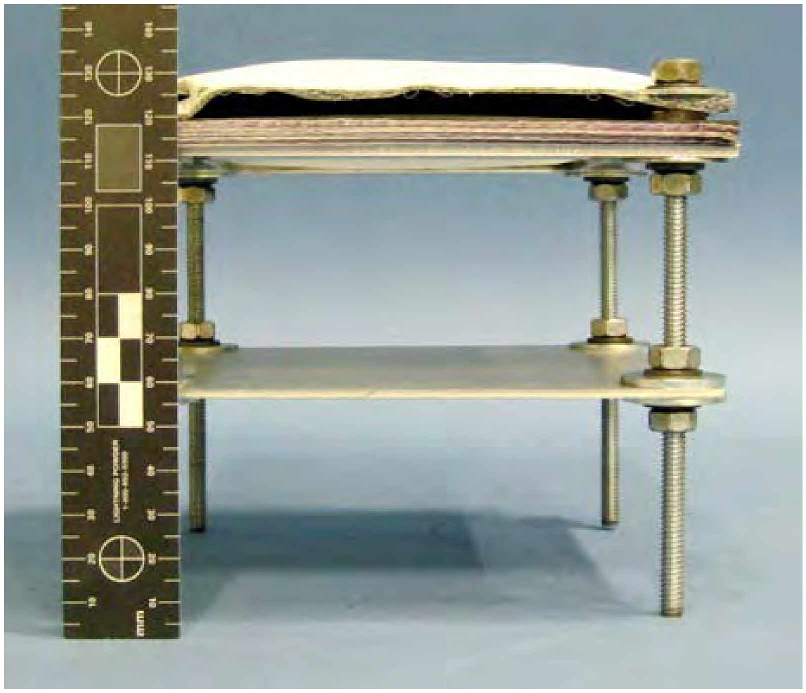


Figure 265 Overall Side View of Sample (scale in 5mm increments)

Figure 266 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12298 / Test #16 (continued)

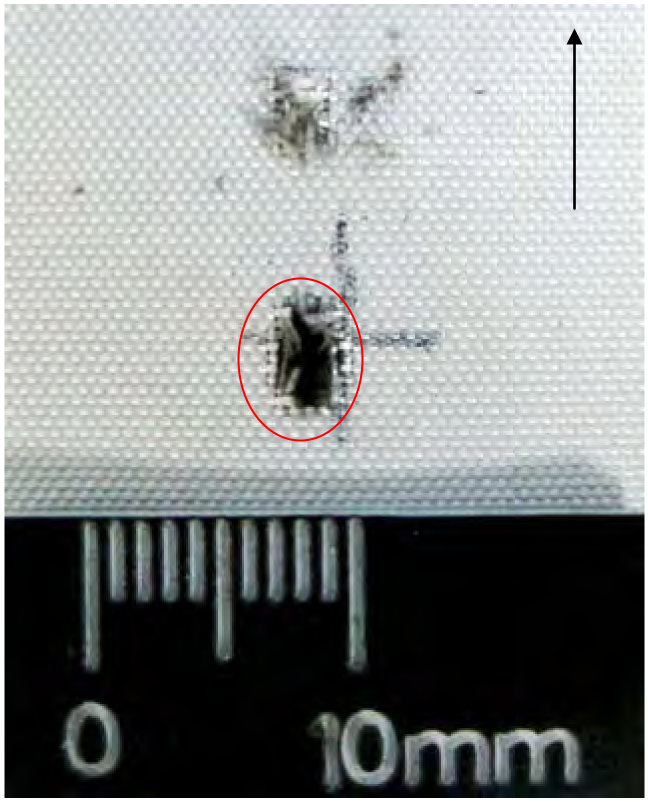


Figure 267 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile / projectile impacted within red circle)

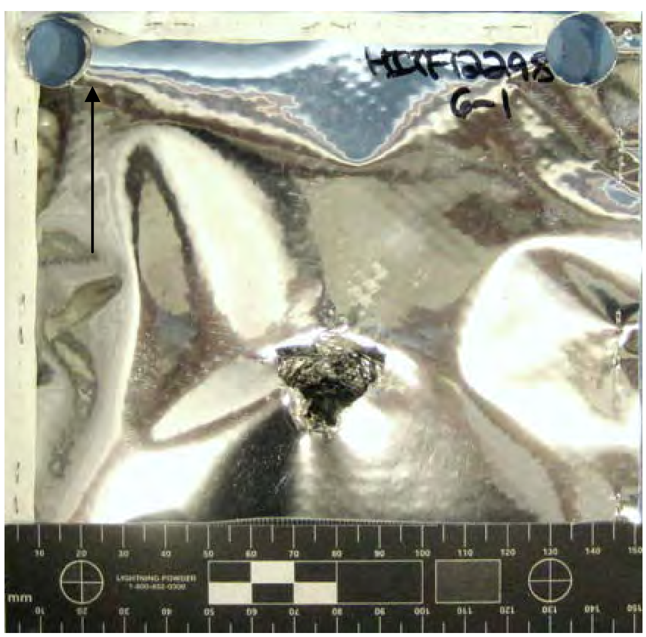


Figure 268 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12298 / Test #16 (continued)

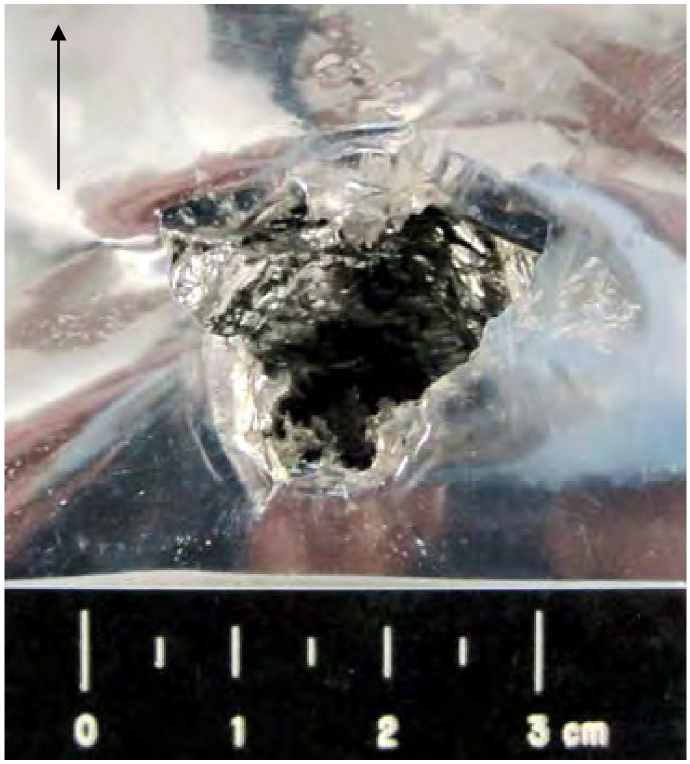


Figure 269 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

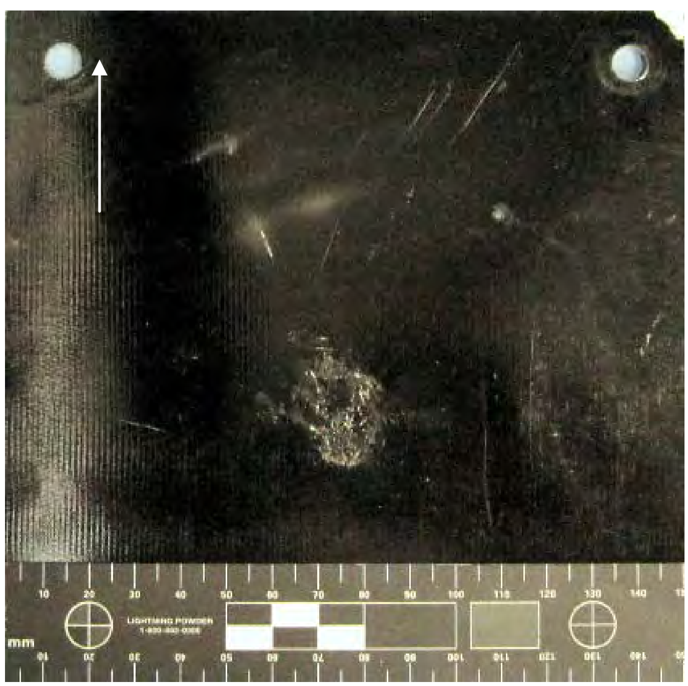


Figure 270 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12298 / Test #16 (continued)

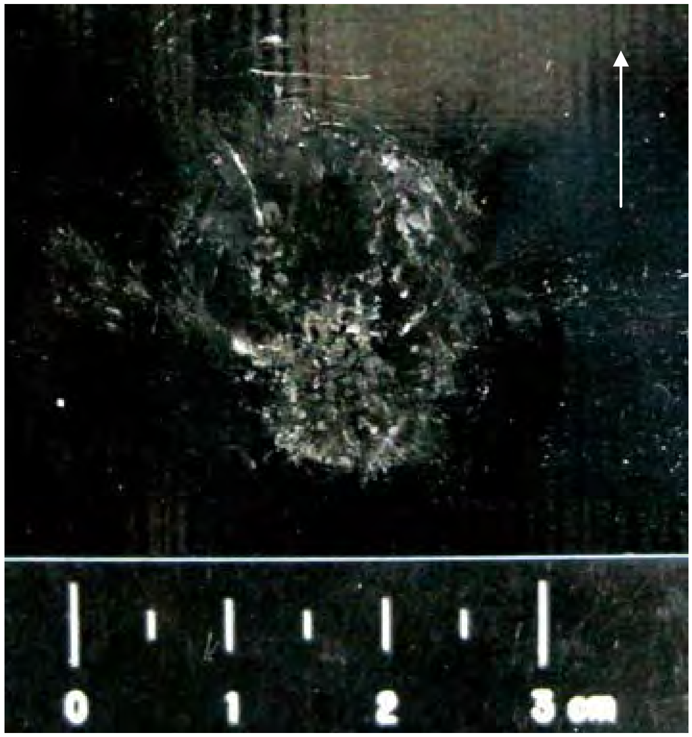


Figure 271 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

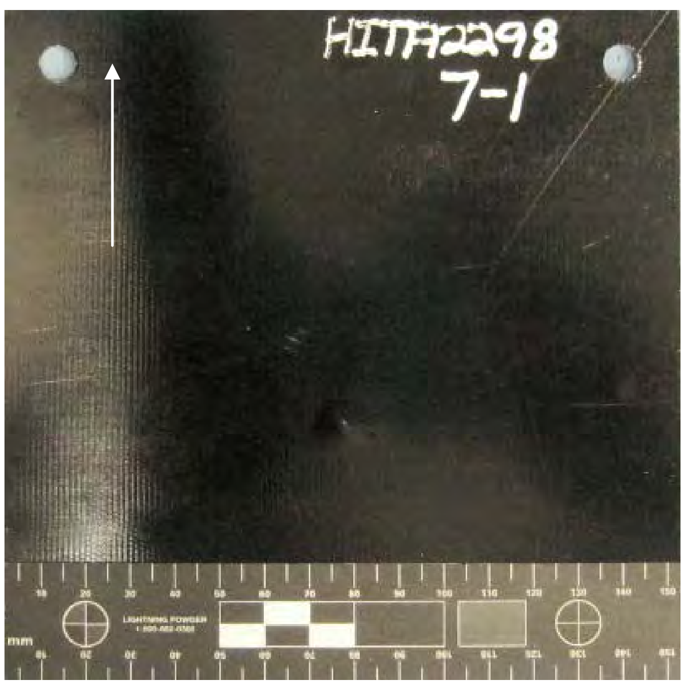


Figure 272 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12298 / Test #16 (continued)

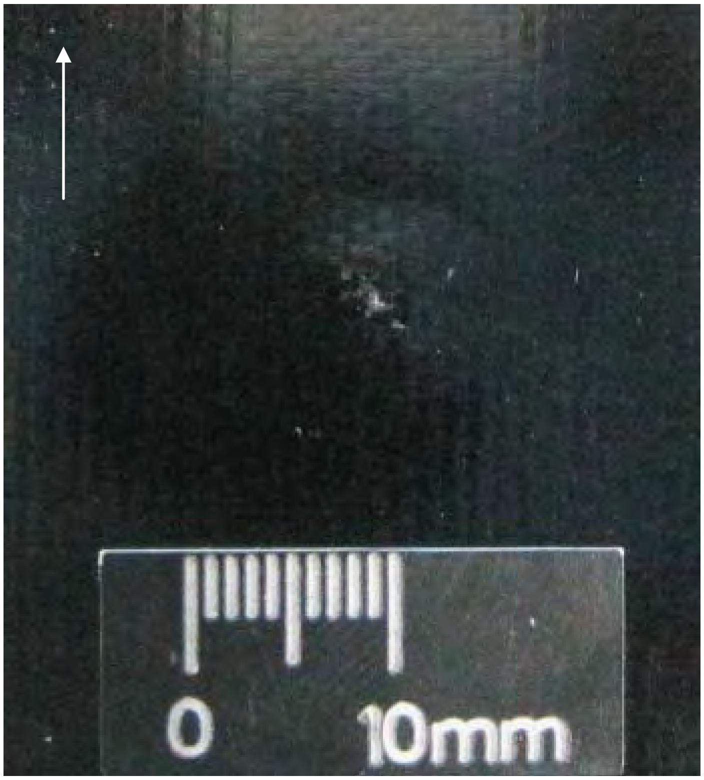


Figure 273 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

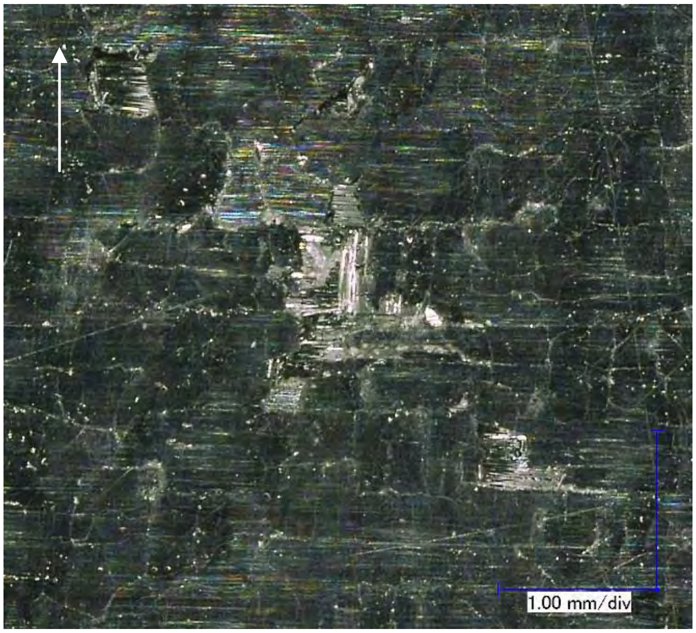


Figure 274 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (white arrow indicates flight path of projectile / damage within red circle in Figure 273)

HITF12298 / Test #16 (continued)

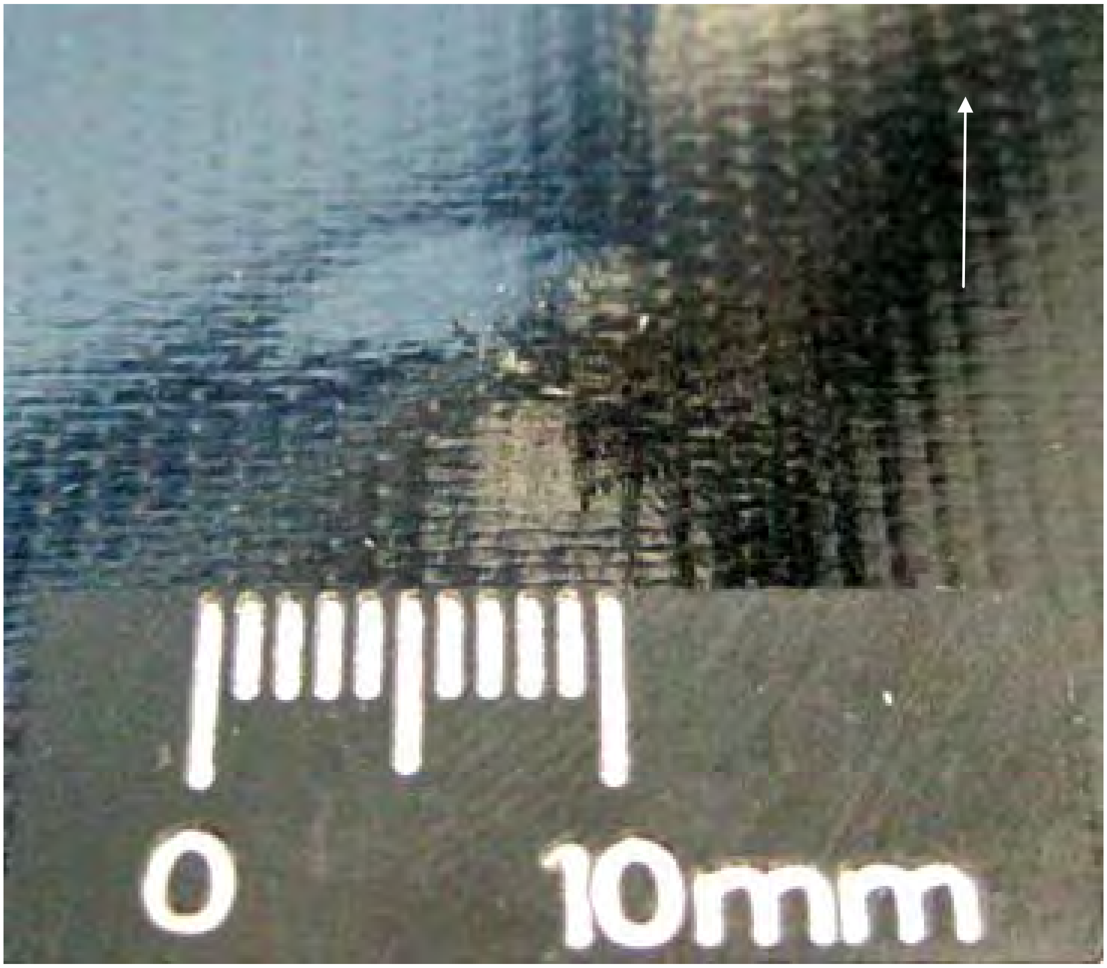


Figure 275 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

HITF12299 / Test #17

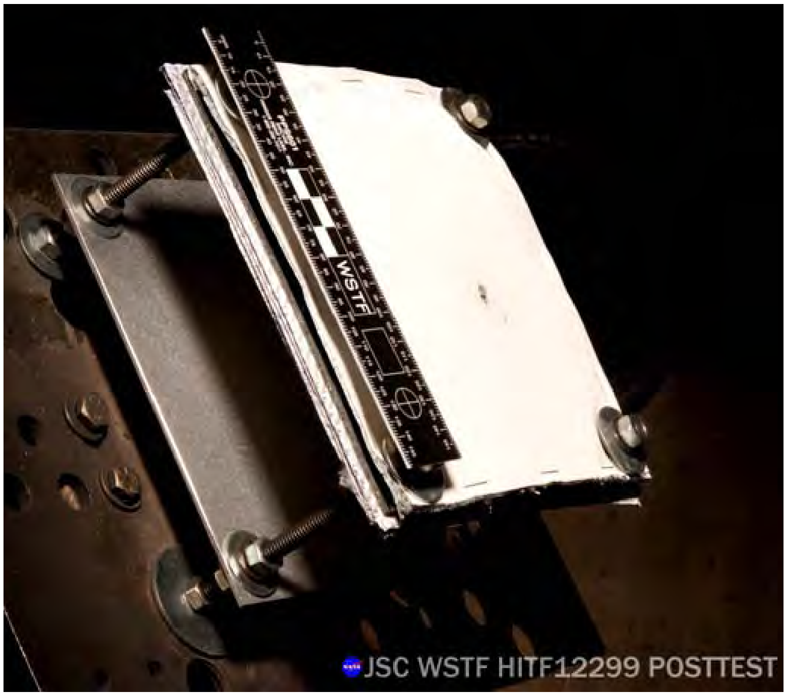


Figure 276 Overall View of Sample in the Target Tank (post-test)

Figure 277 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12299 / Test #17 (continued)

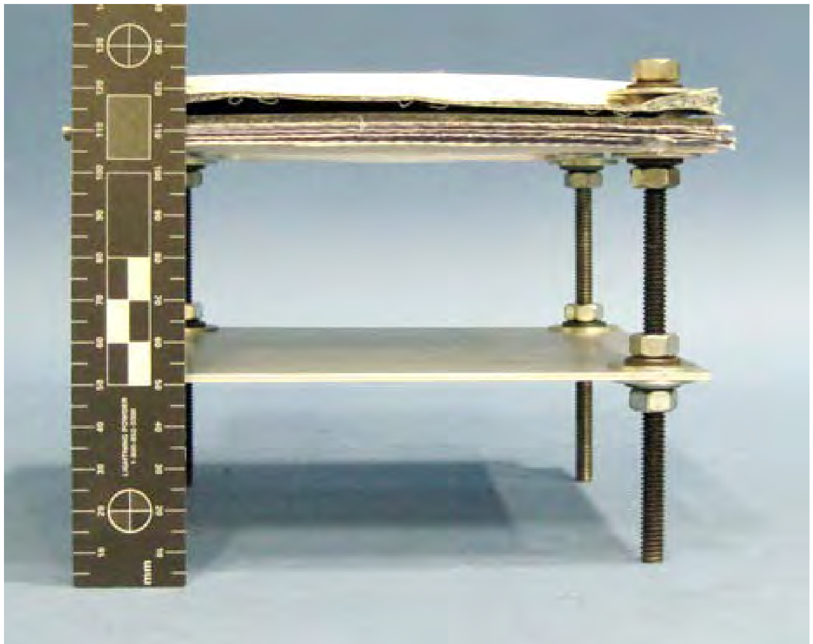


Figure 278 Overall Side View of Sample (scale in 5mm increments)

Figure 279 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12299 / Test #17 (continued)

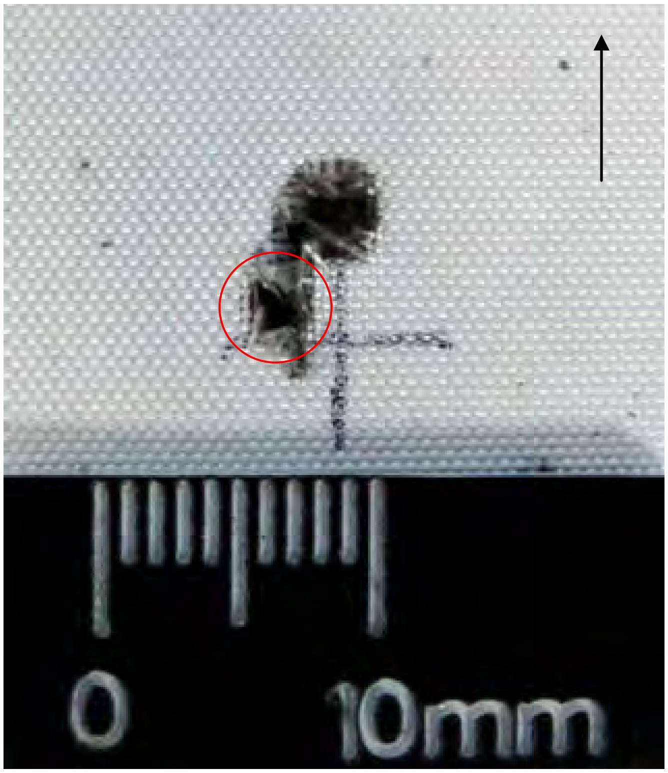


Figure 280 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile / projectile impacted within red circle)

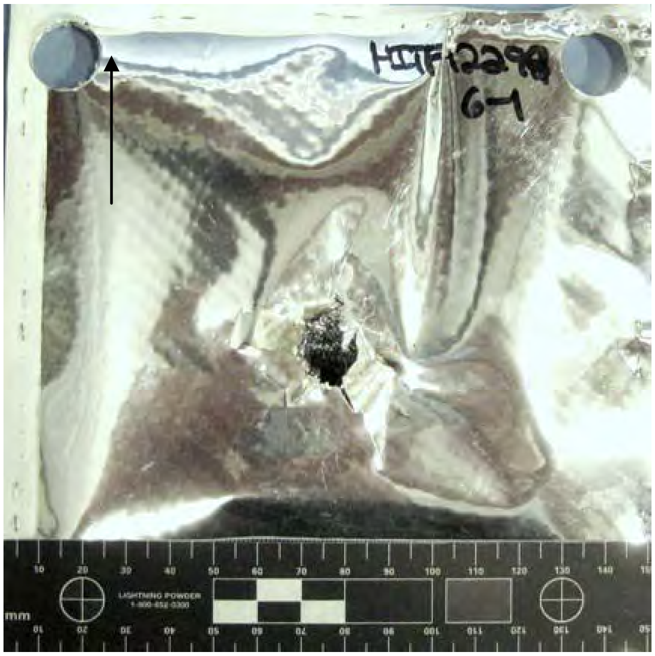


Figure 281 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12299 / Test #17 (continued)

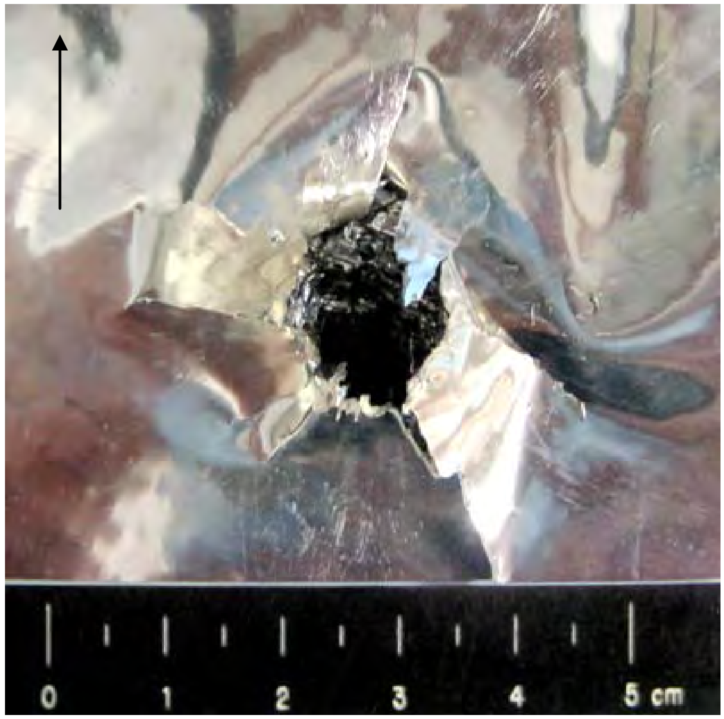


Figure 282 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

Figure 283 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12299 / Test #17 (continued)

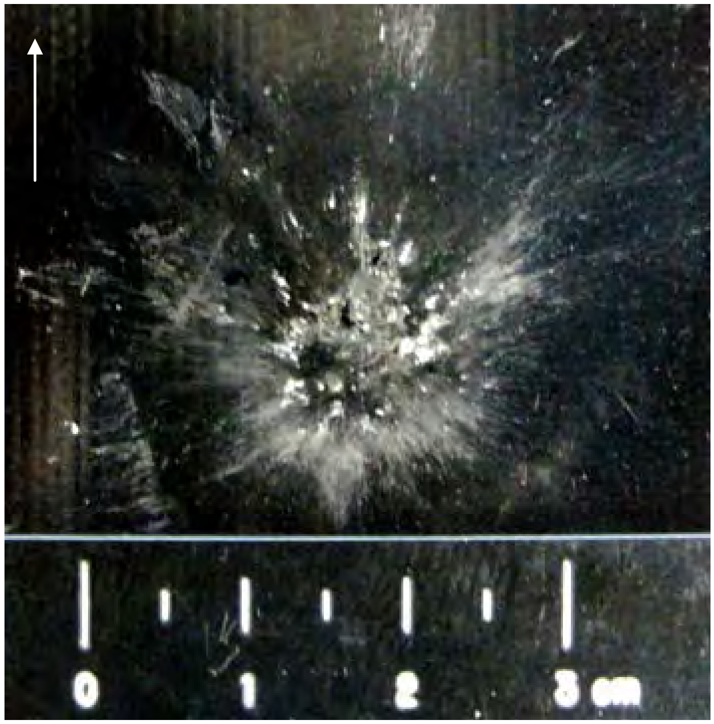


Figure 284 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

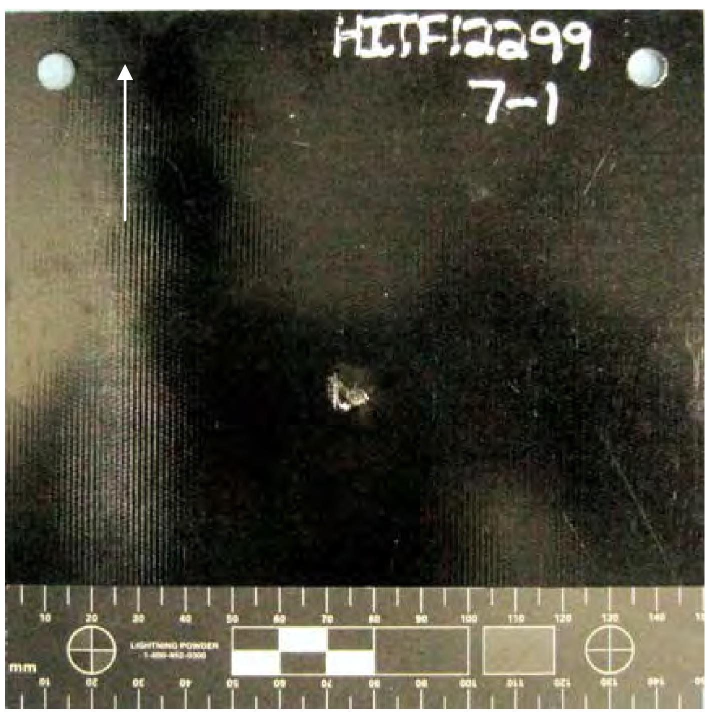


Figure 285 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12299 / Test #17 (continued)

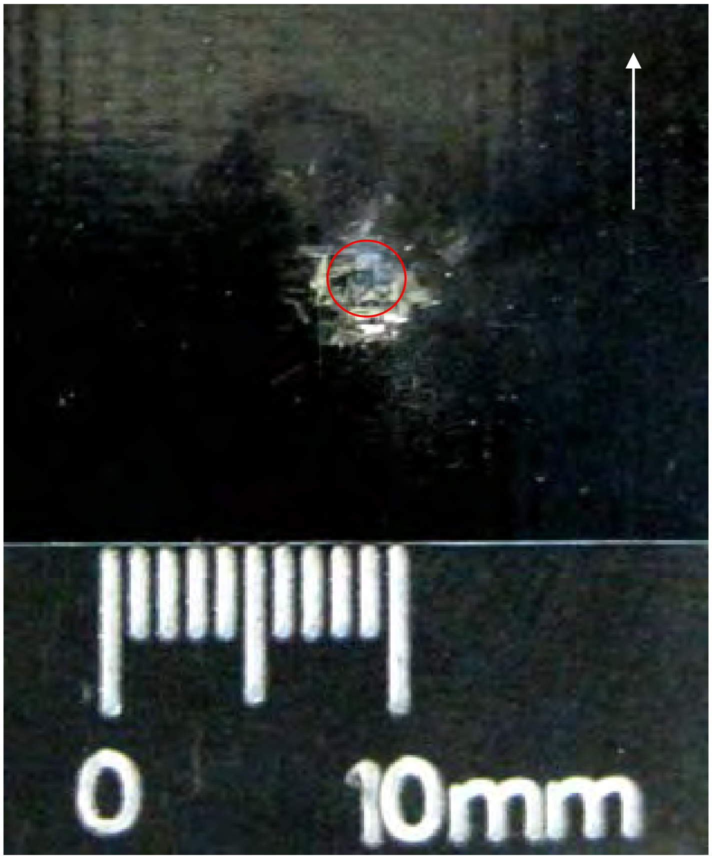


Figure 286 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

Figure 287 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 286)

HITF12299 / Test #17 (continued)

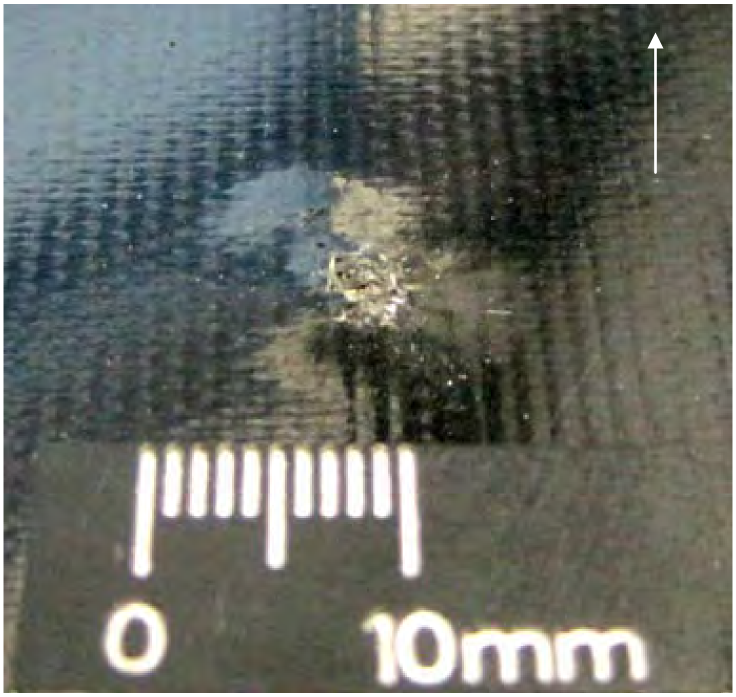


Figure 288 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

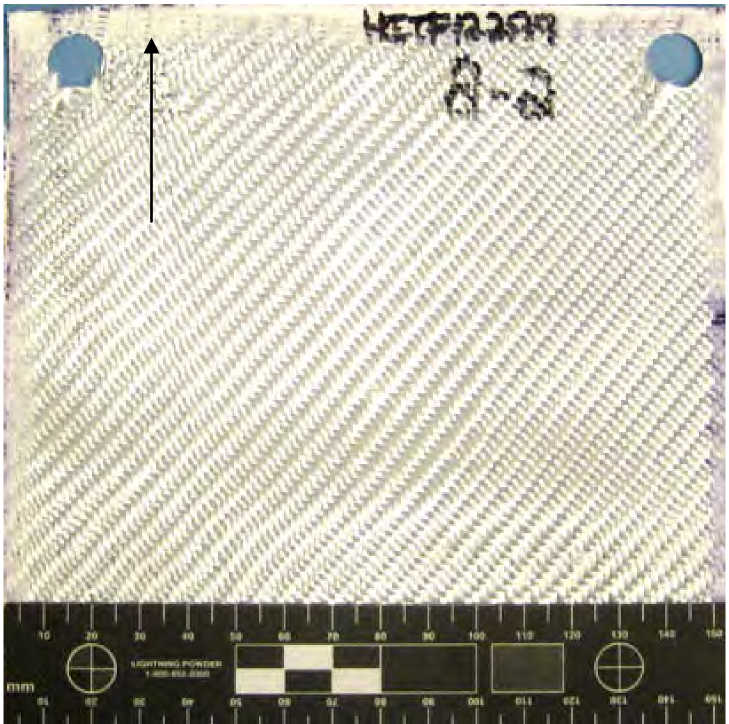


Figure 289 Overall View of Damage to Back Side of 2nd Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12299 / Test #17 (continued)

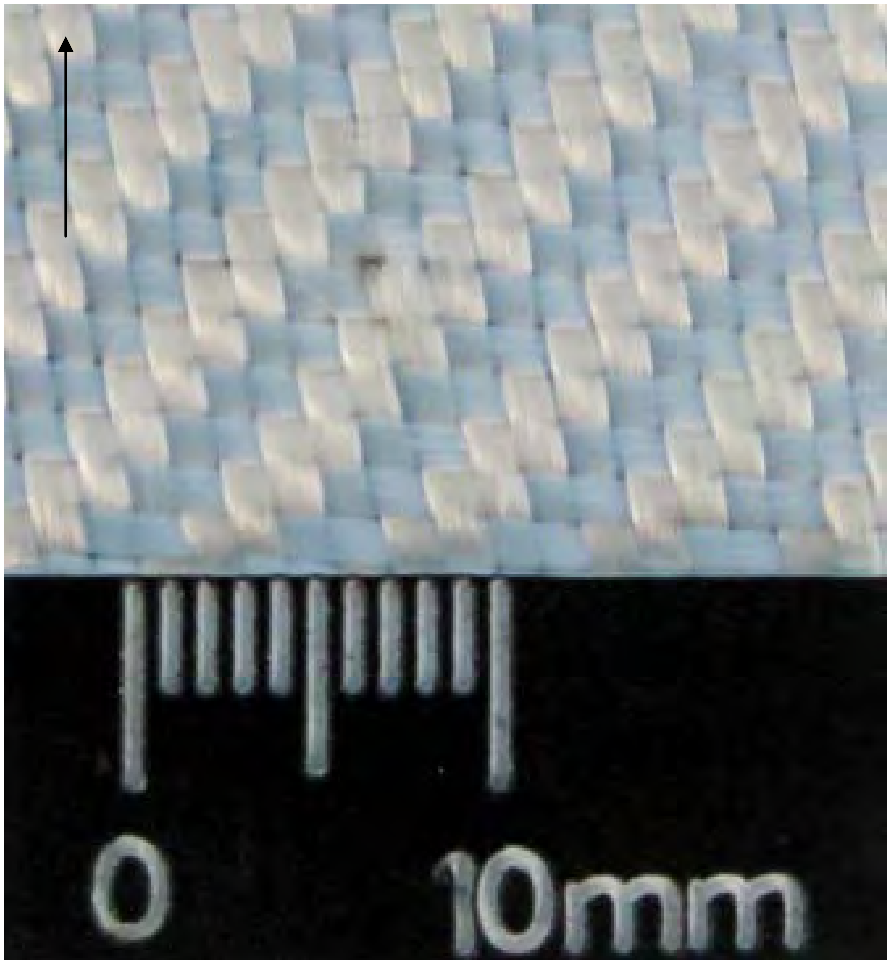


Figure 290 Close-up View of Damage to Back Side of 2nd Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12300 / Test #18

Figure 291 Overall View of Sample in the Target Tank (post-test)

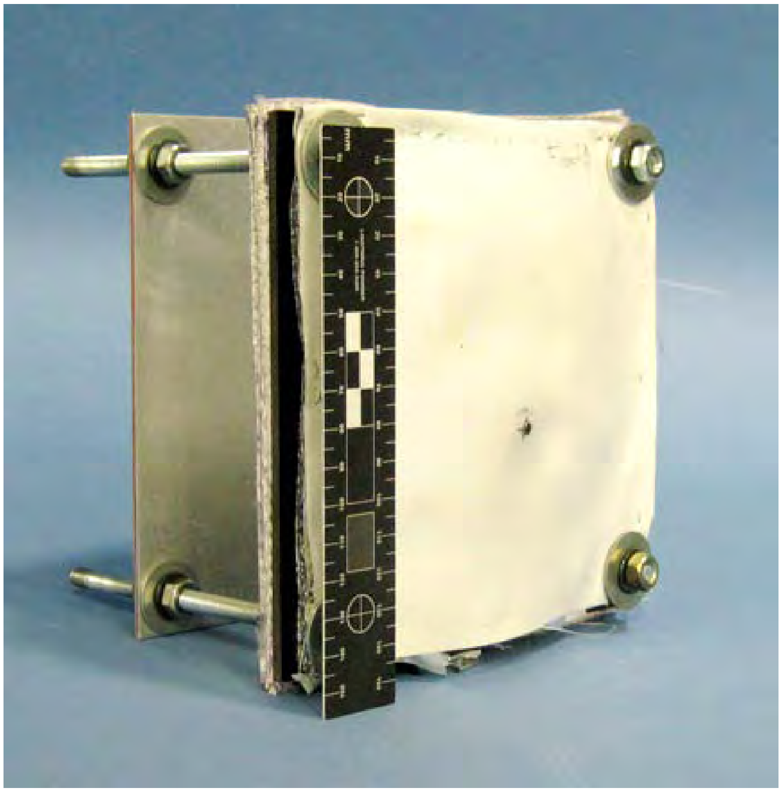


Figure 292 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12300 / Test #18 (continued)

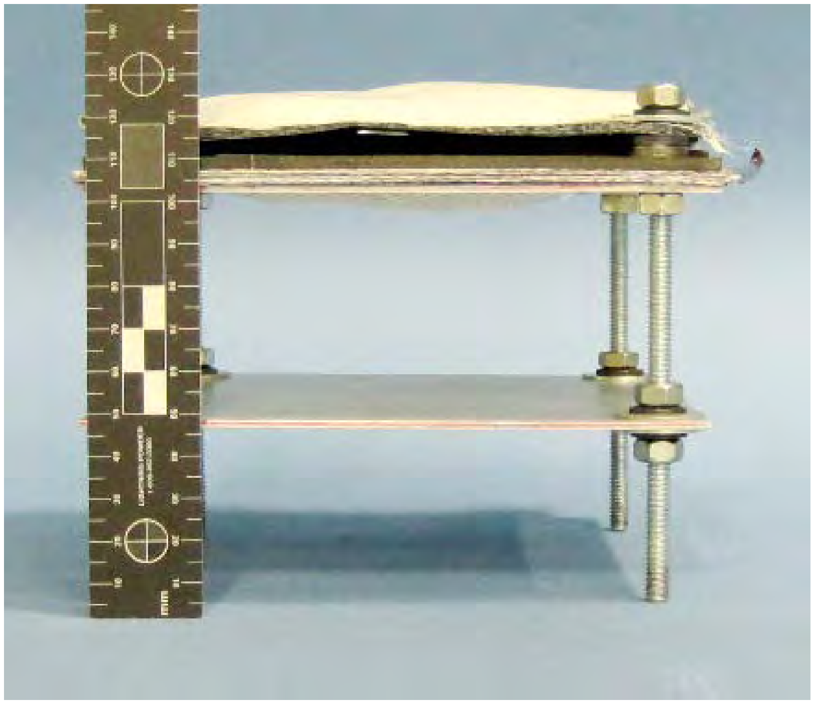


Figure 293 Overall Side View of Sample (scale in 5mm increments)

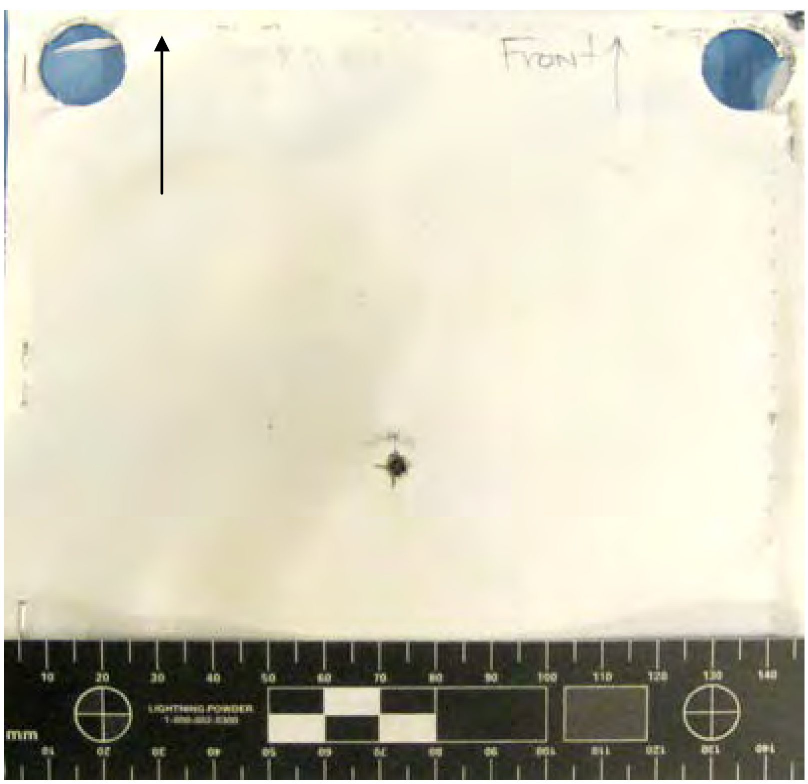


Figure 294 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12300 / Test #18 (continued)

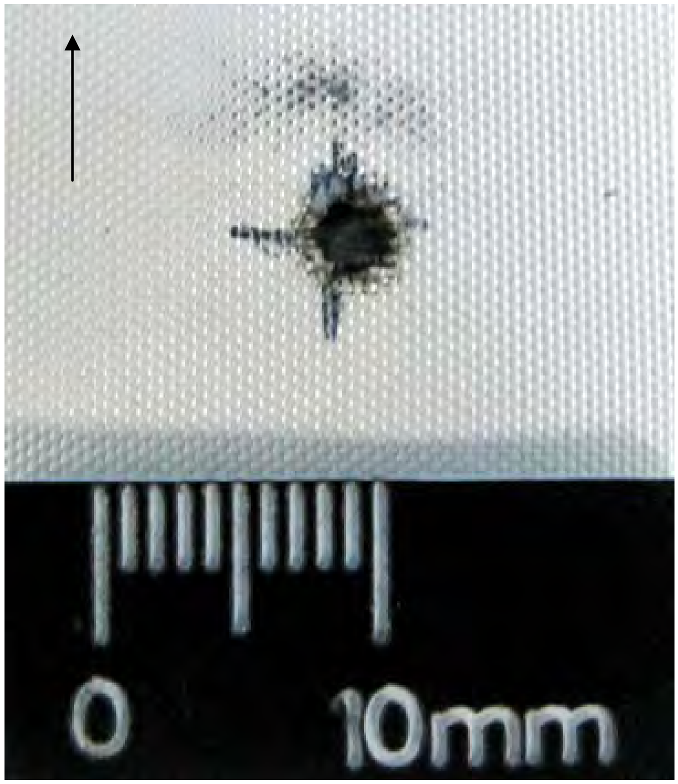


Figure 295 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

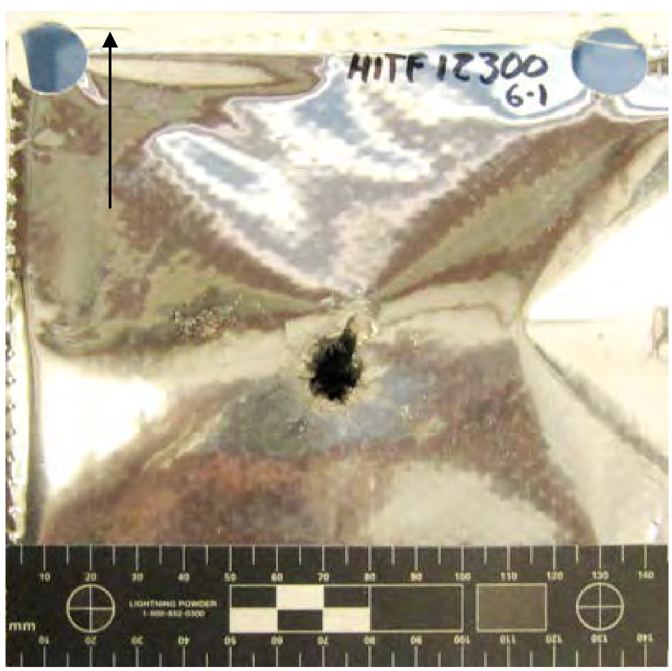


Figure 296 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12300 / Test #18 (continued)

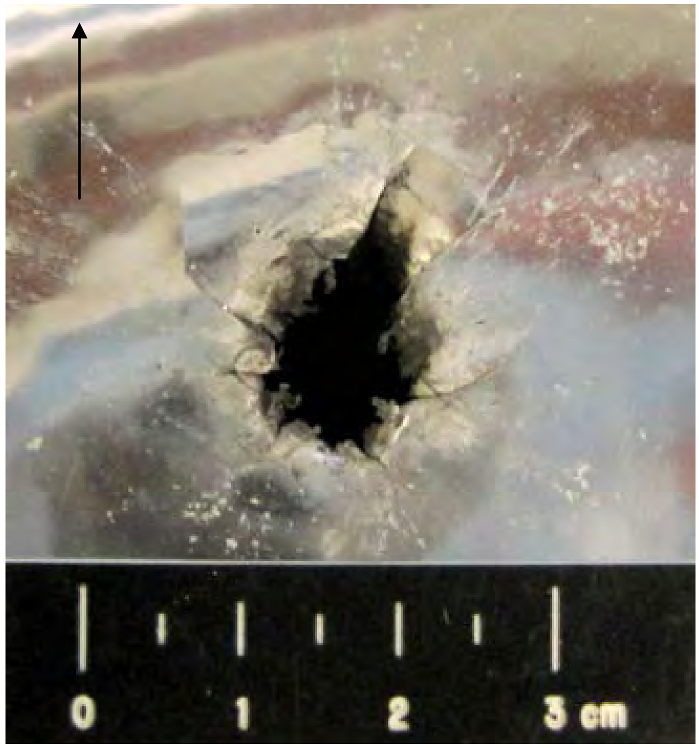


Figure 297 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

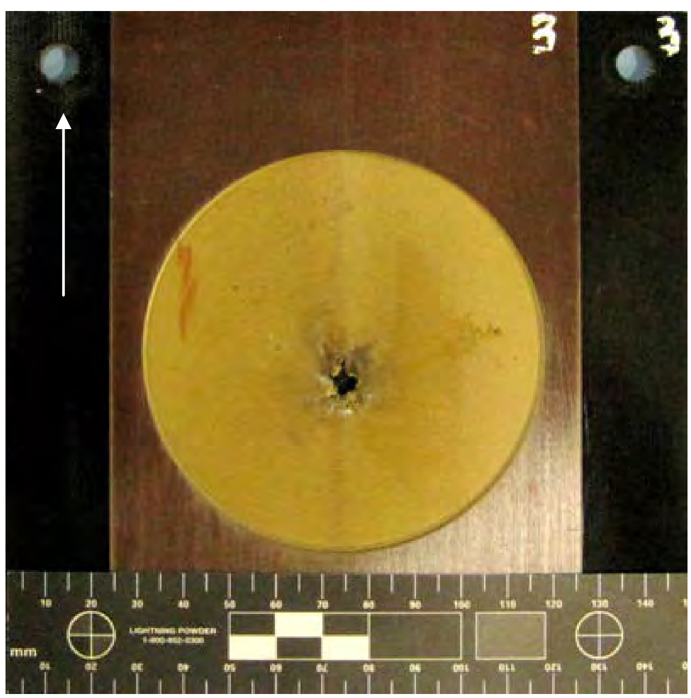


Figure 298 Overall View of Damage to Front of TORLON 5030 (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12300 / Test #18 (continued)

Figure 299 Close-up View of Damage to Front of TORLON 5030 (scale in 5mm increments / white arrow indicates flight path of projectile)

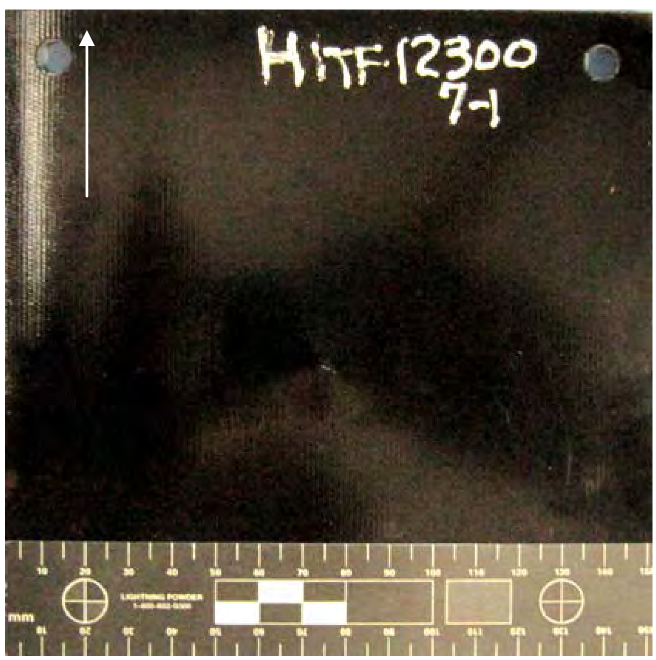


Figure 300 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12300 / Test #18 (continued)

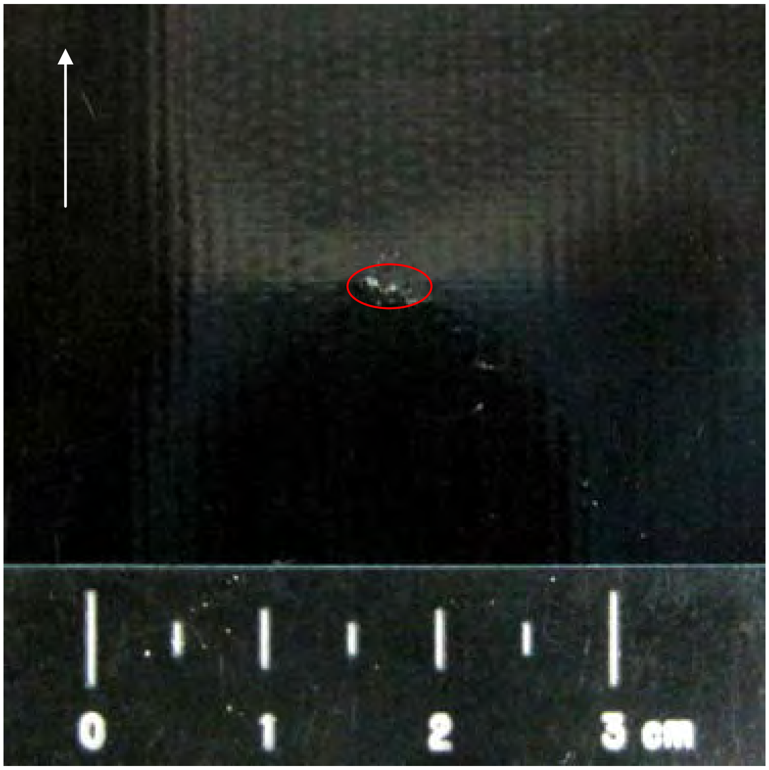


Figure 301 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

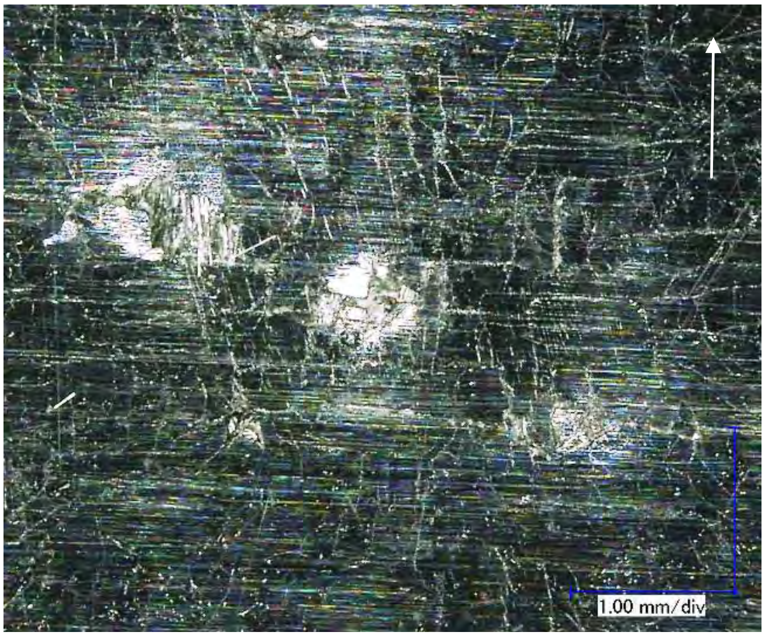


Figure 302 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (white arrow indicates flight path of projectile / damage within red circle in Figure 301)

HITF12300 / Test #18 (continued)

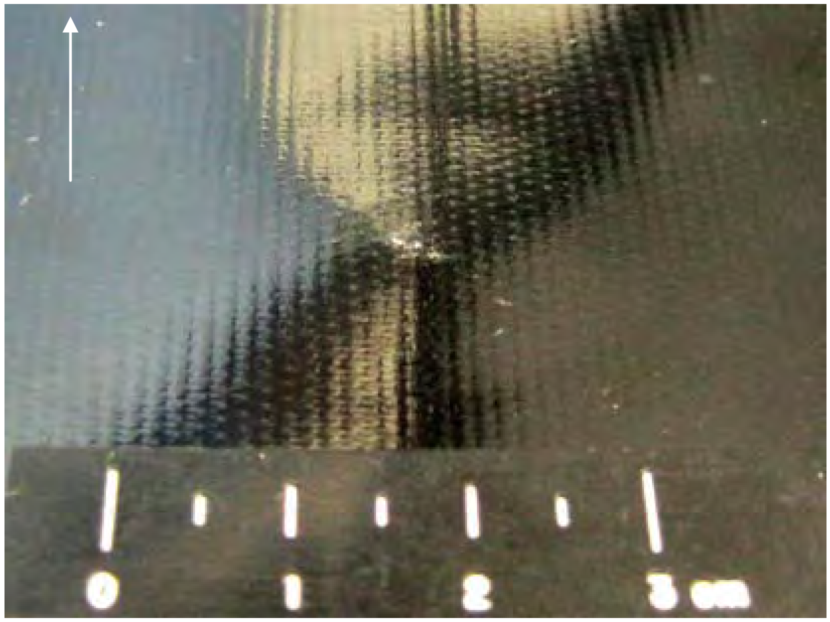


Figure 304 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

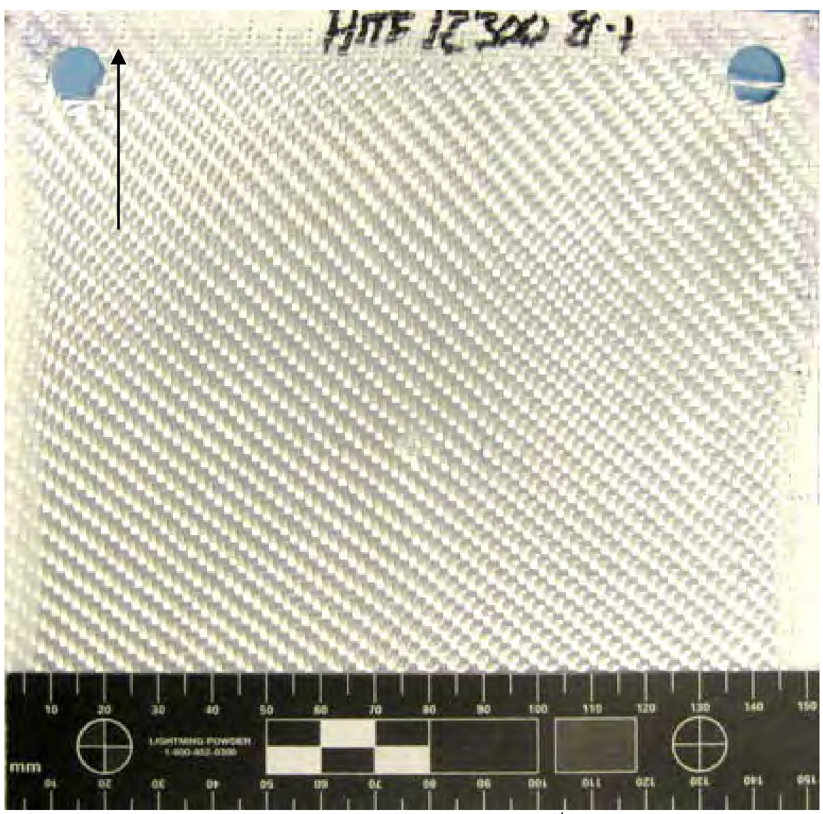


Figure 305 Overall View of Damage to Back Side of 1st Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12300 / Test #18 (continued)

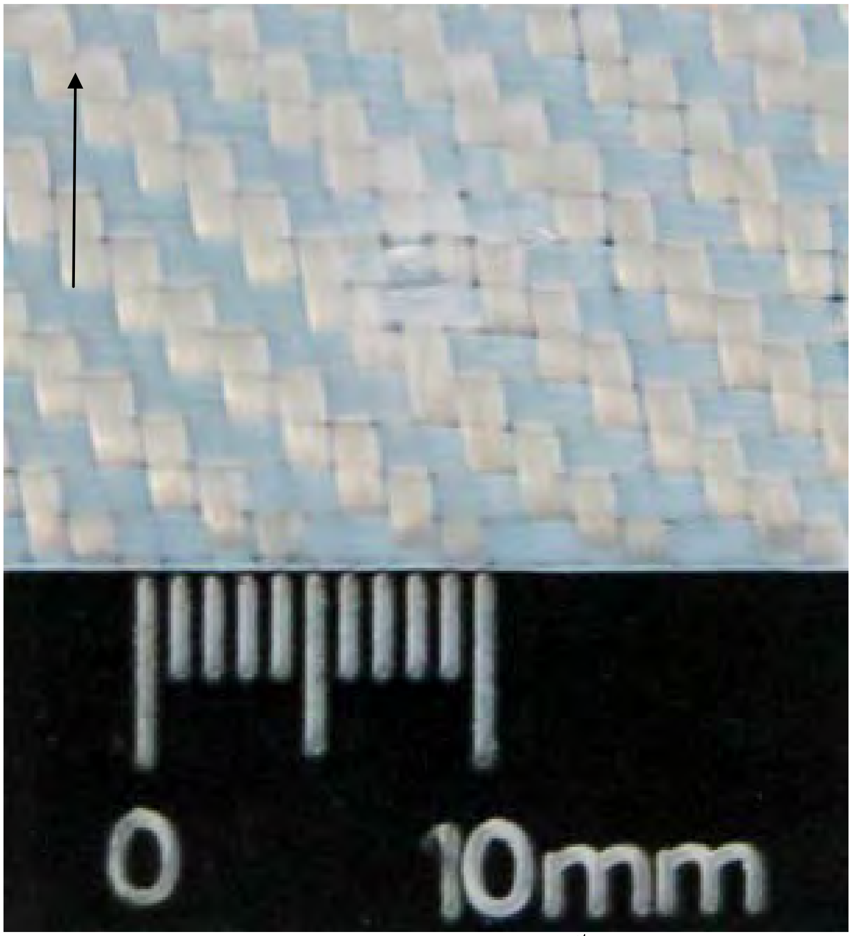


Figure 306 Close-up View of Damage to Back Side of 1st Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12301 / Test #19

Figure 307 Overall View of Sample in the Target Tank (post-test)

Figure 308 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12301 / Test #19 (continued)

Figure 309 Overall Side View of Sample (scale in 5mm increments)

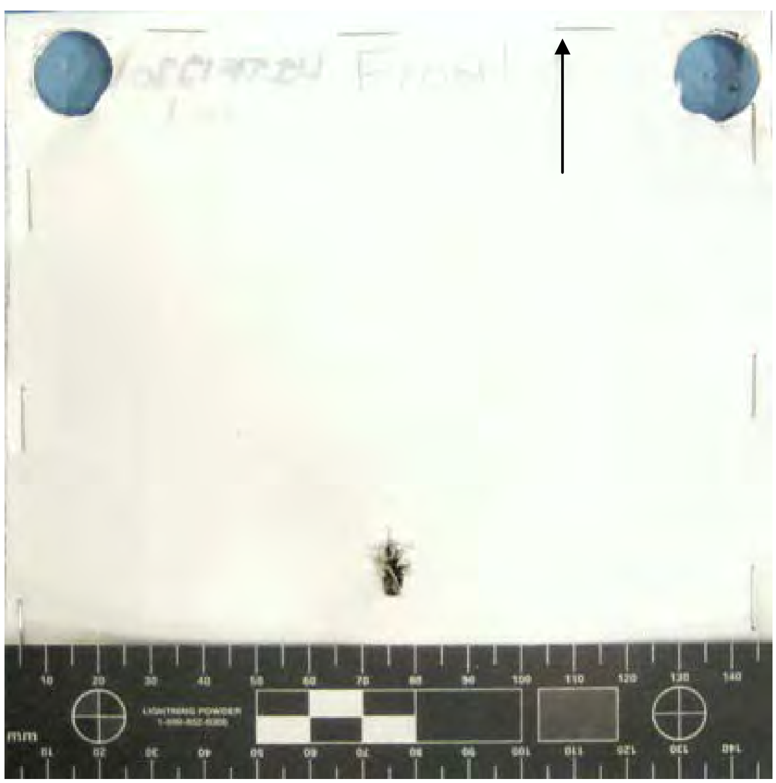


Figure 310 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12301 / Test #19 (continued)

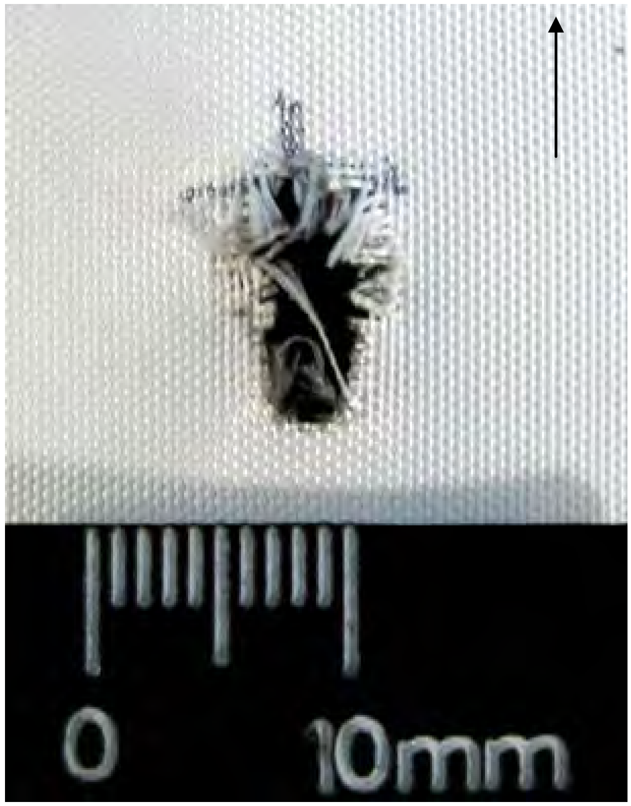


Figure 311 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

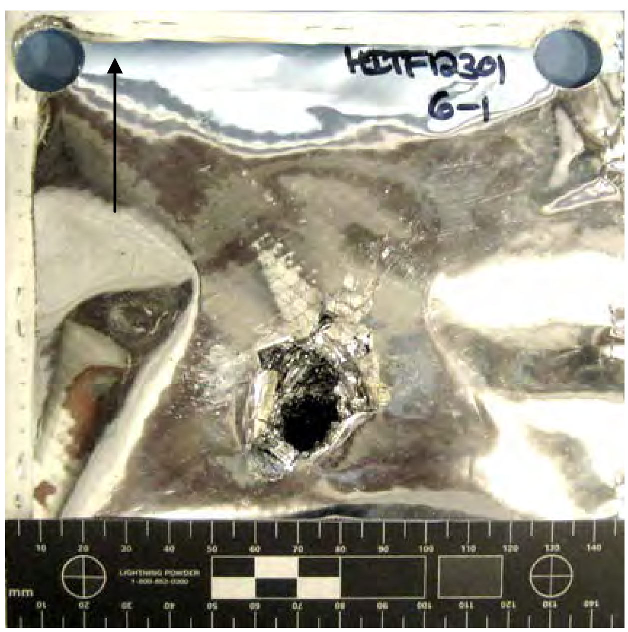


Figure 312 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12301 / Test #19 (continued)

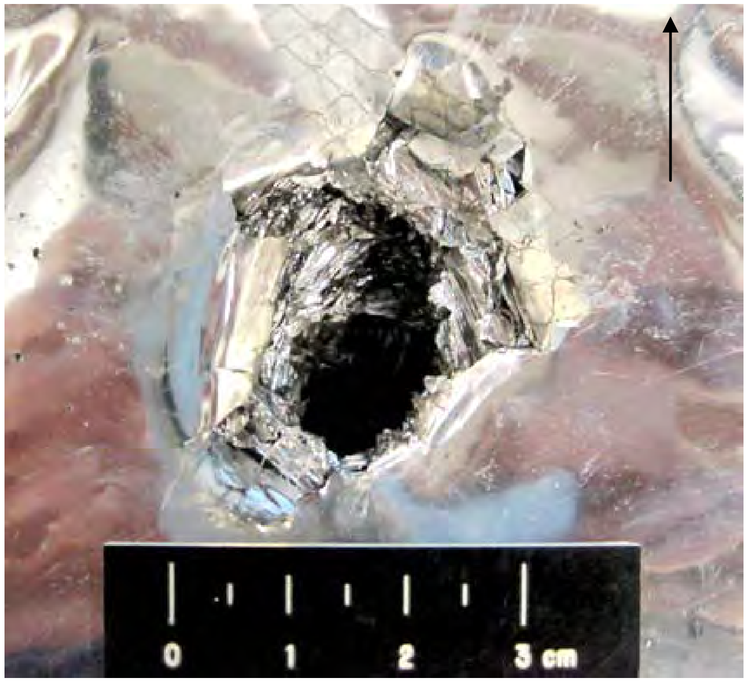


Figure 313 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

Figure 314 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12301 / Test #19 (continued)

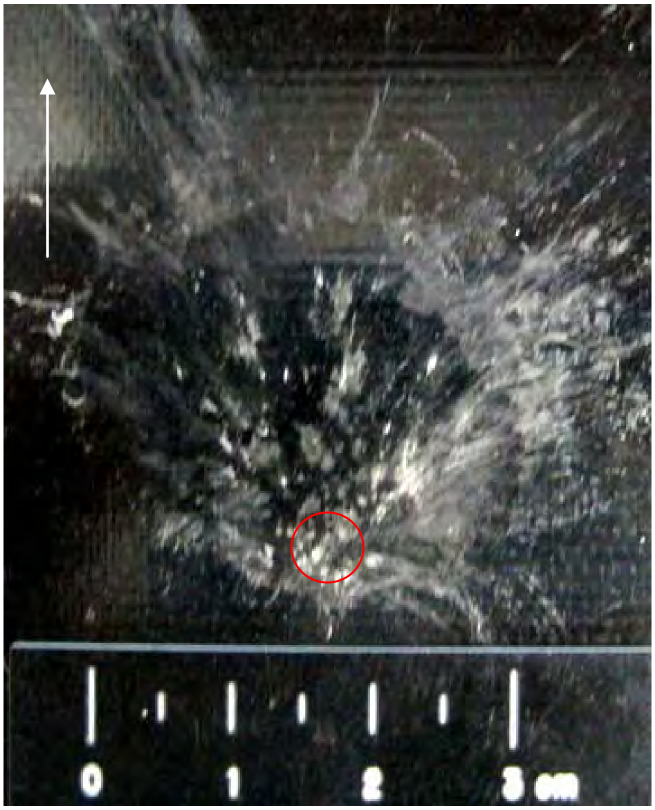


Figure 315 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

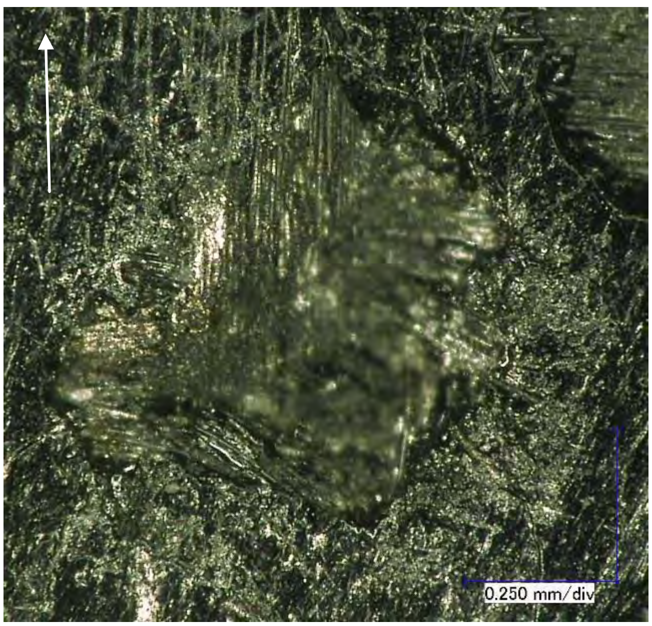


Figure 316 Close-up View of Damage to Front of NP 504 Substrate (white arrow indicates flight path of projectile / damage within red circle in Figure 128)

HITF12301 / Test #19 (continued)

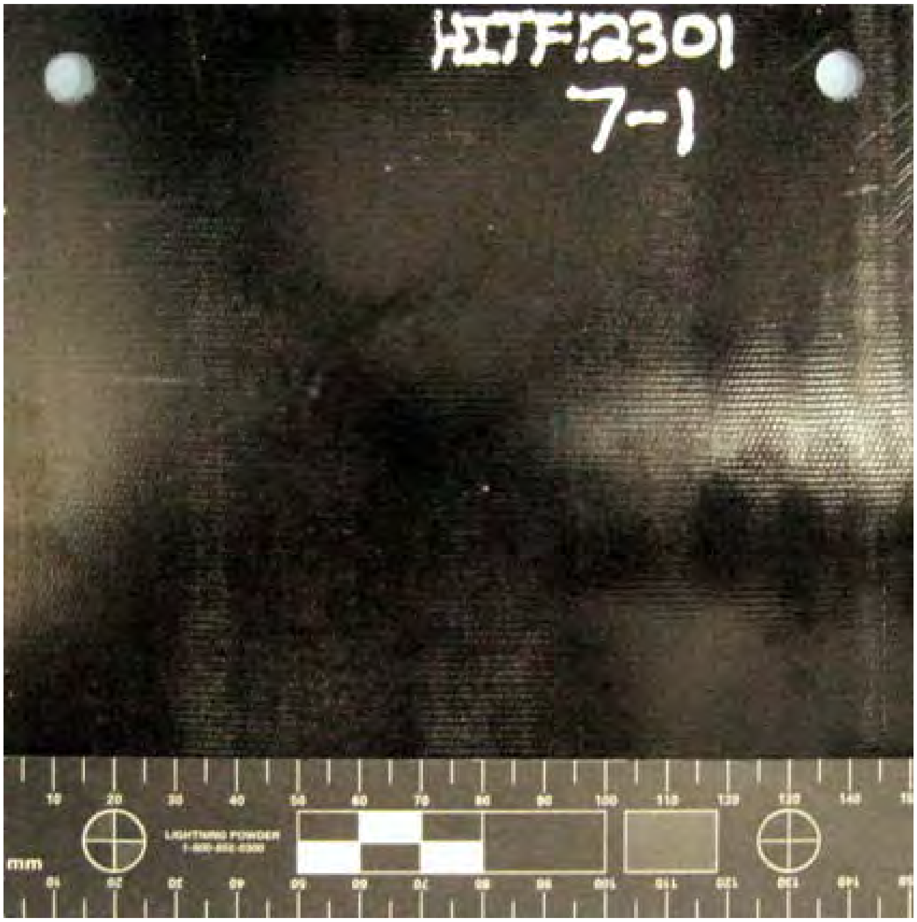


Figure 317 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12302 / Test #20

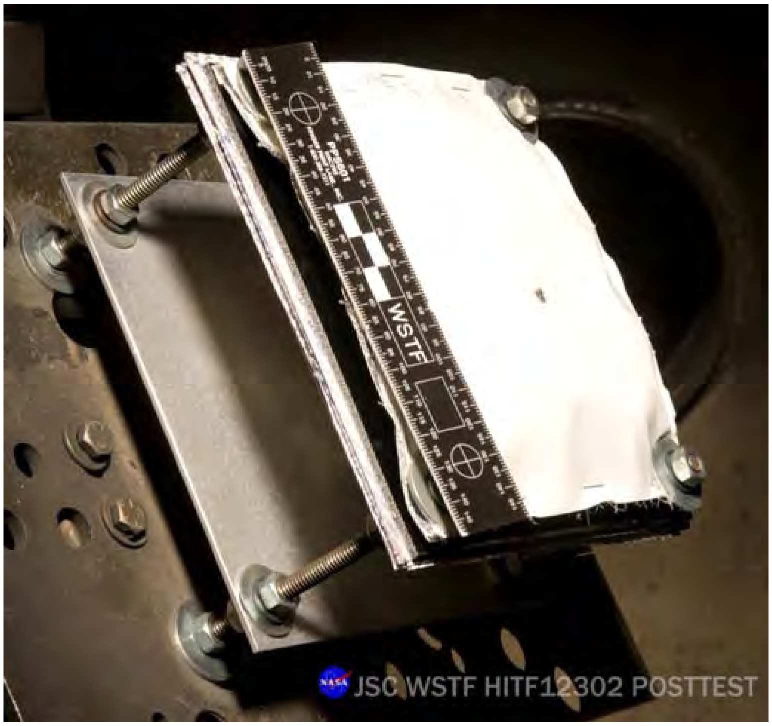


Figure 318 Overall View of Sample in the Target Tank (post-test)

Figure 319 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12302 / Test #20 (continued)

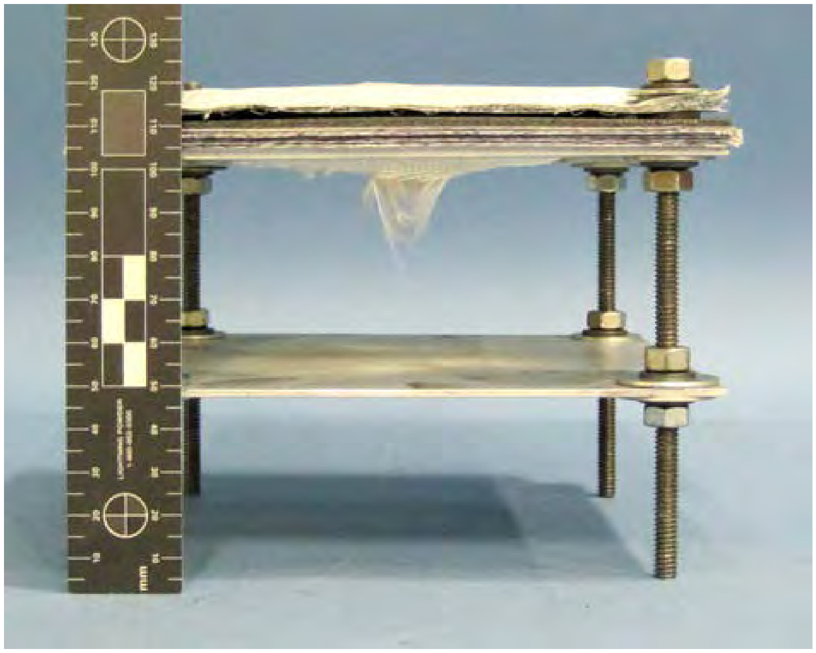


Figure 320 Overall Side View of Sample (scale in 5mm increments)

Figure 321 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12302 / Test #20 (continued)

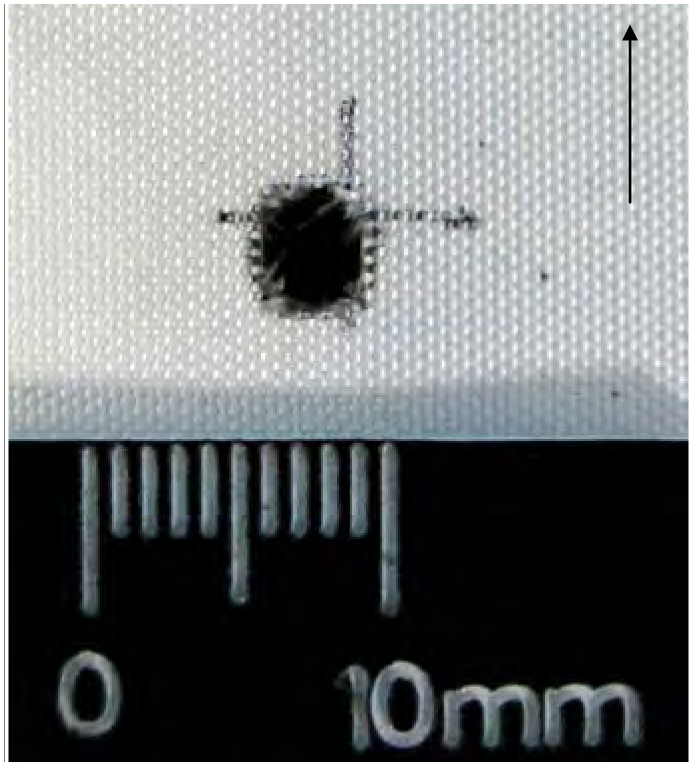


Figure 322 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

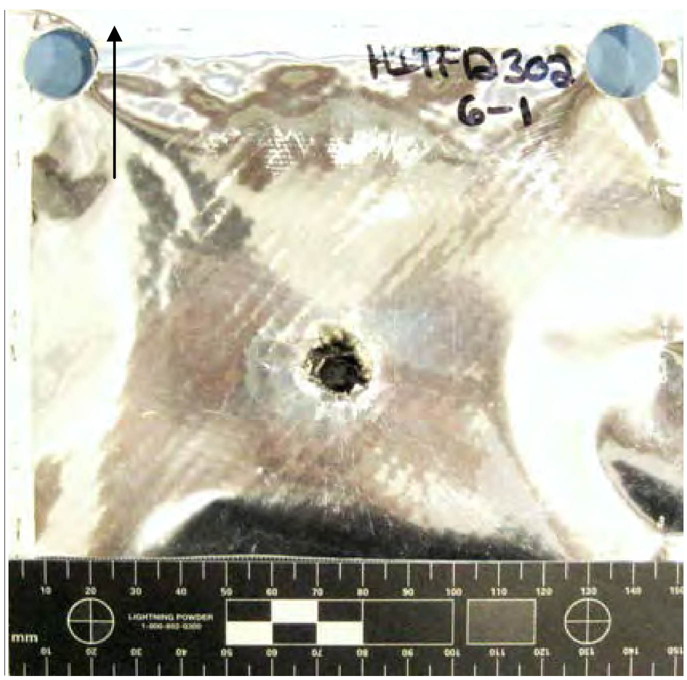


Figure 323 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12302 / Test #20 (continued)

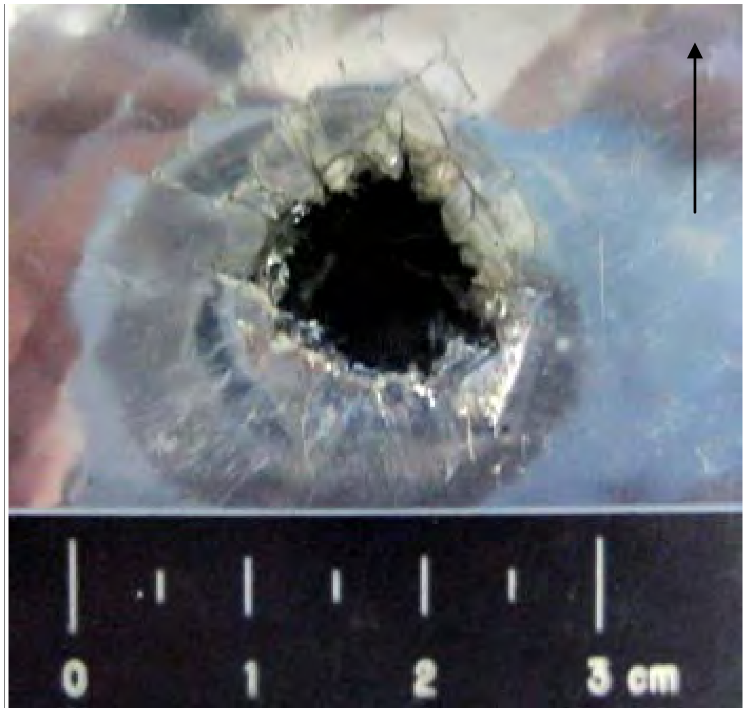


Figure 324 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

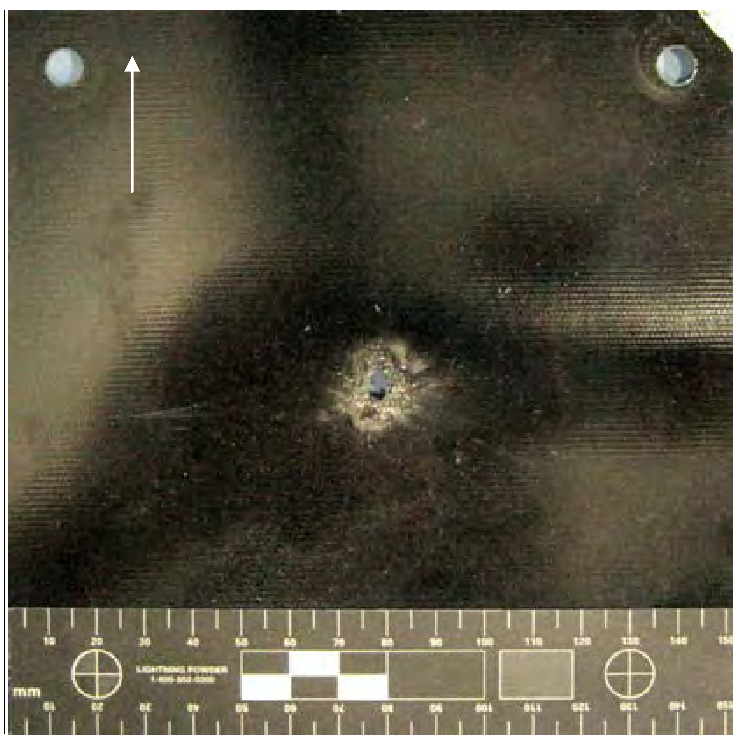


Figure 325 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12302 / Test #20 (continued)

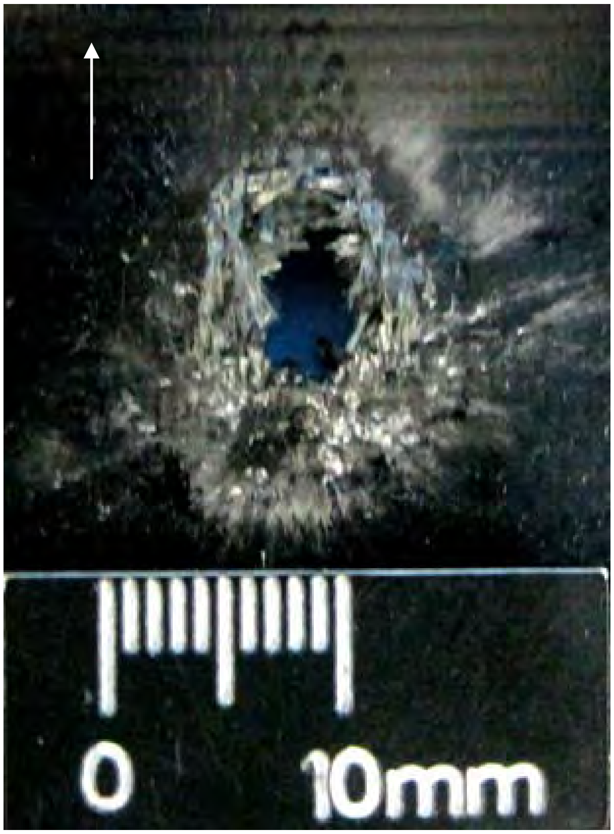


Figure 326 Close-up View of Damage to Front of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

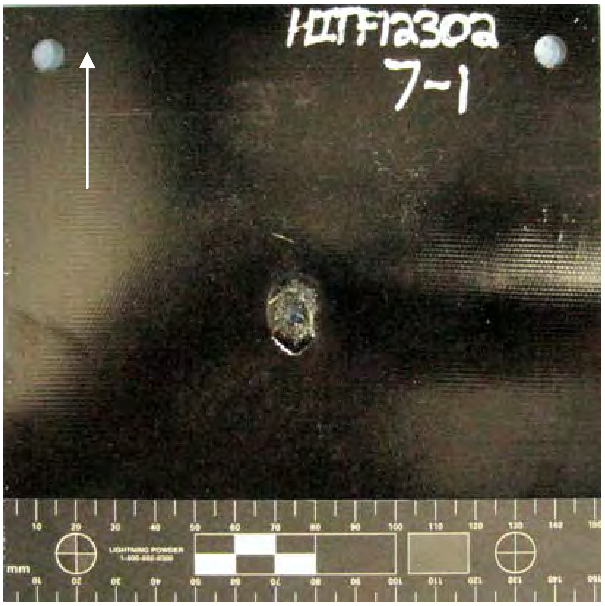


Figure 327 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12302 / Test #20 (continued)

Figure 328 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

Figure 329 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

HITF12302 / Test #20 (continued)

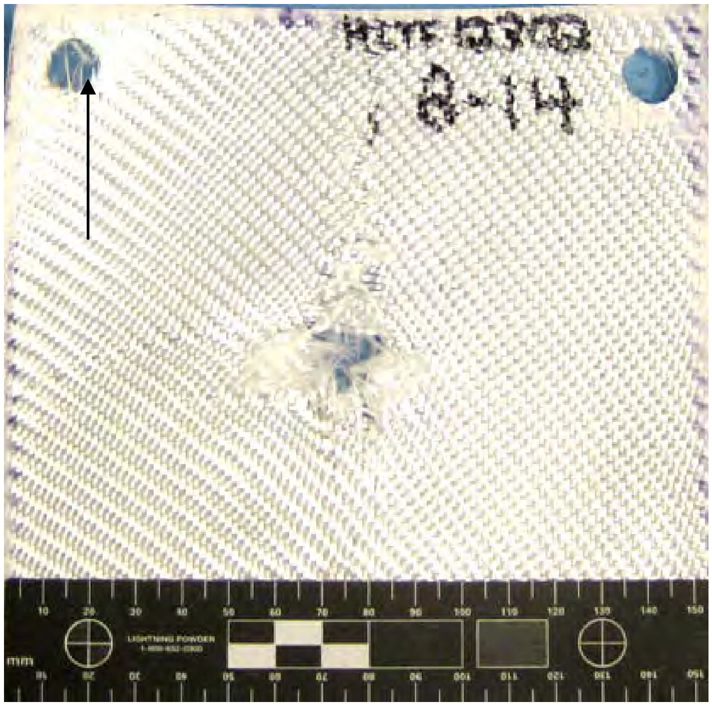


Figure 330 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

Figure 331 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12302 / Test #20 (continued)

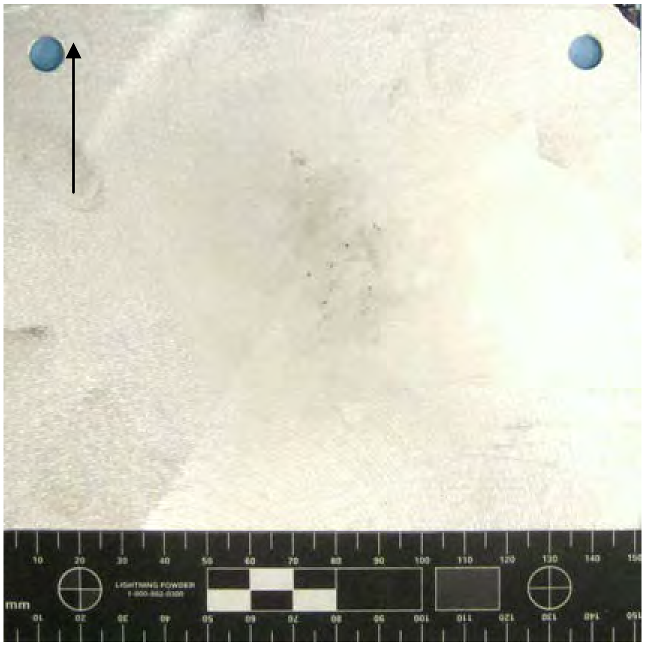


Figure 332 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

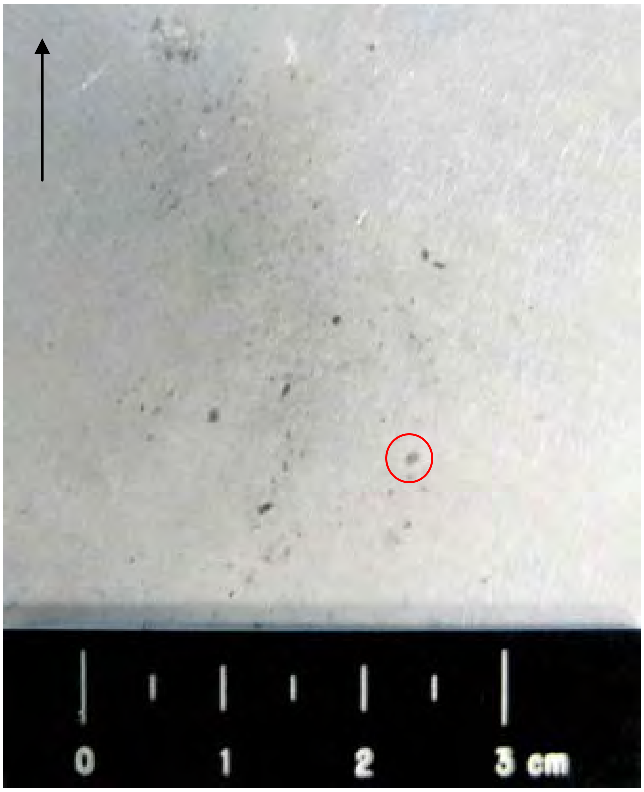


Figure 333 Close-up View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12302 / Test #20 (continued)

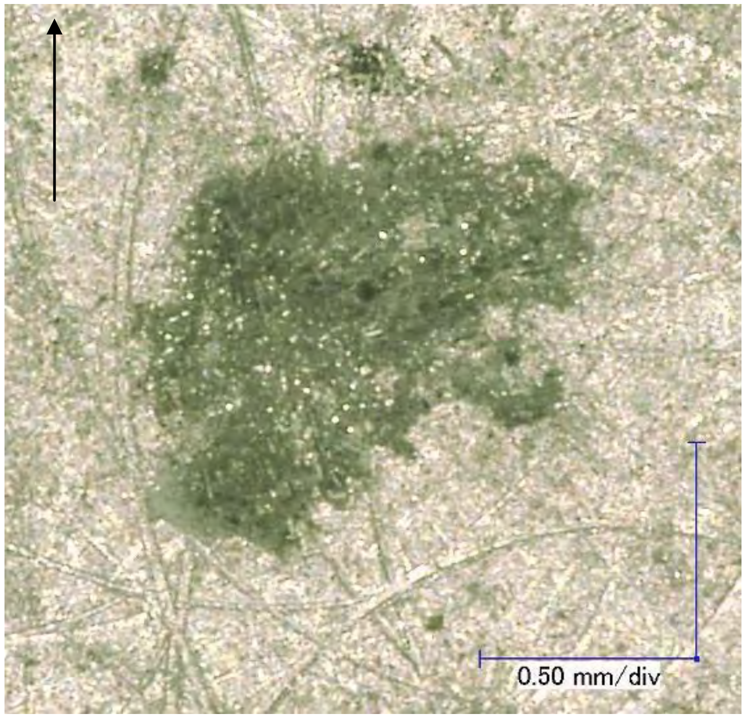


Figure 334 Close-up View of Most Significant Damage to Front of Rear Wall (black arrow indicates flight path of projectile / damage within red circle in Figure 333)

Figure 335 Overall View of Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12303 / Test #21

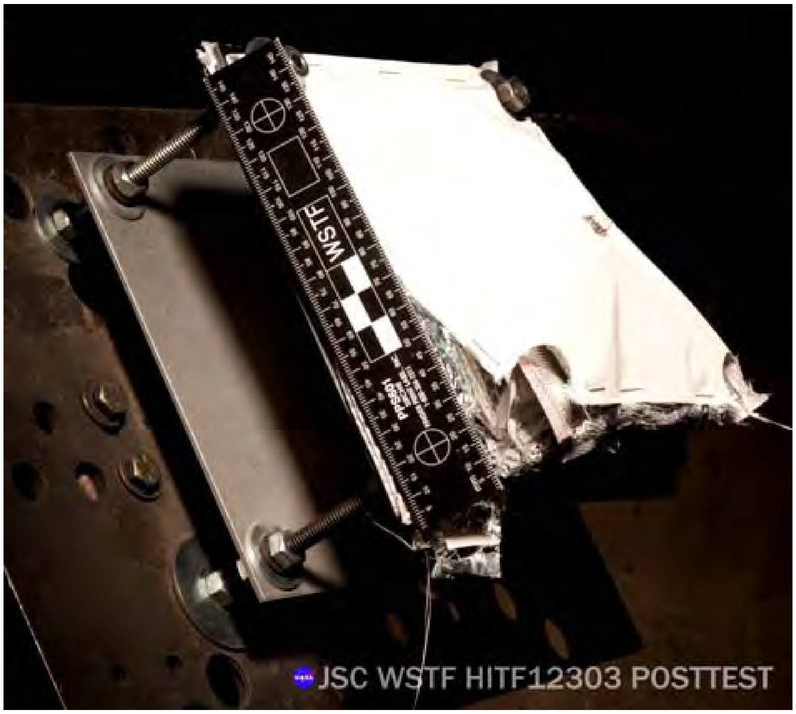


Figure 336 Overall View of Sample in the Target Tank (post-test)

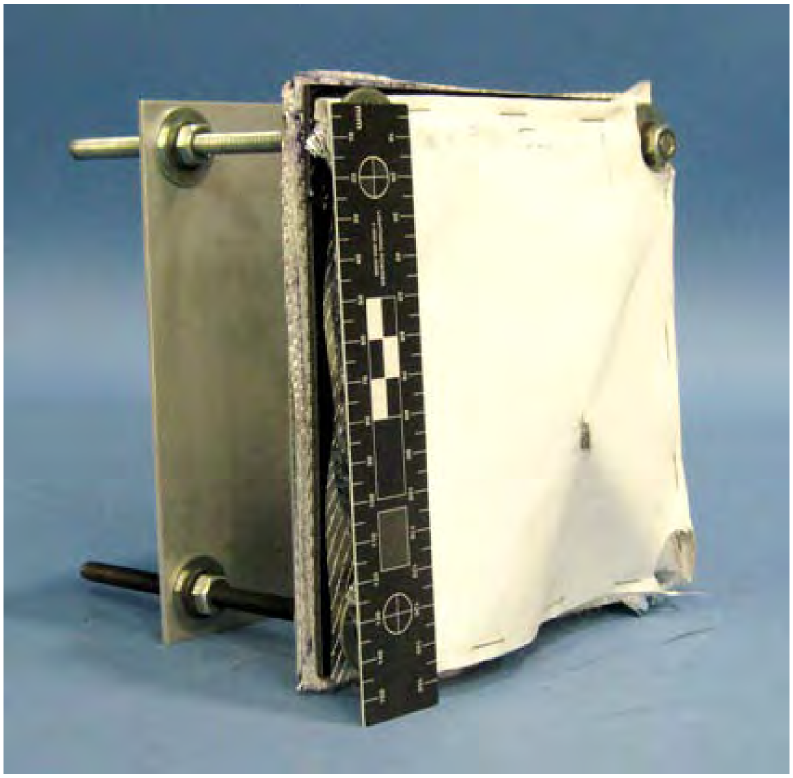


Figure 337 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12303 / Test #21 (continued)

Figure 338 Overall Side View of Sample (scale in 5mm increments)

Figure 339 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12303 / Test #21 (continued)

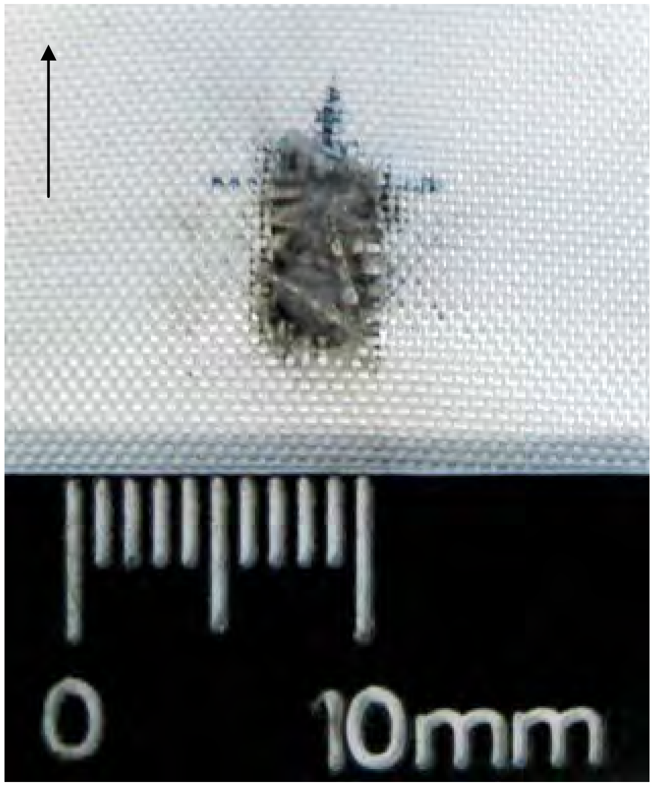


Figure 340 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

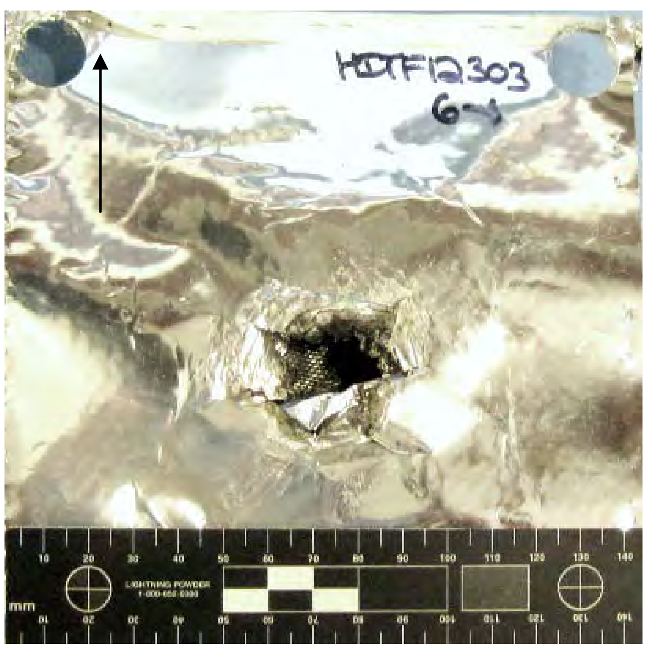


Figure 341 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12303 / Test #21 (continued)

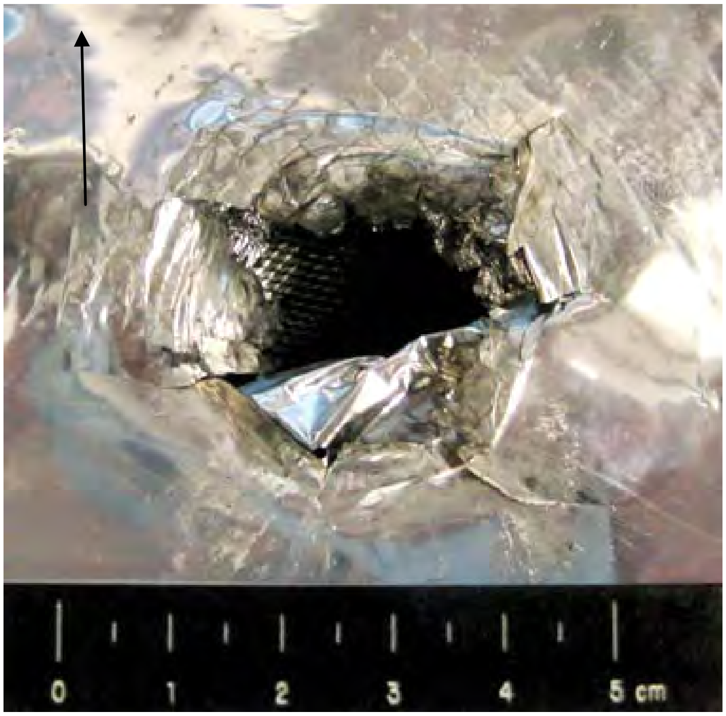


Figure 342 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

Figure 343 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12303 / Test #21 (continued)

Figure 344 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

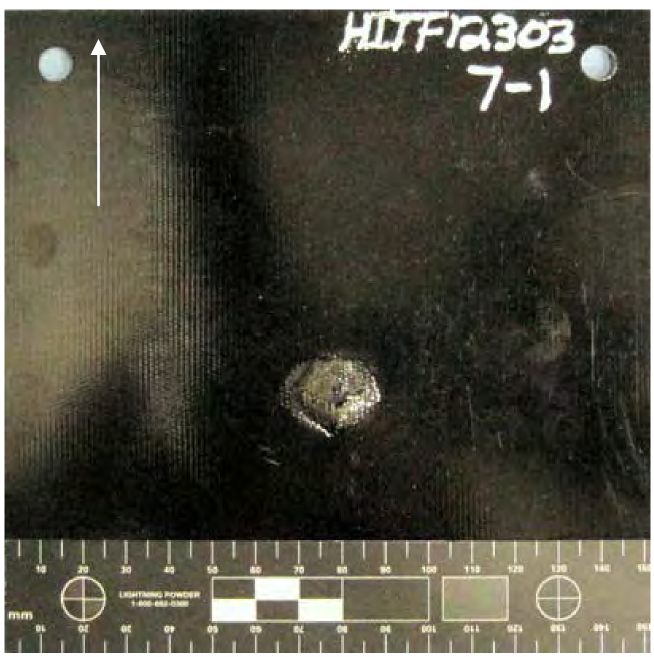


Figure 345 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12303 / Test #21 (continued)

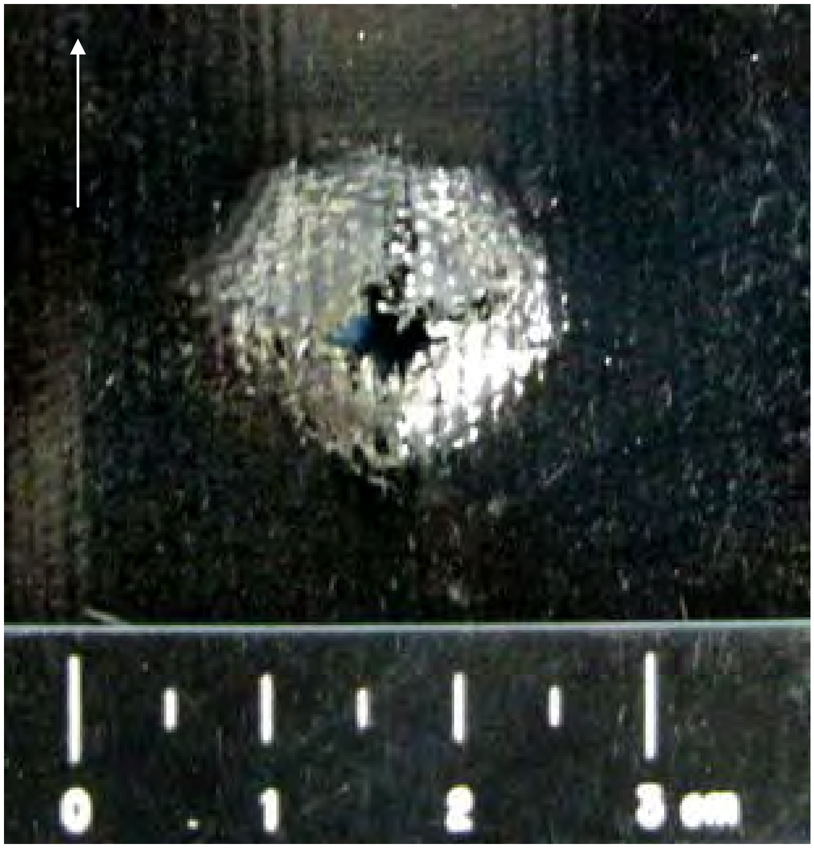


Figure 346 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

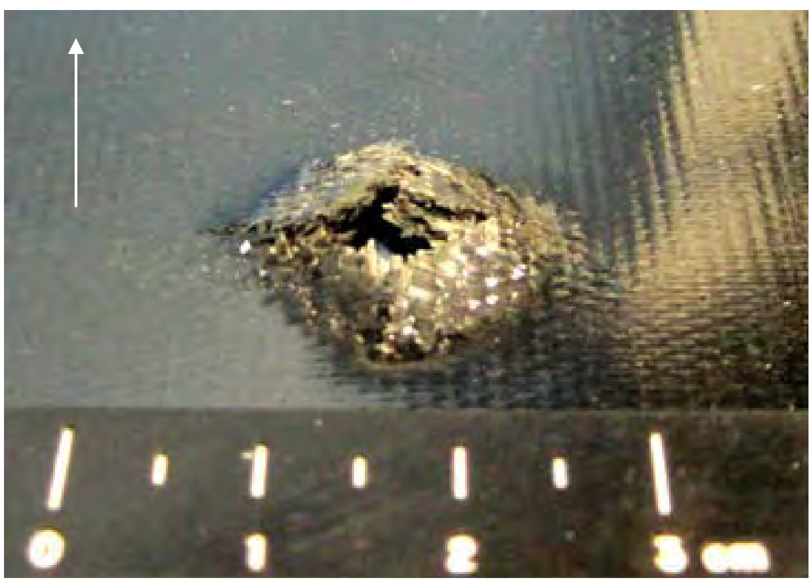


Figure 347 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12303 / Test #21 (continued)

Figure 348 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

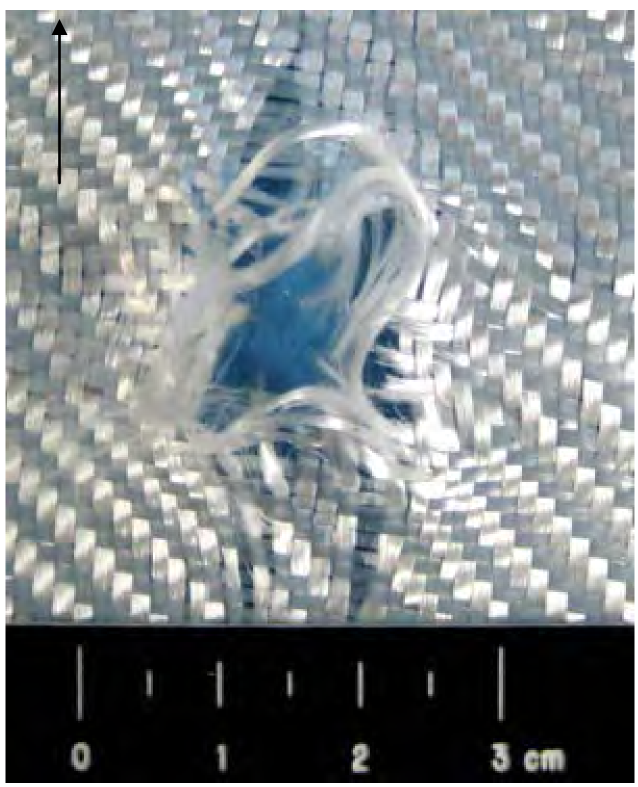


Figure 349 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12303 / Test #21 (continued)

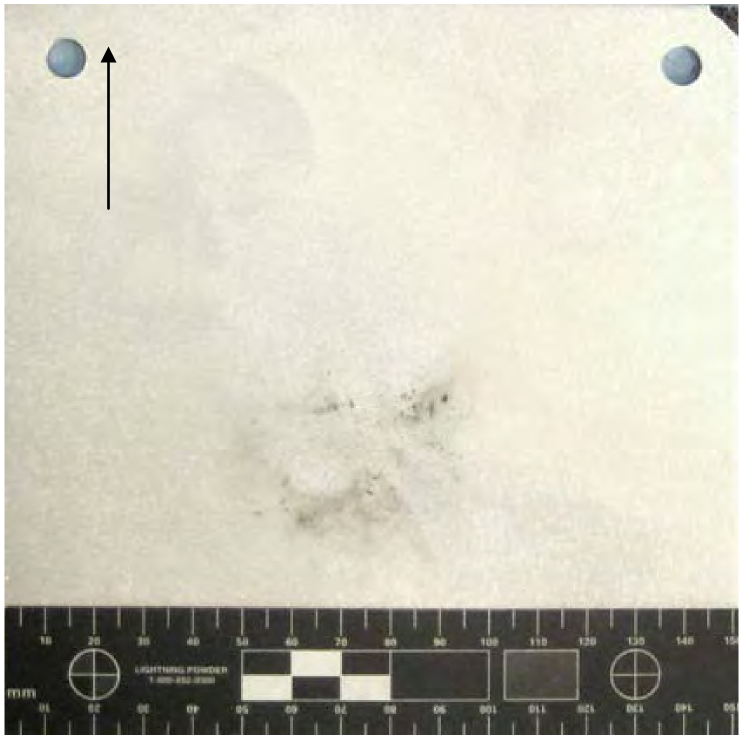


Figure 350 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

Figure 351 Close-up View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12303 / Test #21 (continued)

Figure 352 Close-up View of Most Significant Damage to Front of Rear Wall (black arrow indicates flight path of projectile / damage within red circle in Figure 351)

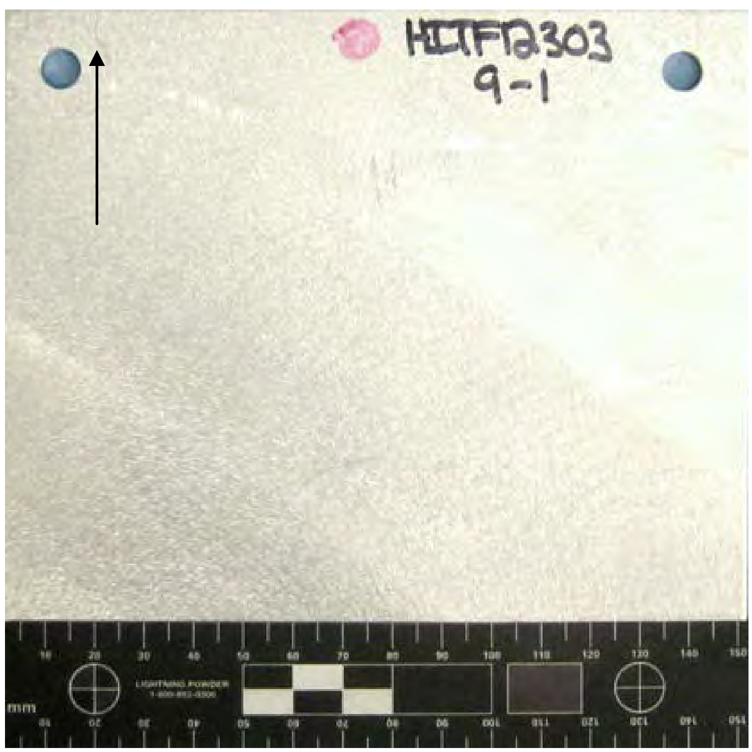


Figure 353 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12304 / Test #22

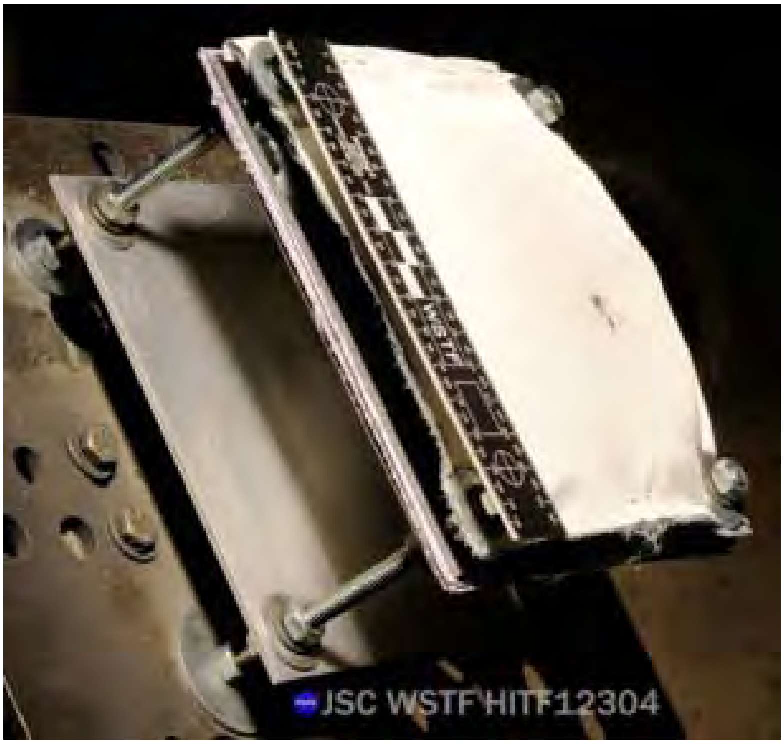


Figure 354 Overall View of Sample in the Target Tank (post-test)

Figure 355 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12304 / Test #22 (continued)

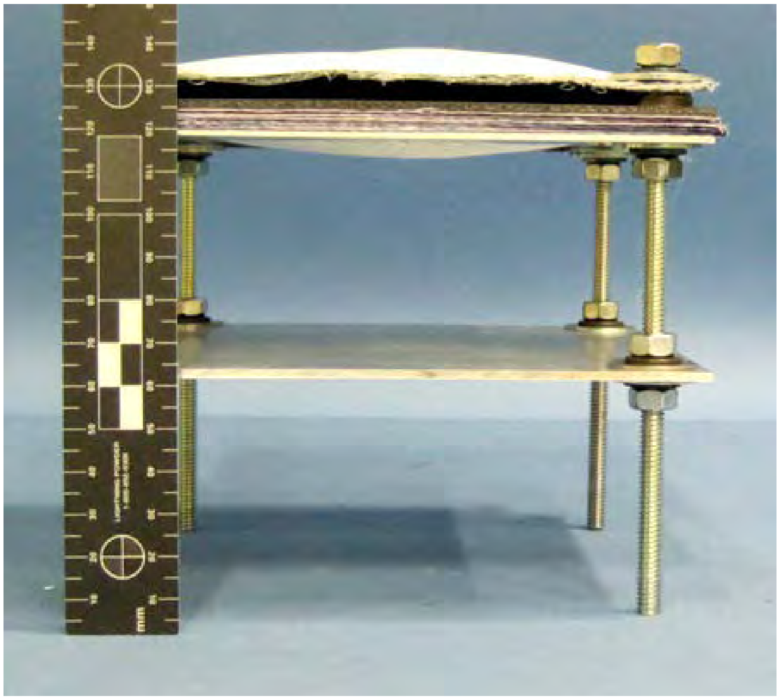


Figure 356 Overall Side View of Sample (scale in 5mm increments)

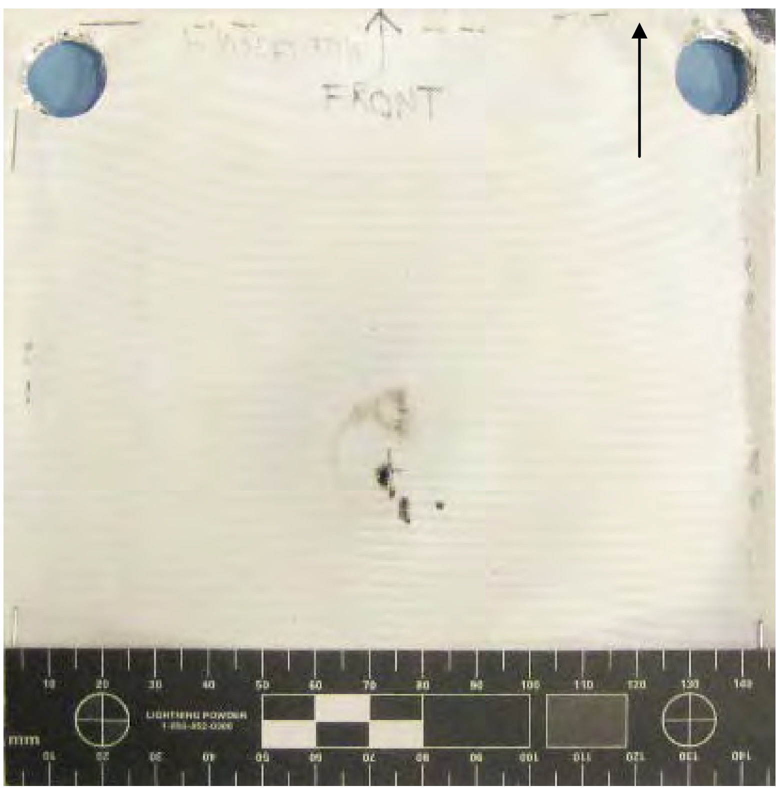


Figure 357 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12304 / Test #22 (continued)

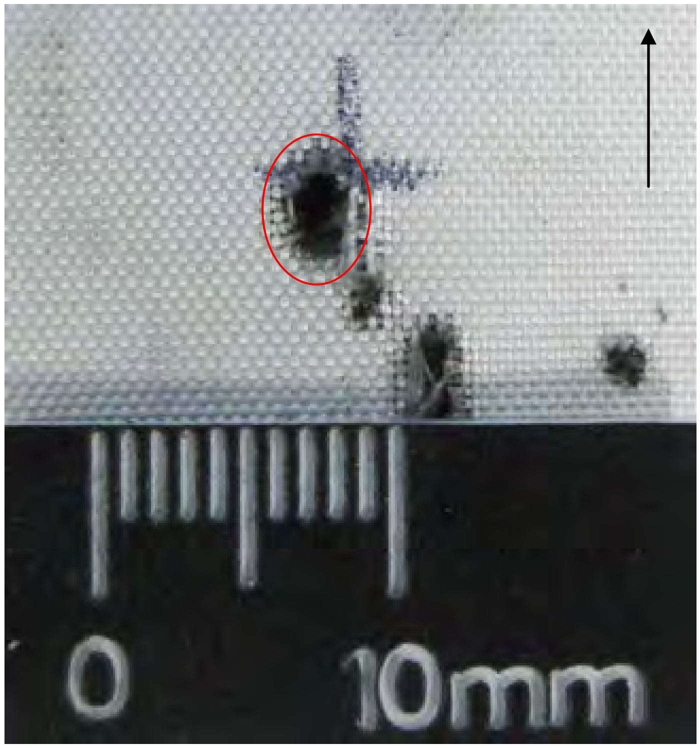


Figure 358 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile / projectile impacted within red circle)

Figure 359 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12304 / Test #22 (continued)

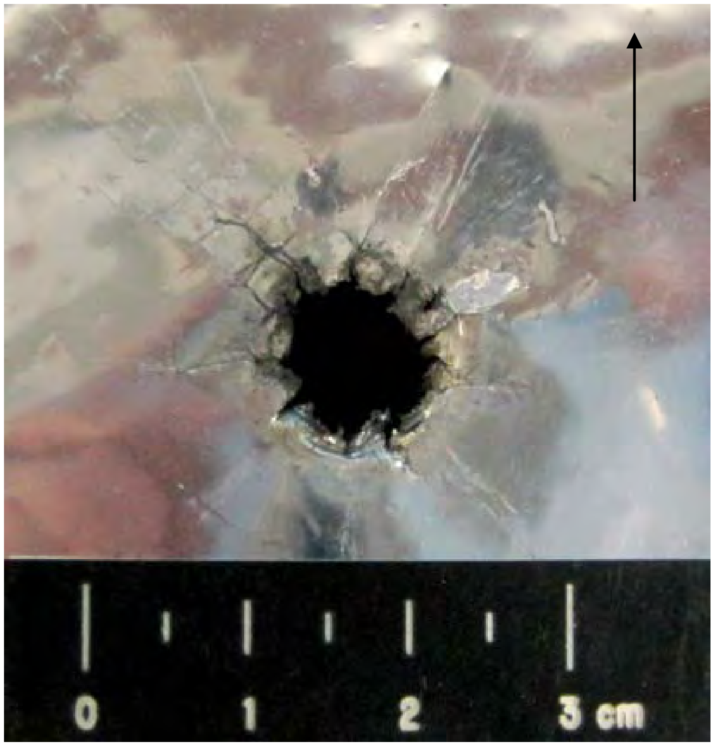


Figure 360 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

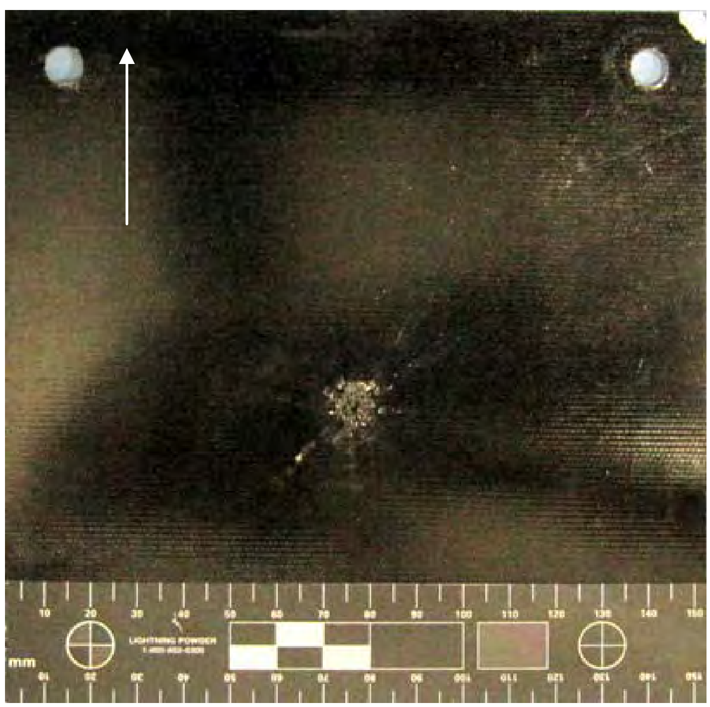


Figure 361 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12304 / Test #22 (continued)

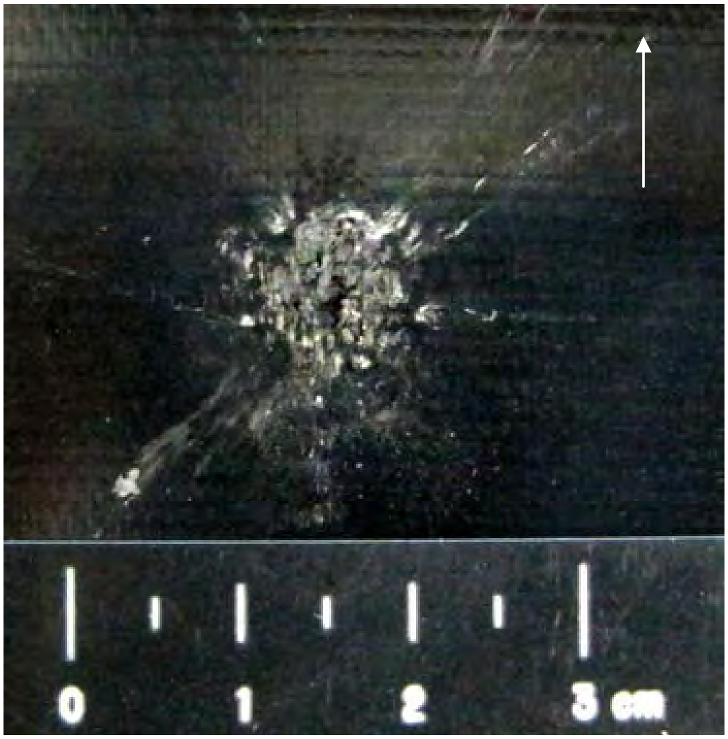


Figure 362 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

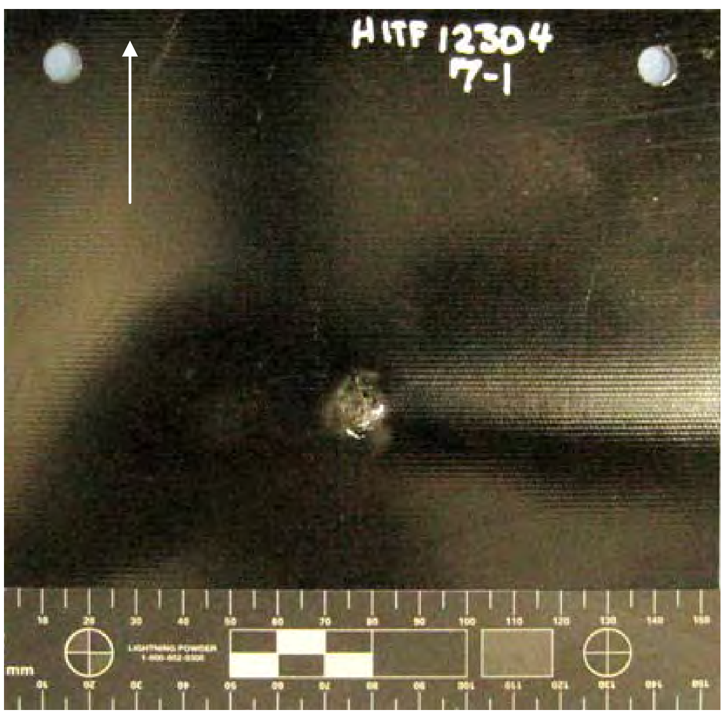


Figure 363 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12304 / Test #22 (continued)

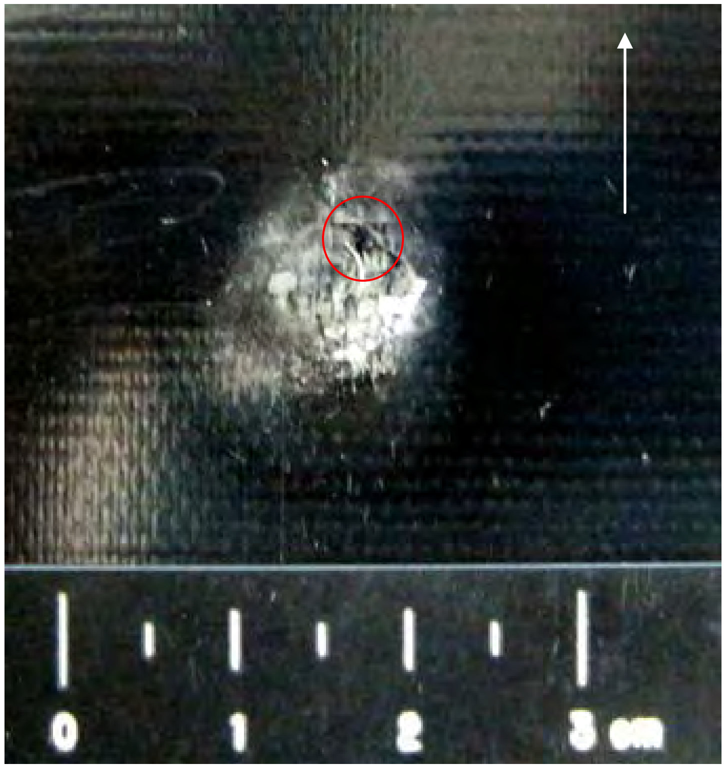


Figure 364 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

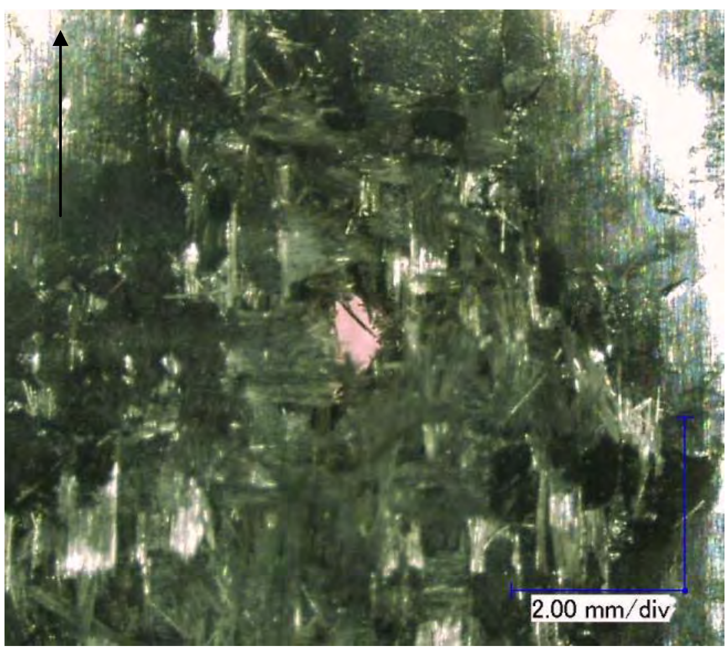


Figure 365 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 364)

HITF12304 / Test #22 (continued)

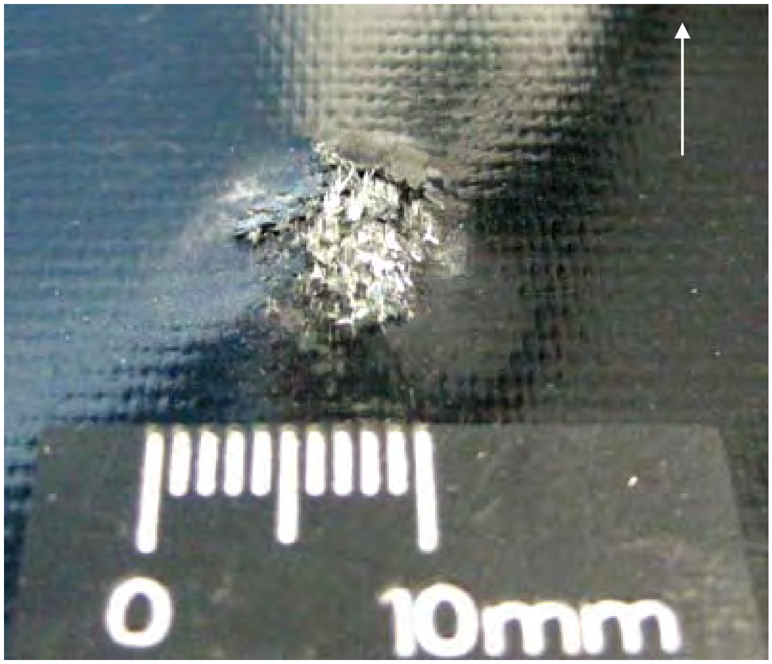


Figure 366 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

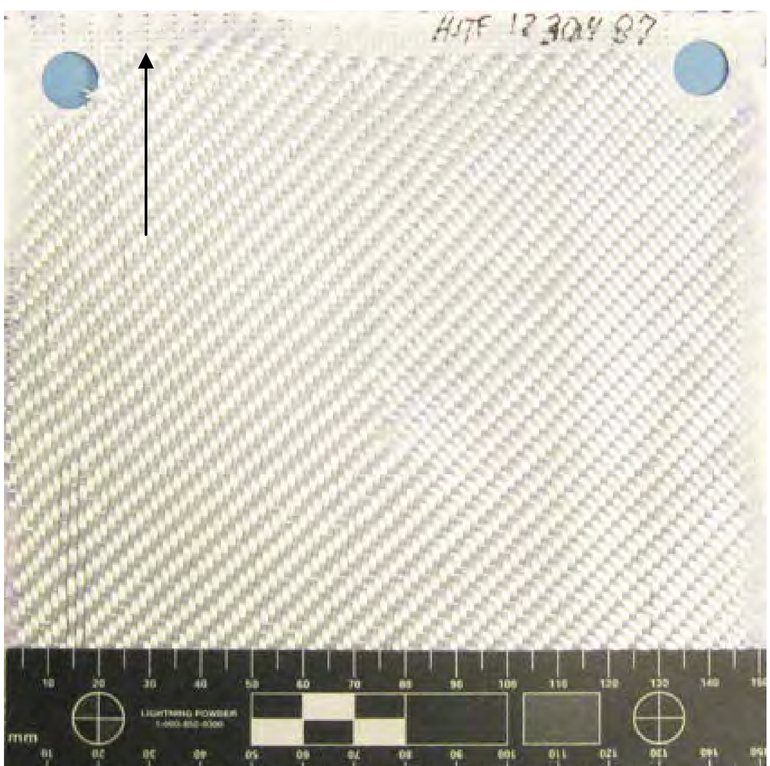


Figure 367 Overall View of Damage to Back Side of 7th Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12304 / Test #22 (continued)

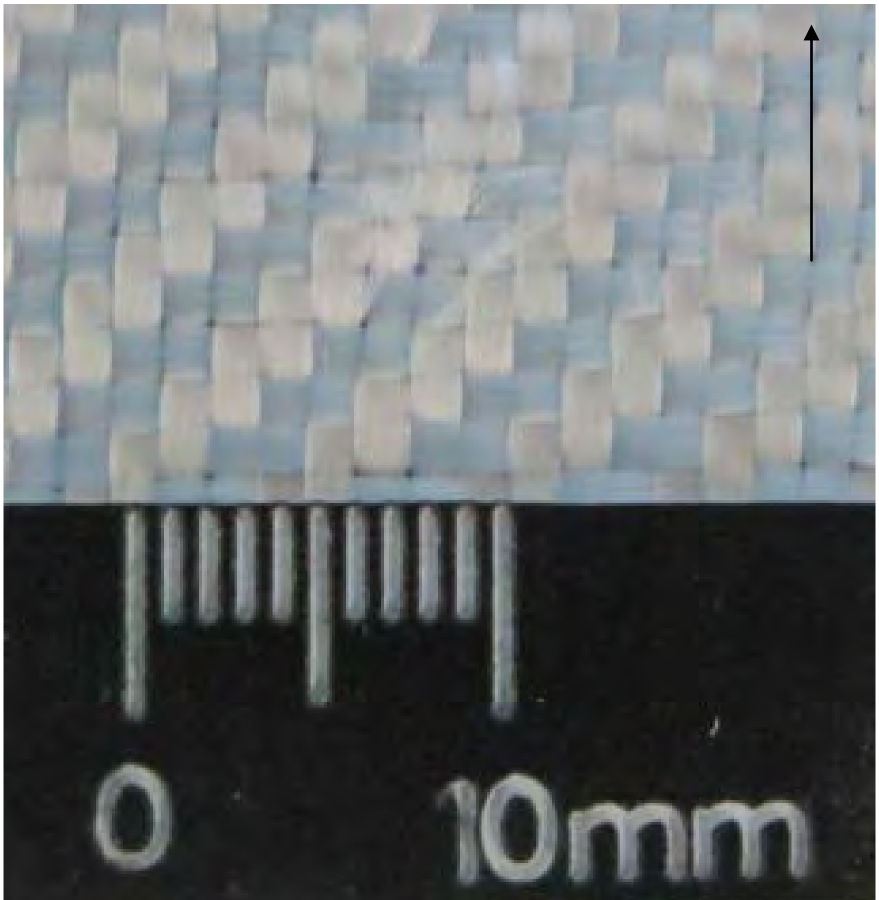


Figure 368 Close-up View of Damage to Back Side of 7th Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12305 / Test #23

Figure 369 Overall View of Sample in the Target Tank (post-test)

Figure 370 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12305 / Test #23 (continued)

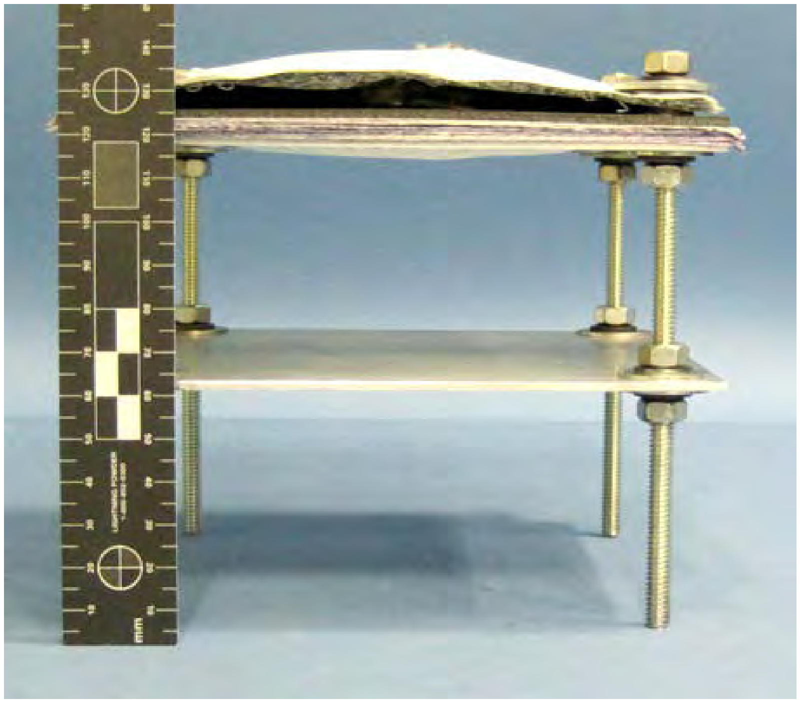


Figure 371 Overall Side View of Sample (scale in 5mm increments)

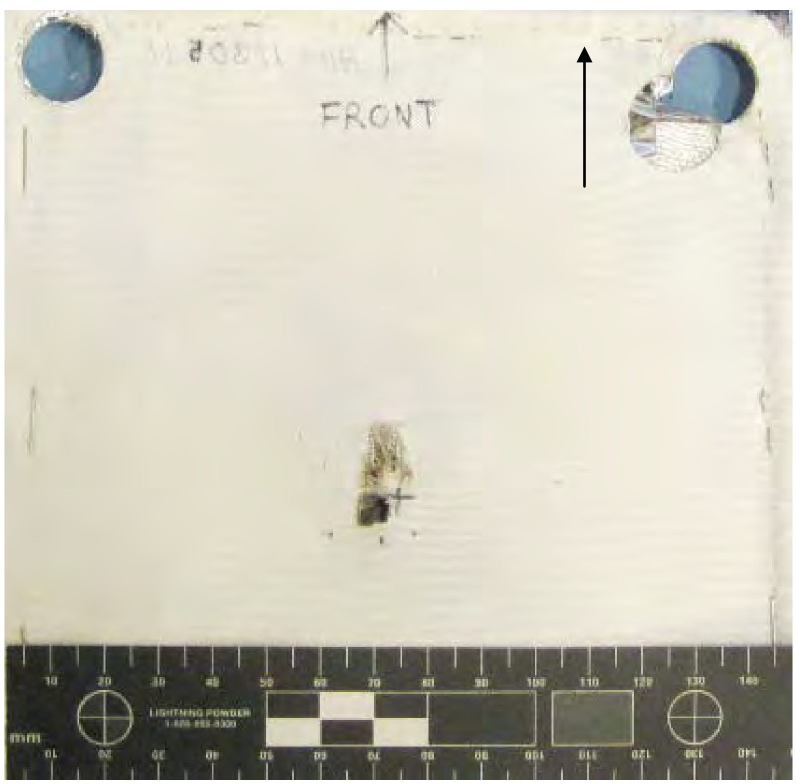


Figure 372 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12305 / Test #23 (continued)

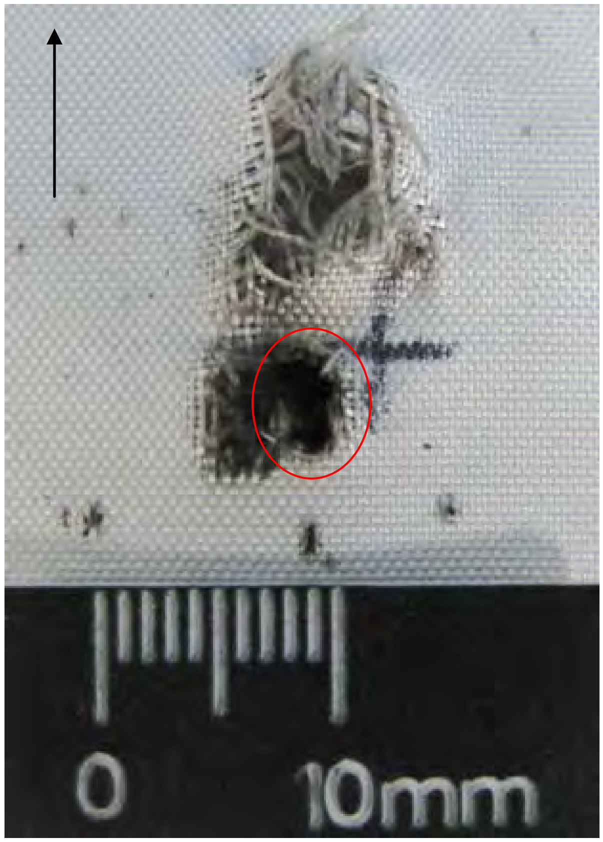


Figure 373 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile / projectile impact within red circle)

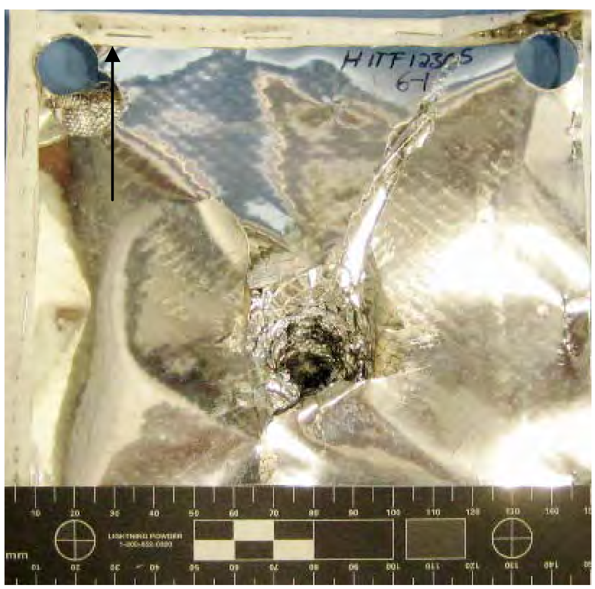


Figure 374 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12305 / Test #23 (continued)

Figure 375 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

Figure 376 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12305 / Test #23 (continued)

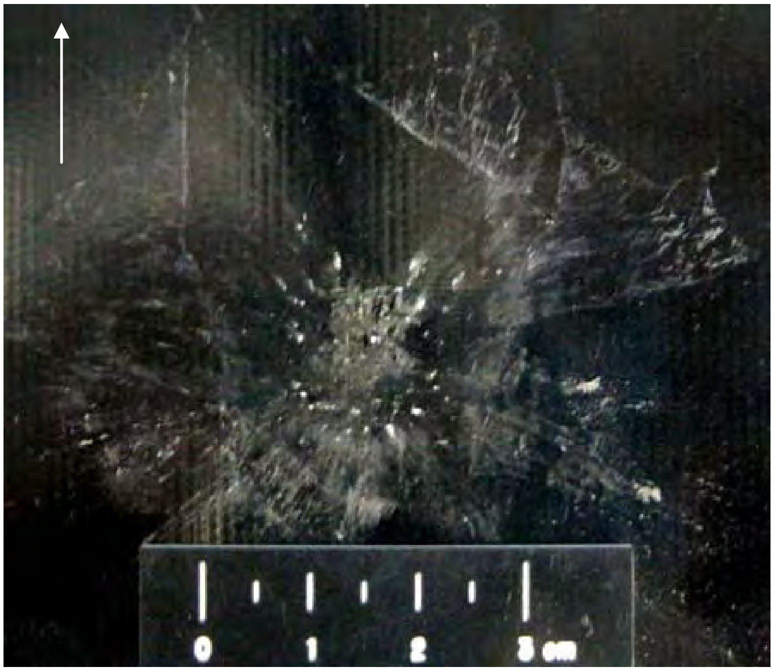


Figure 377 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

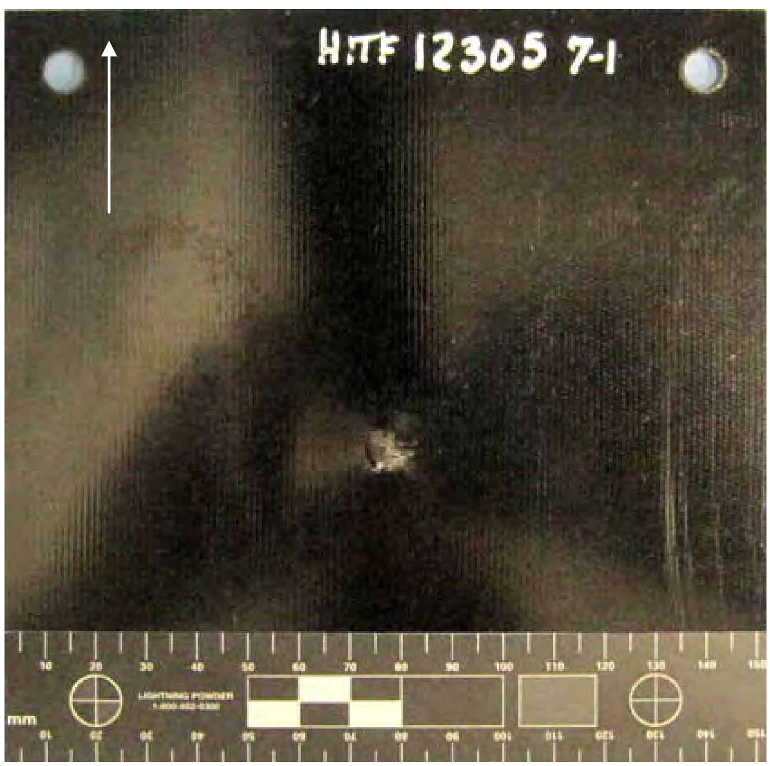


Figure 378 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12305 / Test #23 (continued)

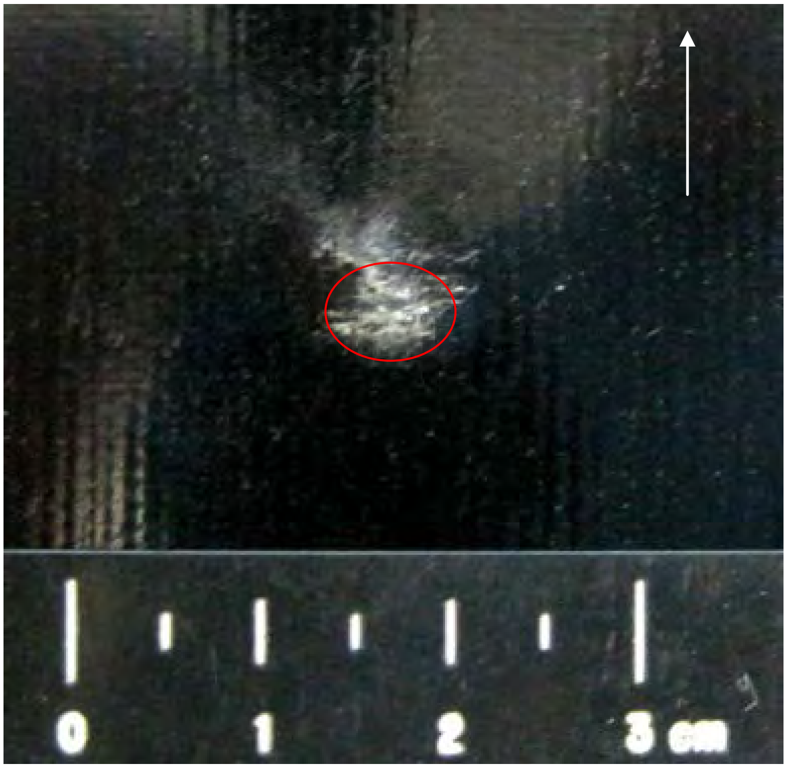


Figure 379 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

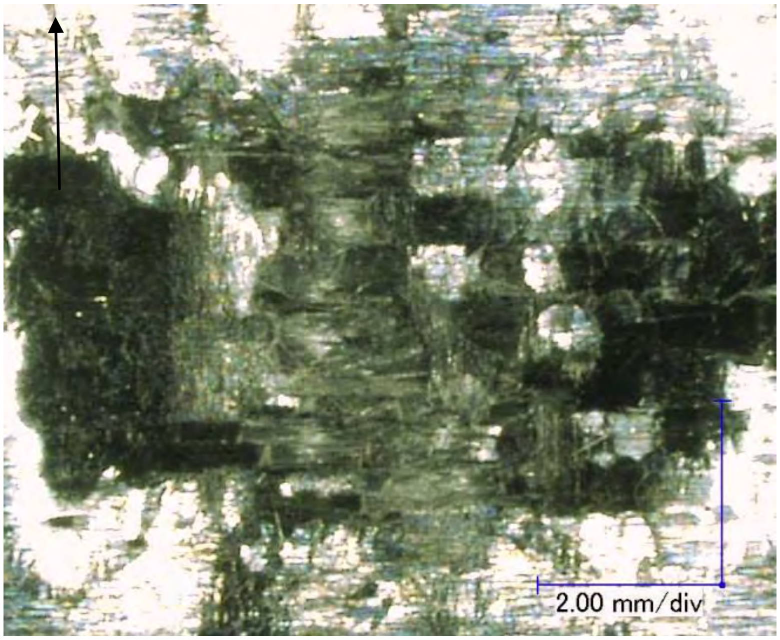


Figure 380 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 379)

HITF12305 / Test #23 (continued)

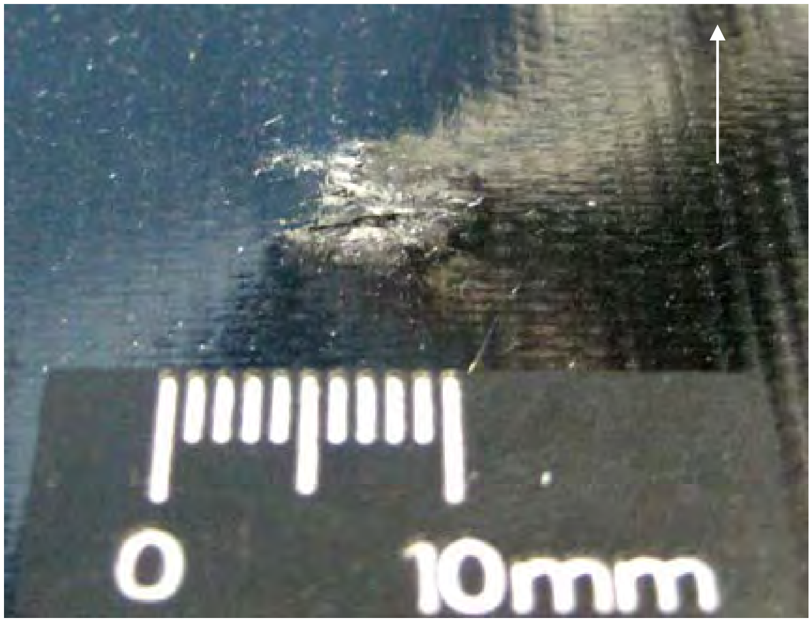


Figure 381 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

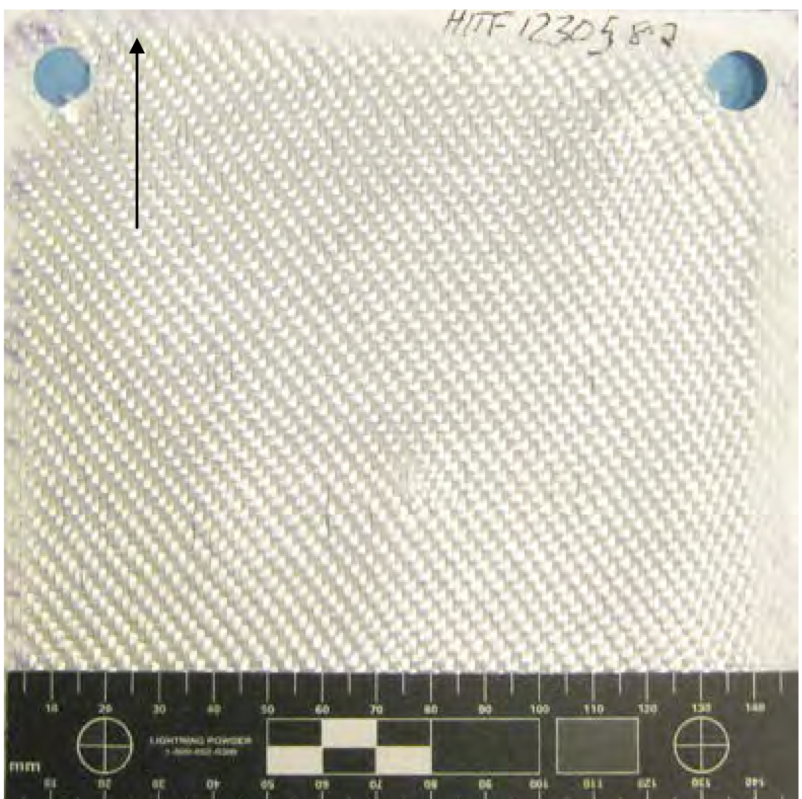


Figure 382 Overall View of Damage to Back Side of 2nd Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12305 / Test #23 (continued)

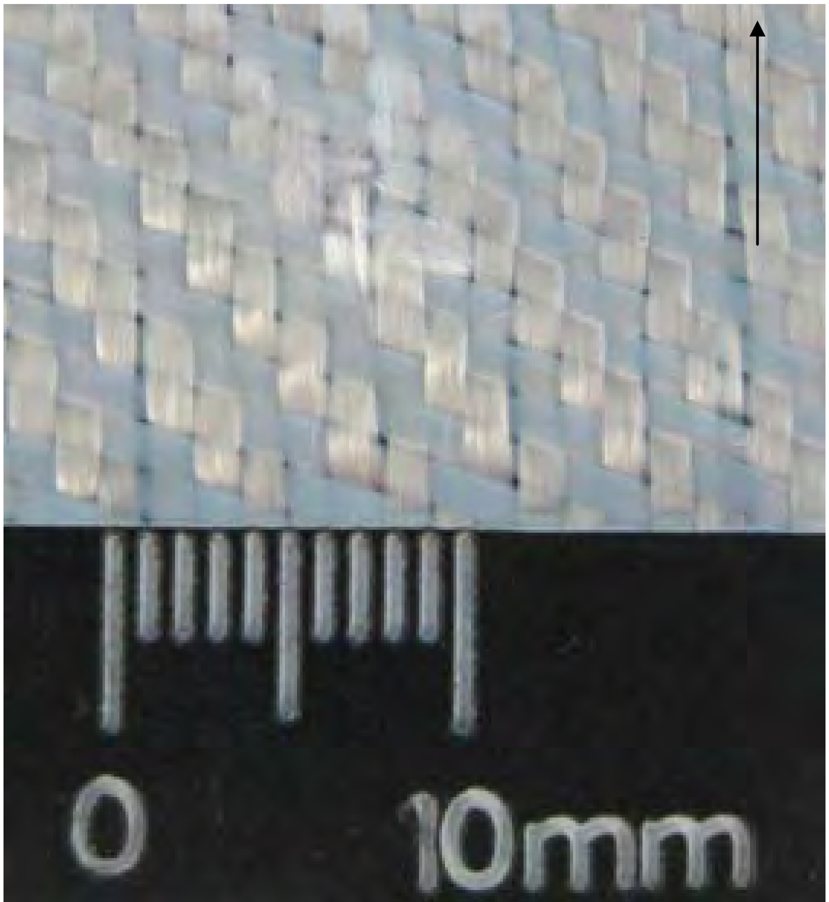


Figure 383 Close-up View of Damage to Back Side of 2nd Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12306 / Test #24

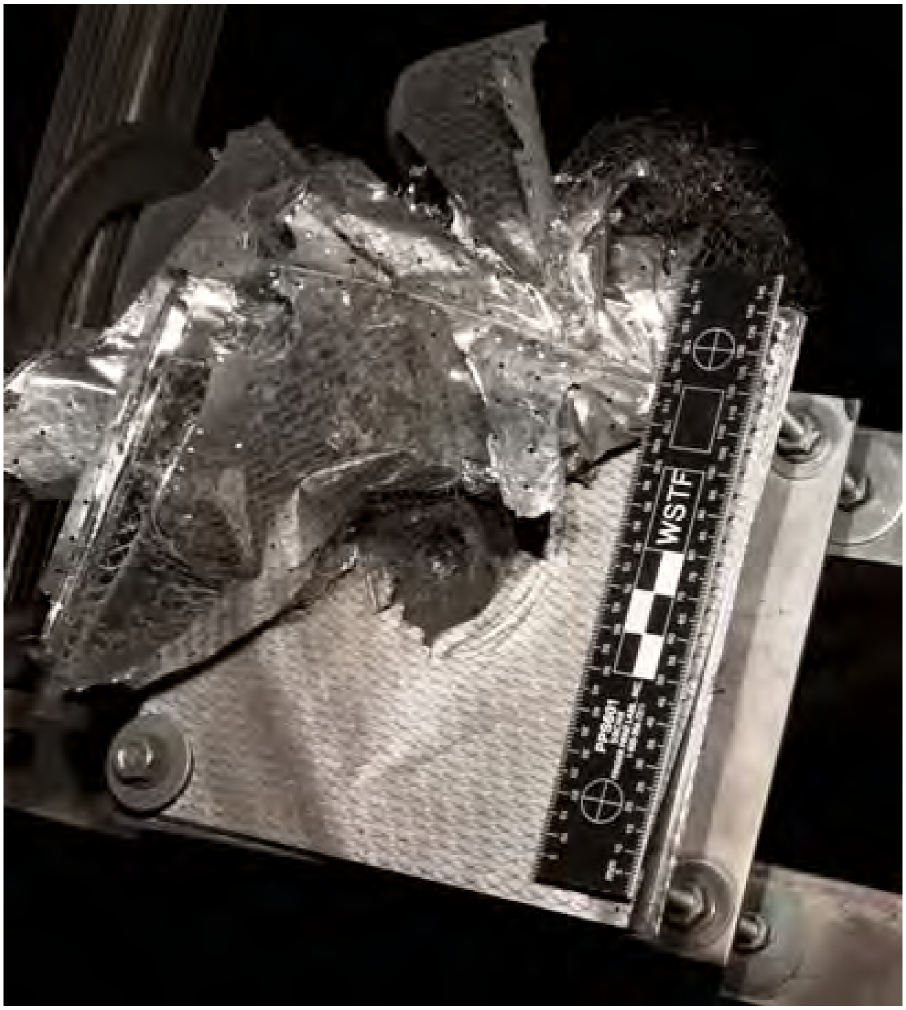


Figure 384 Overall View of Sample in the Target Tank (post-test)

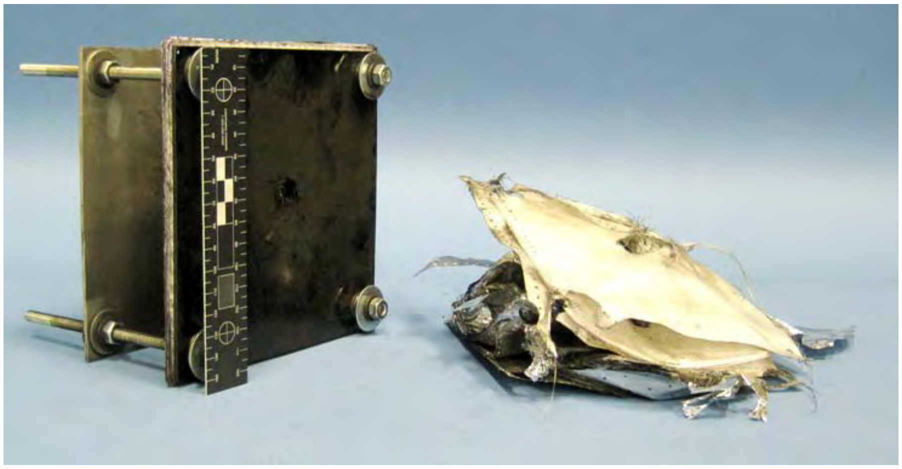


Figure 385 Overall Front Oblique View of Sample and Dislodged MLI Blanket from Test Configuration (scale in 5mm increments)

HITF12306 / Test #24 (continued)

Figure 386 Overall Front Oblique View of Sample (scale in 5mm increments / with MLI displaced from configuration)

Figure 387 Overall Side View of Sample (scale in 5mm increments)

HITF12306 / Test #24 (continued)

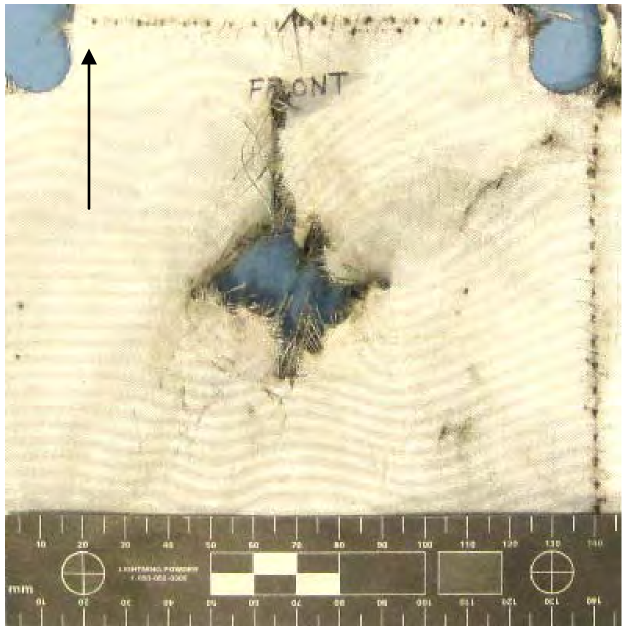


Figure 388 Overall View of Entry Damage to Front Layer of MLI Blanket (black arrow indicates flight path of projectile / scale in 5mm increments)

Figure 389 Close-up View of Entry Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12306 / Test #24 (continued)

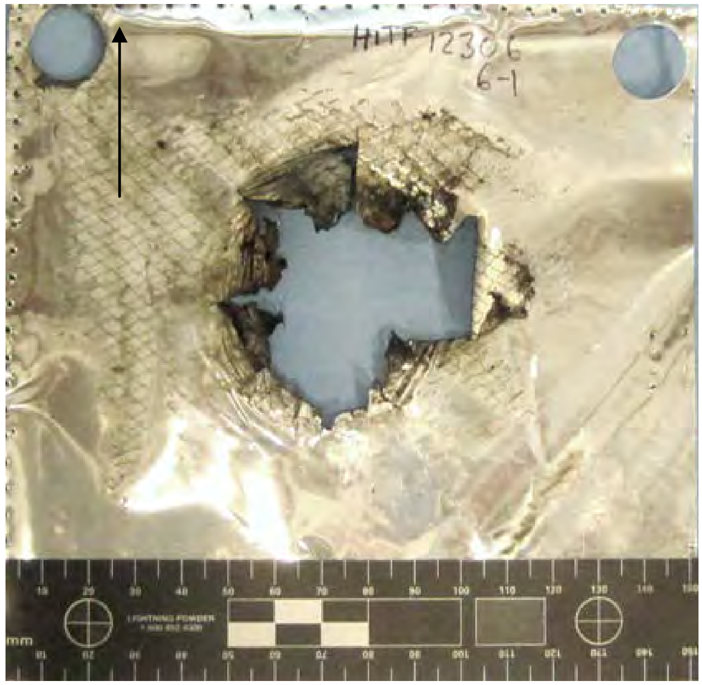


Figure 390 Overall View of Exit Damage to Last Layer of MLI Blanket (scale in 5mm increments / black arrow indicates flight path of projectile)

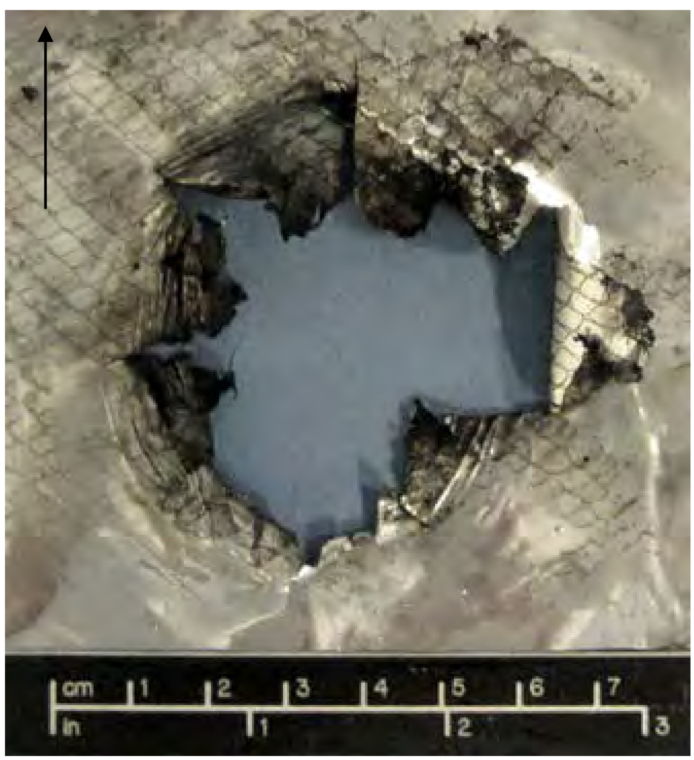


Figure 391 Close-up View of Exit Damage to Last Layer of MLI Blanket (scale in 1cm increments / black arrow indicates flight path of projectile)

HITF12306 / Test #24 (continued)

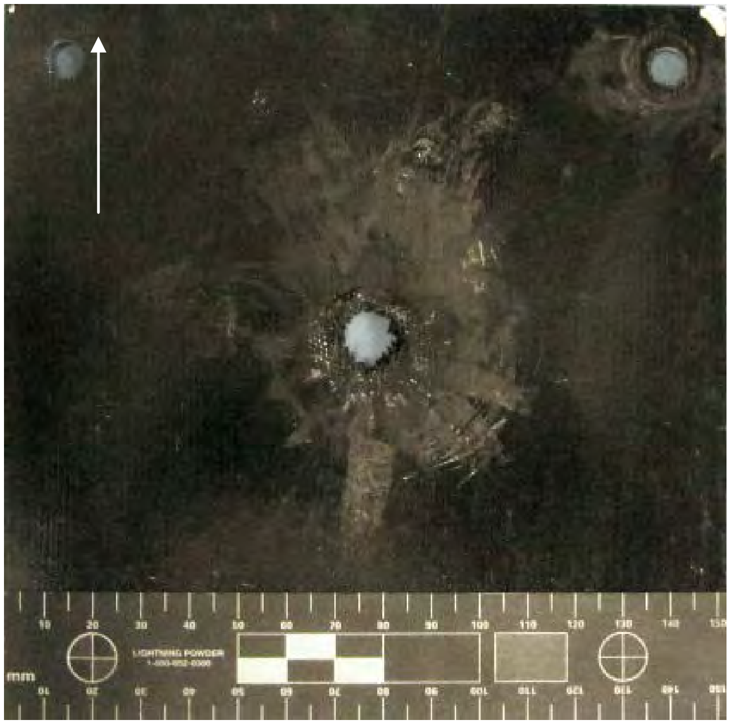


Figure 392 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

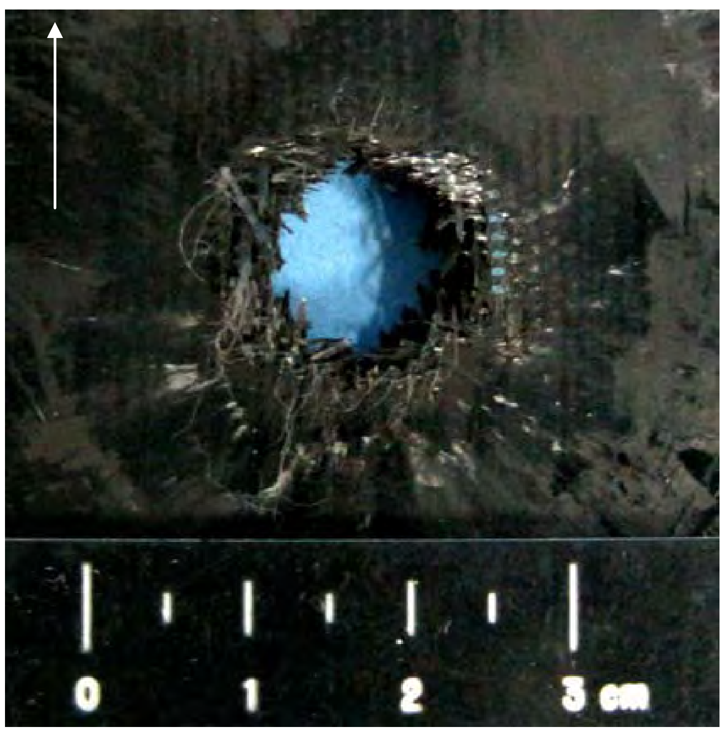


Figure 393 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12306 / Test #24 (continued)

Figure 394 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

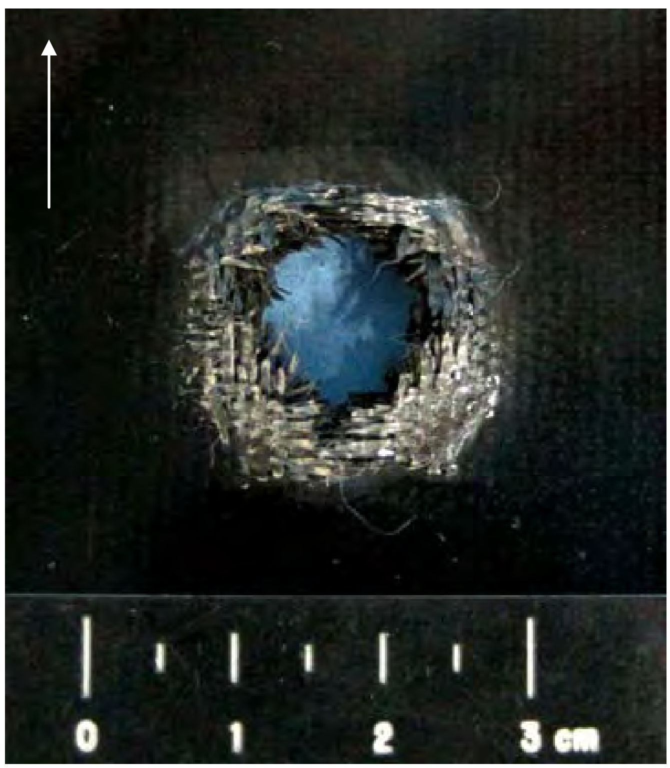


Figure 395 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

HITF12306 / Test #24 (continued)

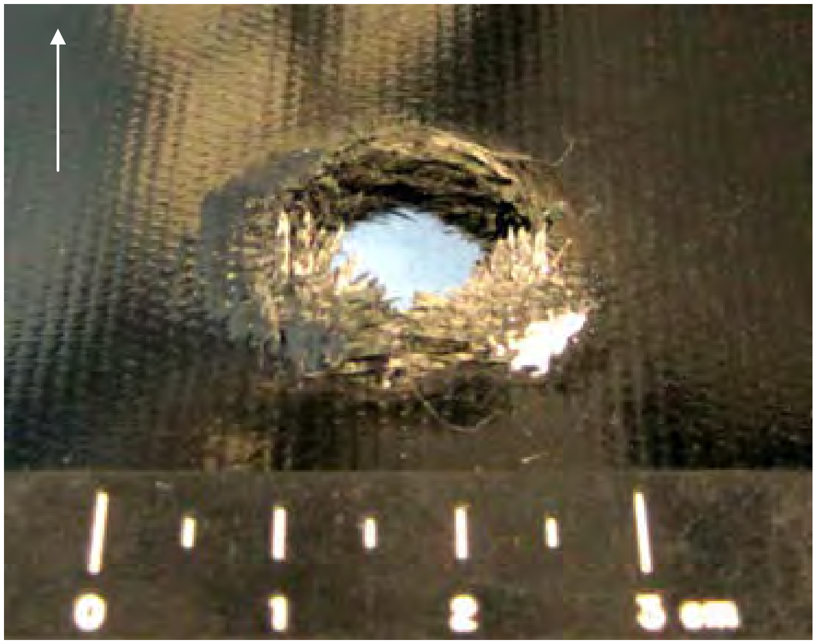


Figure 396 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

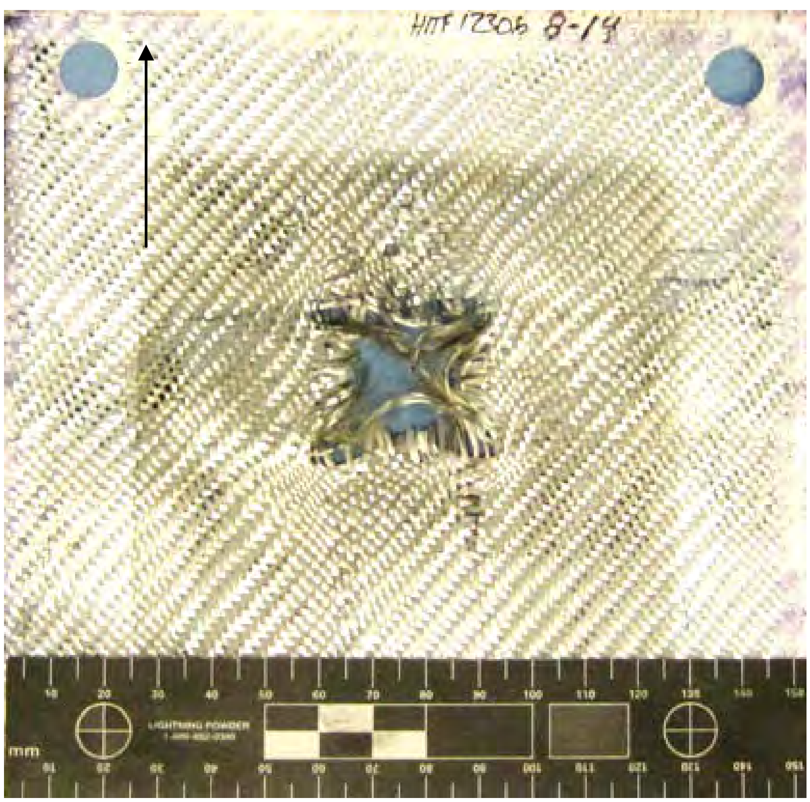


Figure 397 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12306 / Test #24 (continued)

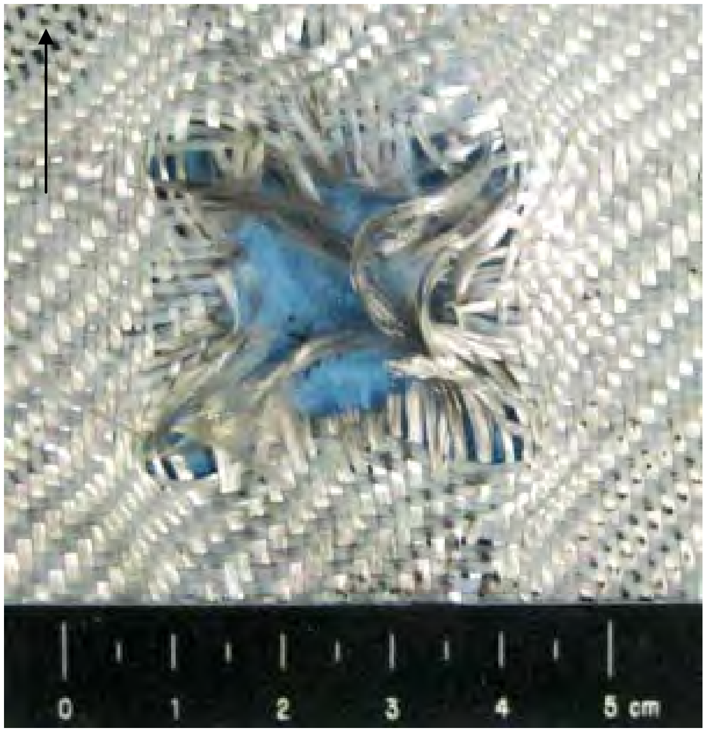


Figure 398 Close-up View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

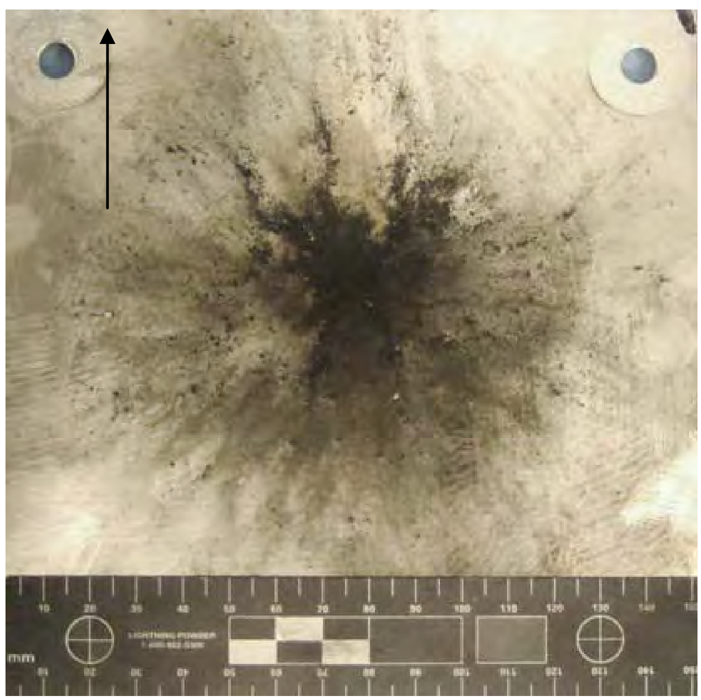


Figure 399 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile / uncleaned)

HITF12306 / Test #24 (continued)

Figure 400 Close-up View of Damage to Front of Rear Wall (scale in 1cm increments / black arrow indicates flight path of projectile / uncleaned)

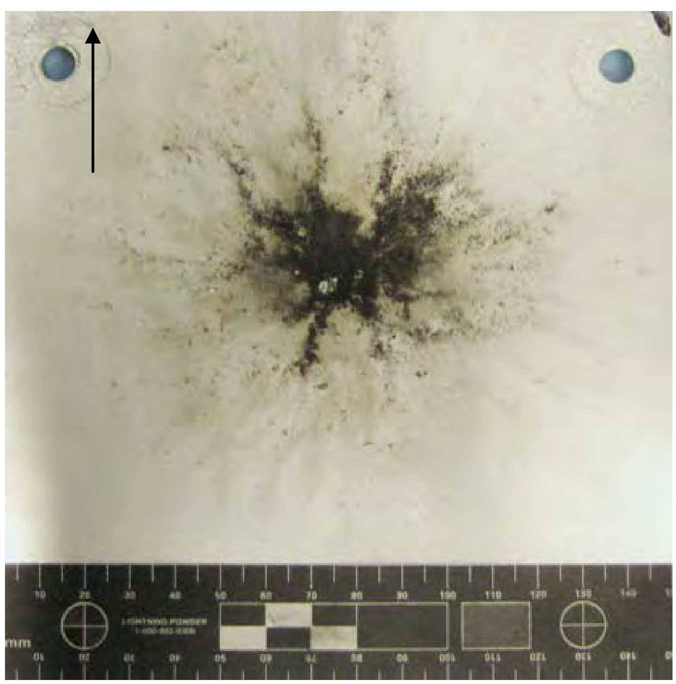


Figure 401 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile / cleaned)

HITF12306 / Test #24 (continued)

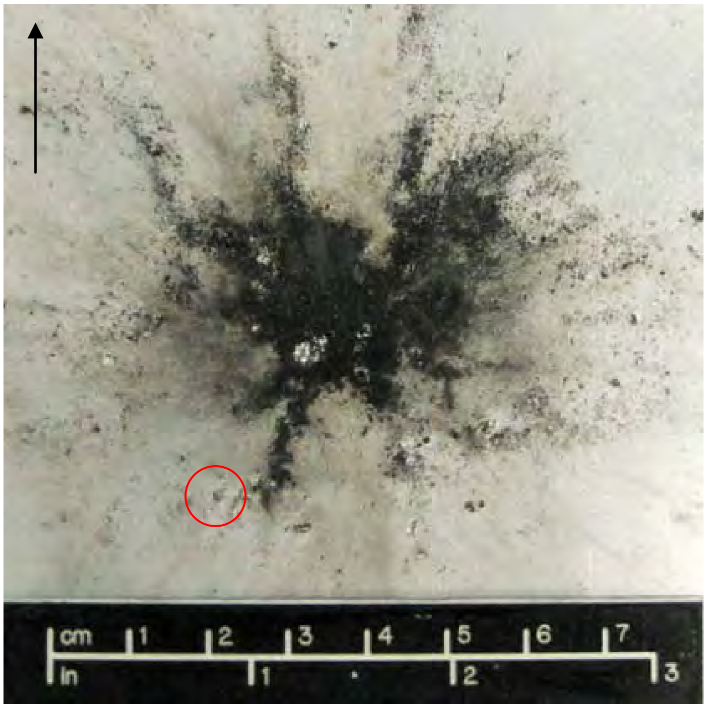


Figure 402 Overall View of Damage to Front of Rear Wall (scale in 1cm increments / black arrow indicates flight path of projectile / cleaned)

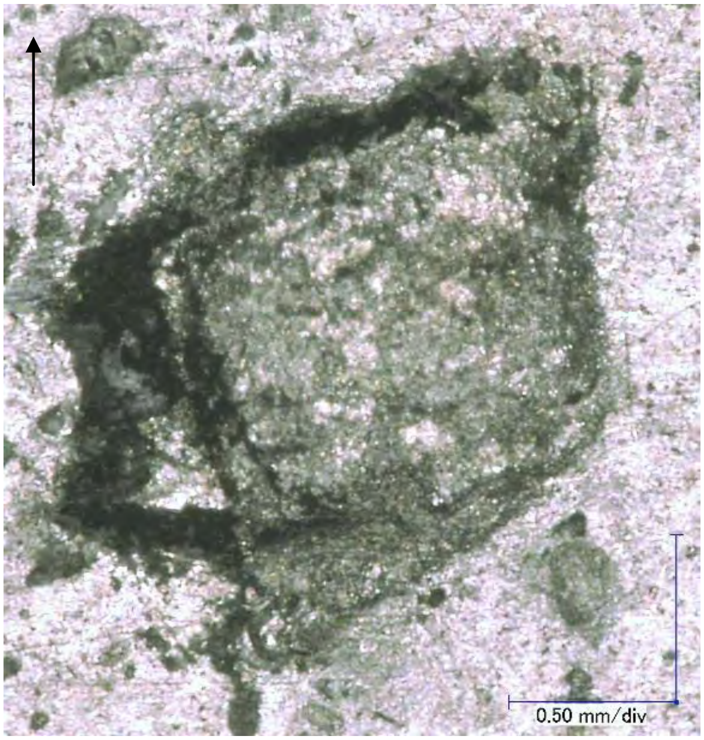


Figure 403 Close-up View of Most Significant Visible Damage to Front of Rear Wall (black arrow indicates flight path of projectile / damage within red circle in Figure 402)

HITF12306 / Test #24 (continued)

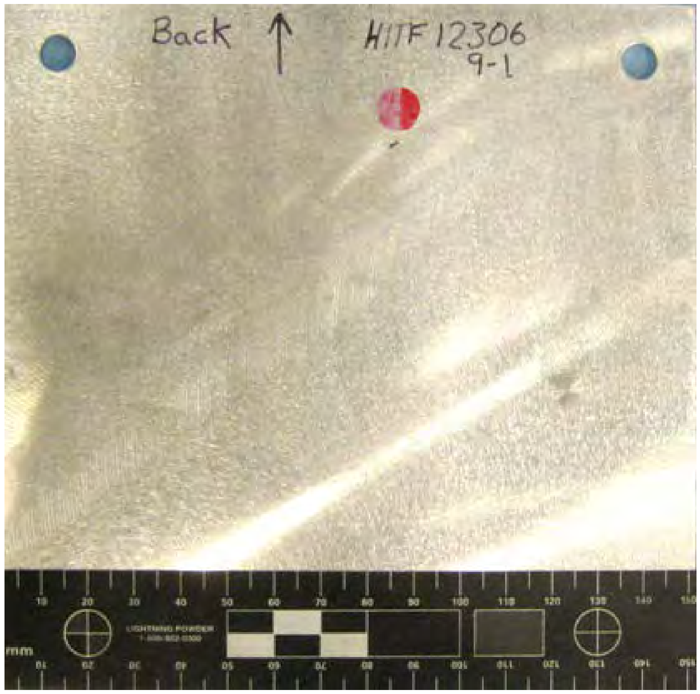


Figure 404 Overall View of Damage on Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

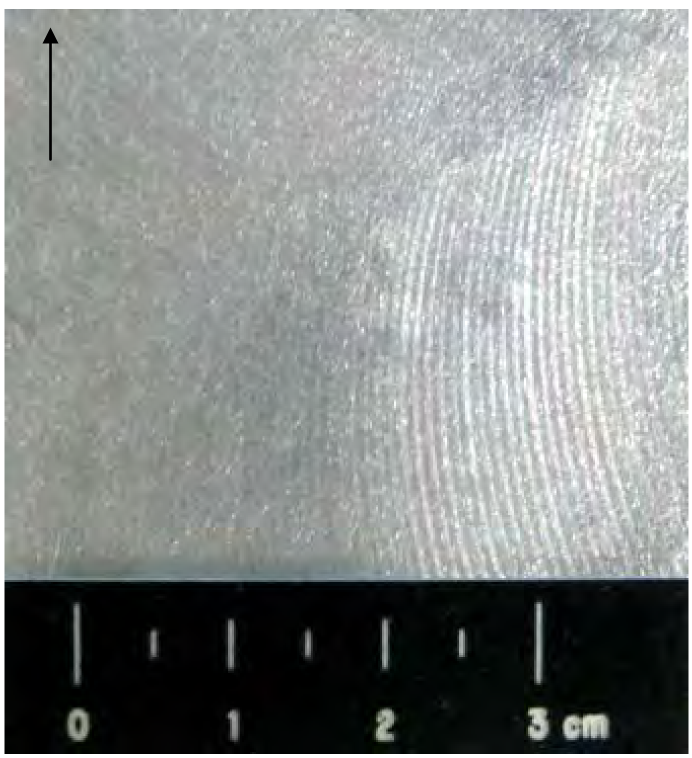


Figure 405 Close-up View of Damage on Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12306 / Test #24 (continued)

Figure 406 Close-up Oblique Side View of Damage on Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12307 / Test #25

Figure 407 Overall View of Sample in the Target Tank (post-test)

Figure 408 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12307 / Test #25 (continued)

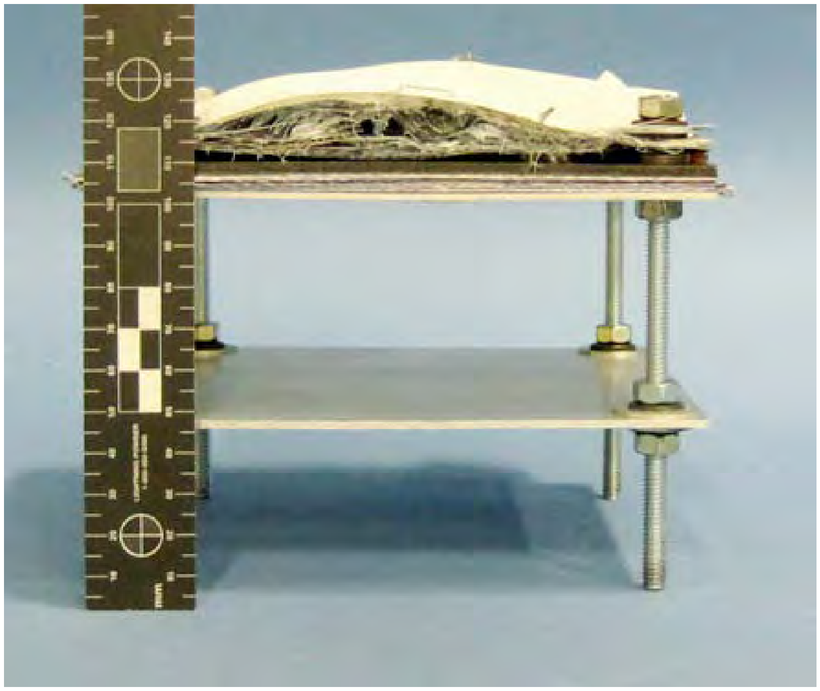


Figure 409 Overall Side View of Sample (scale in 5mm increments)

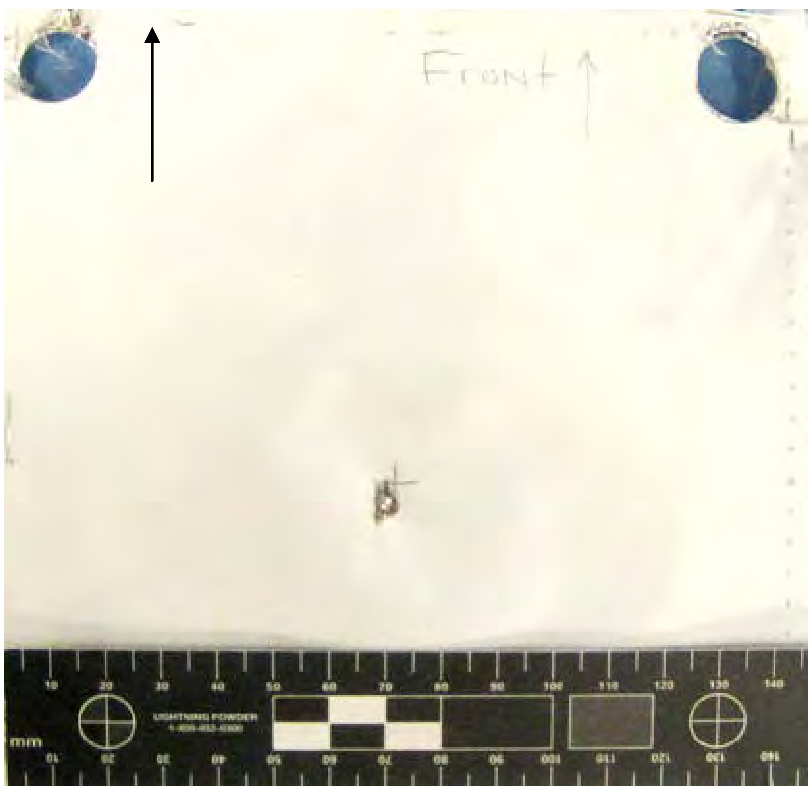


Figure 410 Overall View of Damage to Front of MLI (black arrow indicates flight path of projectile / scale in 5mm increments)

HITF12307 / Test #25 (continued)

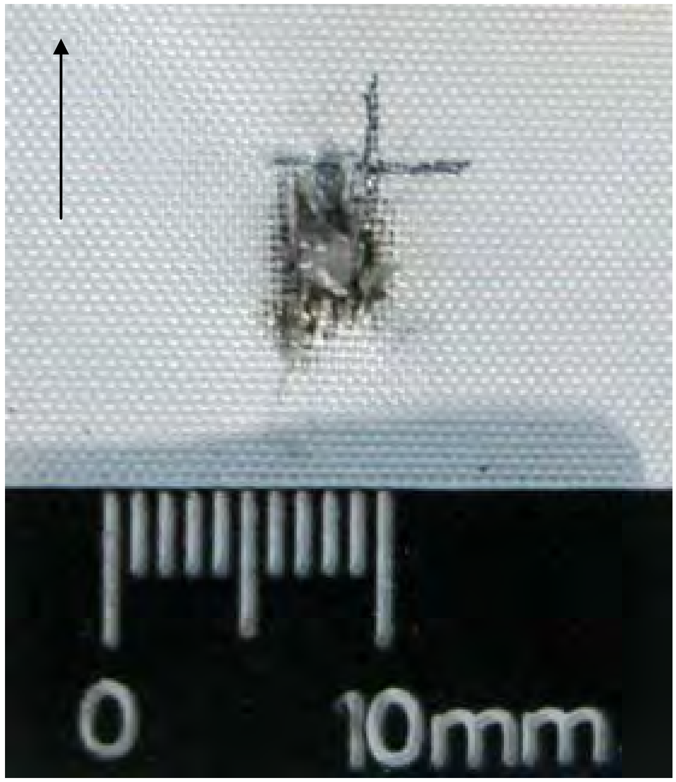


Figure 411 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

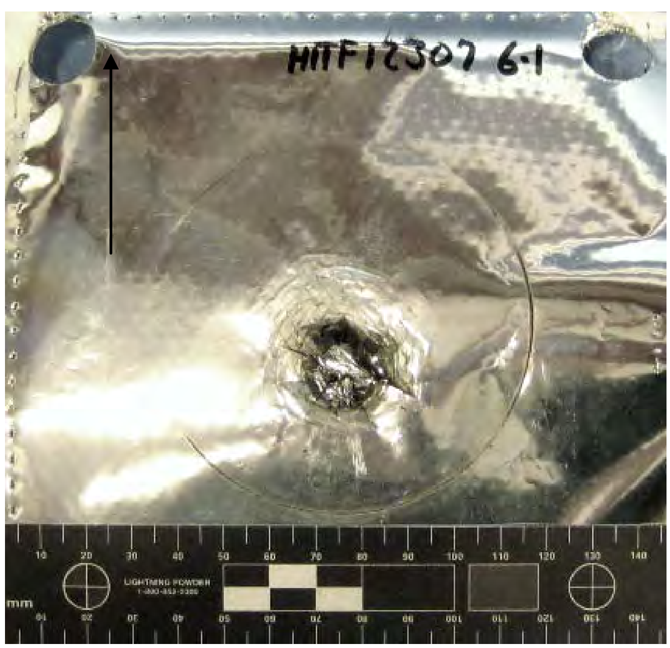


Figure 412 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12307 / Test #25 (continued)

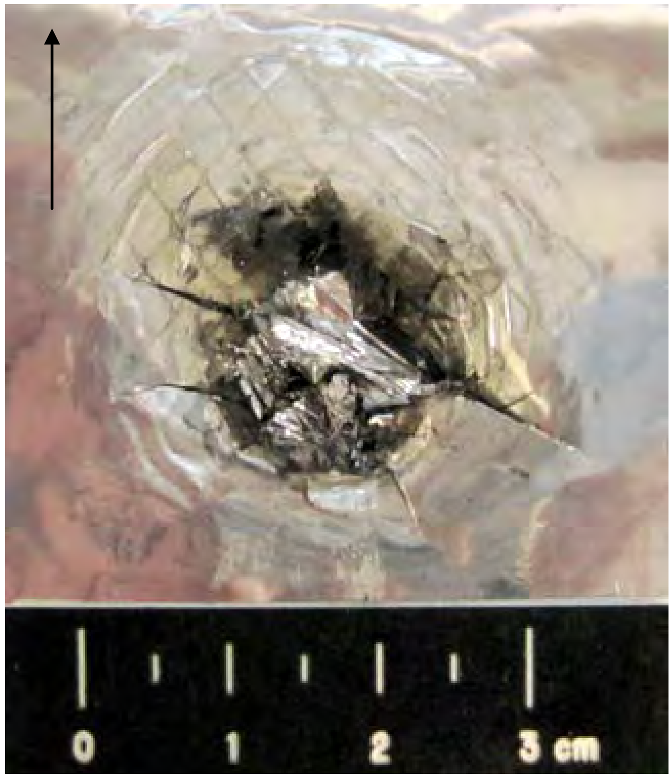


Figure 413 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

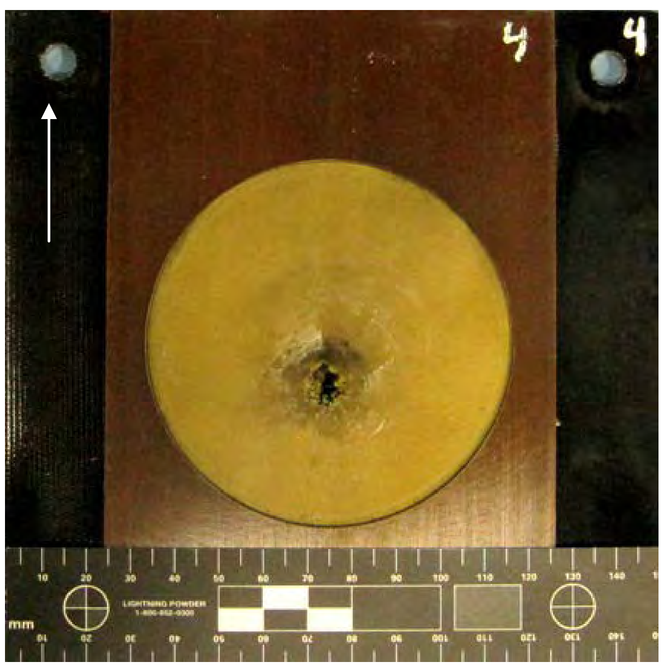


Figure 414 Overall View of Damage to Front of TORLON 5030 (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12307 / Test #25 (continued)

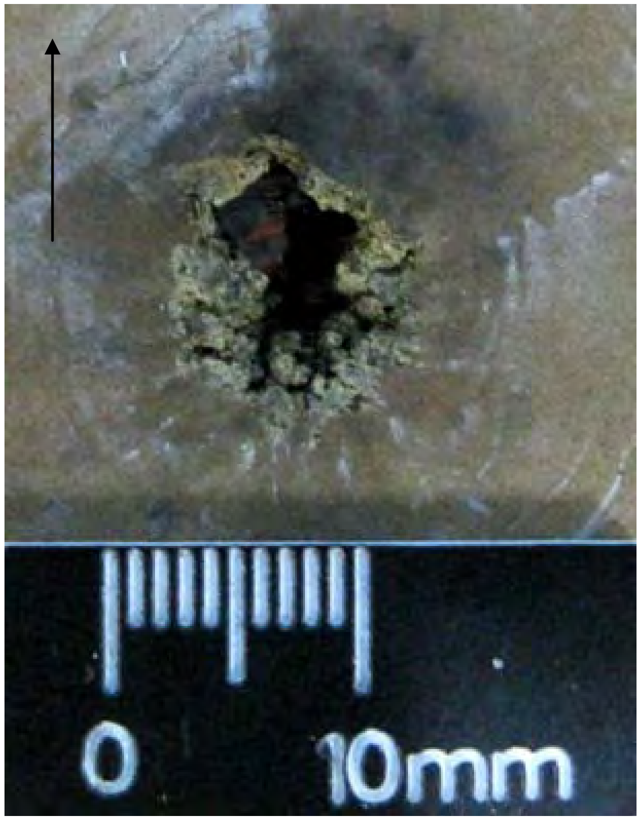


Figure 415 Close-up View of Damage to Front of TORLON 5030 (scale in 1mm increments / black arrow indicates flight path of projectile)

Figure 416 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12307 / Test #25 (continued)

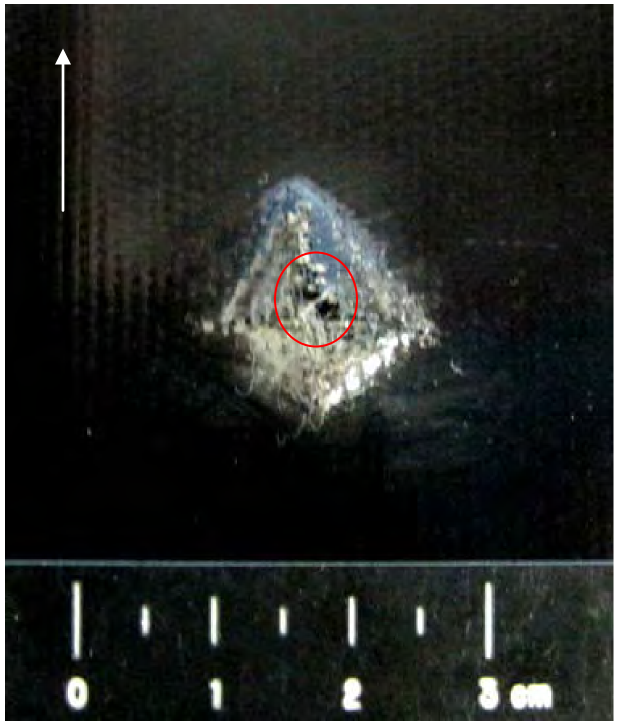


Figure 417 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

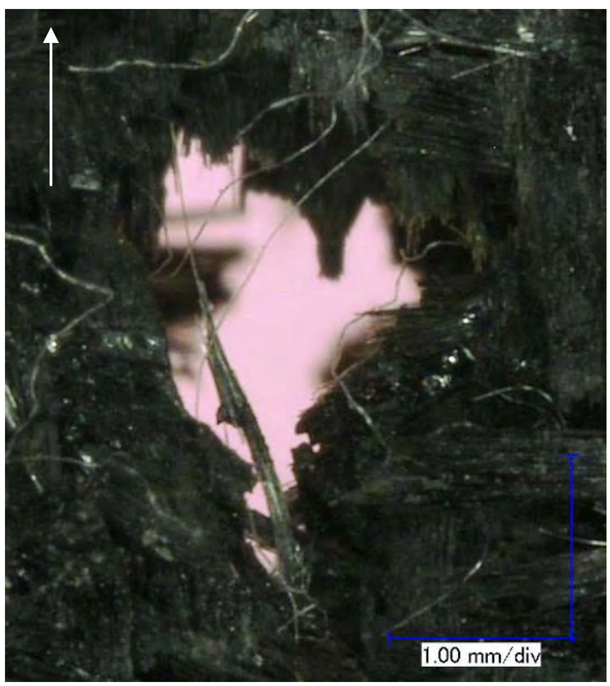


Figure 418 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 417)

HITF12307 / Test #25 (continued)

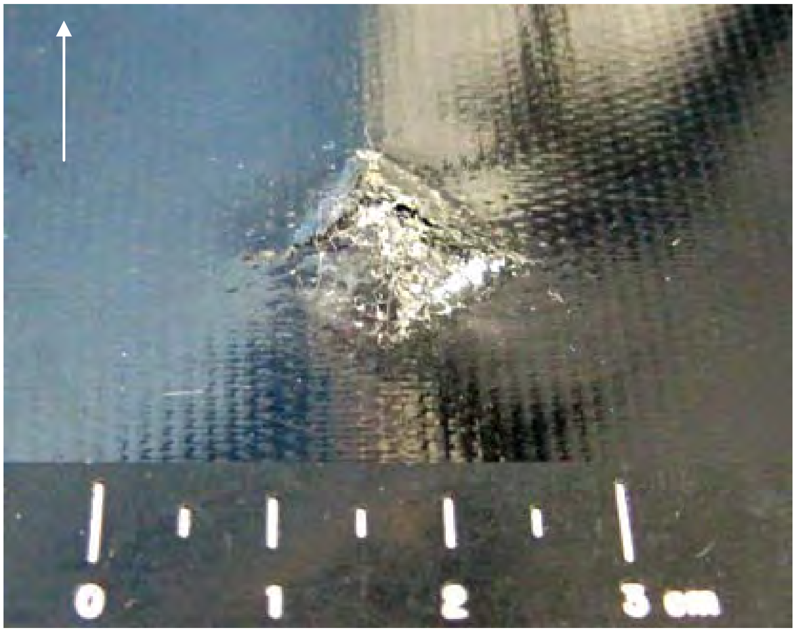


Figure 419 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

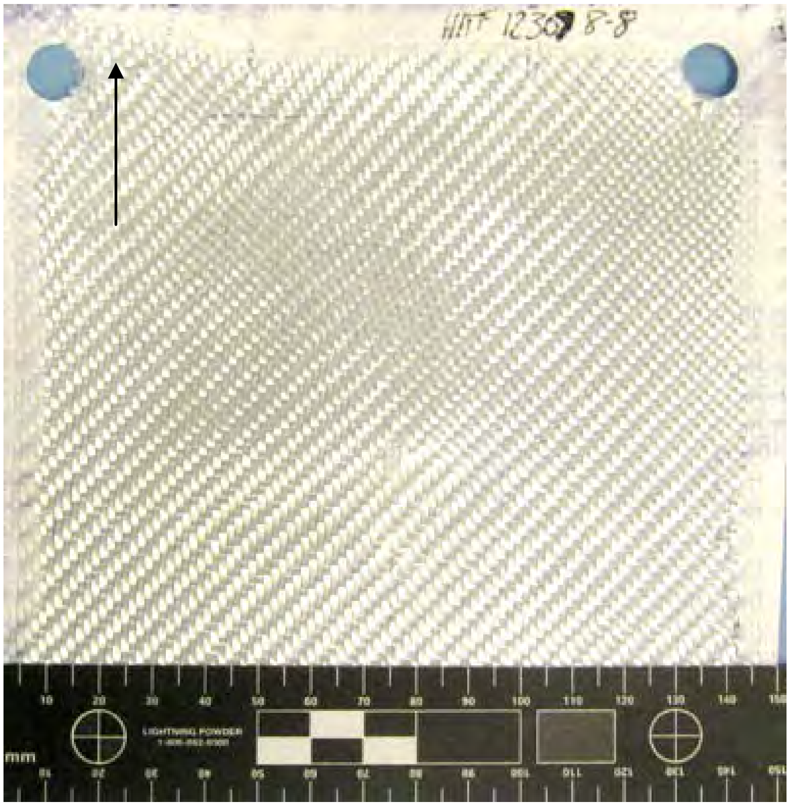


Figure 420 Overall View of Damage to Back Side of 8th Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12307 / Test #25 (continued)

Figure 421 Close-up View of Damage to Back Side of 8th Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12308 / Test #26

Figure 422 Overall View of Sample in the Target Tank (post-test)

Figure 423 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12308 / Test #26 (continued)

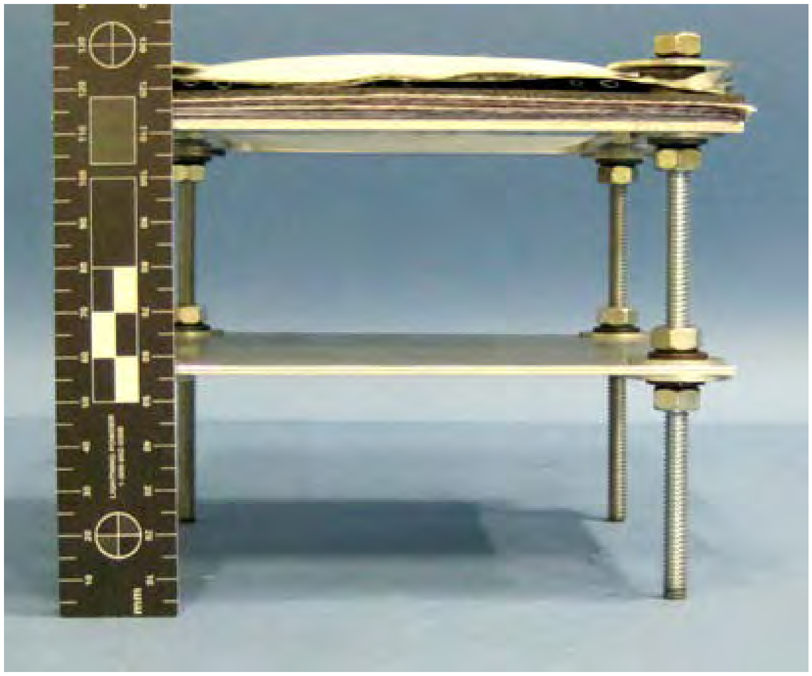


Figure 424 Overall Side View of Sample (scale in 5mm increments)

Figure 425 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12308 / Test #26 (continued)

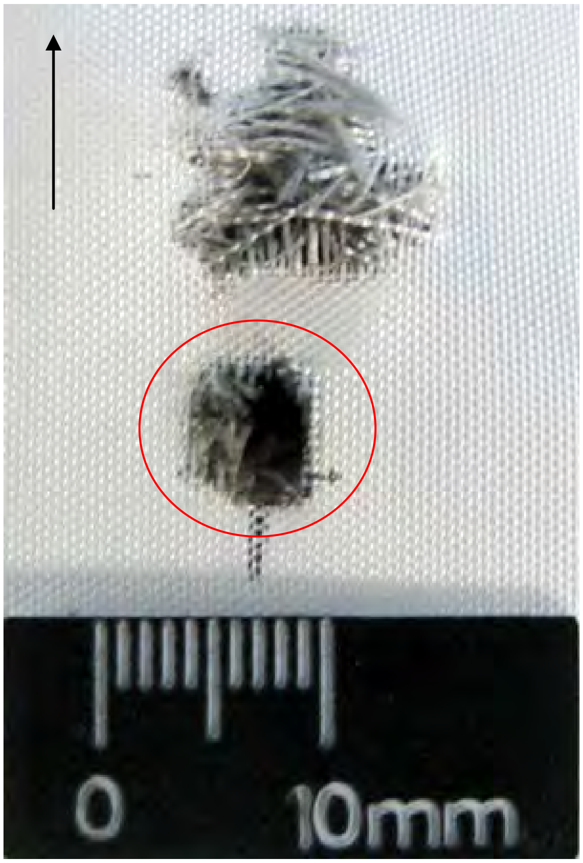


Figure 426 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile / projectile impact within red circle)

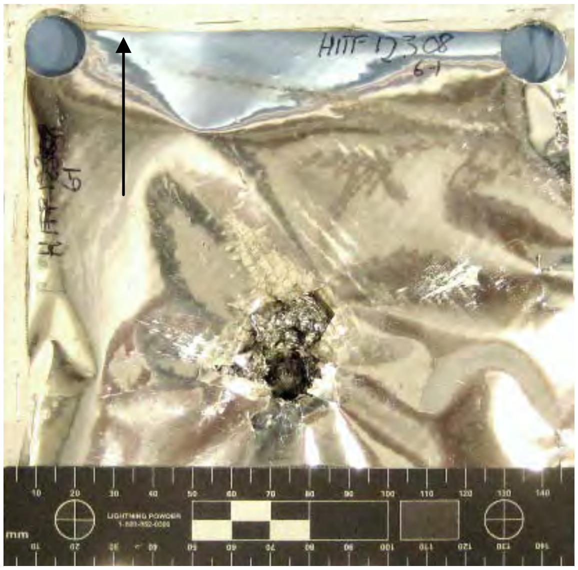


Figure 427 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12308 / Test #26 (continued)

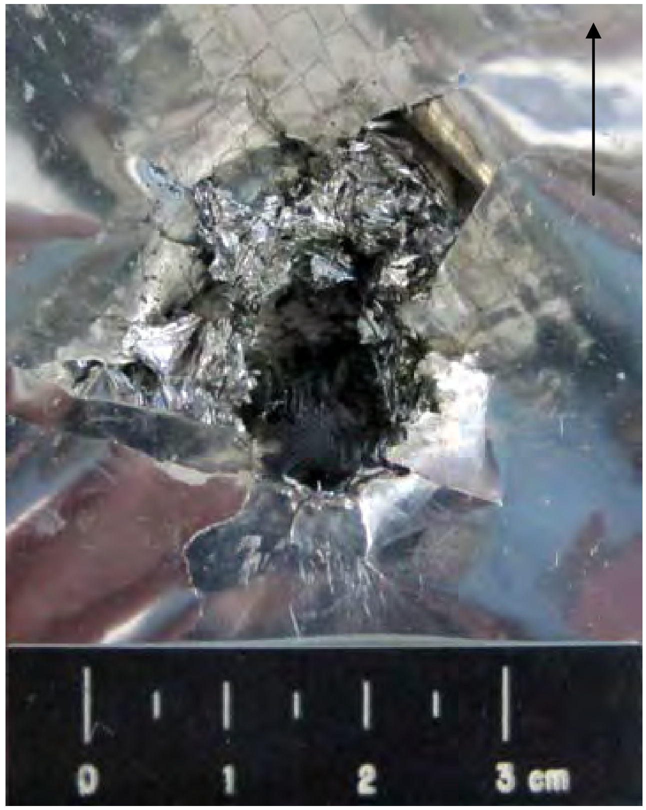


Figure 428 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

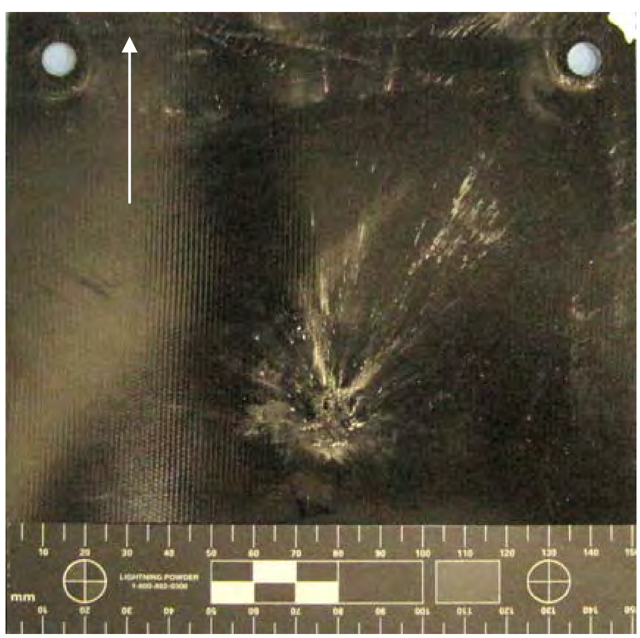


Figure 429 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12308 / Test #26 (continued)

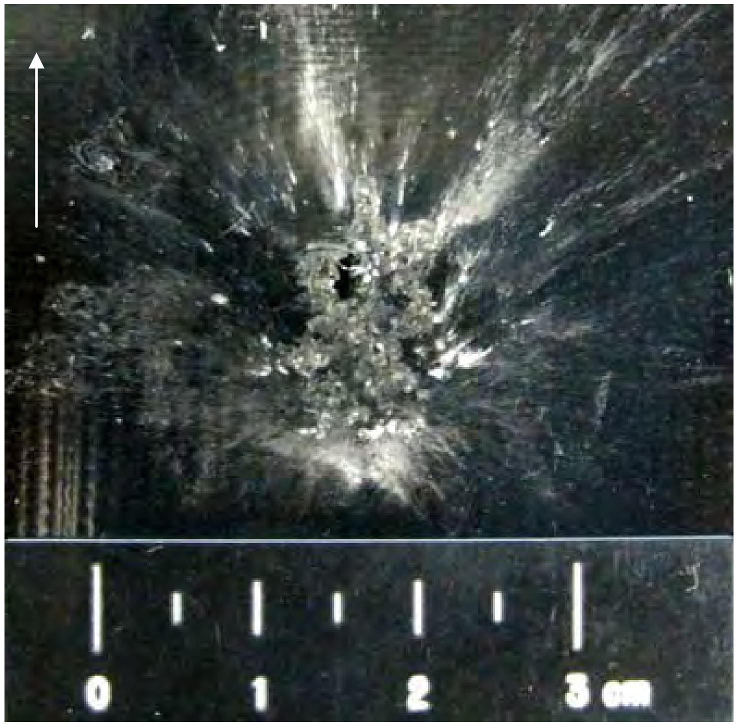


Figure 430 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

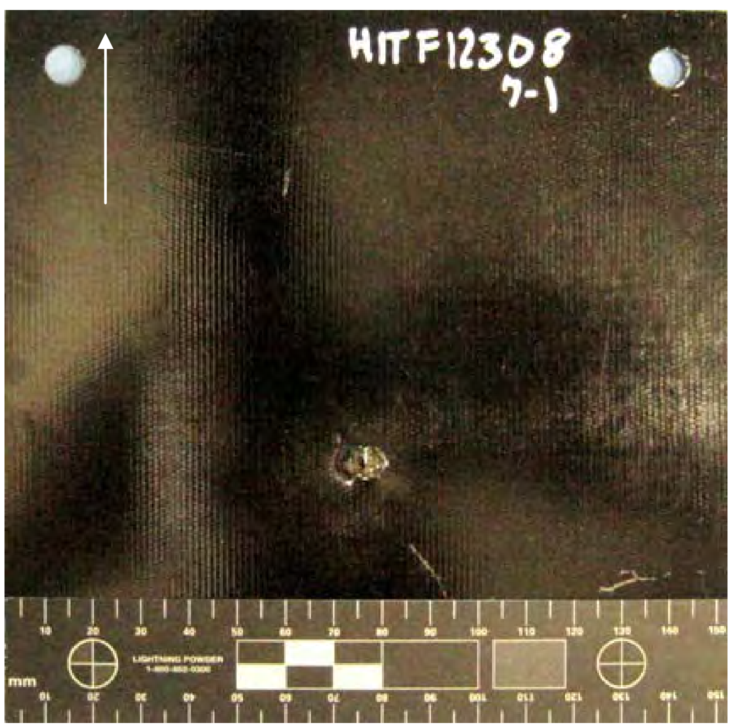


Figure 431 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12308 / Test #26 (continued)

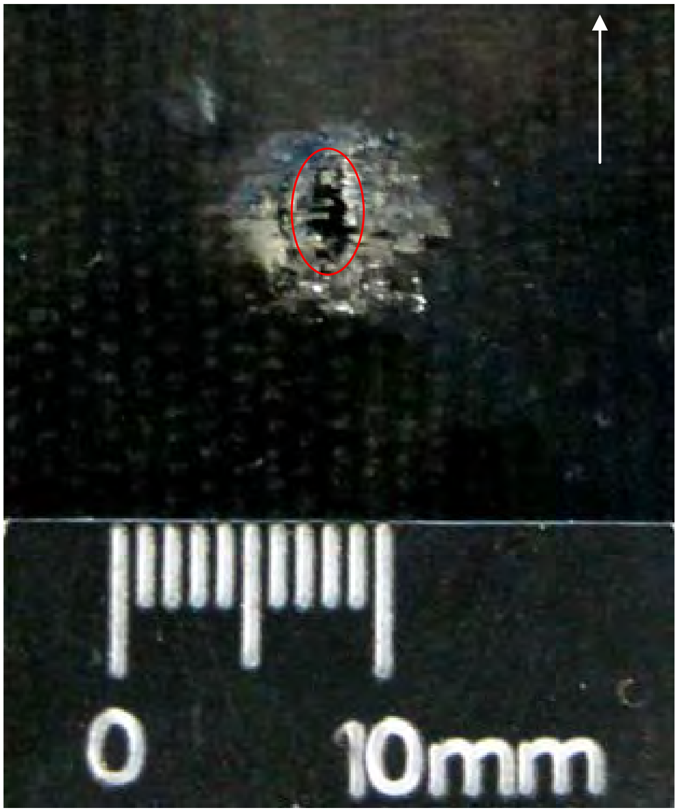


Figure 432 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

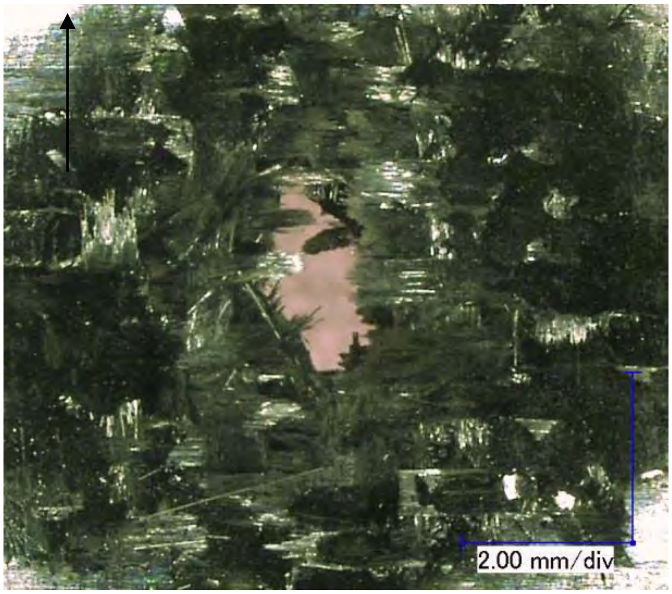


Figure 433 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 247)

HITF12308 / Test #26 (continued)

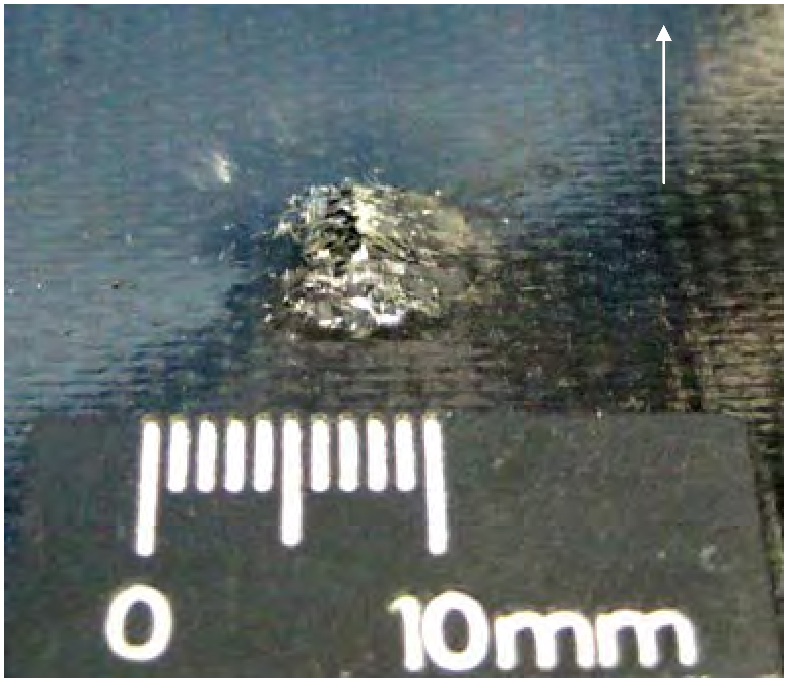


Figure 434 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

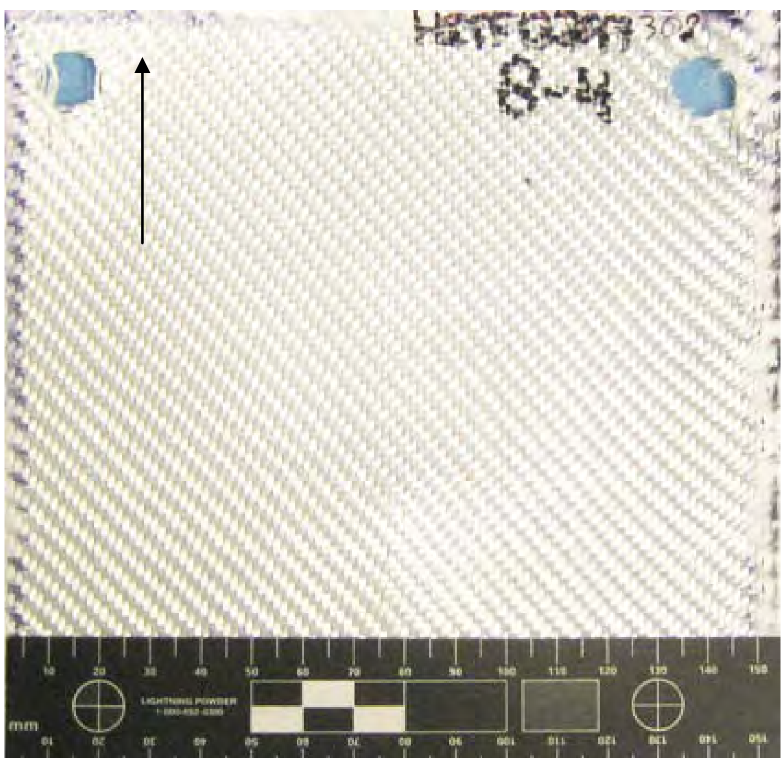


Figure 435 Overall View of Damage to Back Side of 4th Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12308 / Test #26 (continued)

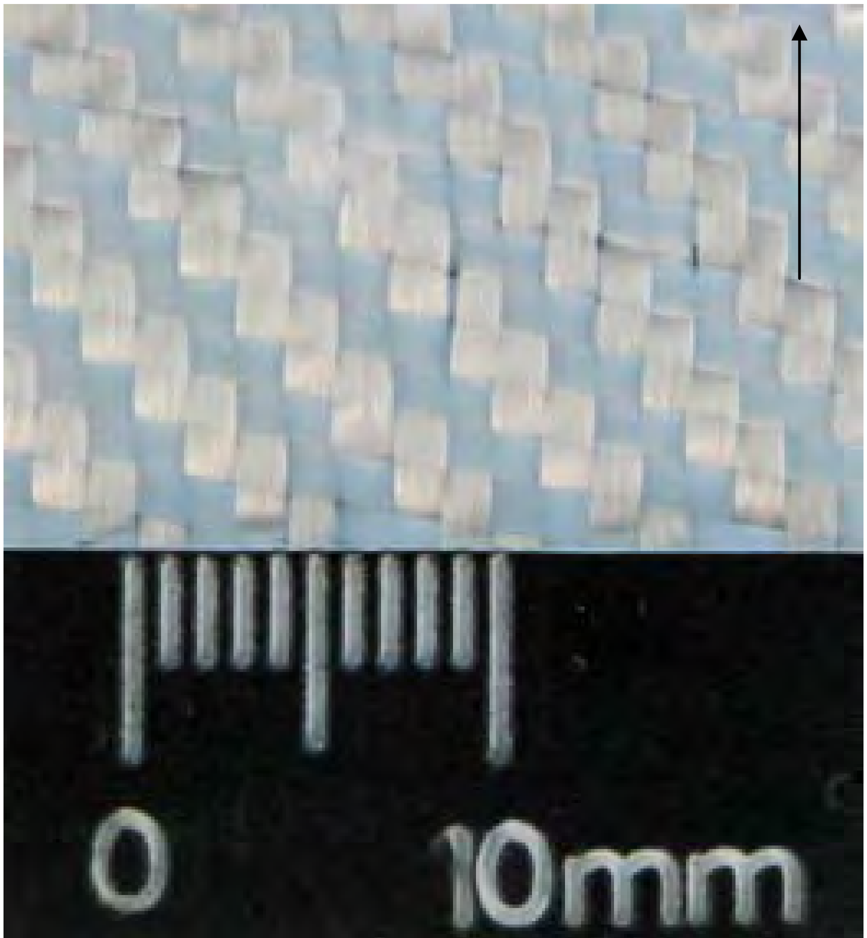


Figure 436 Overall View of Damage to Back Side of 4th Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12308-B / Test #26-B

Figure 437 Overall View of Sample in the Target Tank (post-test)

Figure 438 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12308-B / Test #26-B (continued)

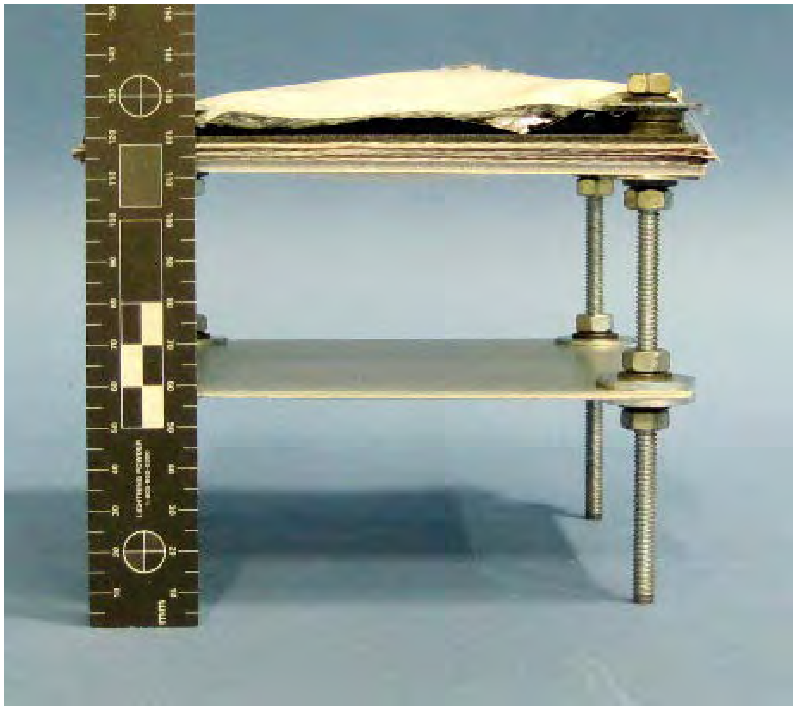


Figure 439 Overall Side View of Sample (scale in 5mm increments)

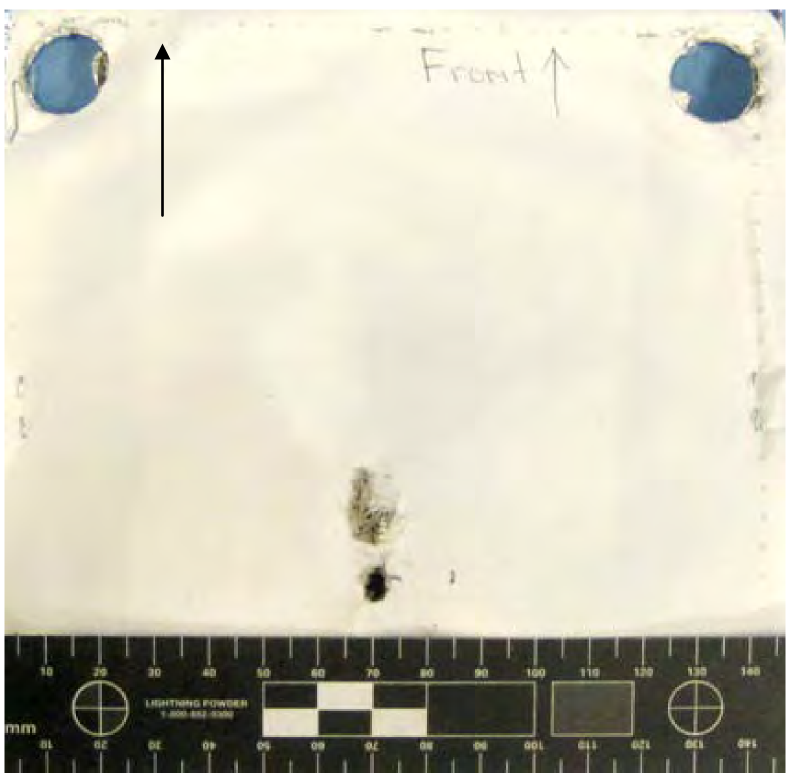


Figure 440 Overall View of Damage to Front of MLI (black arrow indicates flight path of projectile / scale in 5mm increments)

HITF12308-B / Test #26-B (continued)

Figure 441 Close-up View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile / projectile impacted within red circle)

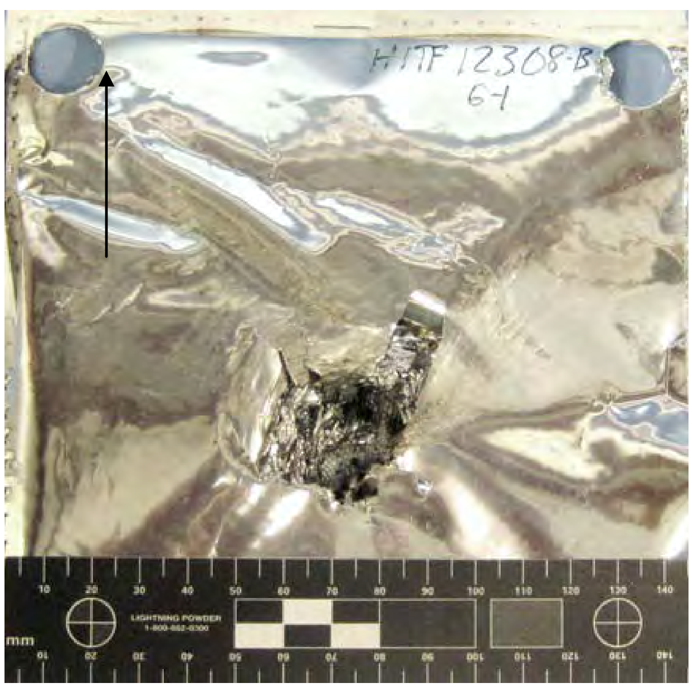


Figure 442 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12308-B / Test #26-B (continued)

Figure 443 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

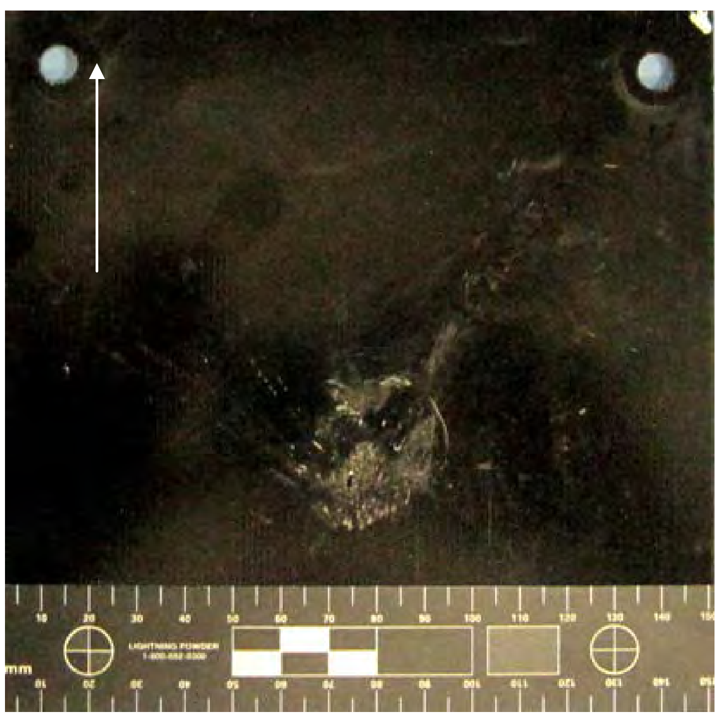


Figure 444 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12308-B / Test #26-B (continued)

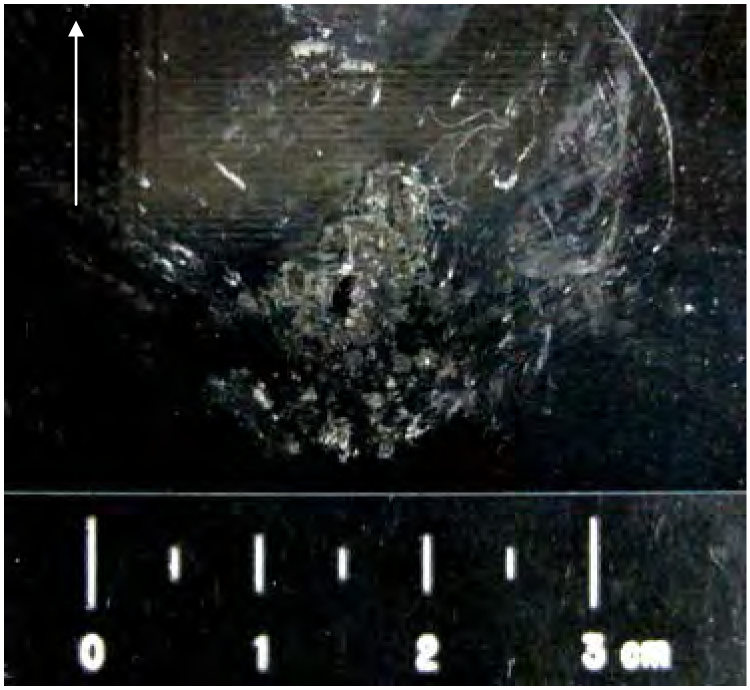


Figure 445 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

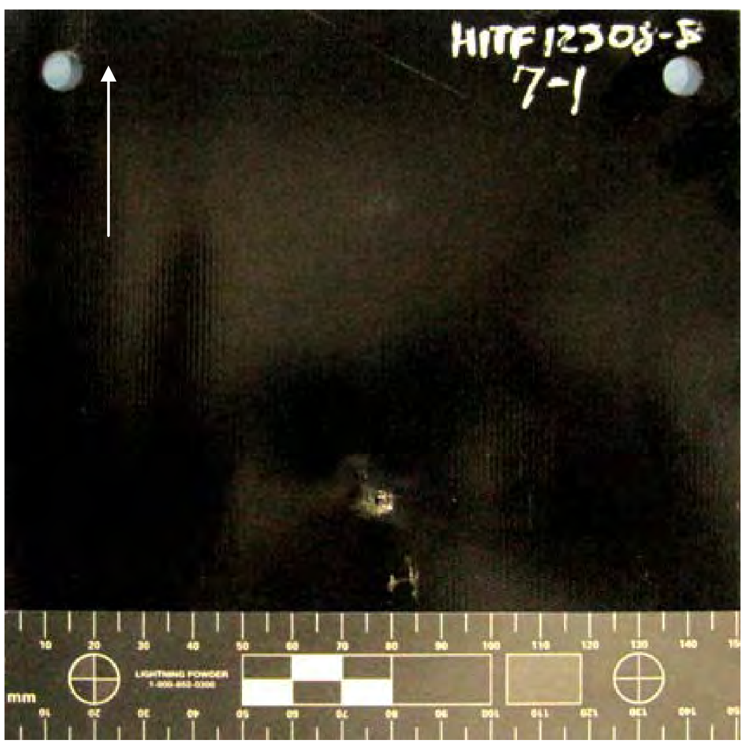


Figure 446 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12308-B / Test #26-B (continued)

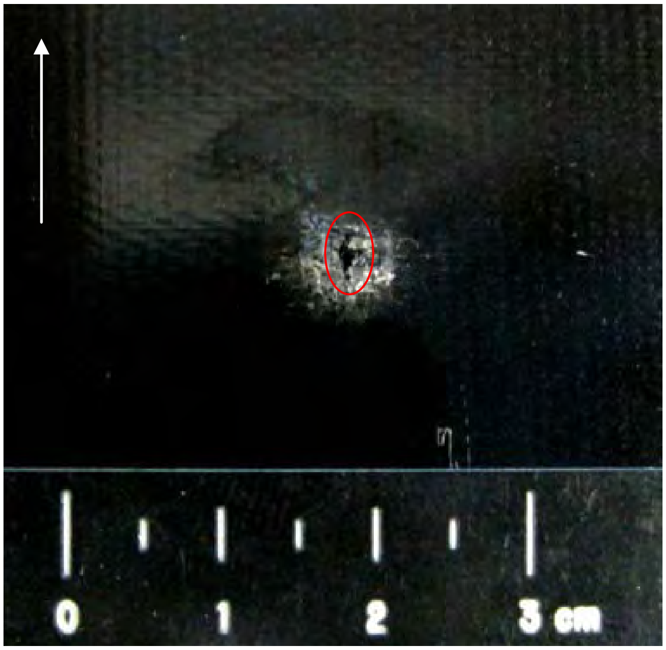


Figure 447 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

Figure 448 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 472)

HITF12308-B / Test #26-B (continued)

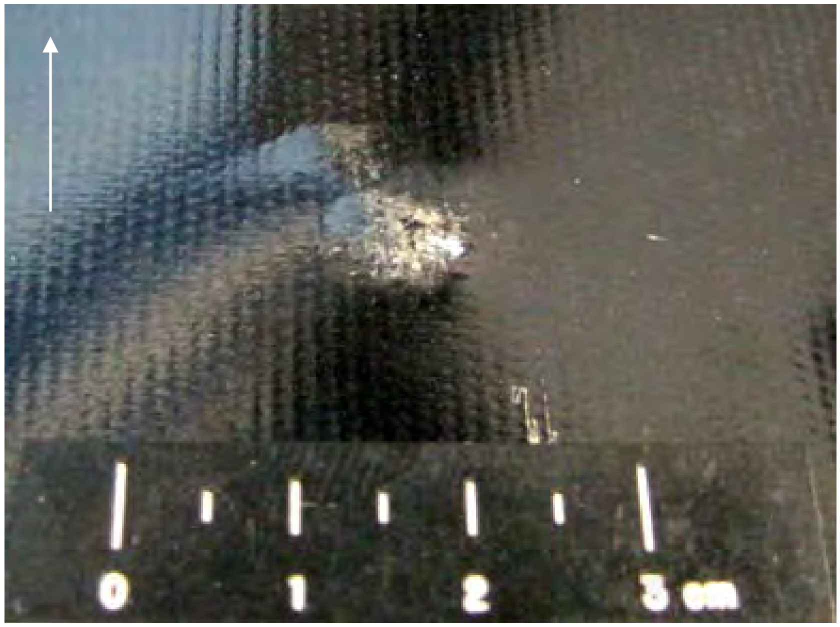


Figure 449 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

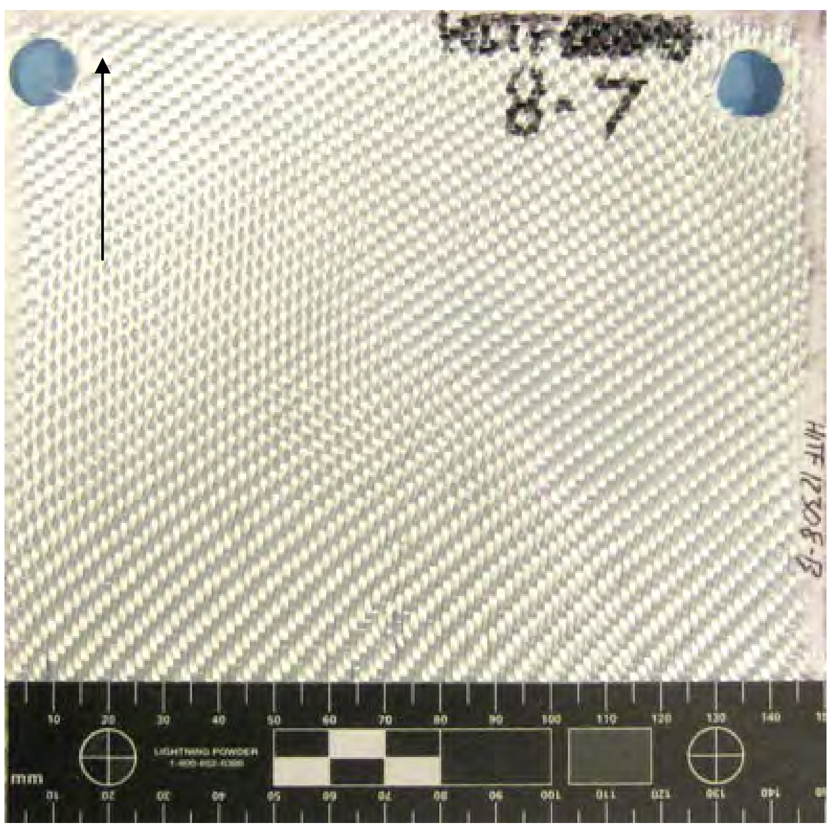


Figure 450 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12308-B / Test #26-B (continued)

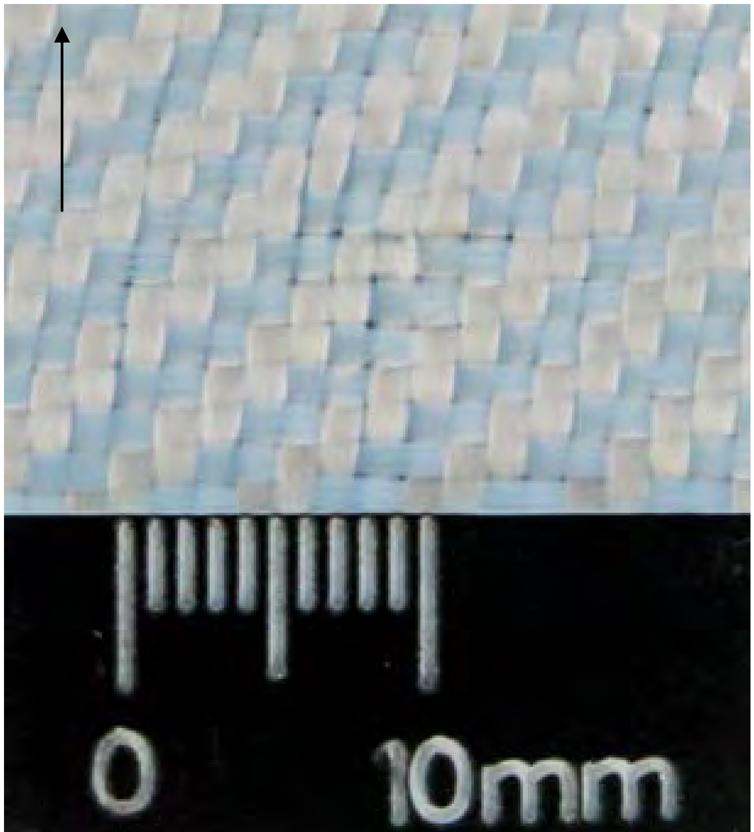


Figure 451 Close-up View of Damage to Back Side of 7th Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12309 / Test #27

Figure 452 Overall View of Sample in the Target Tank (post-test)

Figure 453 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12309 / Test #27 (continued)

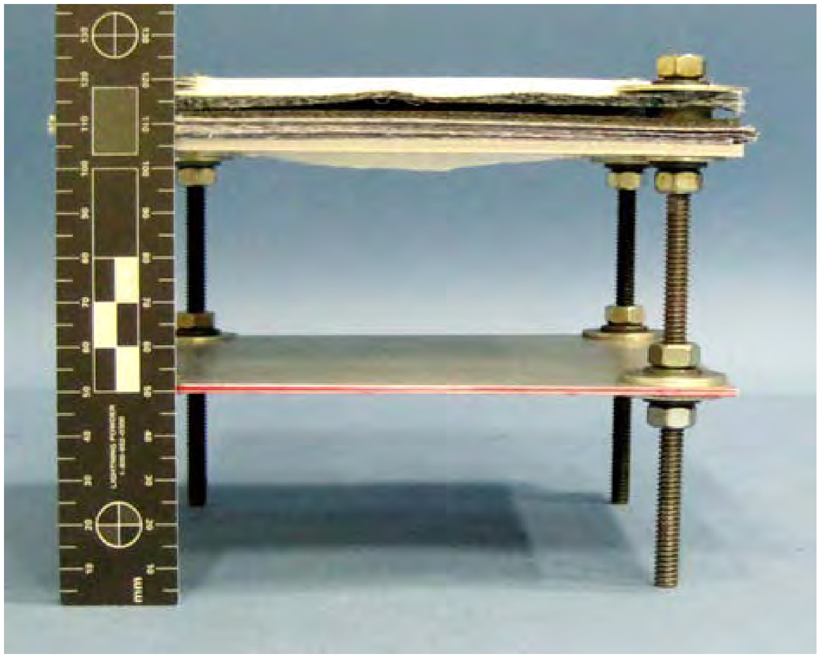


Figure 454 Overall Side View of Sample (scale in 5mm increments)

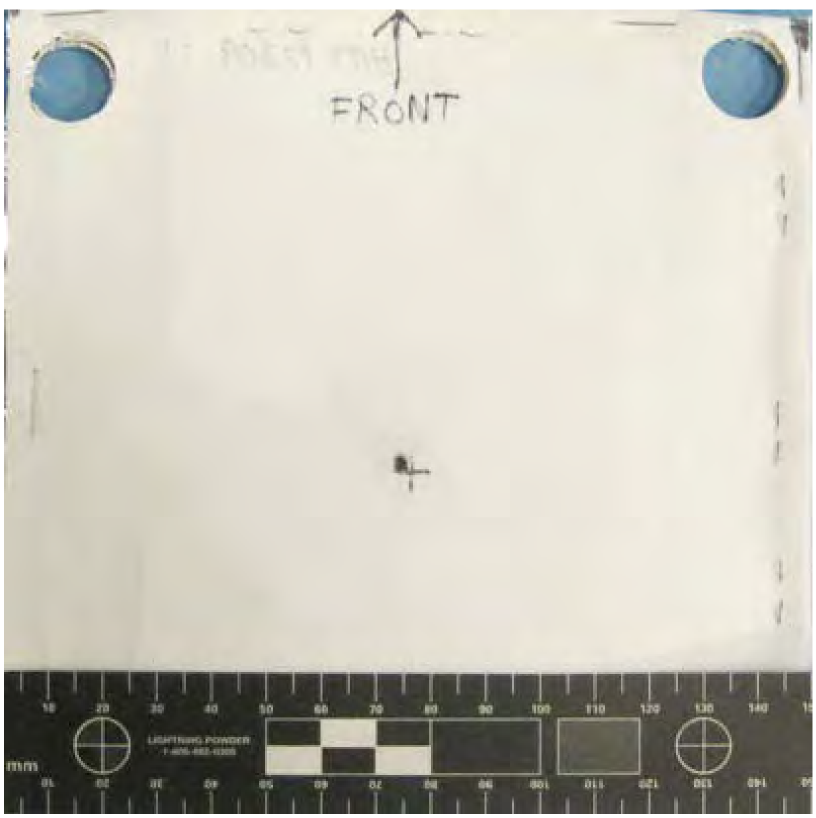


Figure 455 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12309 / Test #27 (continued)

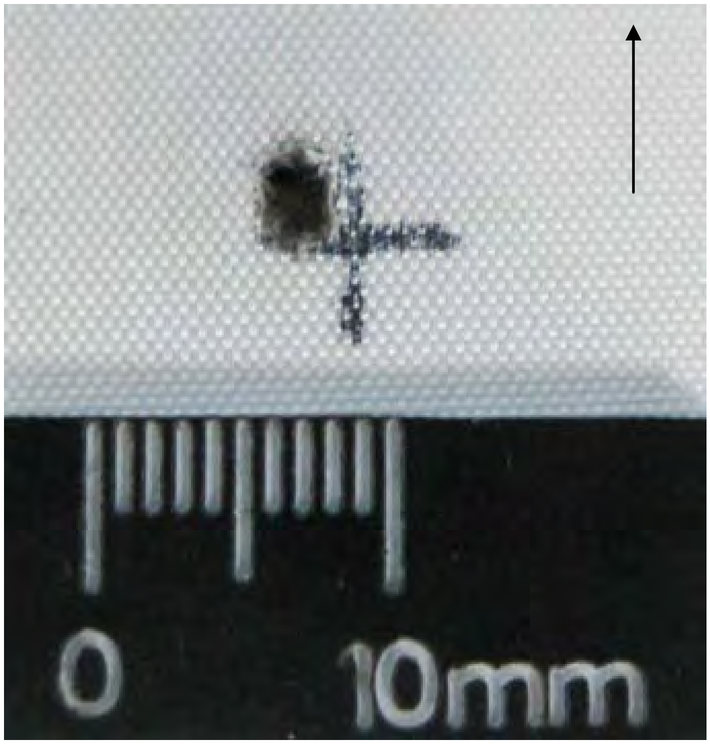


Figure 456 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

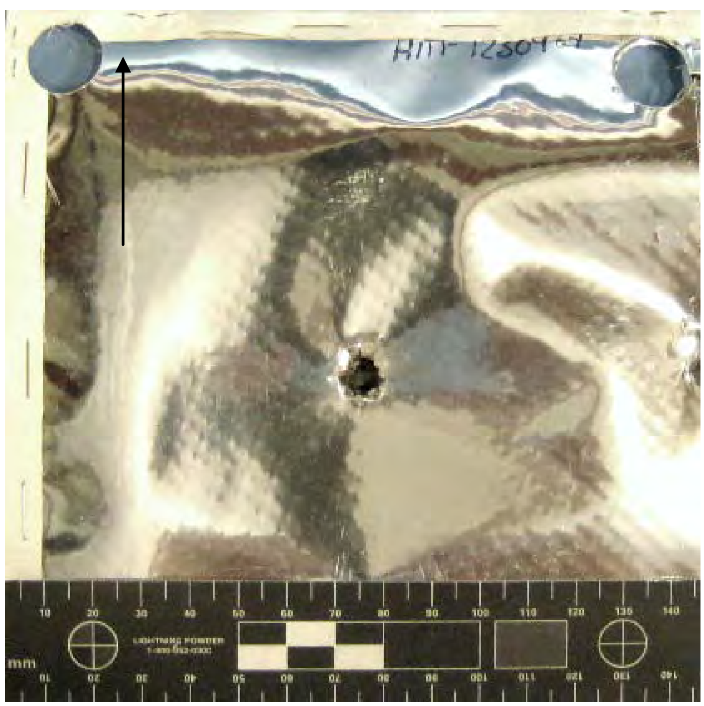


Figure 457 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12309 / Test #27 (continued)

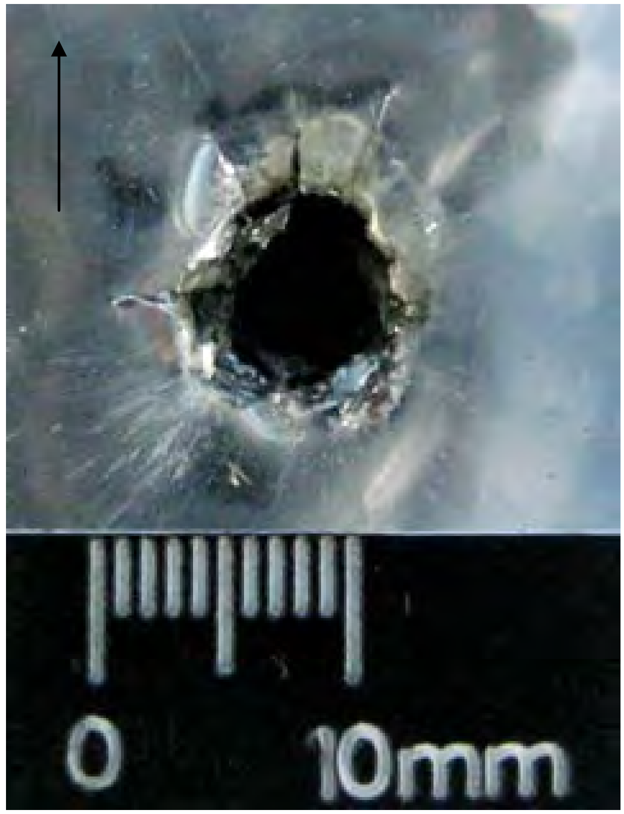


Figure 458 Close-up View of Damage to Back Side of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

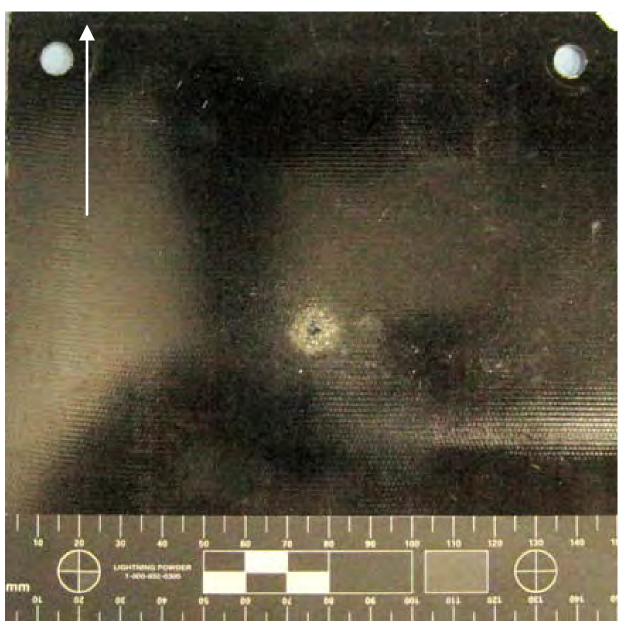


Figure 459 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12309 / Test #27 (continued)

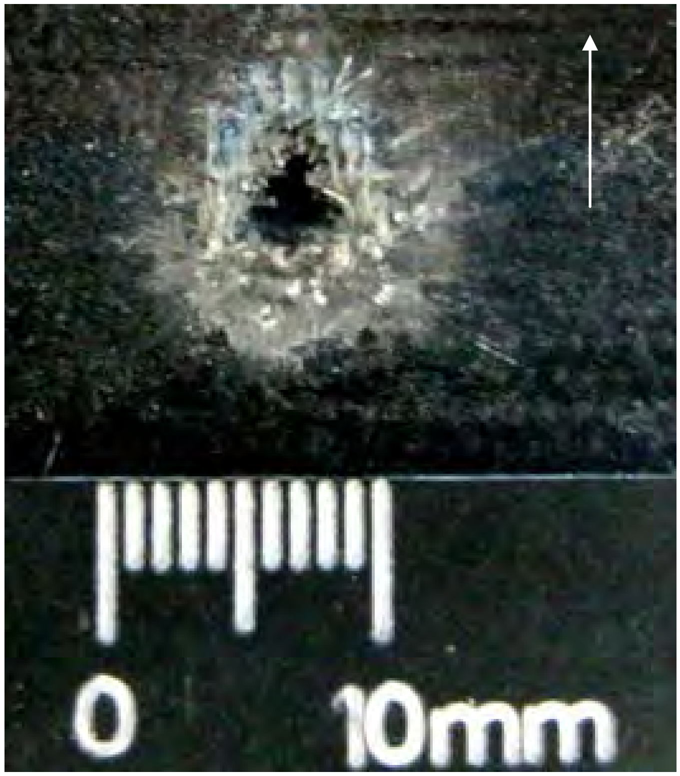


Figure 460 Close-up View of Damage to Front of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

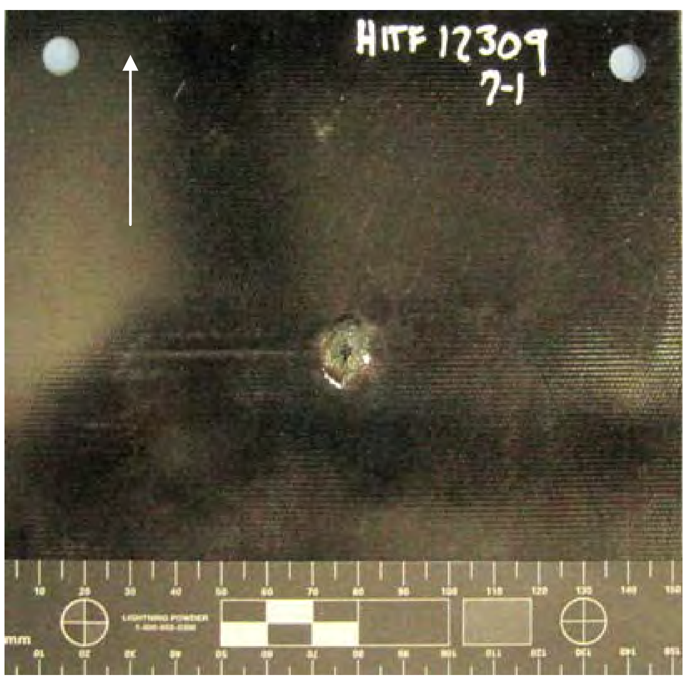


Figure 461 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12309 / Test #27 (continued)

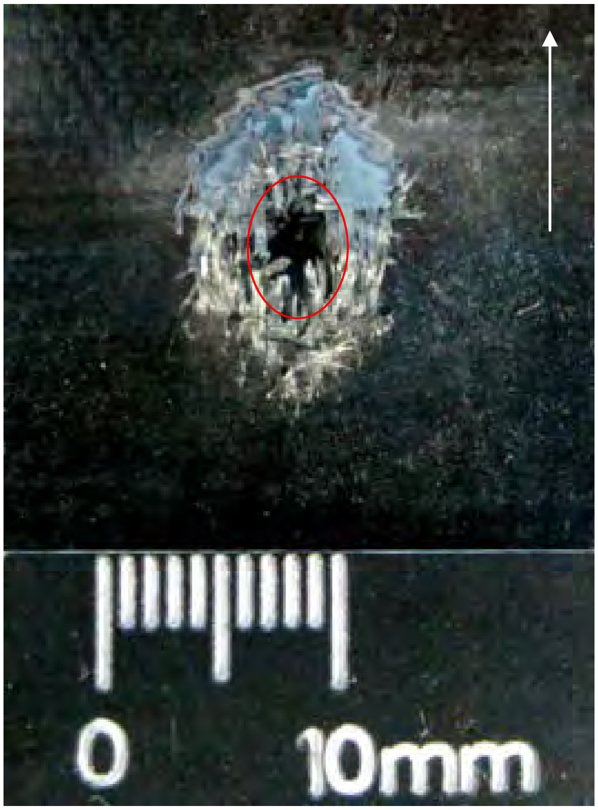


Figure 462 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

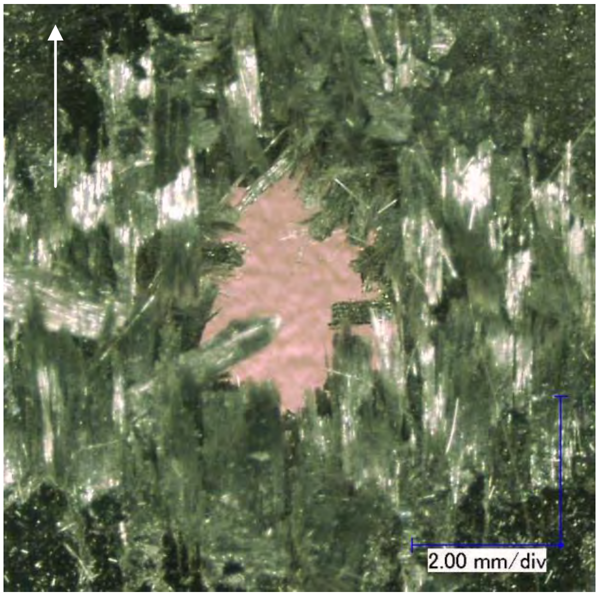


Figure 463 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (white arrow indicates flight path of projectile / damage within red circle in Figure 462)

HITF12309 / Test #27 (continued)

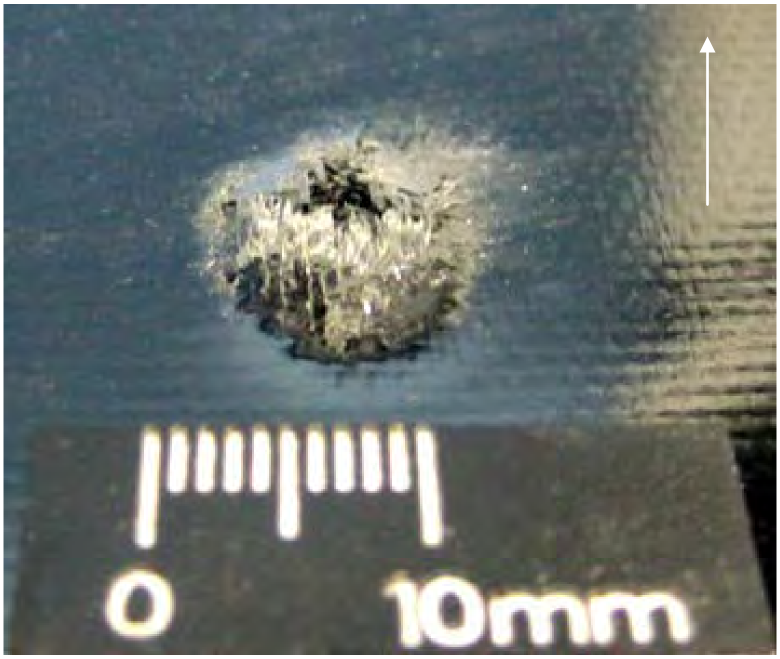


Figure 464 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

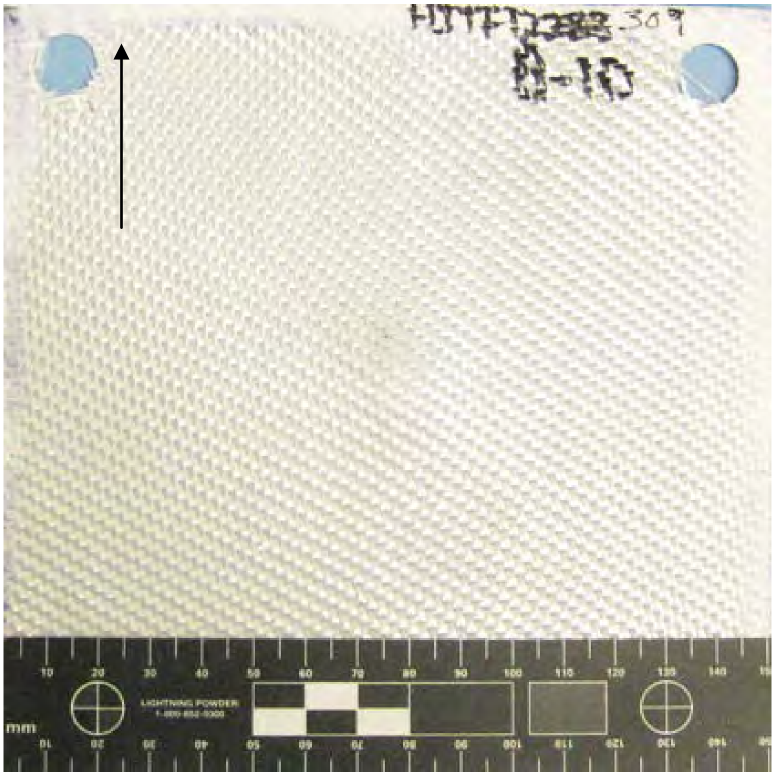


Figure 465 Overall View of Damage to Back Side of 10th Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12309 / Test #27 (continued)

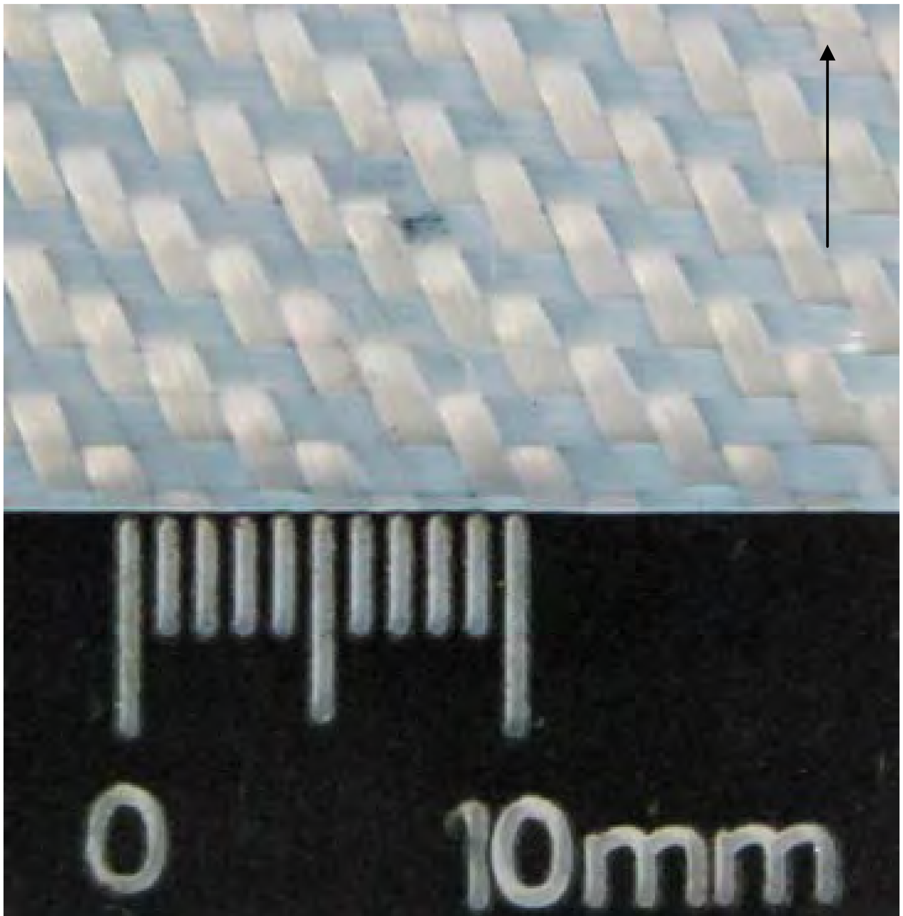


Figure 466 Close-up View of Damage to Back Side of 10th Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12310 / Test #28

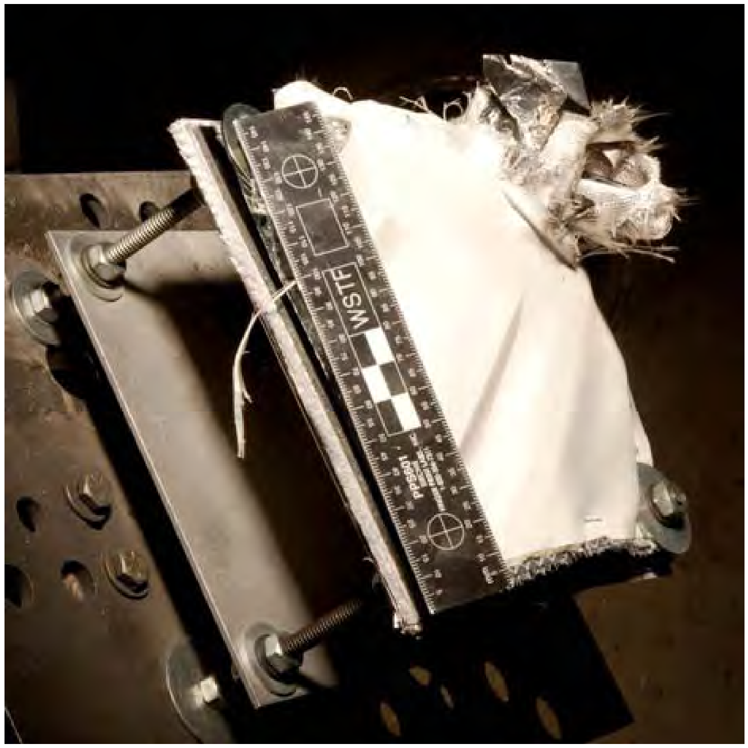


Figure 467 Overall View of Sample in the Target Tank (post-test)

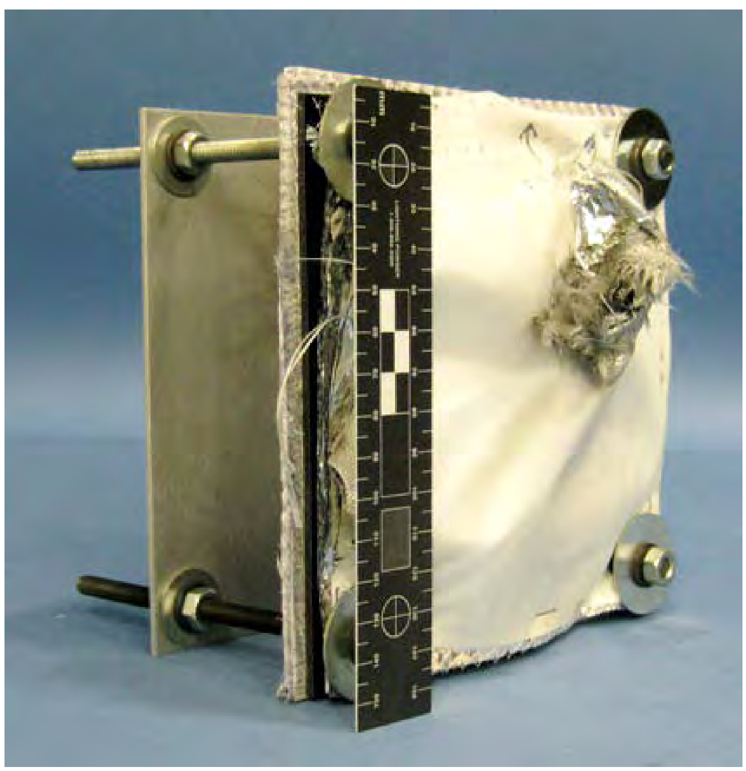


Figure 468 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12310 / Test #28 (continued)

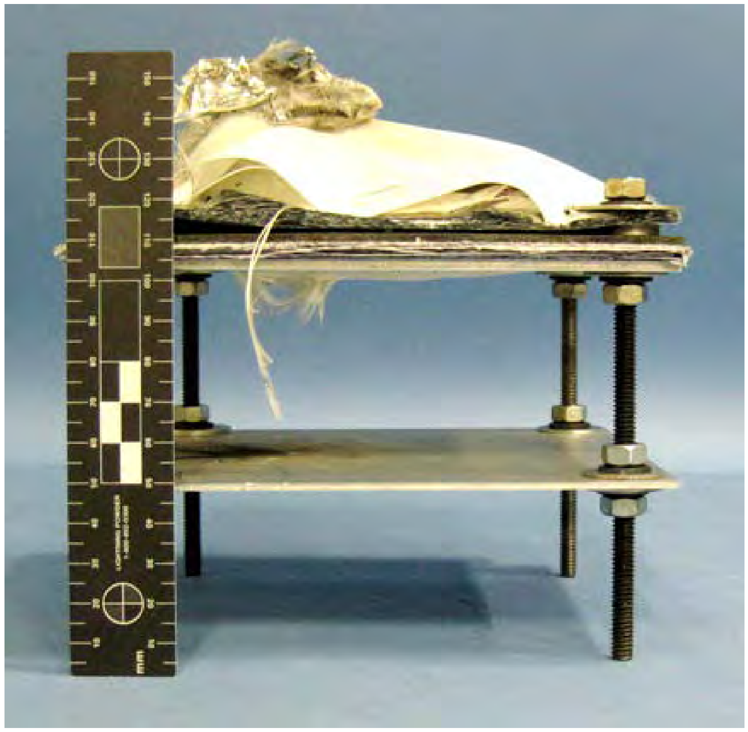


Figure 469 Overall Side View of Sample (scale in 5mm increments)

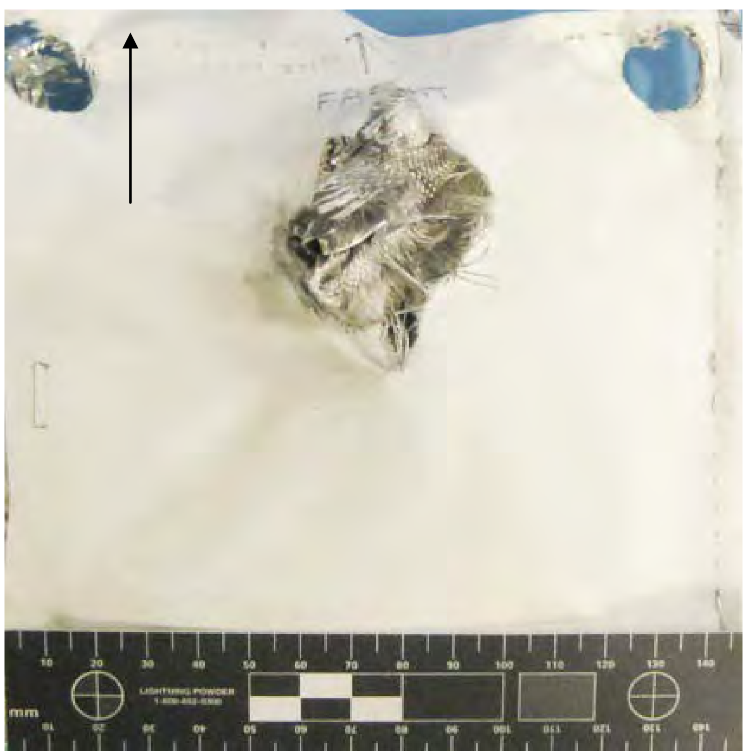


Figure 470 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12310 / Test #28 (continued)

Figure 471 Close-up View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

Figure 472 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12310 / Test #28 (continued)

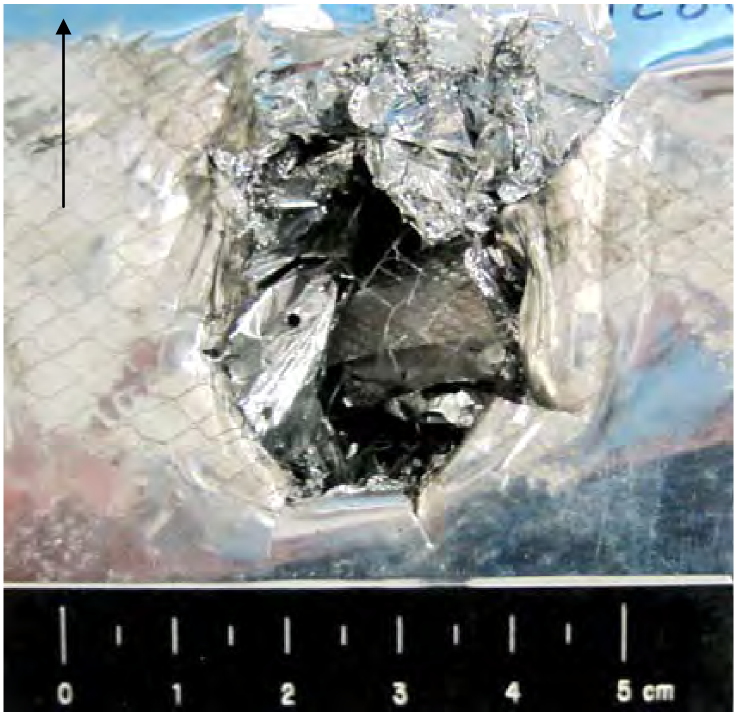


Figure 473 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

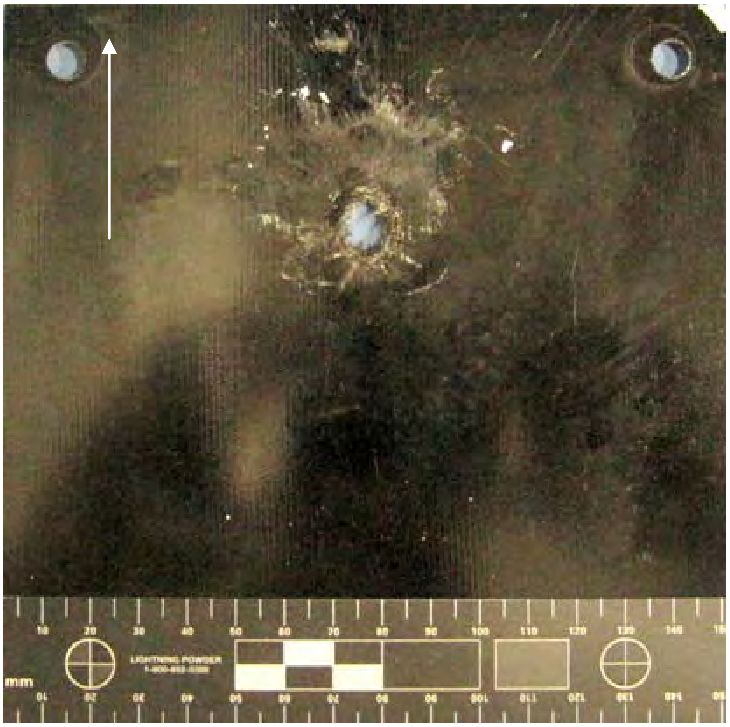


Figure 474 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12310 / Test #28 (continued)

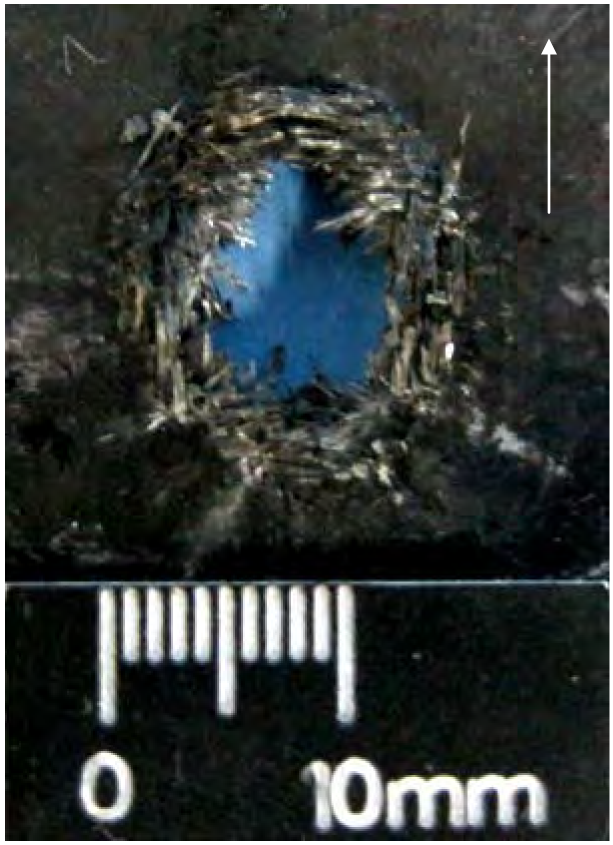


Figure 475 Close-up View of Damage to Front of NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

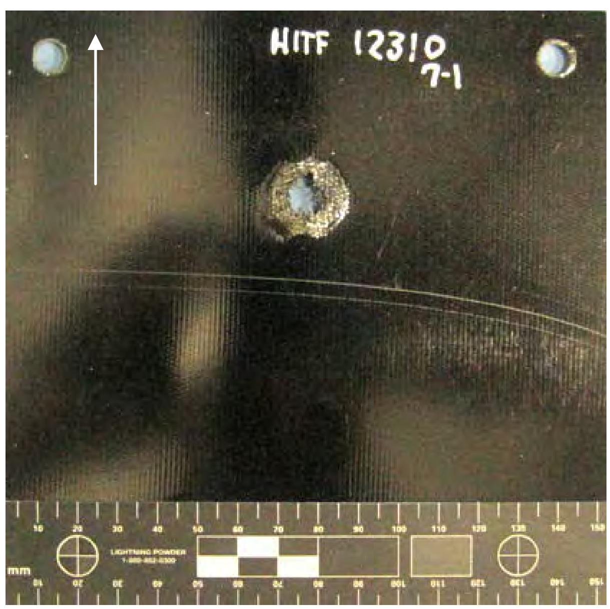


Figure 476 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12310 / Test #28 (continued)

Figure 477 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

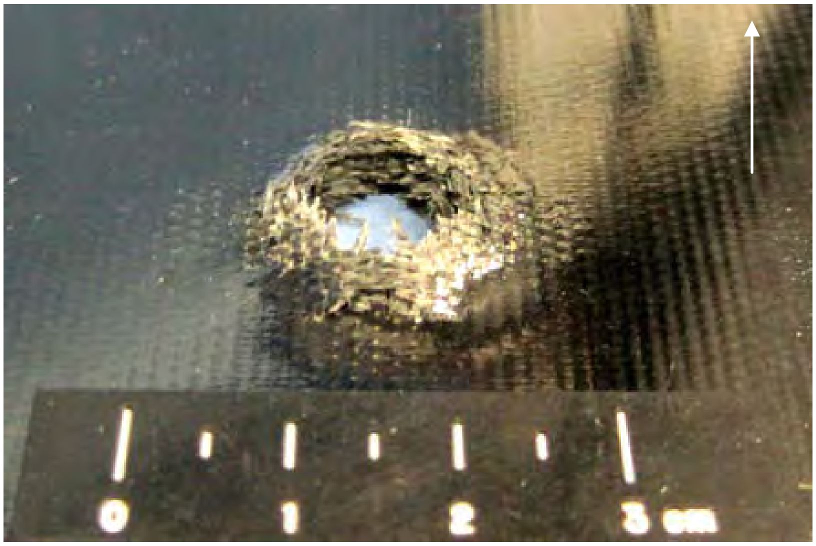


Figure 478 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12310 / Test #28 (continued)

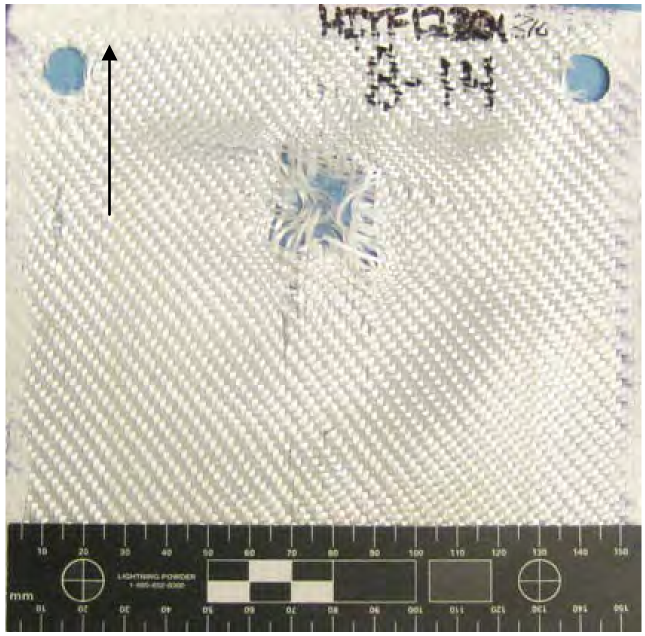


Figure 479 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

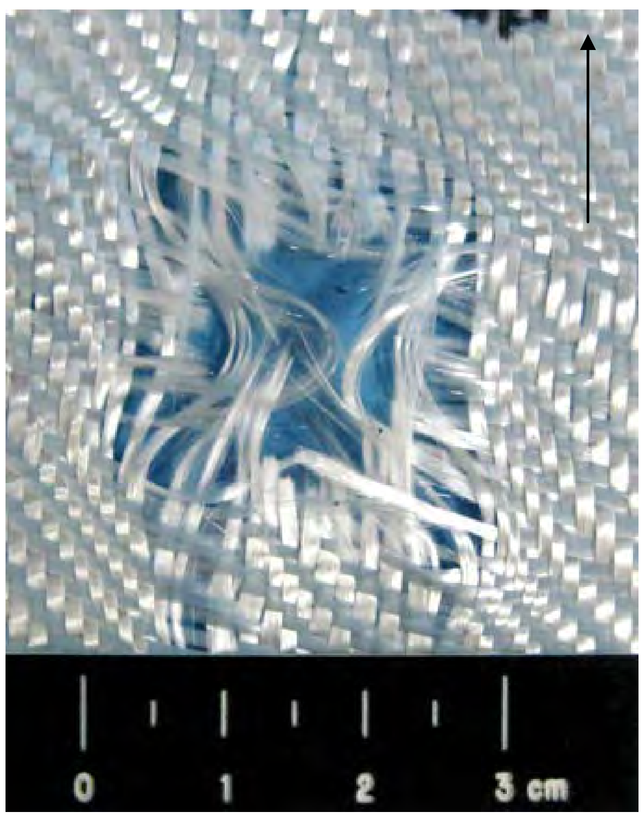


Figure 480 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12310 / Test #28 (continued)

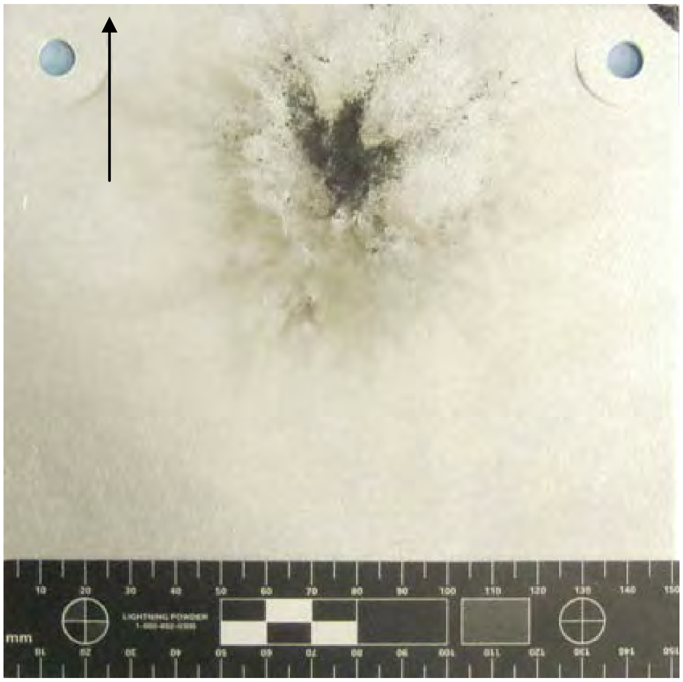


Figure 481 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

Figure 482 Close-up View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12310 / Test #28 (continued)

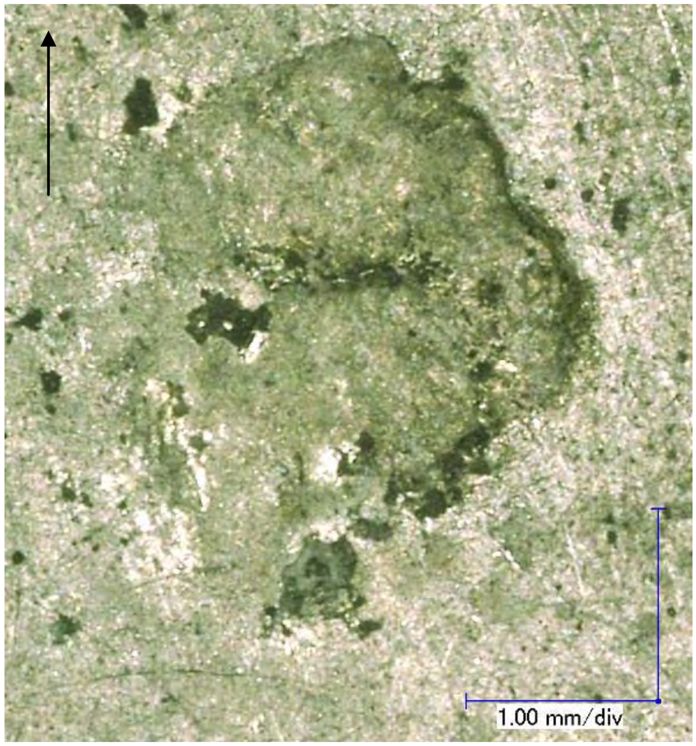


Figure 483 Close-up View of Most Significant Damage to Front of Rear Wall (black arrow indicates flight path of projectile / damage within red circle in Figure 482)

Figure 484 Overall View of Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12310 / Test #28 (continued)

Figure 485 Close-up Oblique Side View of Damage to Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12311 / Test #29

Figure 486 Overall View of Sample in the Target Tank (post-test)

Figure 487 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12311 / Test #29 (continued)

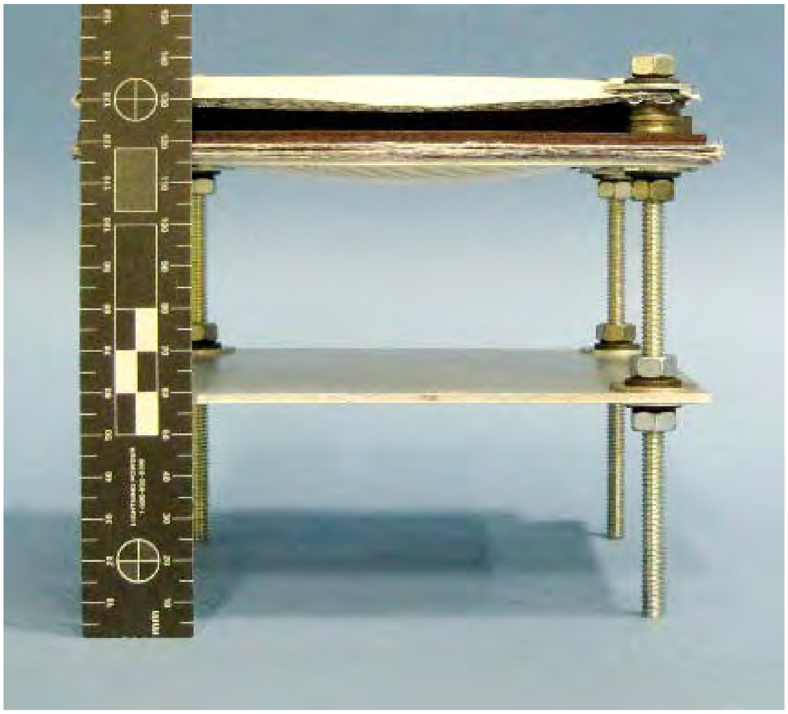


Figure 488 Overall Side View of Sample (scale in 5mm increments)

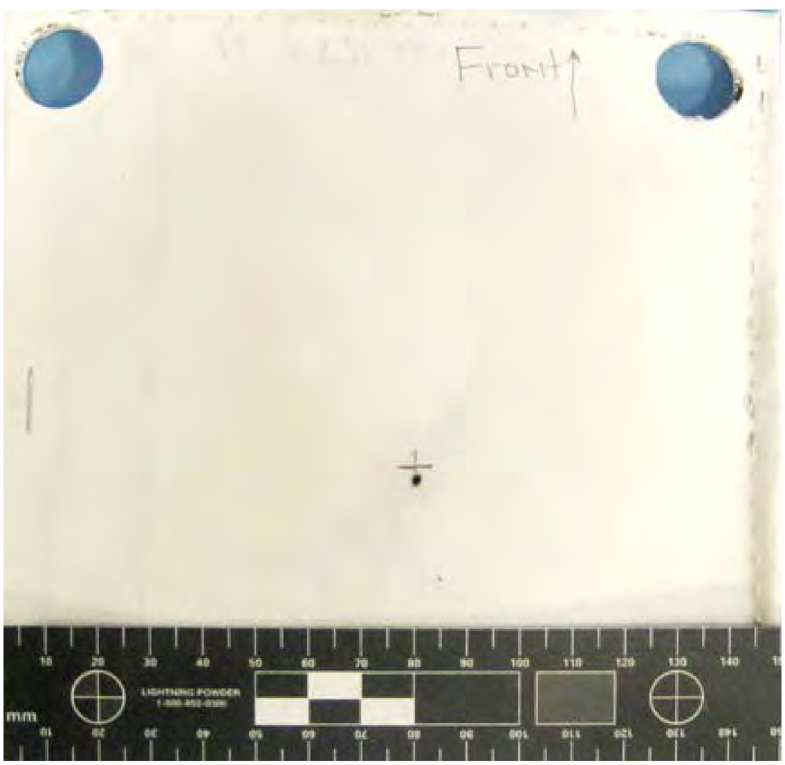


Figure 489 Overall View of Damage to Front of MLI (black arrow indicates flight path of projectile / scale in 5mm increments)

HITF12311 / Test #29 (continued)

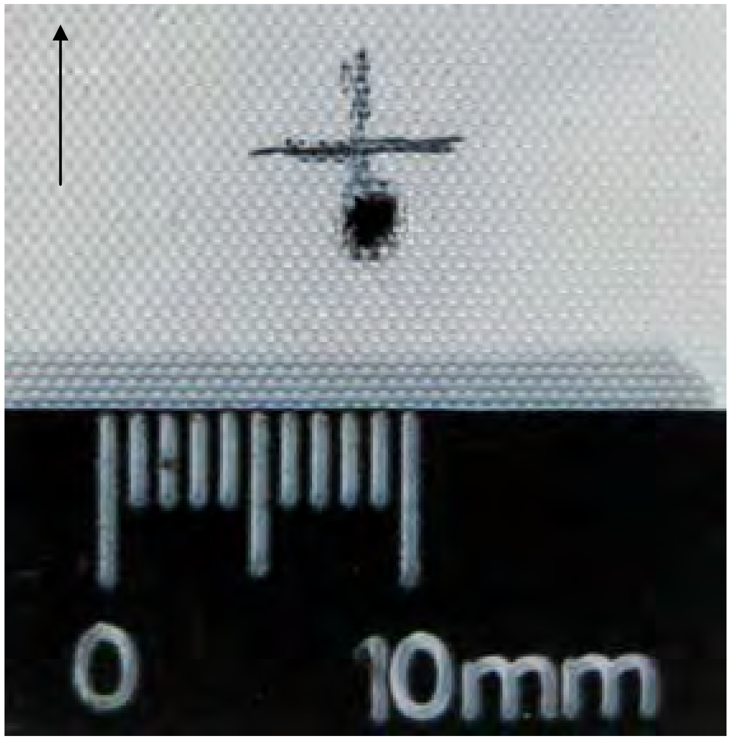


Figure 490 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

Figure 491 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12311 / Test #29 (continued)

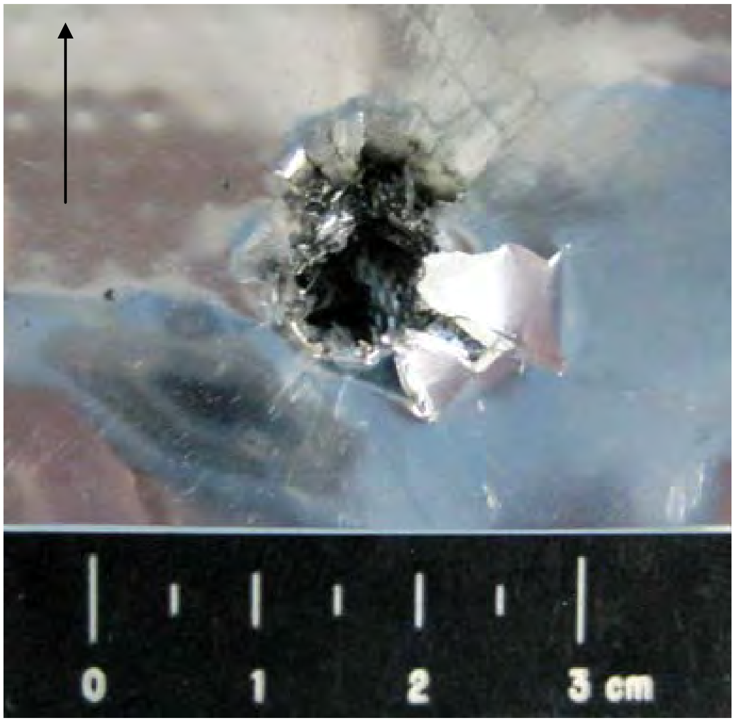


Figure 492 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

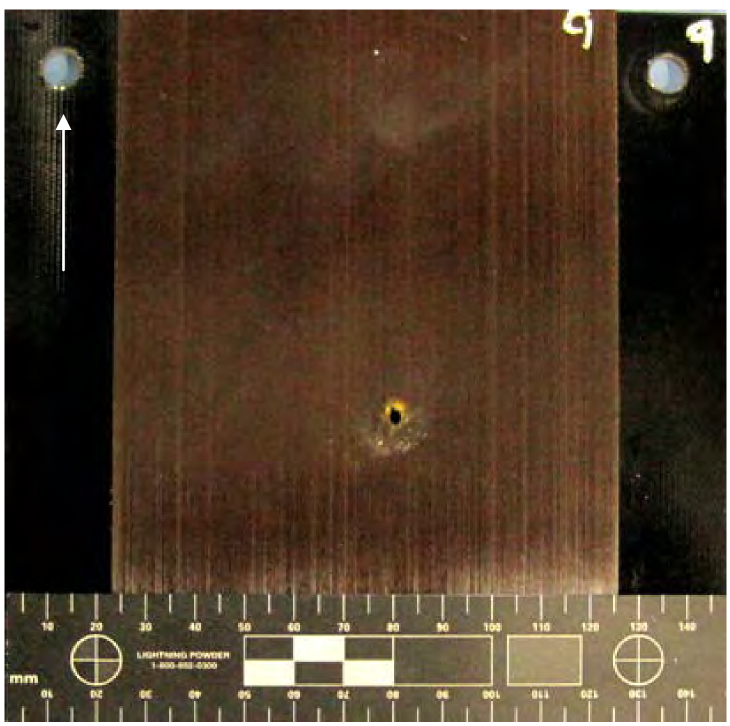


Figure 493 Overall View of Damage to Front of TORLON 5030 (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12311 / Test #29 (continued)

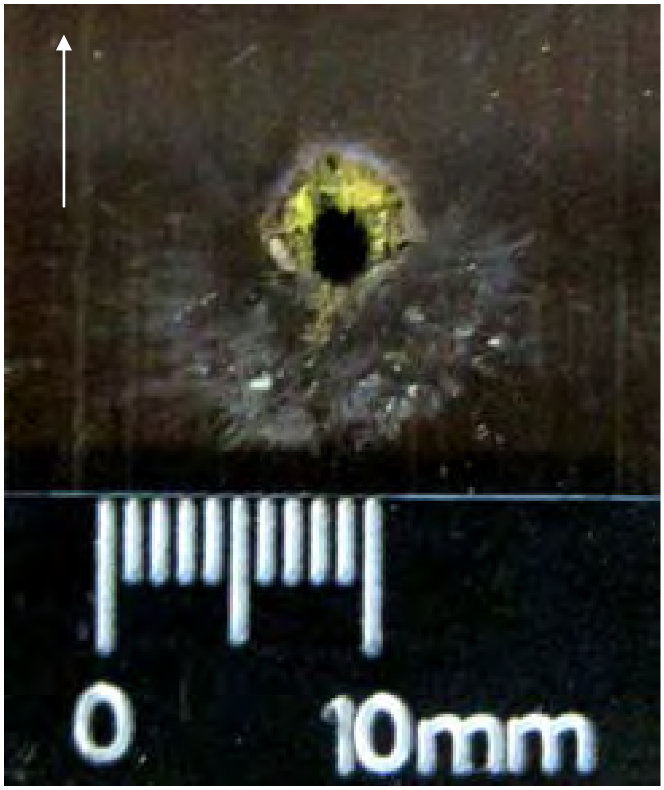


Figure 494 Close-up View of Damage to Front of TORLON 5030 (scale in 1mm increments / white arrow indicates flight path of projectile)

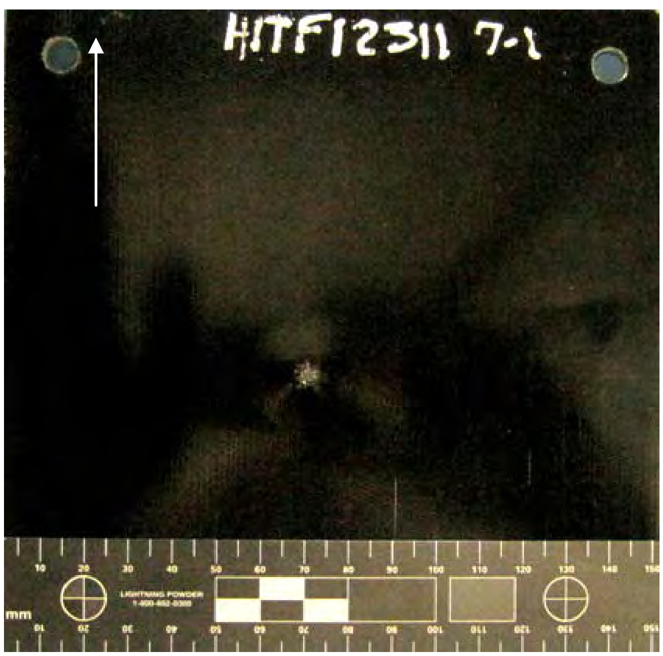


Figure 495 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12311 / Test #29 (continued)

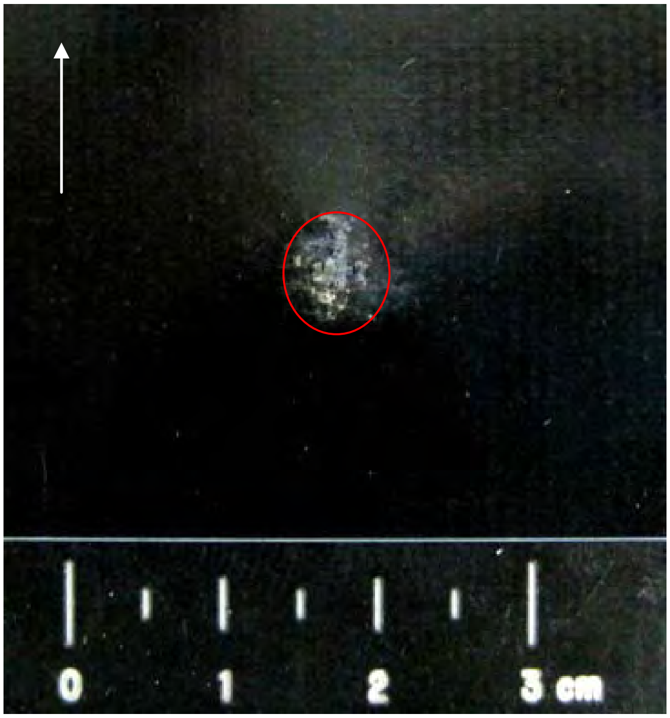


Figure 496 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

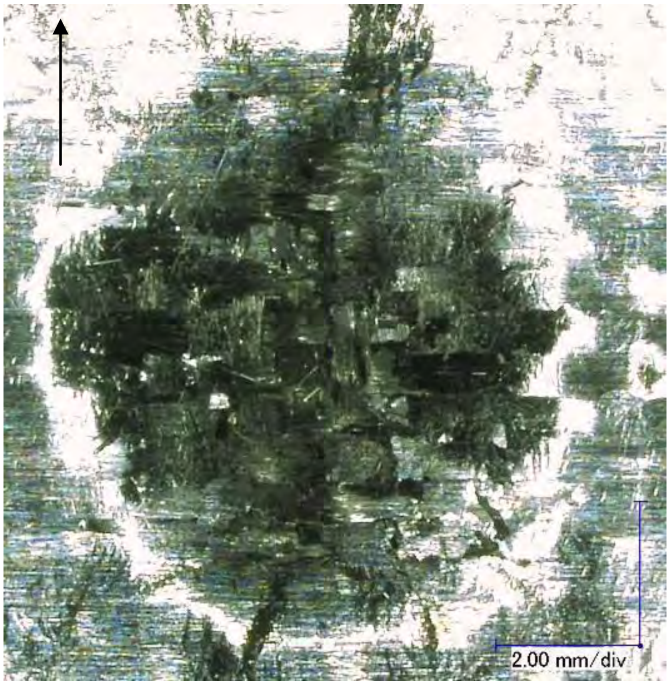


Figure 497 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 496)

HITF12311 / Test #29 (continued)

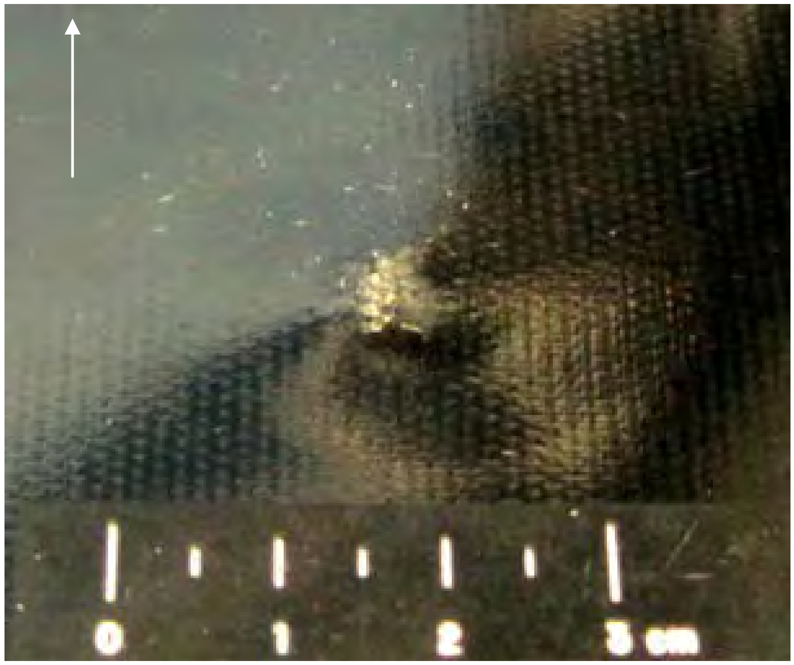


Figure 498 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

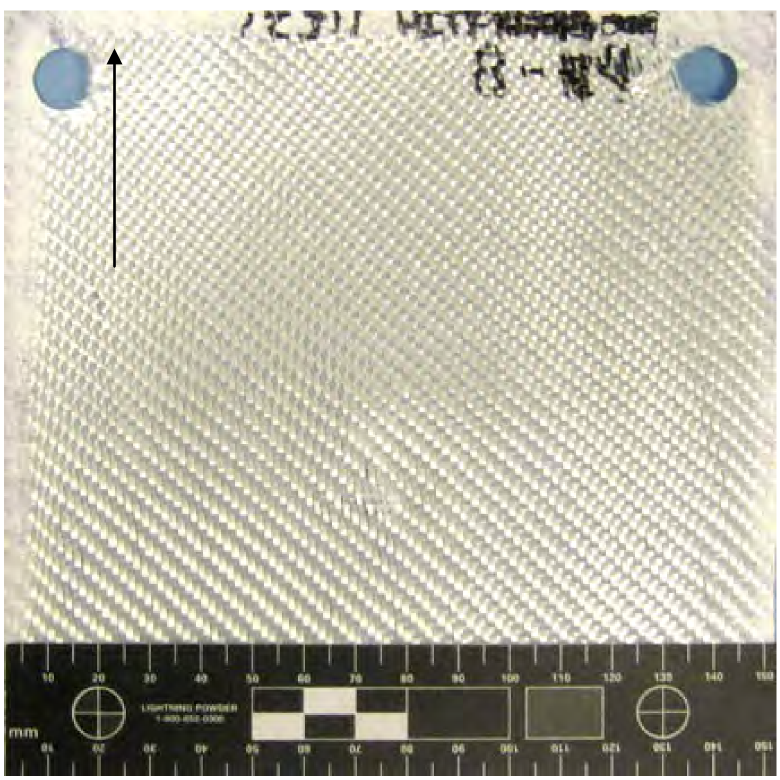


Figure 499 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12311 / Test #29 (continued)

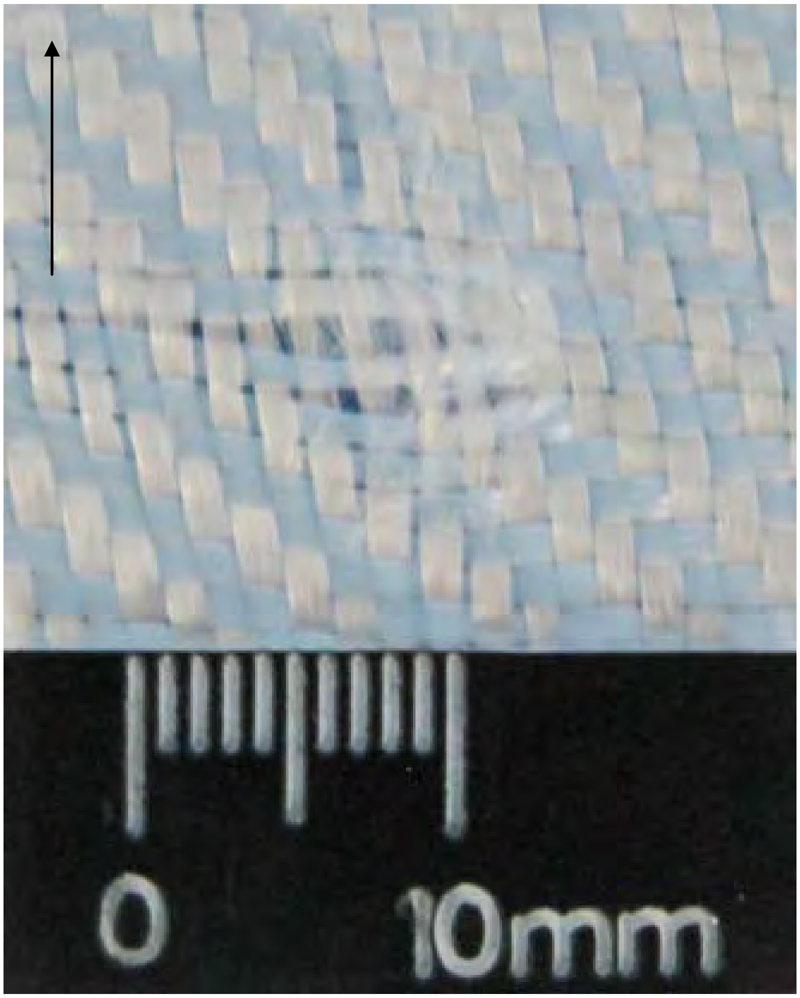


Figure 500 Close-up View of Damage to Back Side of Last Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12311-B / Test #29-B

Figure 501 Overall View of Sample in the Target Tank (post-test)

Figure 502 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12311-B / Test #29-B (continued)

Figure 503 Overall Side View of Sample (scale in 5mm increments)

Figure 504 Overall View of Damage to Front of MLI (black arrow indicates flight path of projectile / scale in 5mm increments)

HITF12311-B / Test #29-B (continued)

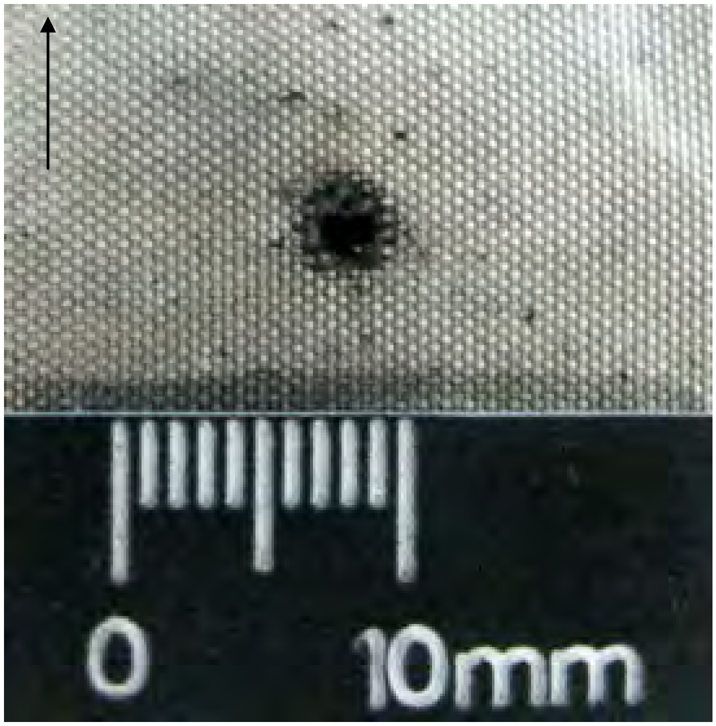


Figure 505 Close-up View of Damage to Front of MLI (scale in 1mm increments / black arrow indicates flight path of projectile)

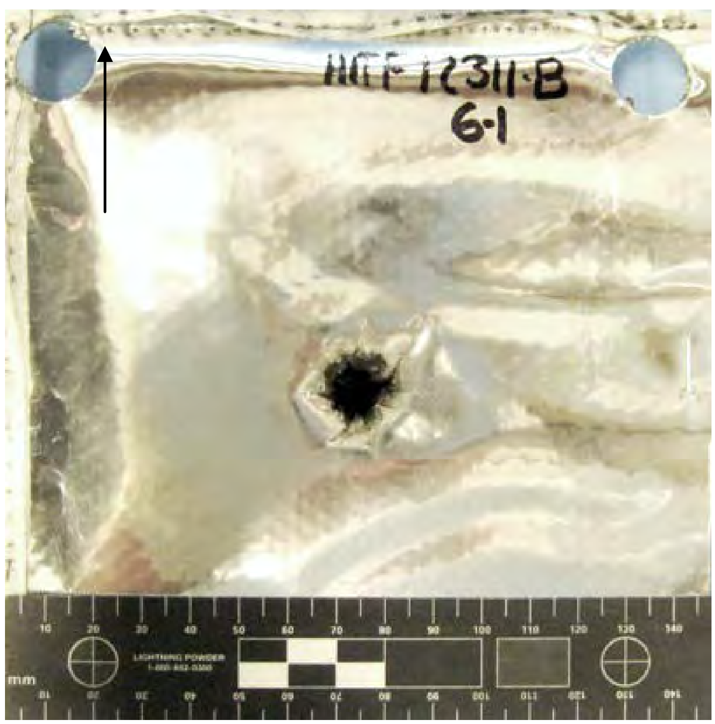


Figure 506 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12311-B / Test #29-B (continued)

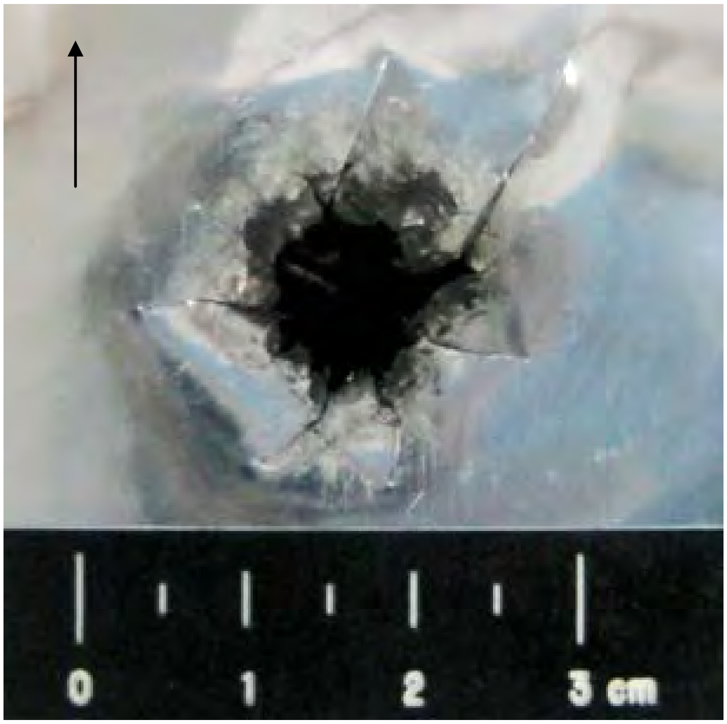


Figure 507 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

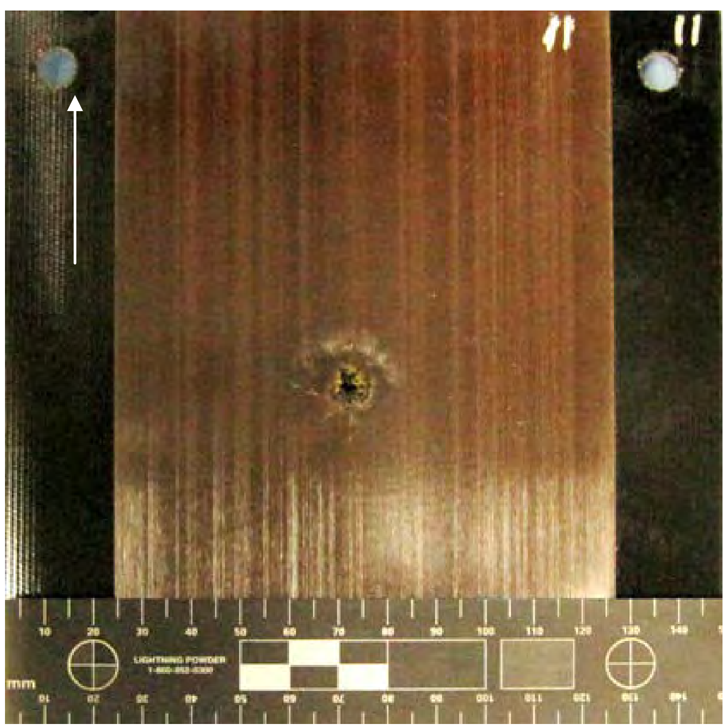


Figure 508 Overall View of Damage to Front of TORLON 5030 (scale in 5mm increments / white arrow indicates flight path of projectile)

<u>**HITF12311-B / Test #29-B (continued)**</u>

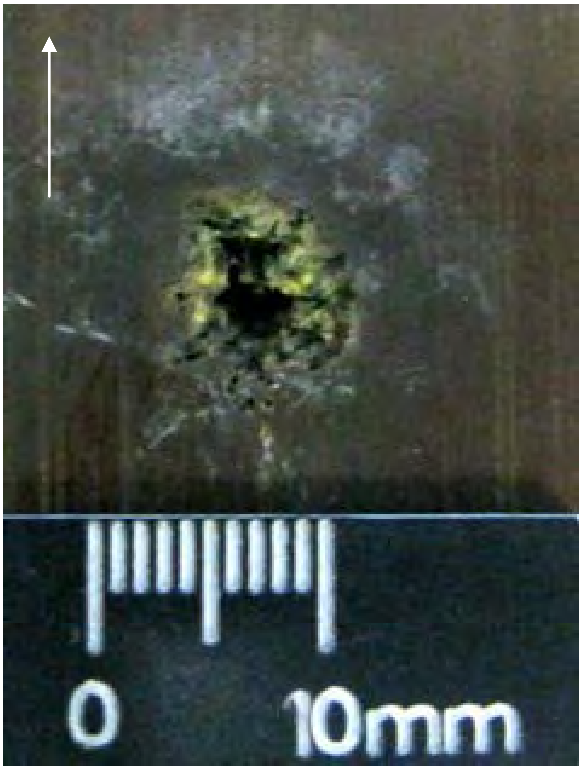


Figure 509 Close-up View of Damage to Front of TORLON 5030 (scale in 1mm increments / white arrow indicates flight path of projectile)

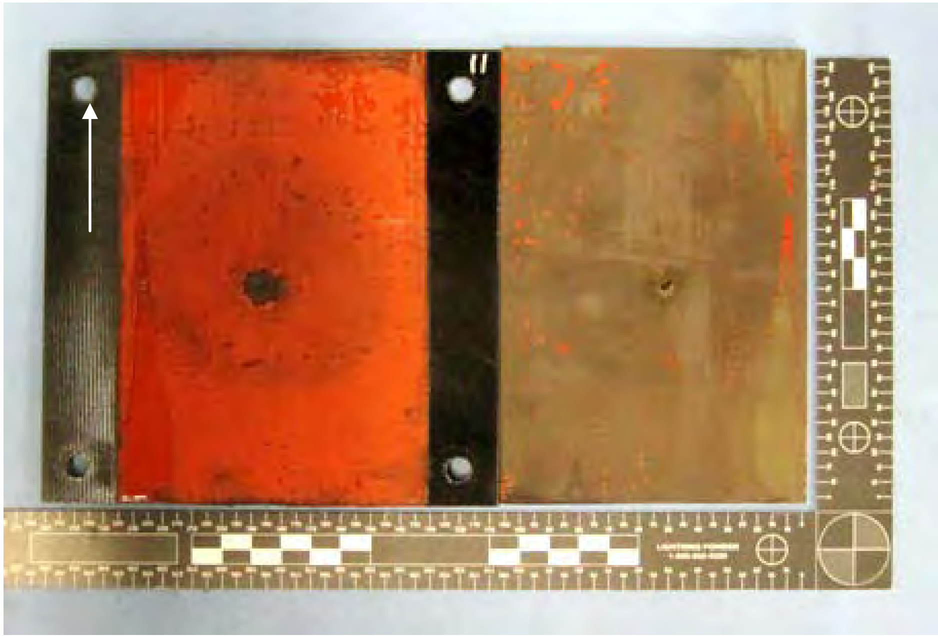


Figure 510 Overall View of Delamination of NP 504 Substrate and TORLON 5030 which exposed the Exit Damage of the TORLON 5030 and Entry Damage to the NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12311-B / Test #29-B (continued)

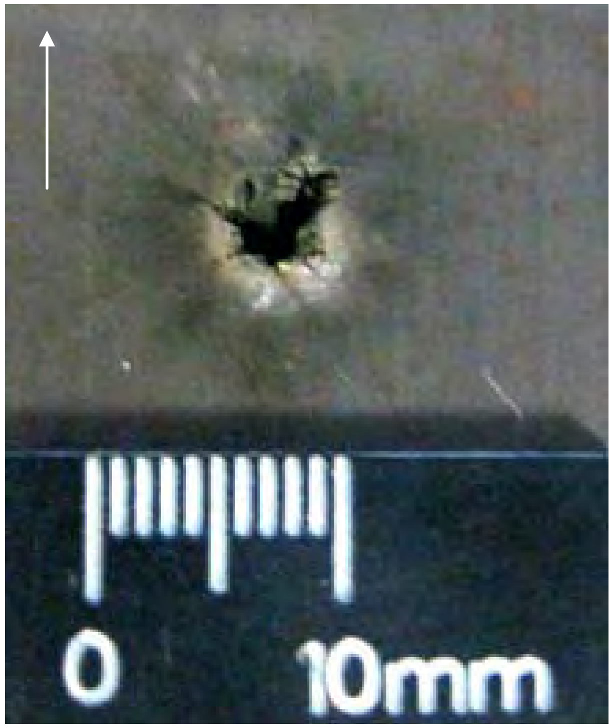


Figure 511 Close-up View of Exit Damage to TORLON 503 (scale in 1mm increments / white arrow indicates flight path of projectile)

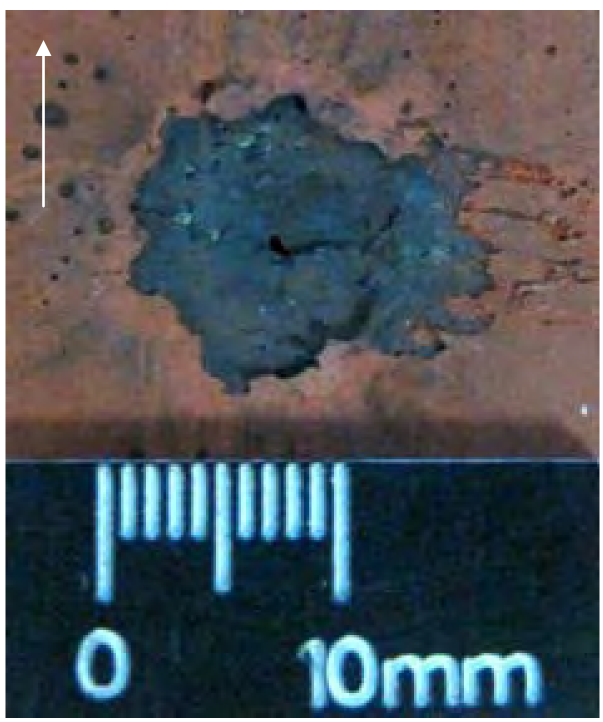


Figure 512 Close-up View of Entry Damage to NP 504 Substrate (scale in 1mm increments / white arrow indicates flight path of projectile)

HITF12311-B / Test #29-B (continued)

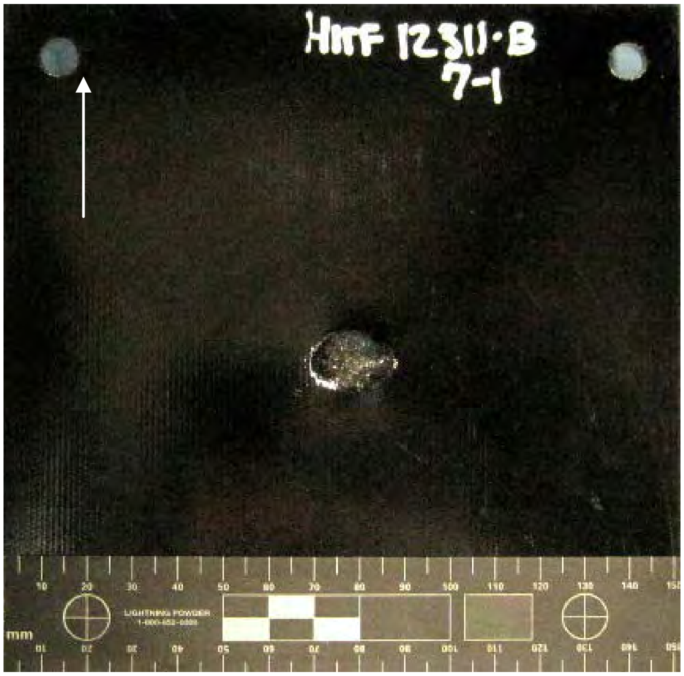


Figure 513 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

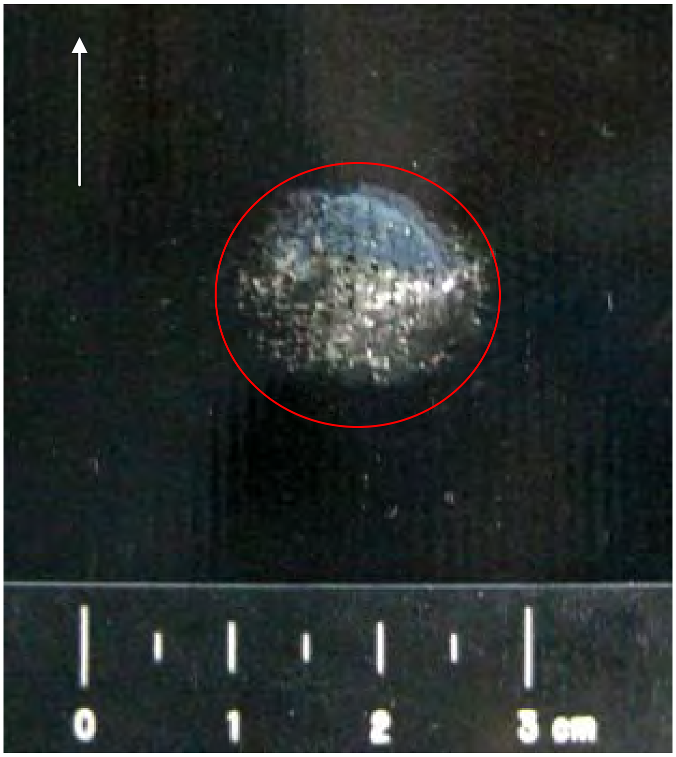


Figure 514 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12311-B / Test #29-B (continued)

Figure 515 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 514)

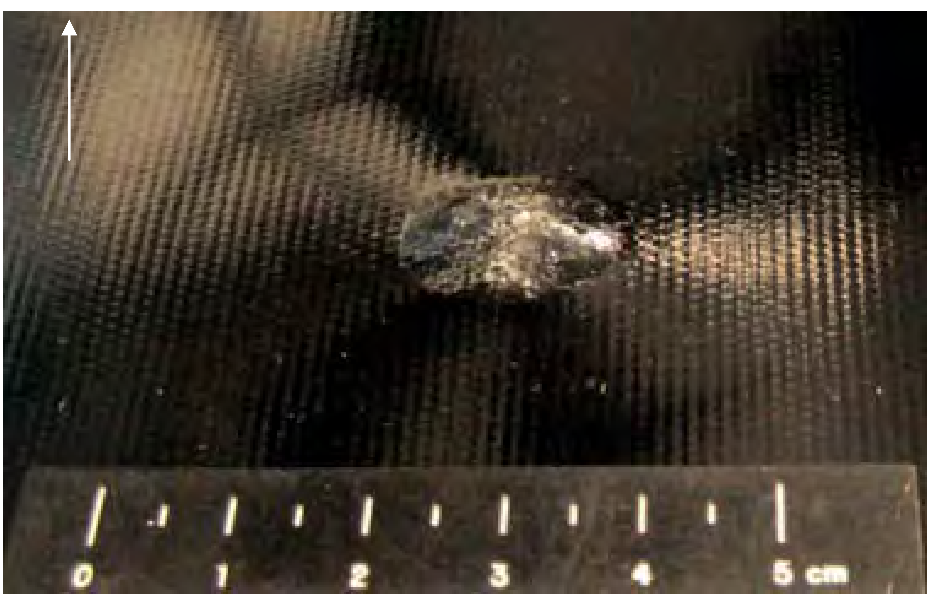


Figure 516 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12311-B / Test #29-B (continued)

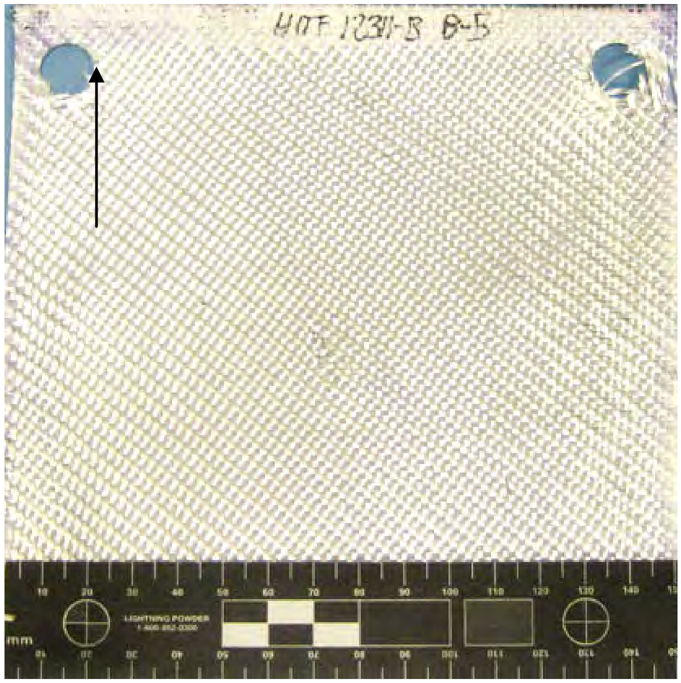


Figure 517 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

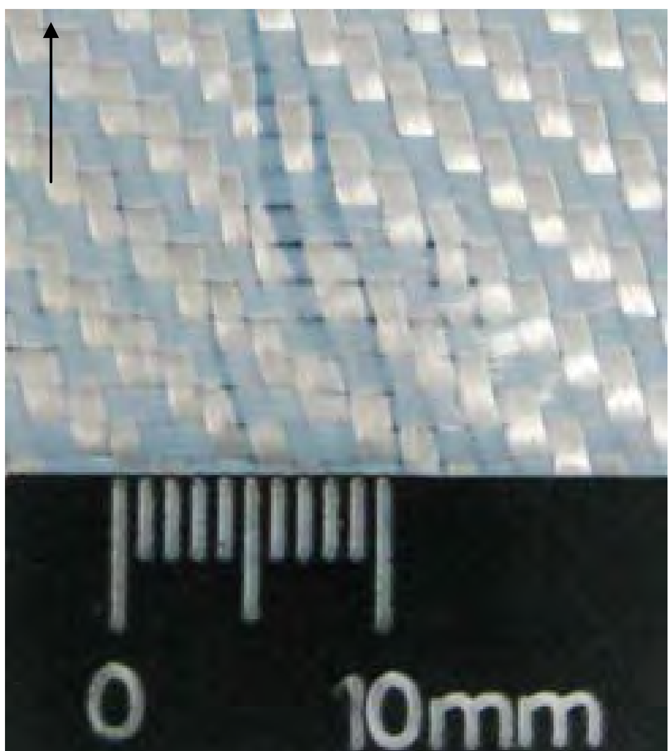


Figure 518 Close-up View of Damage to Back Side of 5th Fiberglass Layer (scale in 1mm increments / black arrow indicates flight path of projectile)

HITF12312 / Test #30

Figure 519 Overall View of Sample in the Target Tank (post-test)

Figure 520 Overall View of TORLON 5030 Delaminated from NP 504 Substrate and MLI Blanket Displaced from Test Configuration All Bi-products of the Impact Test (scale in 5mm increments)

HITF12312 / Test #30 (continued)

Figure 521 Overall Oblique Front View of Sample (scale in 5mm increments / with TORLON 5030 and MLI displaced from test configuration)

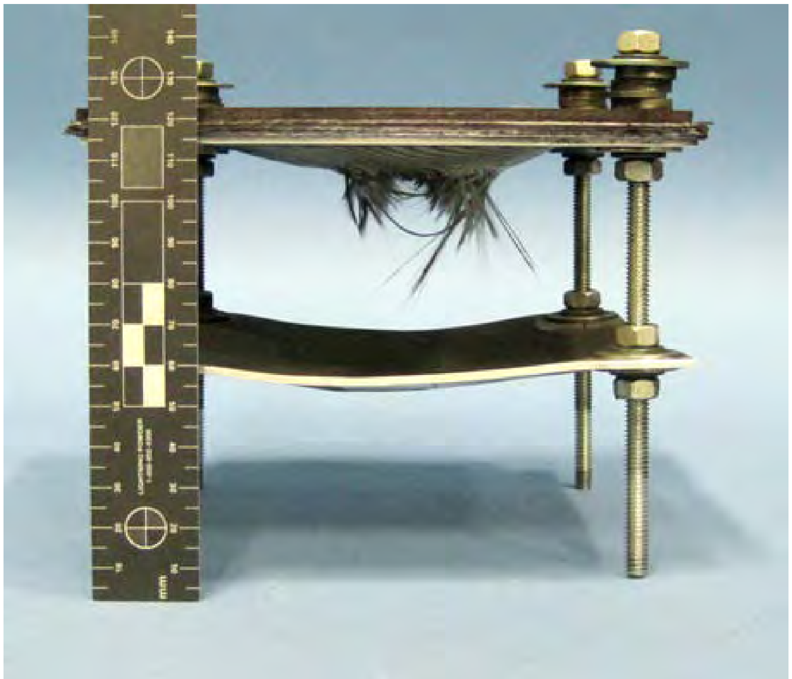


Figure 522 Overall Side View of Sample (scale in 5mm increments / with TORLON 5030 and MLI displaced from test configuration)

HITF12312 / Test #30 (continued)

Figure 523 Overall View of Damage to Front of TORLON 5030 Delaminated from Substrate (black arrow indicates flight path of projectile / scale in 1cm increments)

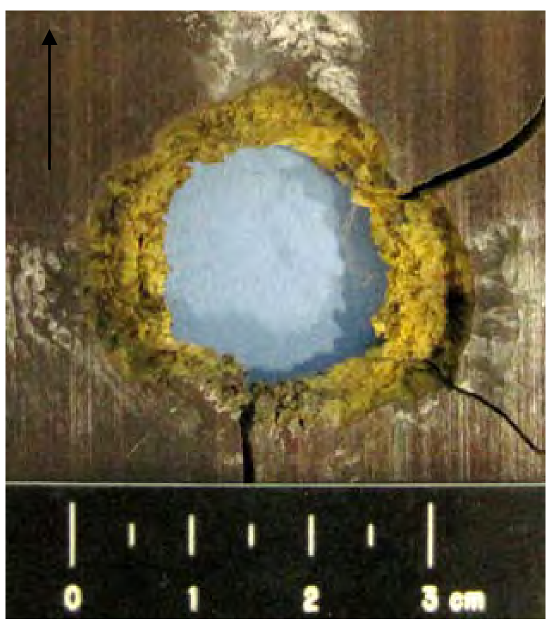


Figure 524 Overall View of Damage to Front of TORLON 5030 Delaminated from Substrate (black arrow indicates flight path of projectile / scale in 5mm increments)

HITF12312 / Test #30 (continued)

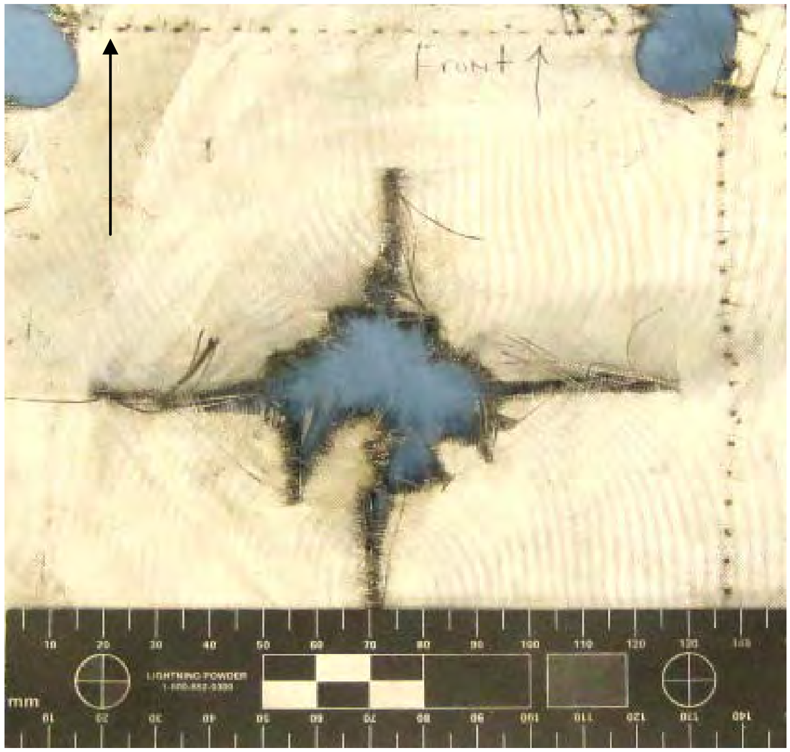


Figure 525 Overall View of Entry Damage to Front Layer of MLI Blanket (black arrow indicates flight path of projectile / scale in 5mm increments)

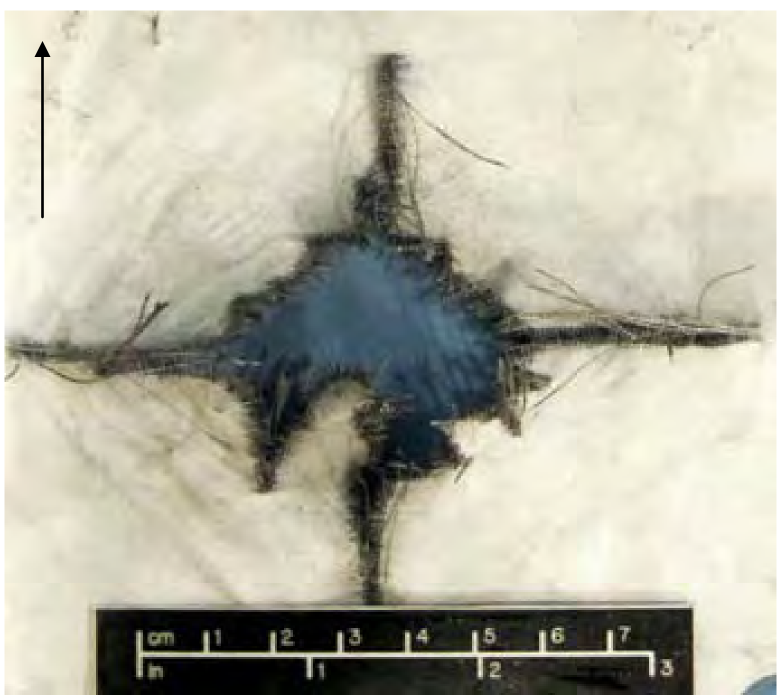


Figure 526 Close-up View of Entry Damage to Front of MLI (scale in 1cm increments / black arrow indicates flight path of projectile)

HITF12312 / Test #30 (continued)

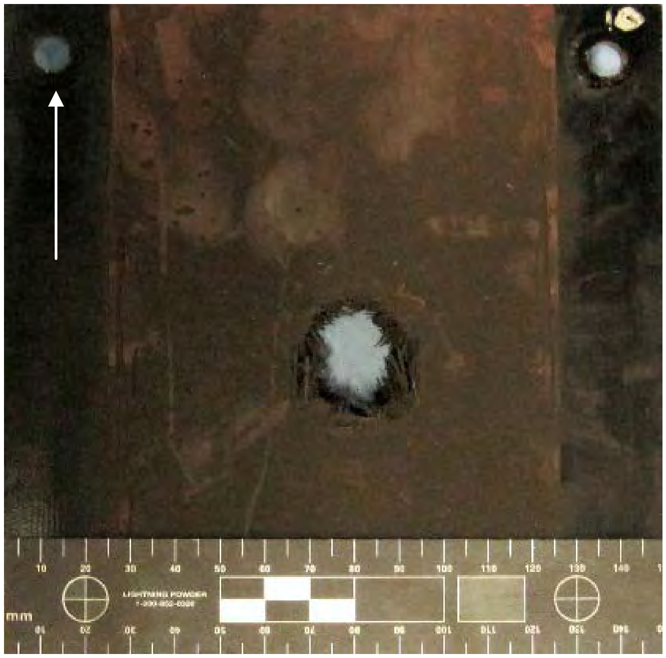


Figure 527 Overall View of Damage to Front NP 504 Substrate with TORLON 5030 Delaminated (scale in 5mm increments / white arrow indicates flight path of projectile)

Figure 528 Close-up View of Damage to Front NP 504 Substrate with TORLON 5030 Delaminated (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12312 / Test #30 (continued)

Figure 529 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / black arrow indicates flight path of projectile)

Figure 530 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12312 / Test #30 (continued)

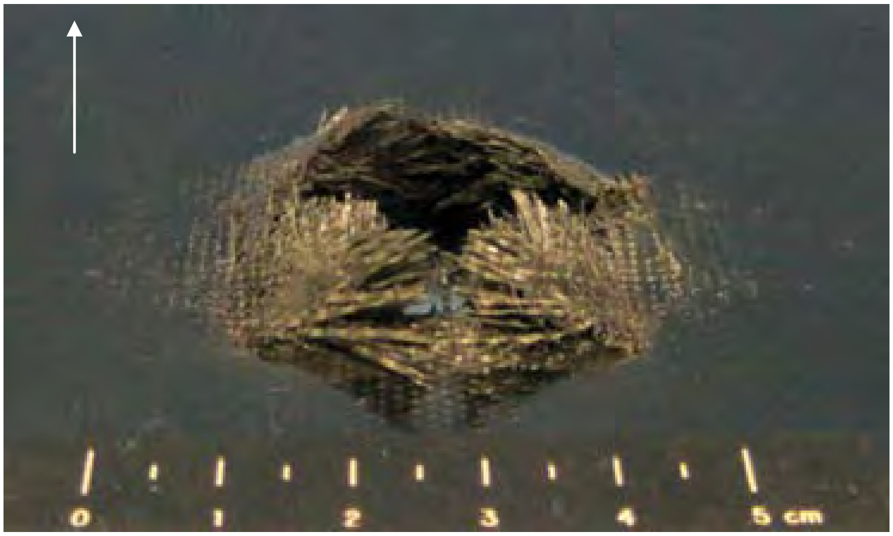


Figure 531 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

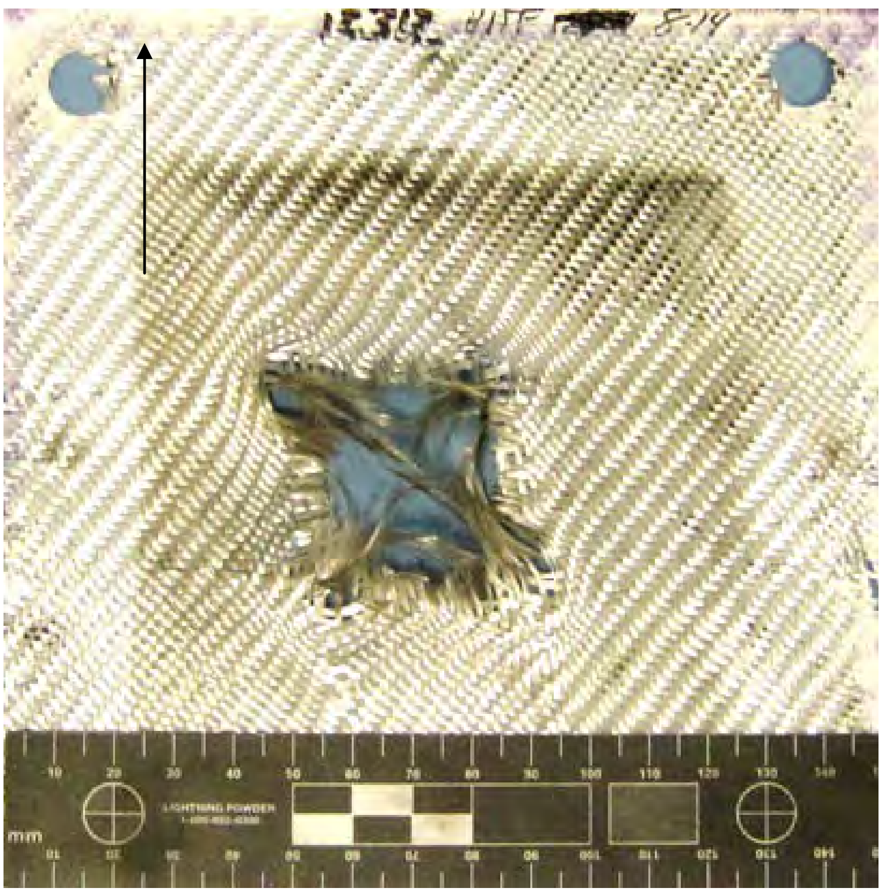


Figure 532 Overall View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12312 / Test #30 (continued)

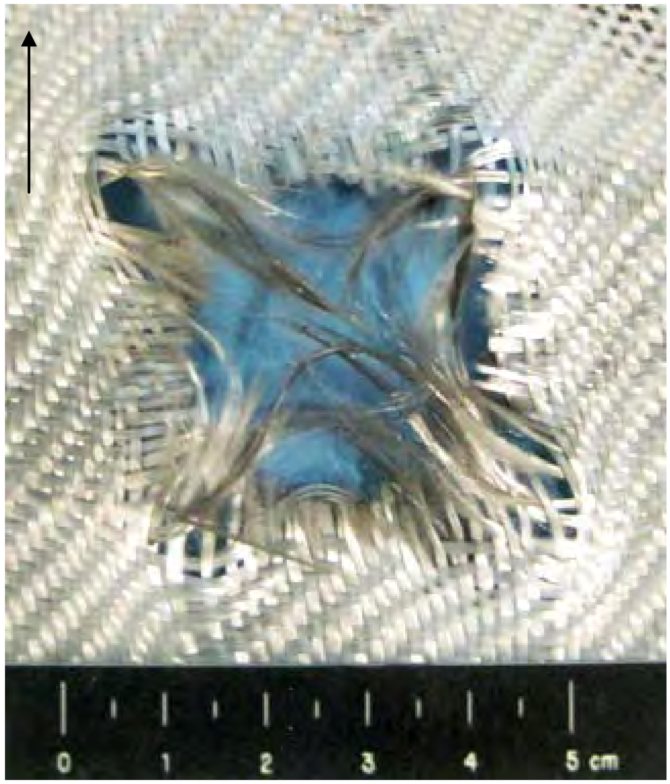


Figure 533 Close-up View of Damage to Back Side of Last Fiberglass Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

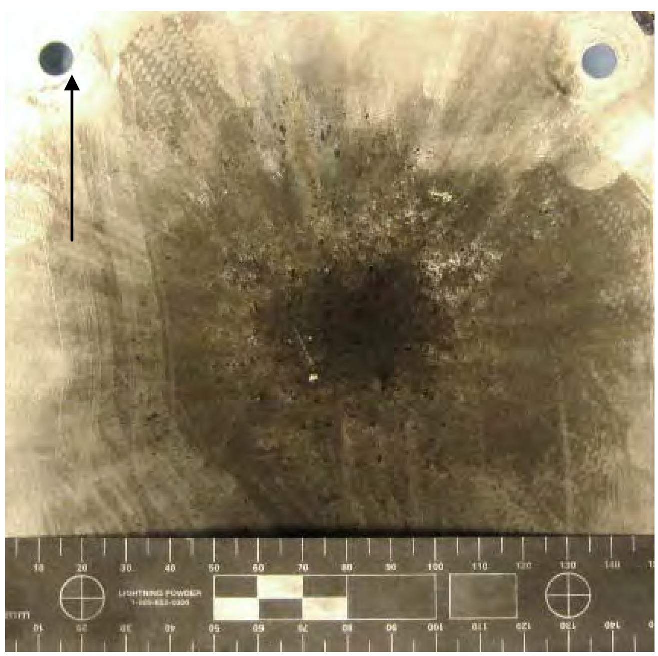


Figure 534 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile / uncleaned)

HITF12312 / Test #30 (continued)

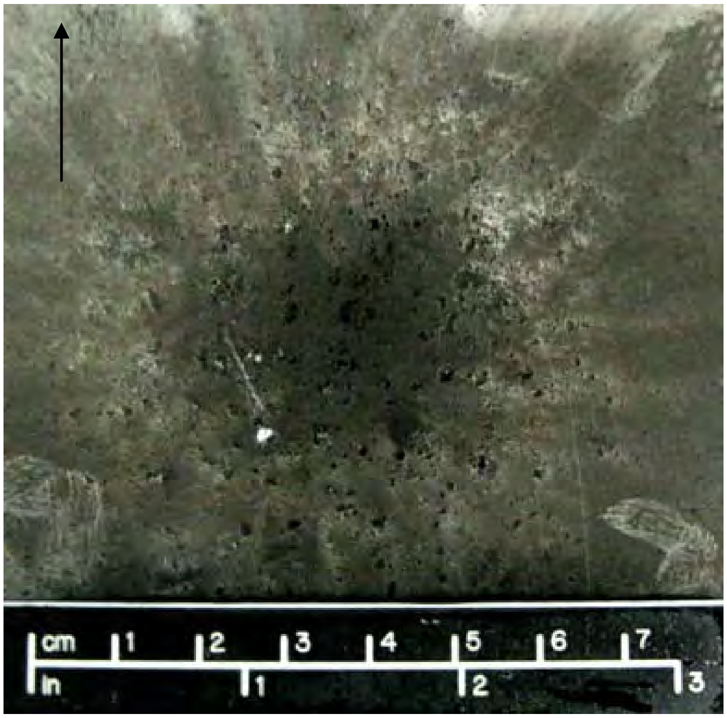


Figure 535 Close-up View of Damage to Front of Rear Wall (scale in 1cm increments / black arrow indicates flight path of projectile / uncleaned)

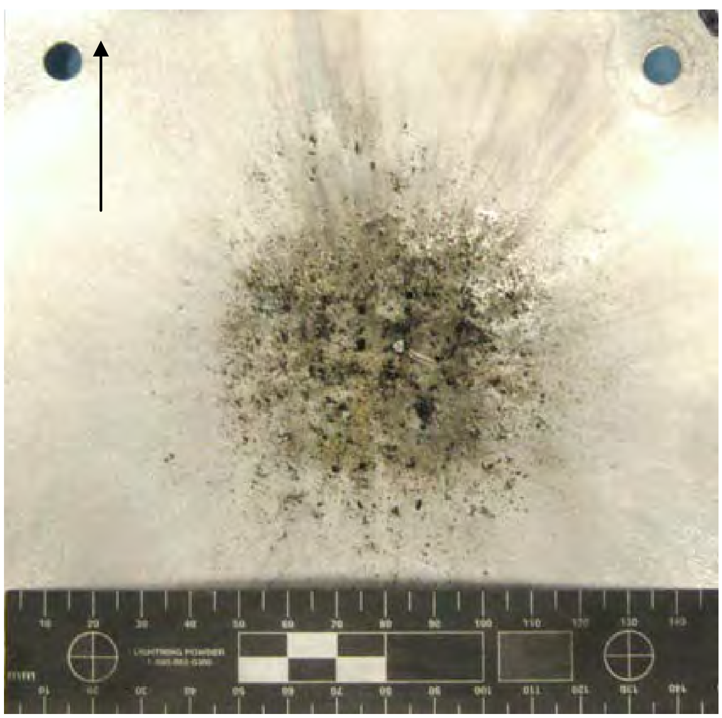


Figure 536 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile / cleaned)

HITF12312 / Test #30 (continued)

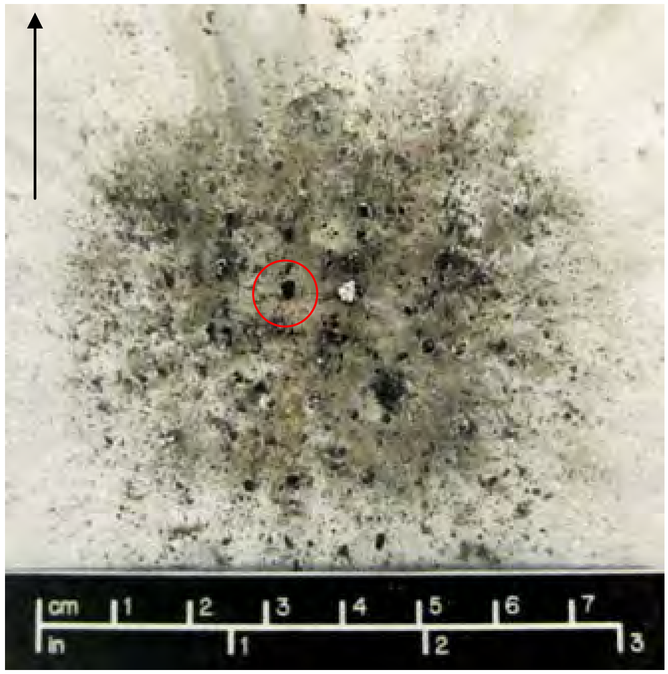


Figure 537 Close-up View of Damage to Front of Rear Wall (scale in 1cm increments / black arrow indicates flight path of projectile / cleaned)

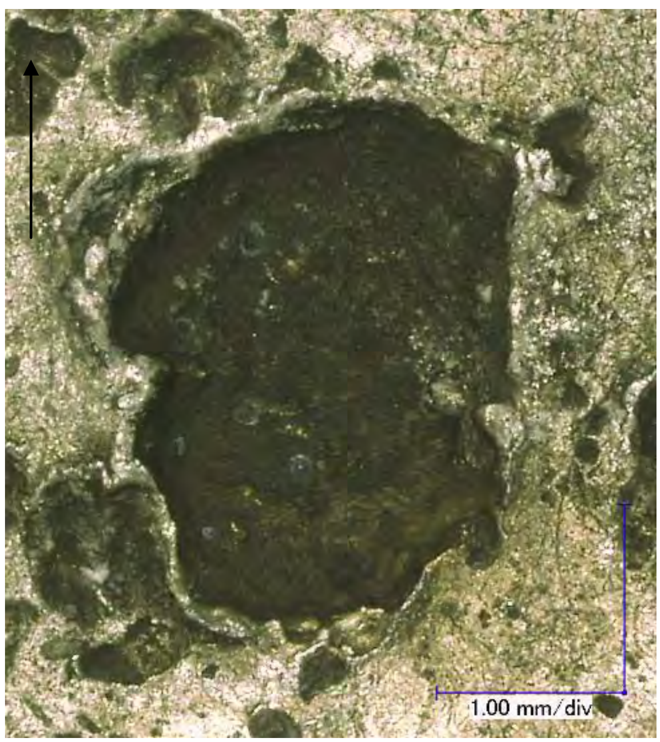


Figure 538 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 537)

HITF12312 / Test #30 (continued)

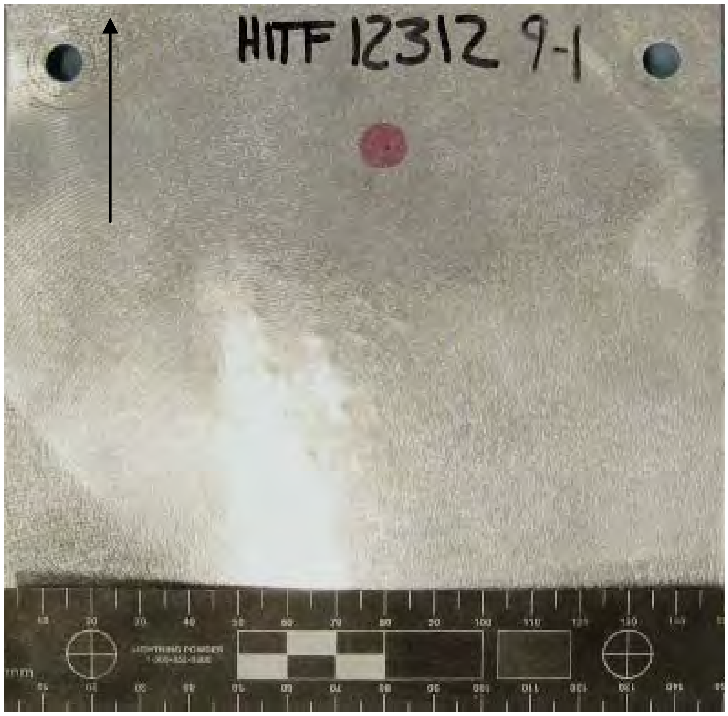


Figure 539 Overall View of Damage to Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

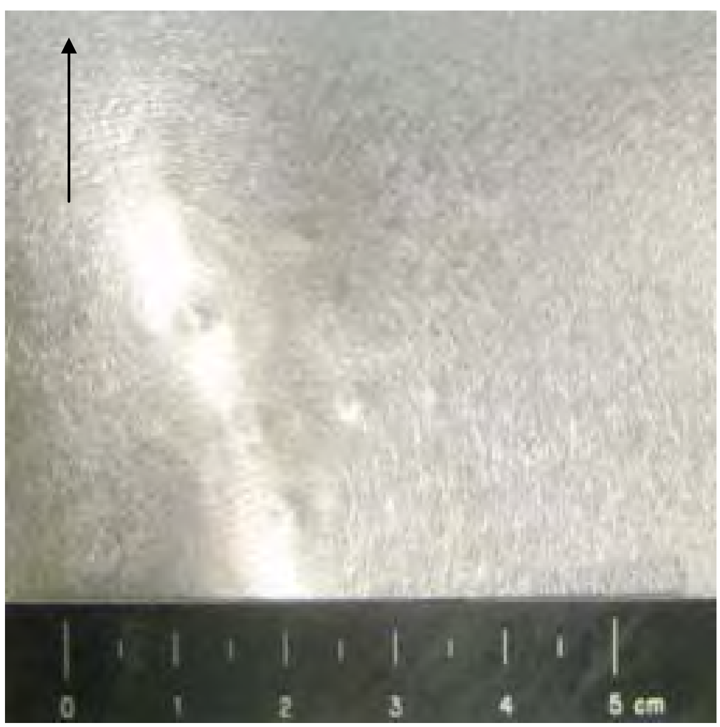


Figure 540 Close View of Damage to Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12312 / Test #30 (continued)

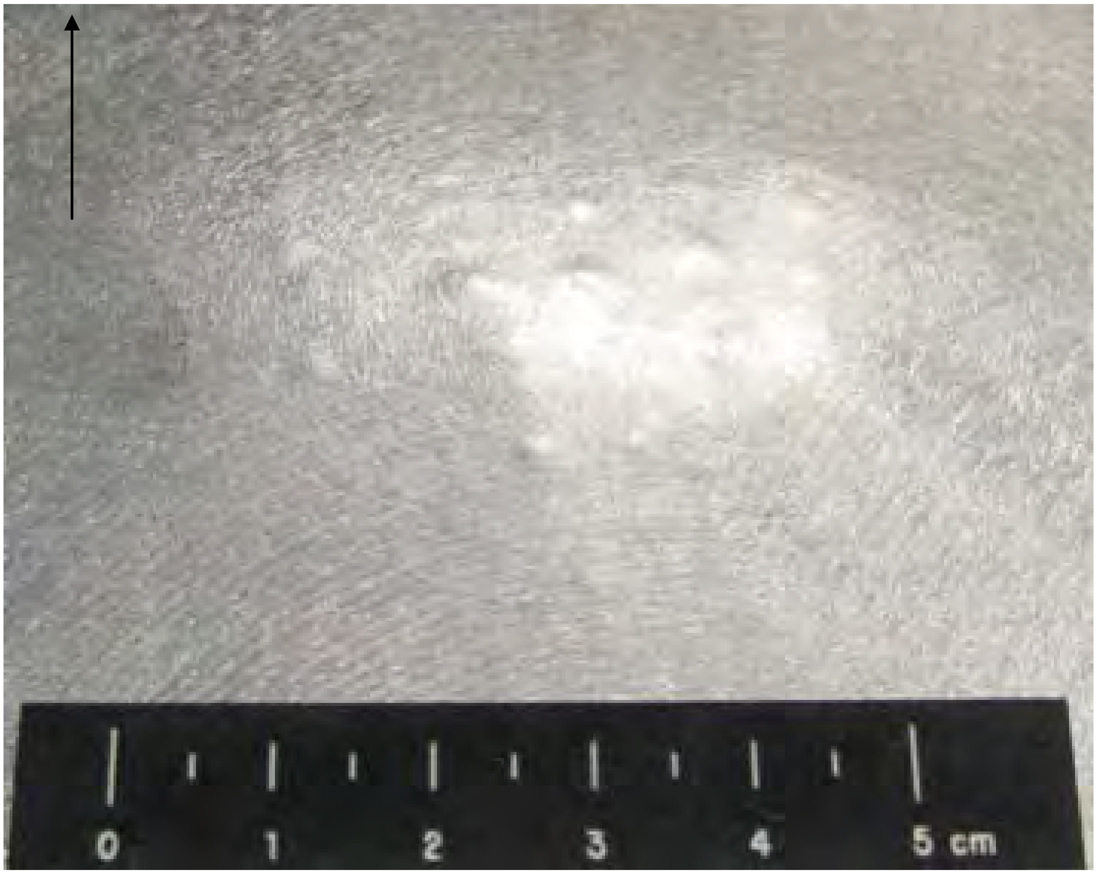


Figure 541 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / black arrow indicates flight path of projectile)

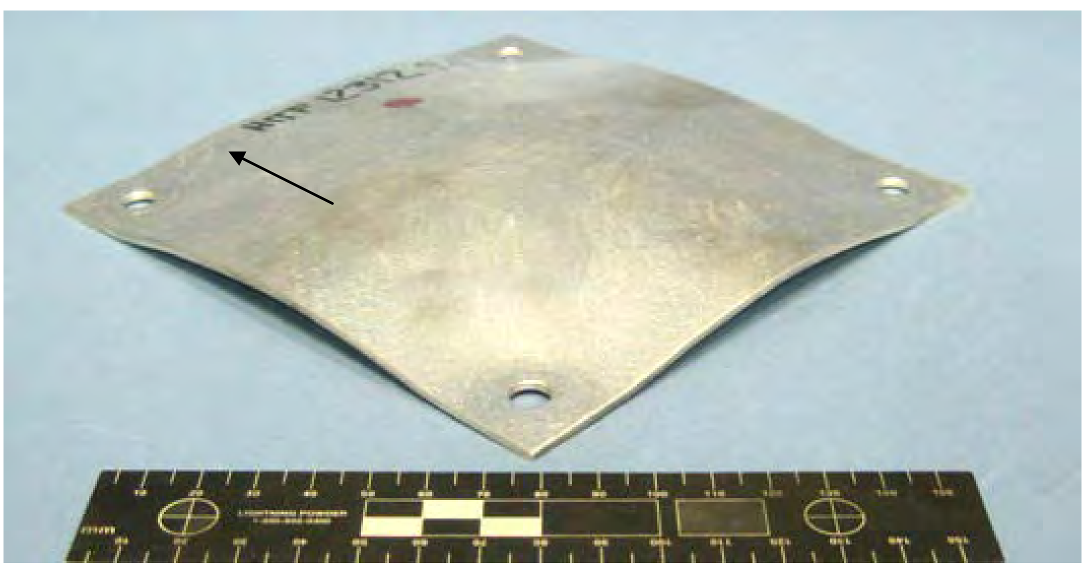


Figure 542 Overall Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12313 / Test #31

Figure 543 Overall View of Sample in the Target Tank (post-test)

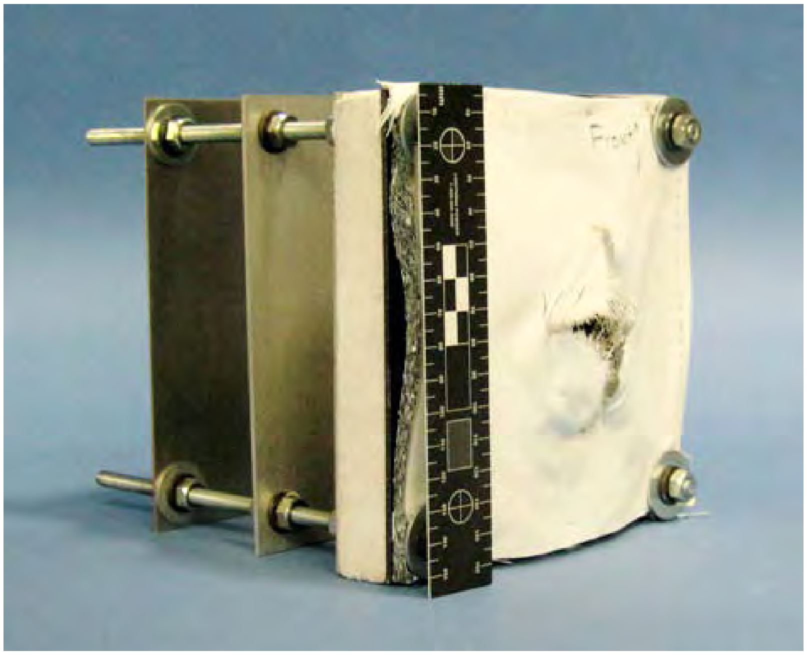


Figure 544 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12313 / Test #31 (continued)

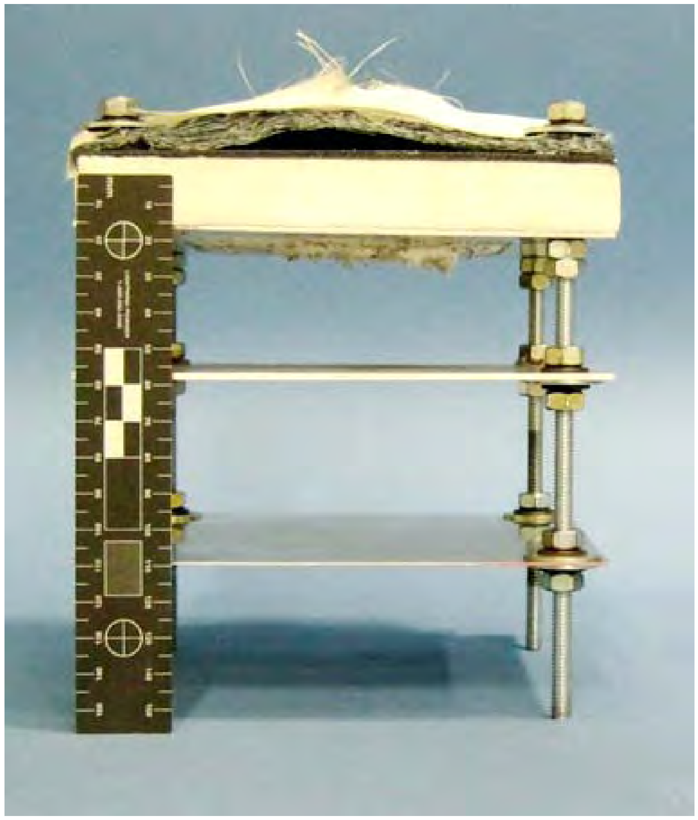


Figure 545 Overall Side View of Sample (scale in 5mm increments)

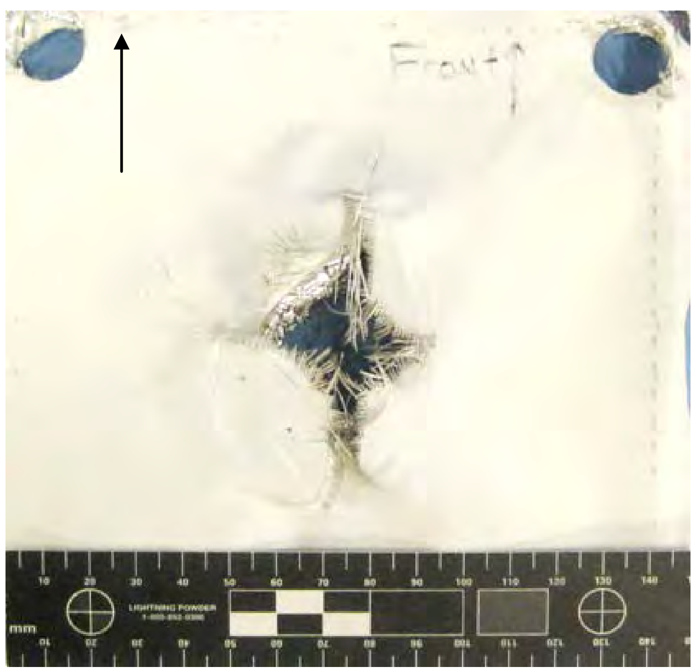


Figure 546 Overall View of Damage to Front of MLI (black arrow indicates flight path of projectile / scale in 5mm increments)

HITF12313 / Test #31 (continued)

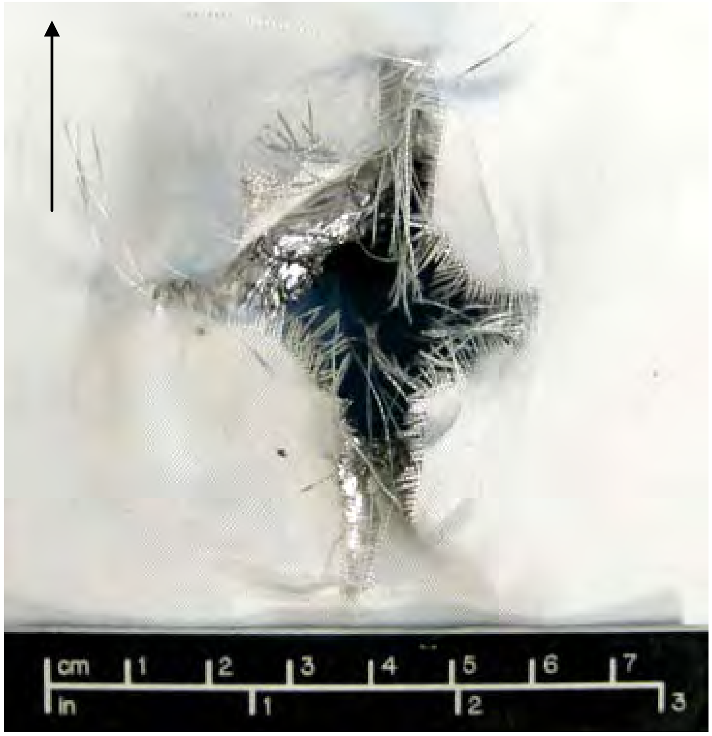


Figure 547 Close-up View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

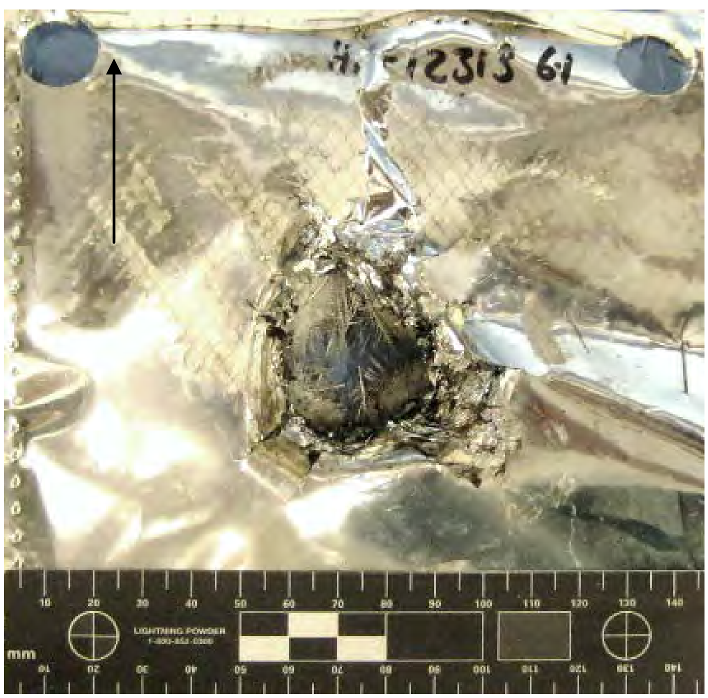


Figure 548 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12313 / Test #31 (continued)

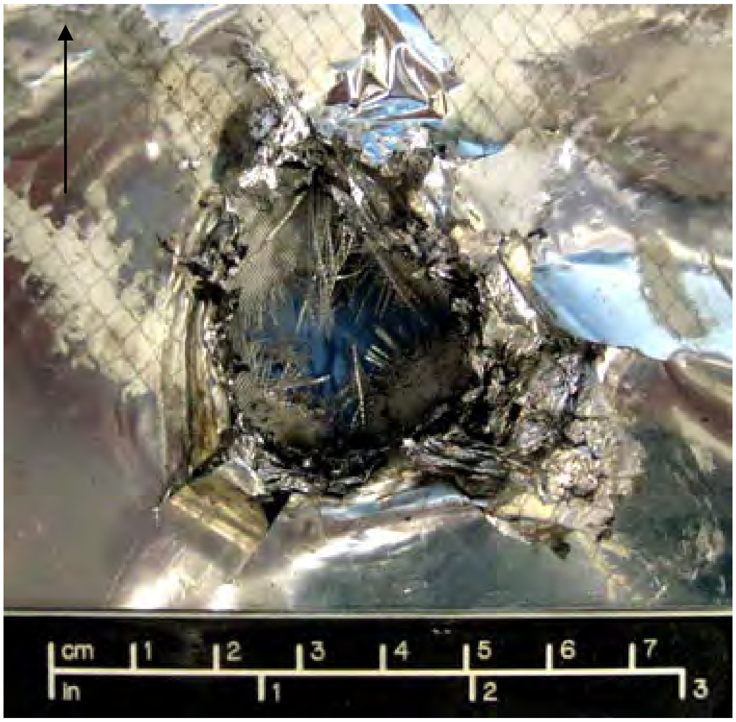


Figure 549 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

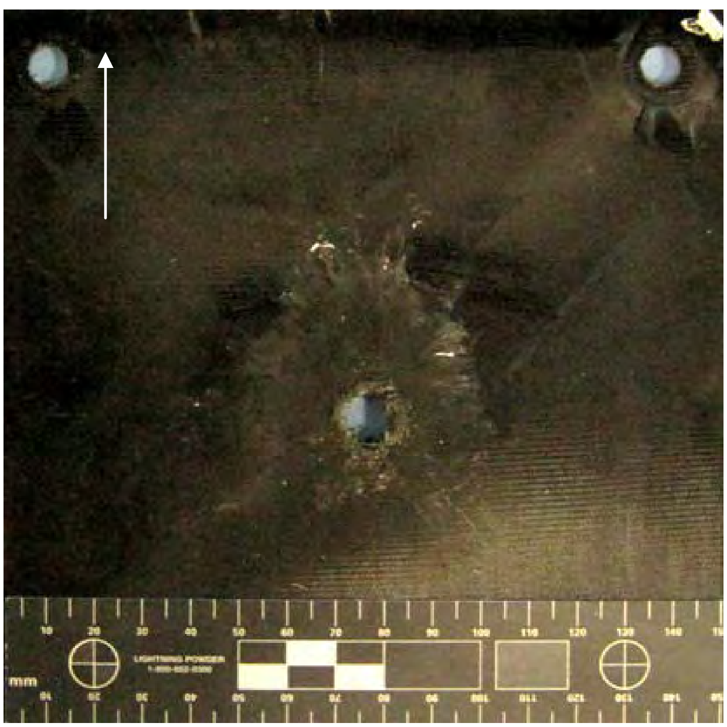


Figure 550 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12313 / Test #31 (continued)

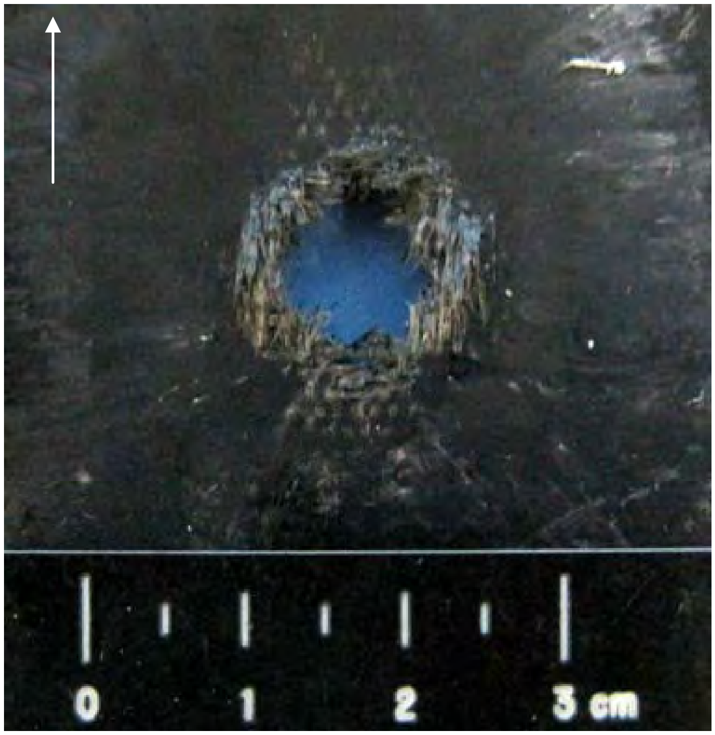


Figure 551 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

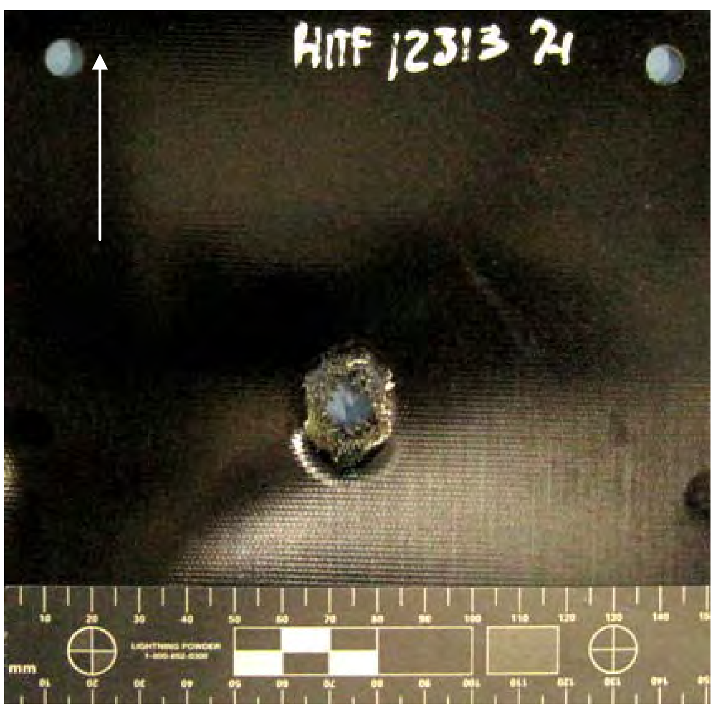


Figure 552 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12313 / Test #31 (continued)

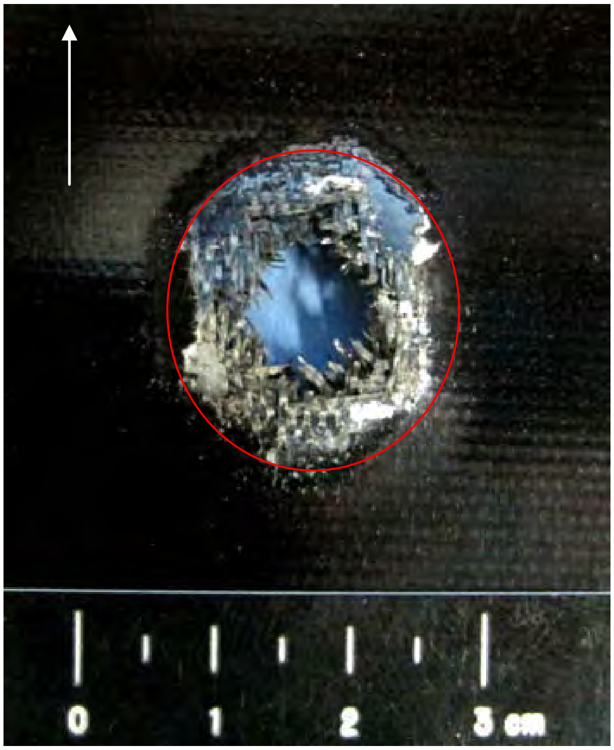


Figure 553 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

Figure 554 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 584)

HITF12313 / Test #31 (continued)

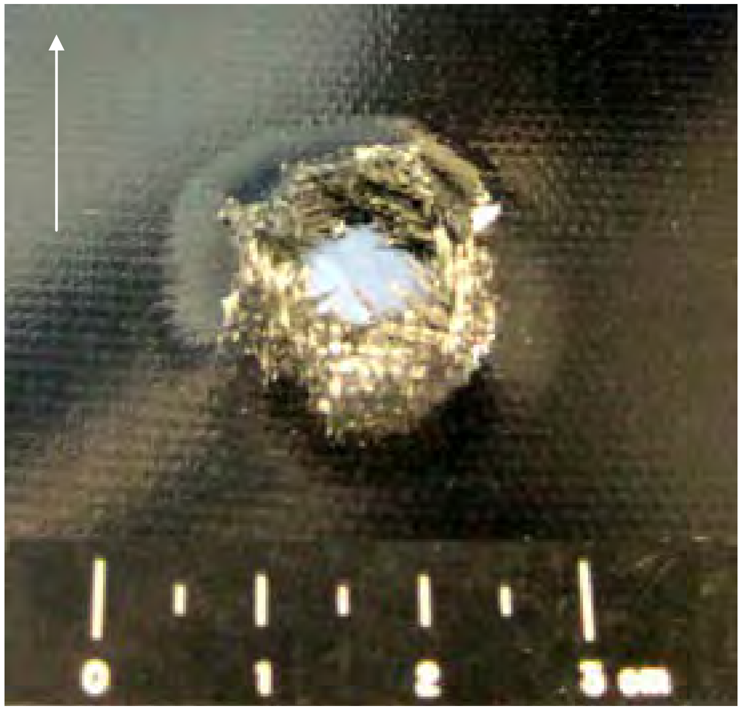


Figure 555 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

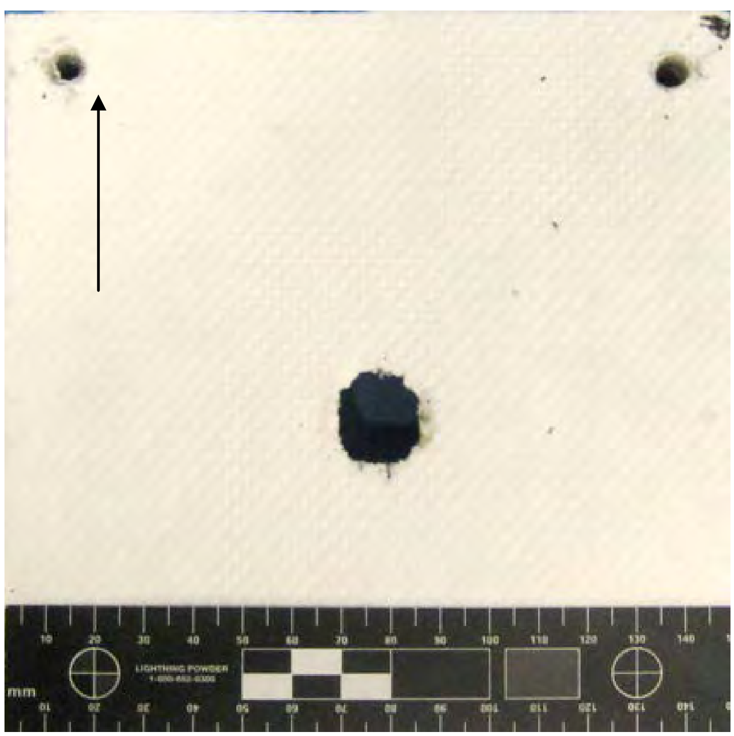


Figure 556 Overall View of Damage to Front of Saffil Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12313 / Test #31 (continued)

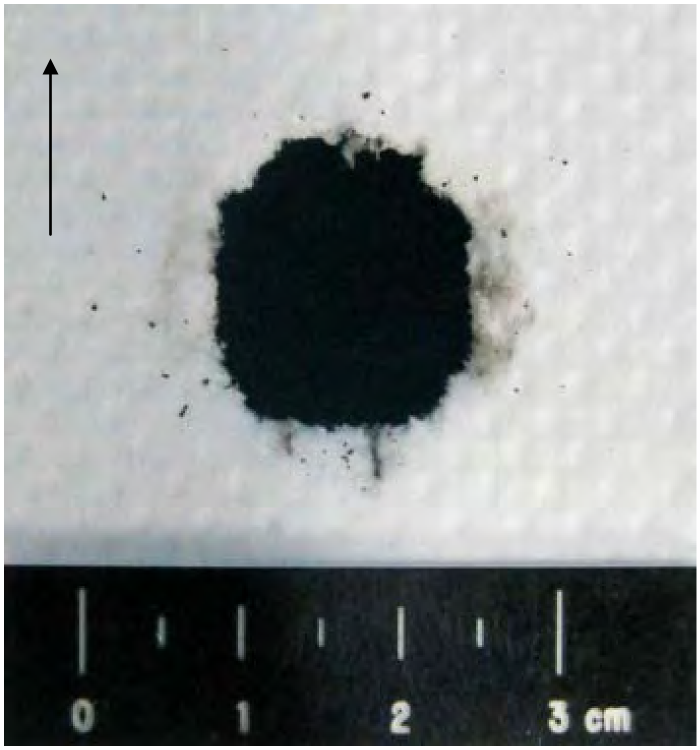


Figure 557 Close-up View of Damage to Front of Saffil Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

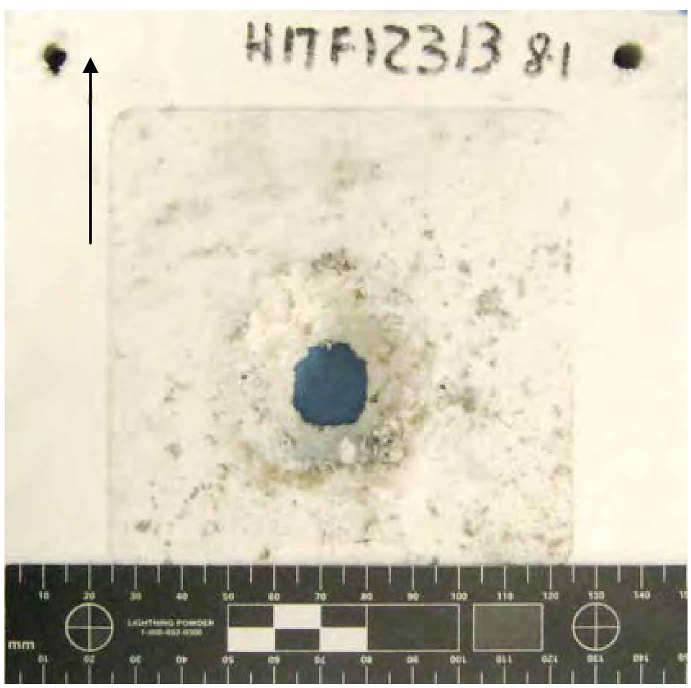


Figure 558 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12313 / Test #31 (continued)

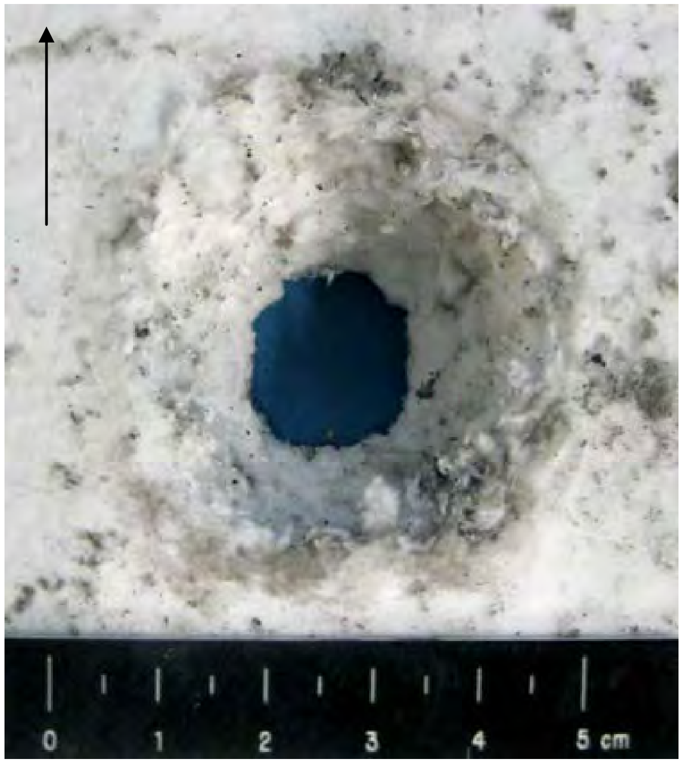


Figure 559 Close-up View of Damage to Front of Saffil (scale in 5mm increments / black arrow indicates flight path of projectile)

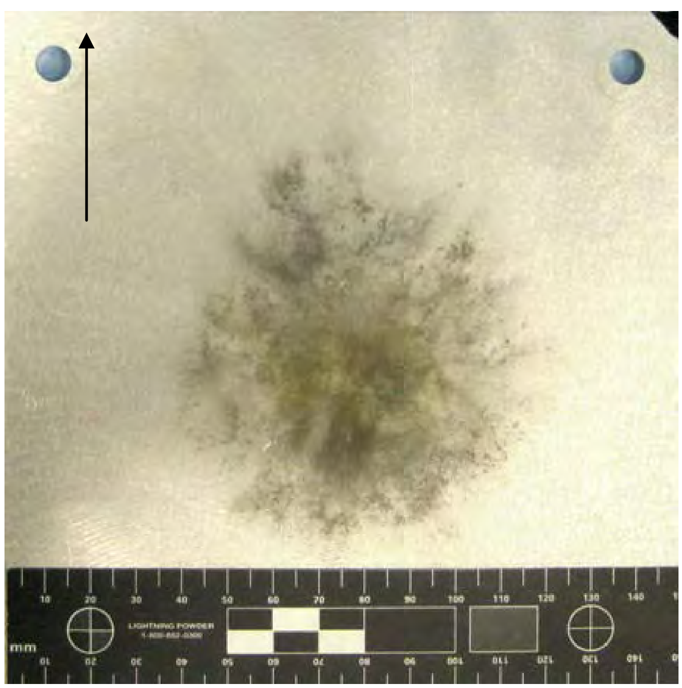


Figure 560 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12313 / Test #31 (continued)

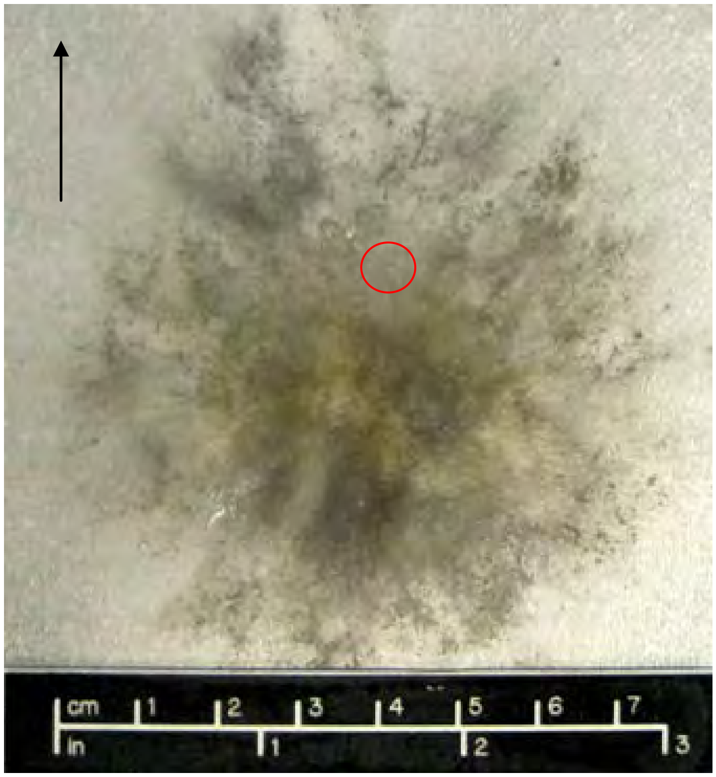


Figure 561 Close-up View of Damage to Front of Rear Wall (scale in 1cm increments / black arrow indicates flight path of projectile)

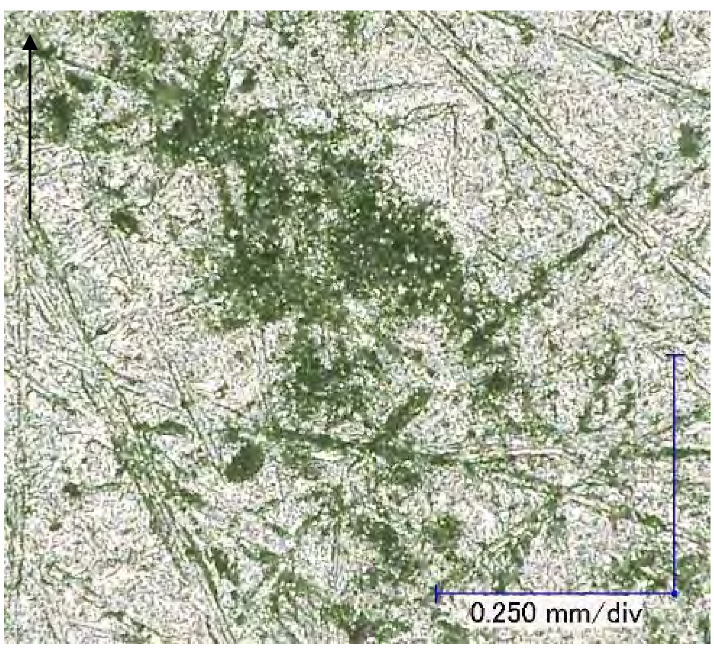


Figure 562 Close-up View of Most Significant Damage to Front of Rear Wall (black arrow indicates flight path of projectile / damage within red circle in Figure 592)

HITF12313 / Test #31 (continued)

Figure 563 Overall View of Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12314 / Test #32

Figure 564 Overall View of Sample in the Target Tank (post-test)

Figure 565 Overall Front Oblique View of Sample (scale in 5mm increments)

HITF12314 / Test #32 (continued)

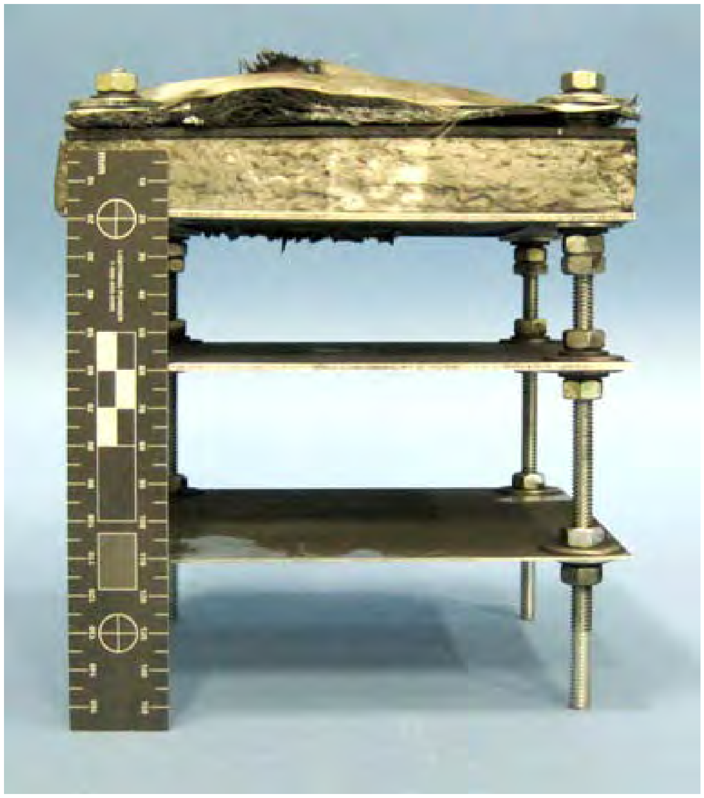


Figure 566 Overall Side View of Sample (scale in 5mm increments)

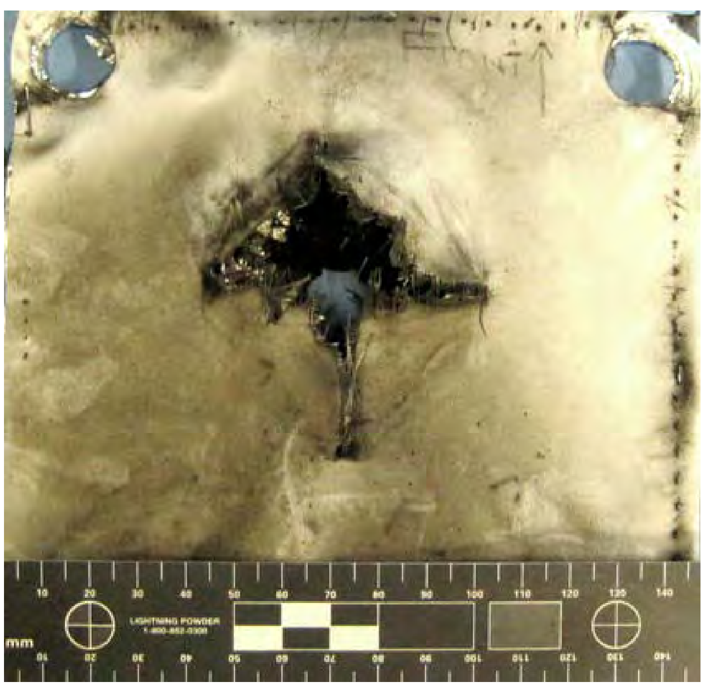


Figure 567 Overall View of Damage to Front of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12314 / Test #32 (continued)

Figure 568 Close-up View of Damage to Front of MLI (scale in 1cm increments / black arrow indicates flight path of projectile)

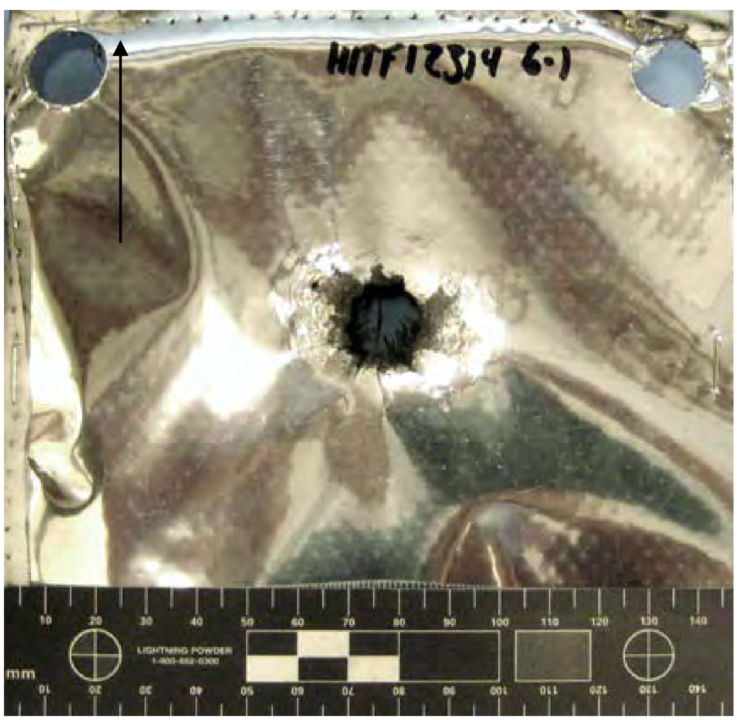


Figure 569 Overall View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12314 / Test #32 (continued)

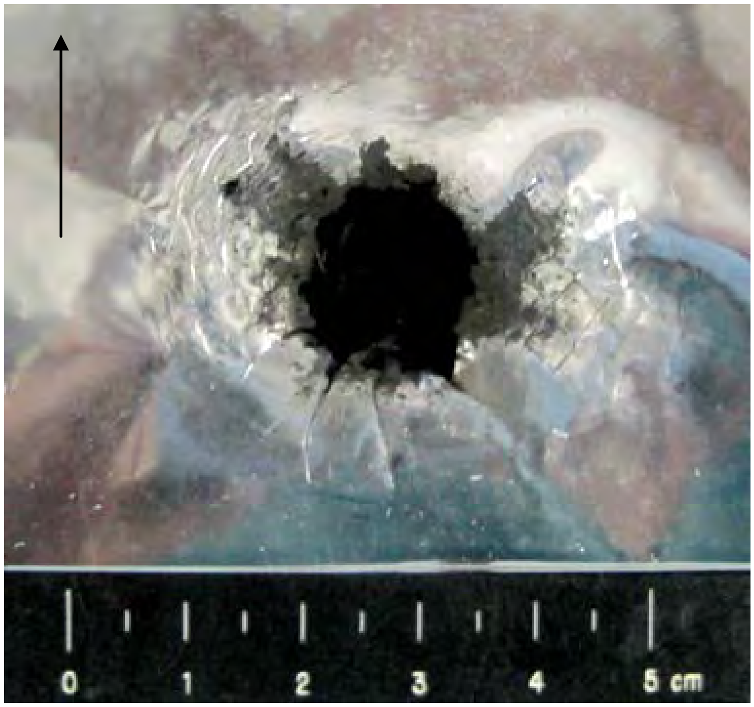


Figure 570 Close-up View of Damage to Back Side of MLI (scale in 5mm increments / black arrow indicates flight path of projectile)

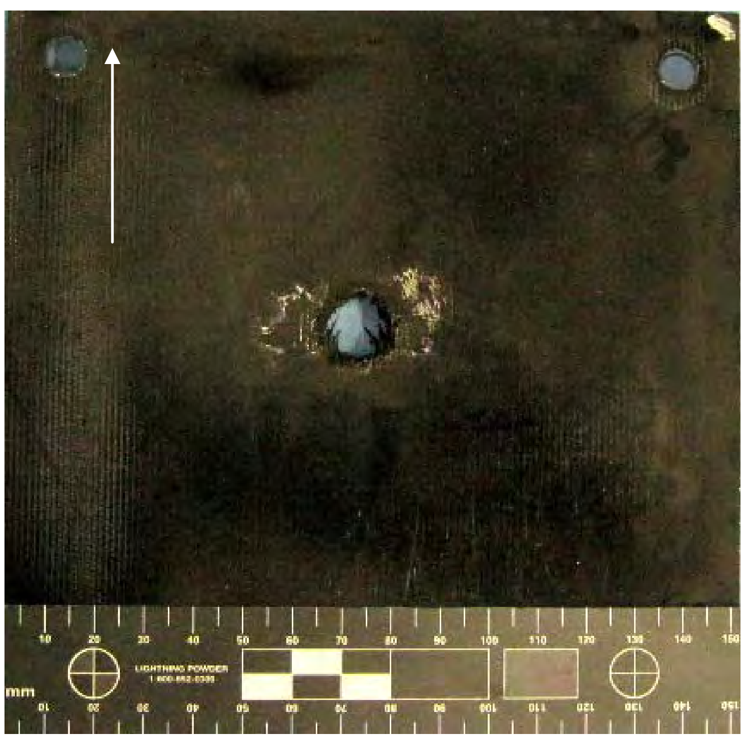


Figure 571 Overall View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12314 / Test #32 (continued)

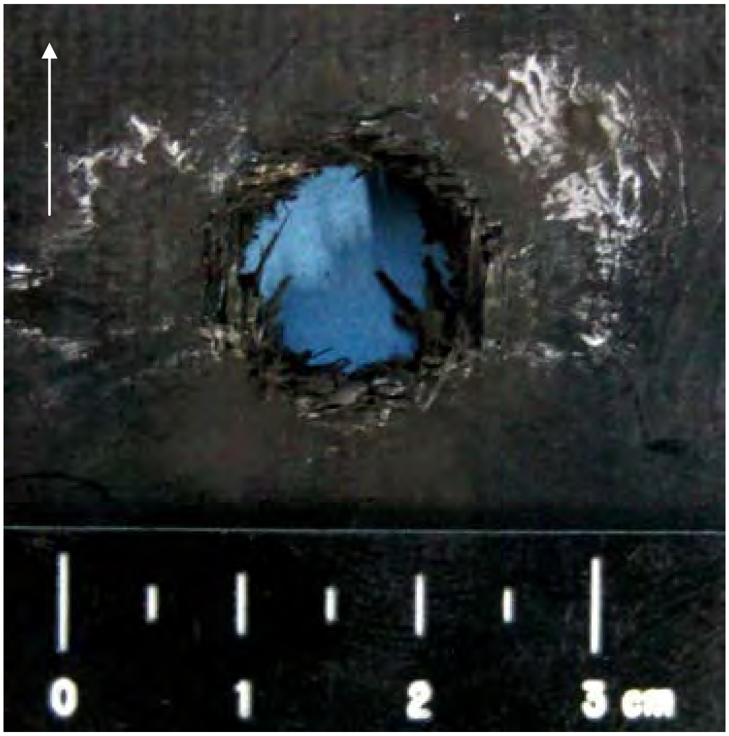


Figure 572 Close-up View of Damage to Front of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

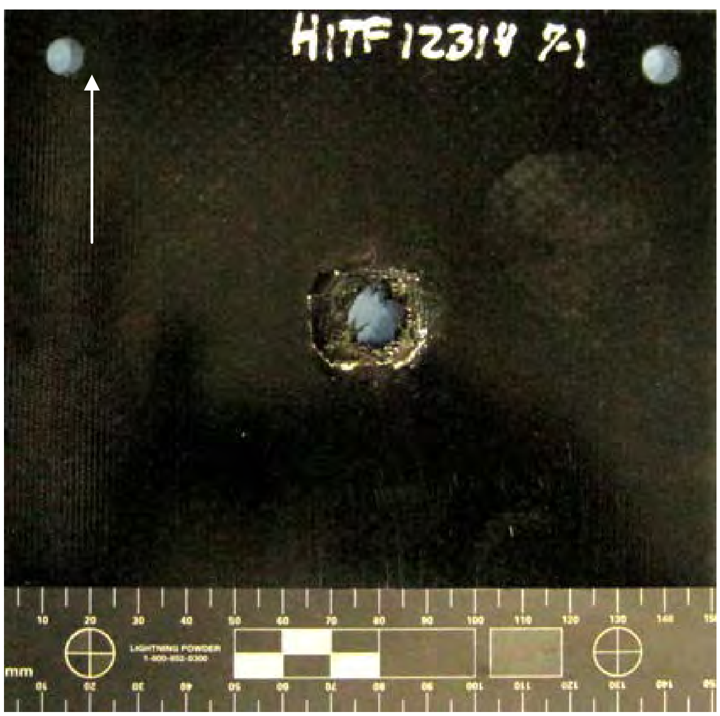


Figure 573 Overall View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

HITF12314 / Test #32 (continued)

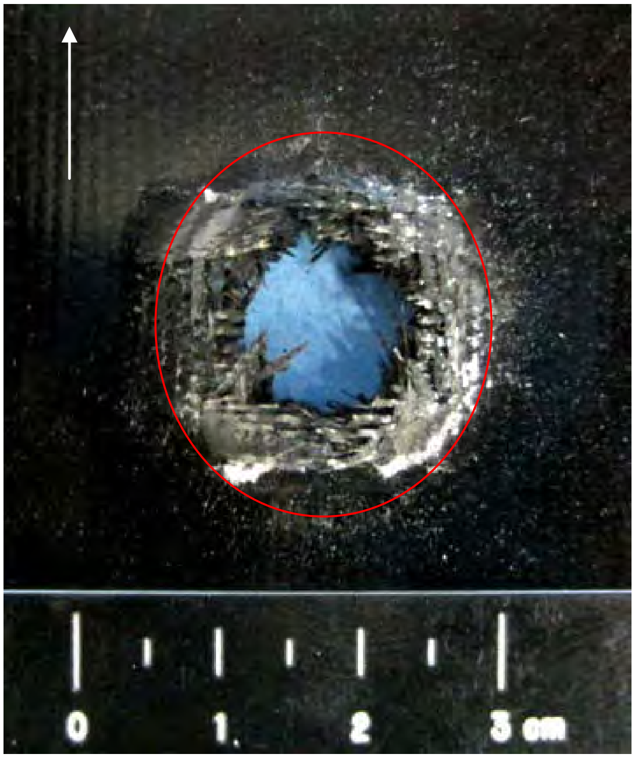


Figure 574 Close-up View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

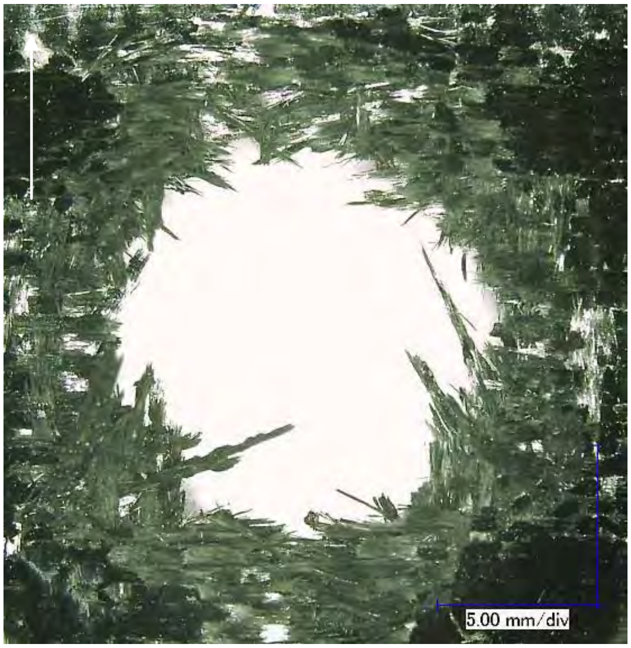


Figure 575 Close-up View of Most Significant Damage to Back Side of NP 504 Substrate (black arrow indicates flight path of projectile / damage within red circle in Figure 574)

HITF12314 / Test #32 (continued)

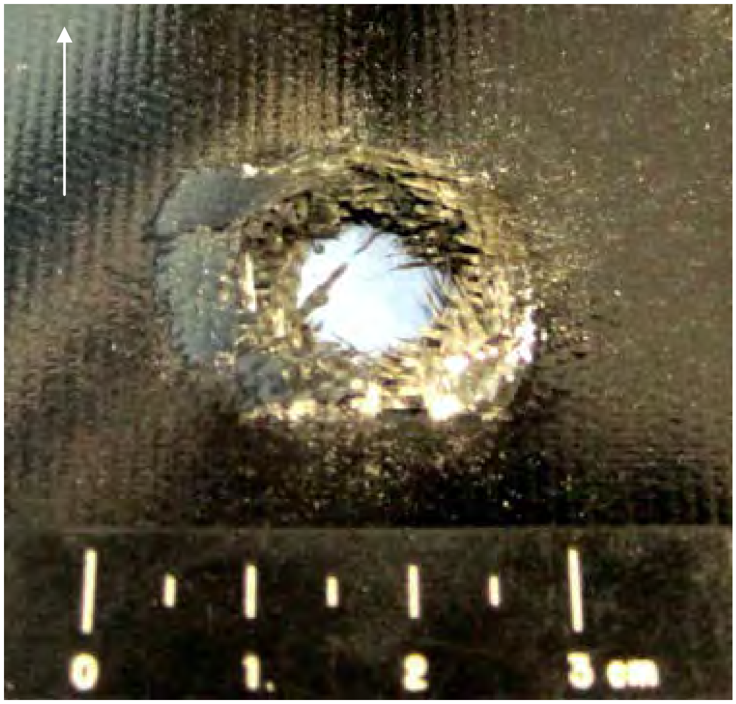


Figure 576 Close-up Oblique Side View of Damage to Back Side of NP 504 Substrate (scale in 5mm increments / white arrow indicates flight path of projectile)

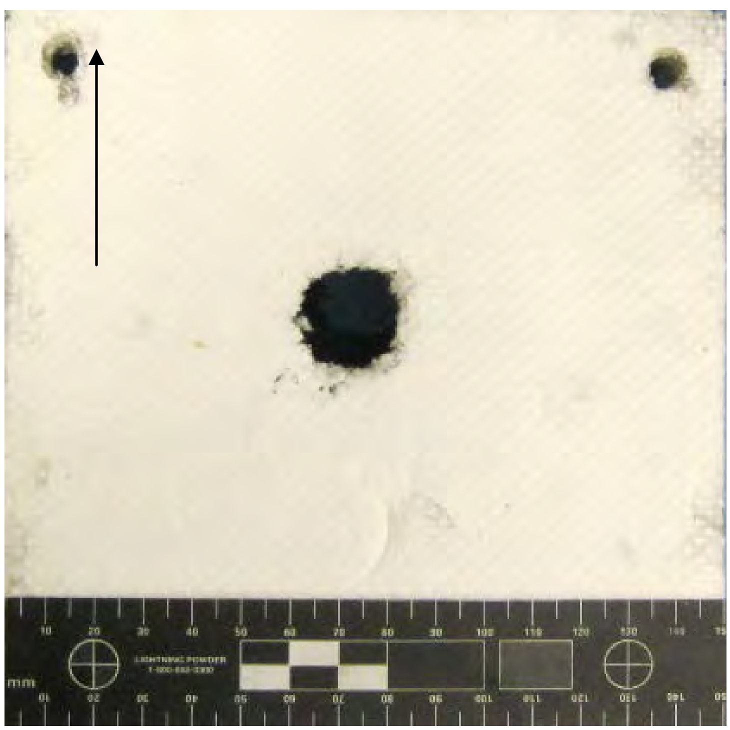


Figure 577 Overall View of Damage to Front of Saffil Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12314 / Test #32 (continued)

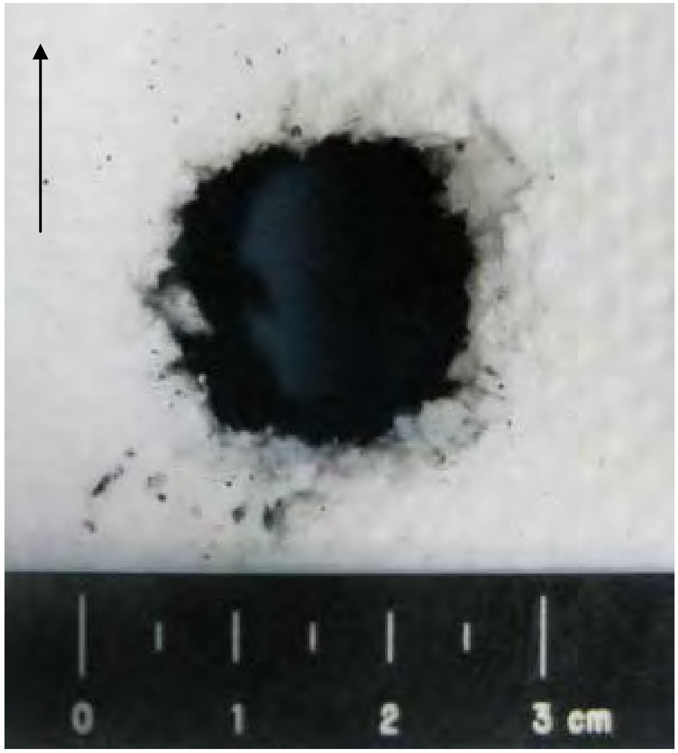


Figure 578 Close-up View of Damage to Front of Saffil Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

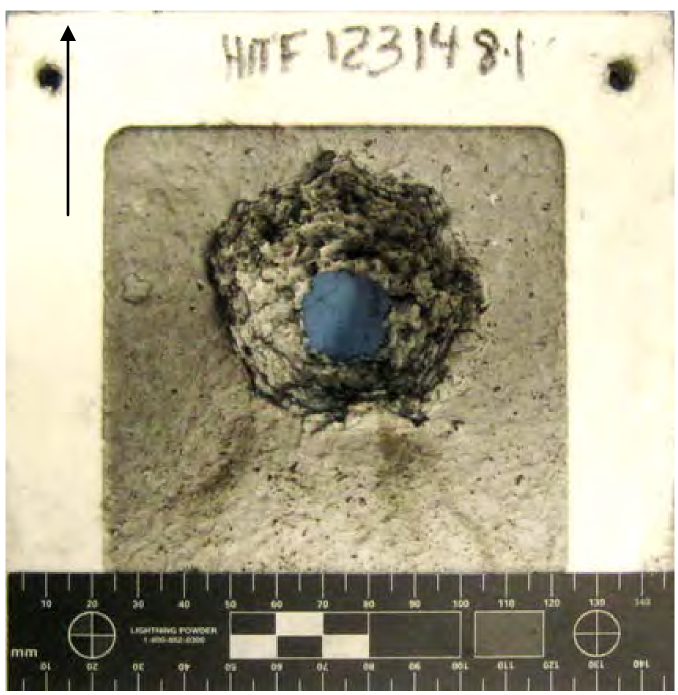


Figure 579 Overall View of Damage to Back Side of Saffil Layer (scale in 5mm increments / black arrow indicates flight path of projectile)

HITF12314 / Test #32 (continued)

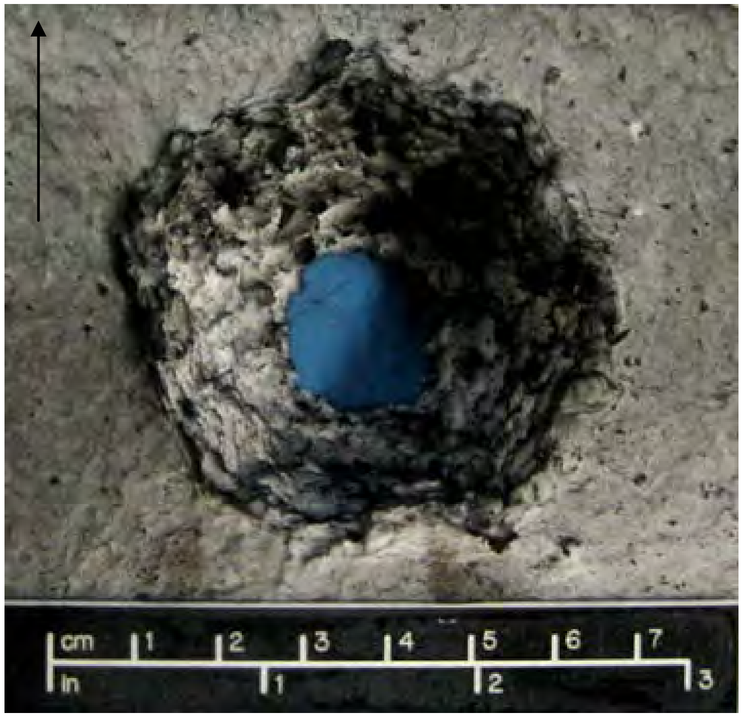


Figure 580 Close-up View of Damage to Back Side of Saffil Layer (scale in 1cm increments / black arrow indicates flight path of projectile)

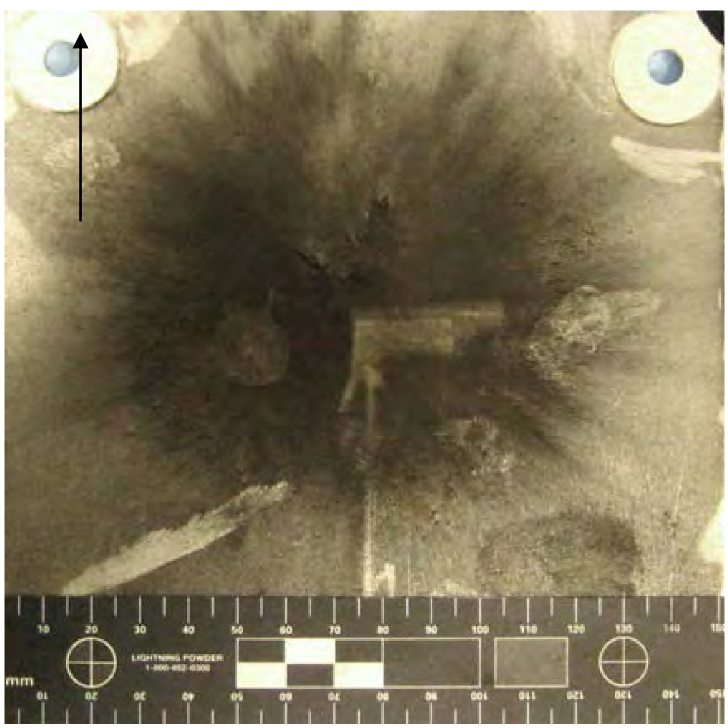


Figure 581 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile / uncleaned)

HITF12314 / Test #32 (continued)

Figure 582 Overall View of Damage to Front of Rear Wall (scale in 1cm increments / black arrow indicates flight path of projectile / uncleaned)

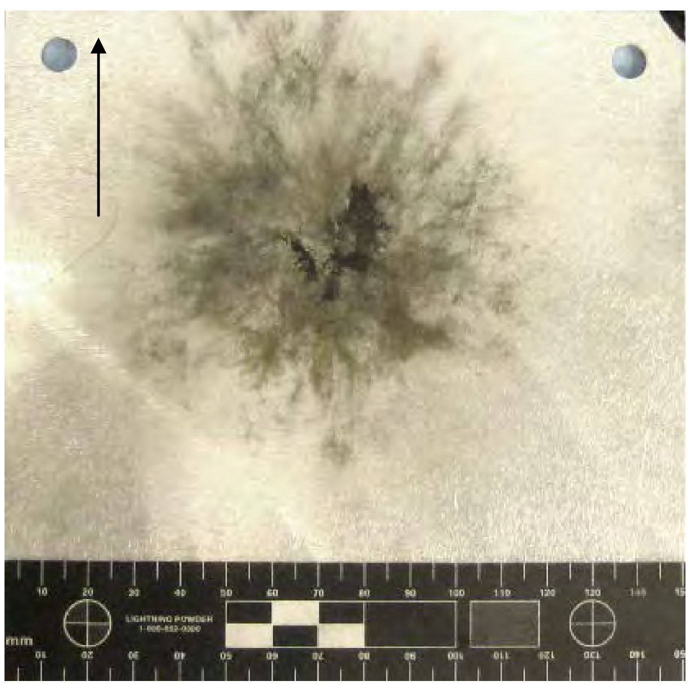


Figure 583 Overall View of Damage to Front of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile / cleaned)

HITF12314 / Test #32 (continued)

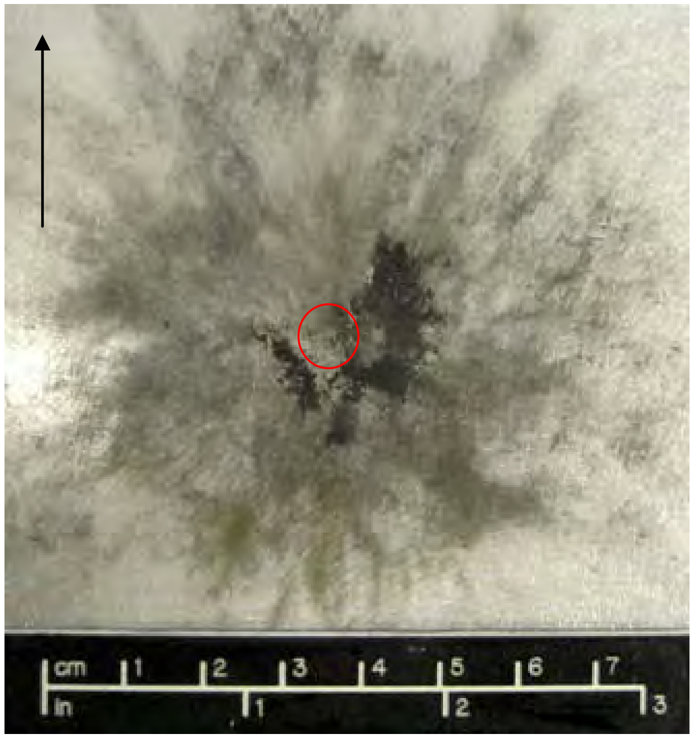


Figure 584 Close-up View of Damage to Front of Rear Wall (scale in 1cm increments / black arrow indicates flight path of projectile / cleaned)

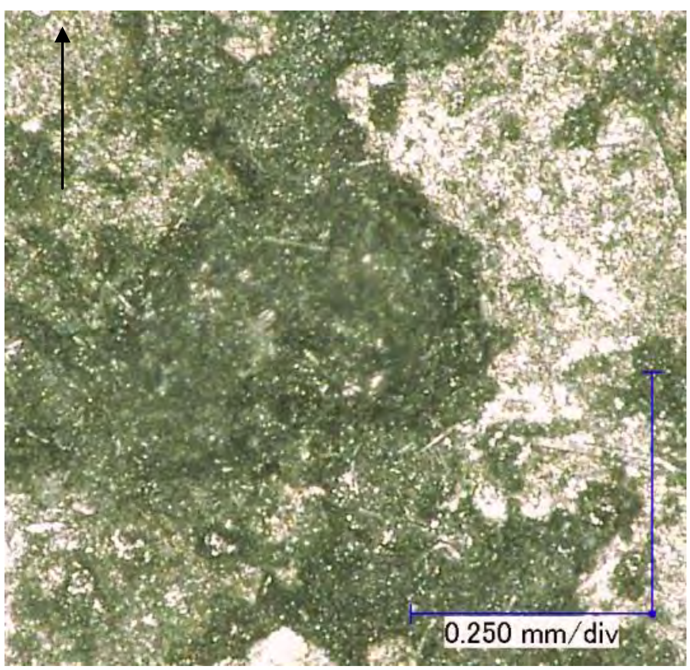


Figure 585 Close-up View of Most Significant Damage to Front of Rear Wall (black arrow indicates flight path of projectile / cleaned / damage within red circle in Figure 616)

HITF12314 / Test #32 (continued)

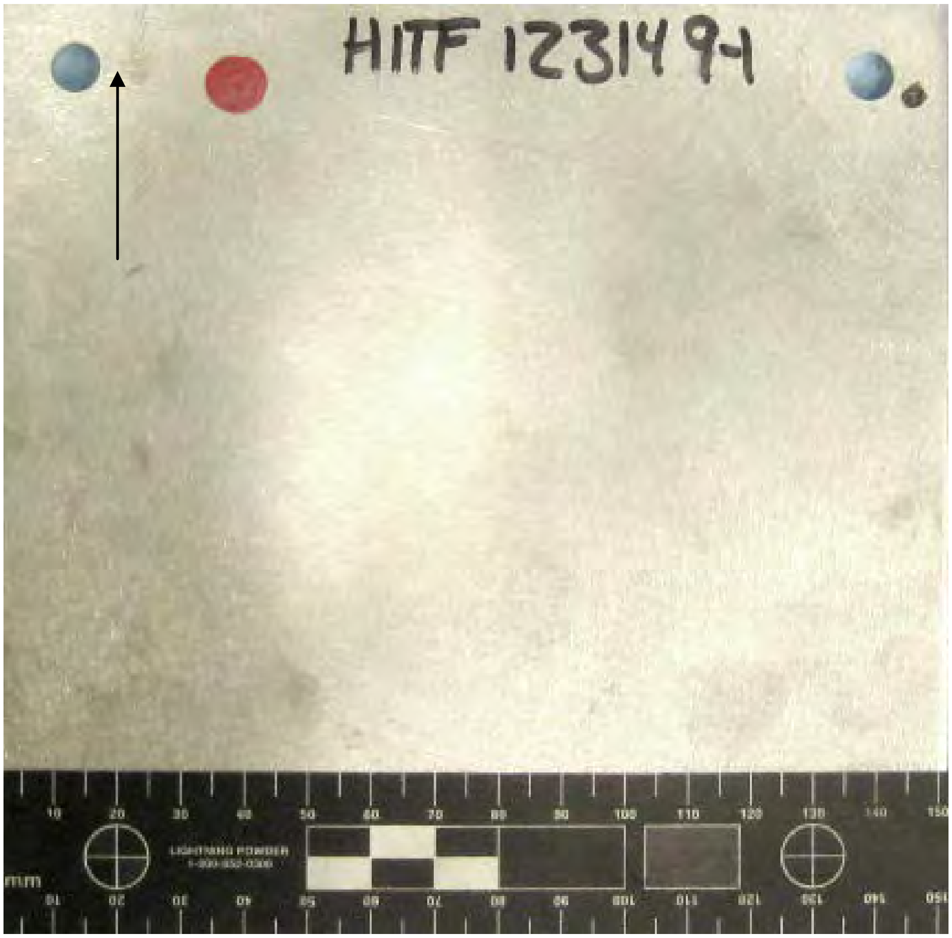


Figure 586 Overall View of Damage to Back Side of Rear Wall (scale in 5mm increments / black arrow indicates flight path of projectile)

7.0 Conclusions

There were three different regions of the backshell TPS evaluated within this test program: an averaged thin region (which is representative of the leeward side / Type 1 test configuration), an averaged medium and thick region (which is representative of the windward side to which the TPS varies in thickness / Type 2 and Type 3 test configurations). There is a Type 4 test configuration, which is the same as the Type 1 except that a Saffil insulator is used instead of fiberglass fabric layers behind the fiberglass substrate. The Type 4 tests evaluate how Saffil compares to fiberglass fabric layers. Saffil was in short supply, but is considered to be more representative of the Russian VIM (low density fibrous insulation) than the fiberglass fabric. A direct comparison was conducted between test #32 (averaged thin region with Saffil) and test #24 (averaged thin region with fiberglass fabric). The Saffil provided better shield performance than the fiberglass fabric (with no damage present on back side of pressure shell for test #32 and multiple bumps present on back side of pressure shell for test #24). A total of 35 tests were conducted in this test program: 26 Type 1 tests (average thin region), four (4) Type 2 tests (average medium region), three (3) Type 3 tests (average thick region), and two (2) Type 4 tests (average thin with Saffil). The initial ballistic limit (BL) predictions were non-conservative in nature, where a pass was predicted and a failure occurred (Appendix B). These tests are used to refine the ballistic limit equations (BLEs) for the TPS configurations (see Appendix B).

8.0 References

1. E.L. Christiansen and J.L. Crews, *the NASA JSC Hypervelocity Impact Test (HVIT) Group*, AIAA 92-1640, 1992.

2. J.C. Anderson, D.J. Henderson, K.M. Rodriguez, *.17-caliber Light Gas Gun Velocity Measurement Uncertainty Analysis*, WSTF-IR-1086-001-07, April 2007.

3. J.C. Anderson, D.J. Henderson, K.M. Rodriguez, *.50-caliber Light Gas Gun Velocity Measurement Uncertainty Analysis*, WSTF-IR-1103-001-08.C, January 2011.

4. E.L. Christiansen, Ballistic limits for Soyuz DM TPS, personal communication, January 2013.

5. K. Poormon, Summary of NASA NESC Phase 1 Hypervelocity Impact Tests at UDRI, personal communication, 7 February 2013. (Note, results to be described in a NASA JSC report, pending).

6. J.L. Hyde, Soyuz Descent Module Pressure Shell predicted ballistic limits from Bumper Code, personal communication, 2012.

Appendix A: Work Controlling Documents

Test Matrix

The following table provides the preliminary test plan using steel and aluminum projectiles on the Soyuz DM TPS test articles. This test matrix was updated during the course of testing.

Table A1 – ISS Soyuz Vehicle Descent Module TPS Test Matrix

Test Number / HITF Number	Target Type	Projectile Material	Projectile Density (g/cm^3)	Nominal Projectile Diameter (mm)	Calculated Projectile Mass (g)	Desired Impact Velocity (km/s)	Impact Angle (deg)	Comments
1 HITF12283	Type 1 Average thin	Steel 440C	7.65	1.2	0.0069	7.0	30	
2 HITF12284	Type 1 Average thin	Steel 440C	7.65	1.3	0.0088	7.0	45	
3 HITF12285	Type 1 Average thin	Steel 440C	7.65	1.4	0.0110	5.0	30	
4 HITF12286	Type 2 Average medium	Steel 440C	7.65	1.4	0.0110	7.0	30	
5 HITF12287	Type 1 Average thin	Steel 440C	7.65	1.7	0.0197	7.0	60	
6 HITF12288	Type 1 Average thin	Steel 440C	7.65	2.0	0.0320	3.0	30	
7 HITF12289	Type 1 Average thin	Steel 440C	7.65	2.0	0.0320	4.0	45	If test #6 fails, switch to a 1.8mm projectile
8 HITF12290	Type 1 Average thin	Steel 440C	7.65	TBD	TBD	7.0	30	Increase/decrease projectile size based on #1
9 HITF12291	Type 1 Average thin	Steel 440C	7.65	TBD	TBD	7.0	45	Increase/decrease projectile size based on #2
10 HITF12292	Type 1 Average thin	Steel 440C	7.65	TBD	TBD	5.0	30	Increase/decrease projectile size based on #3
11 HITF12293	Type 2 Average medium	Steel 440C	7.65	TBD	TBD	7.0	30	Increase/decrease projectile size based on #4
12 HITF12294	Type 1 Average thin	Steel 440C	7.65	TBD	TBD	7.0	60	Increase/decrease projectile size based on #5
13 HITF12295	Type 1 Average thin	Steel 440C	7.65	TBD	TBD	3.0	30	Increase/decrease projectile size based on #6
14 HITF12296	Type 1 Average thin	Steel 440C	7.65	TBD	TBD	4.0	45	Increase/decrease projectile size based on #7
15 HITF12297	Type 1 Average thin	Al 2017-T4	2.796	2.0	0.0117	7.0	30	

Table A1 – ISS Soyuz Vehicle Descent Module TPS Test Matrix (continued)								
Test Number / HITF Number	**Target Type**	**Projectile Material**	**Projectile Density (g/cm^3)**	**Nominal Projectile Diameter (mm)**	**Calculated Projectile Mass (g)**	**Desired Impact Velocity (km/s)**	**Impact Angle (deg)**	**Comments**
16 HITF12298	Type 1 Average thin	Al 2017-T4	2.796	2.2	0.0156	7.0	45	
17 HITF12299	Type 1 Average thin	Al 2017-T4	2.796	2.38	0.0197	5.0	30	
18 HITF12300	Type 2 Average medium	Al 2017-T4	2.796	2.38	0.0197	7.0	30	
19 HITF12301	Type 1 Average thin	Al 2017-T4	2.796	2.8	0.0321	7.0	60	
20 HITF12302	Type 1 Average thin	Al 2017-T4	2.796	3.4	0.0575	3.0	30	
21 HITF12303	Type 1 Average thin	Al 2017-T4	2.796	3.18	0.0469	4.0	45	
22 HITF12304	Type 1 Average thin	Al 2017-T4	2.796	TBD	TBD	7.0	30	Increase/decrease projectile size based on #15
23 HITF12305	Type 1 Average thin	Al 2017-T4	2.796	TBD	TBD	7.0	45	Increase/decrease projectile size based on #16
24 HITF12306	Type 1 Average thin	Al 2017-T4	2.796	TBD	TBD	5.0	30	Increase/decrease projectile size based on #17
25 HITF12307	Type 2 Average medium	Al 2017-T4	2.796	TBD	TBD	7.0	30	Increase/decrease projectile size based on #18
26 HITF12308	Type 1 Average thin	Al 2017-T4	2.796	TBD	TBD	7.0	60	Increase/decrease projectile size based on #19
27 HITF12309	Type 1 Average thin	Al 2017-T4	2.796	TBD	TBD	3.0	30	Increase/decrease projectile size based on #20
28 HITF12310	Type 1 Average thin	Al 2017-T4	2.796	TBD	TBD	4.0	45	Increase/decrease projectile size based on #21
29 HITF12311	Type 3 Average thick	Steel 440C	7.65	2.2	0.0427	7.0	30	
30 HITF12312	Type 3 Average thick	Steel 440C	7.65	TBD	TBD	7.0	30	Increase/decrease projectile size based on #29
31 HITF12313	Type 1 Average thin	Al 2017-T4	2.796	6.35	0.3748	7.0	30	Assess pressure shell penetration limits
32 HITF12314	Type 1 Average thin	Al 2017-T4	2.796	TBD	TBD	7.0	30	

Appendix B: Ballistic Limit Predictions

Ballistic Limit Predictions for TPS penetration

Ballistic limit predictions for complete penetration of the average thin (target type 1 and type 4), average medium (target type 2) and average thick (target type 3) regions of the Soyuz descent module TPS are given below for medium density (aluminum) and high-density (steel) debris. The ballistic limit equation (BLE) predicts the impacting particle size on the threshold of complete penetration of the fiberglass substrate of the TPS, where the fiberglass substrate is the NP504 layer in the test article, or the TSP-F-N layer in the actual Soyuz descent module TPS. The Soyuz TPS BLE was adapted from a fiberglass penetration equation by Christiansen [4] used to generate predicted particle sizes on threshold of failure of the TPS substrate, prior to testing:

<u>Original BLE</u>

$$d_c = 1.28 \bullet t_{eq} \bullet (\rho_p / \rho_{tps})^{-0.5} \bullet (V \cos\theta)^{(-2/3)} \tag{1}$$

This equation was updated by E.L. Christiansen based on results from the impact tests reported in this report and from results of >9km/s tests on type 4 targets at the University Dayton Research Institute (UDRI) [5]:

<u>Revised BLE</u>

$$d_c = 0.597 \bullet t_{eq}^{0.9} \bullet (\rho_p / \rho_{tps})^{-0.6} \bullet V^{-0.3} \bullet (\cos\theta)^{(-2/3)} \tag{2}$$

Where,
d_c = critical MMOD particle diameter on penetration threshold of TPS substrate (cm)
t_{eq} = equivalent thickness of the TPS material including MLI (cm)
ρ_{tps} = average density of the TPS material (g/cm^3)
ρ_p = projectile density (g/cm^3)
V = projectile impact velocity (km/s)
θ = impact angle (deg or radian)

The equivalent thickness of the TPS material including MLI and the average density of the TPS material is given in the following table for the various TPS types tested in this report. The last two columns of the table also provide the average TPS parameters used for the Soyuz descent module (values used in the Soyuz TPS risk assessment).

The density of the aluminum and steel projectiles used in the impact testing are 2.796 g/cm^3 and 7.667 g/cm^3, respectively. For the Soyuz TPS risk assessment, density values used for medium density and high-density debris are 2.8 g/cm^3 and 7.8 g/cm^3, respectively.

TPS target type	t_{eq}, TPS equivalent thickness (cm) for test article	ρ_{tps}, average TPS density (g/cm^3) for test article	t_{eq}, TPS equivalent thickness (cm) for Soyuz	ρ_{tps}, average TPS density (g/cm^3) for Soyuz
Average thin region (type 1 & 4)	0.594	1.610	0.641	1.625
Average medium region (type 2)	0.799	1.783	0.781	1.688
Average thick region (type 3)	1.149	1.707	1.209	1.759

Table 1B provides the predicted TPS ballistic limits (projectile diameter in centimeters as a function of impact velocity and angle) using the revised BLE (equation 2) for the Soyuz DM average thin region (type 1 and type 4 targets). Table 2B provides similar predicted ballistic limits for the average medium TPS region (type 2 targets), and Table 3B for the average thick TPS region (type 3 targets). For completeness, the predicted TPS ballistic limit equations using the original BLE (equation 1) are provided in Tables 4B through 6B.

Figures 1B through 9B illustrate the comparison between test results and the predicted ballistic limits using the revised BLE and the original BLE. The revised BLE does a much better job at predicting the results of the impact tests, than the original BLE. Also, generally the results of the impact tests were more penetrating than predicted earlier by the original BLE.

Table B1 Predicted TPS ballistic limits using the revised BLE (equation 2) for Soyuz DM average thin region (type 1 and type 4)

Aluminum projectile critical diameter (cm)						
velocity (km/s)	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**
1	0.2680	0.2743	0.2950	0.3377	0.4254	0.6599
2	0.2177	0.2228	0.2396	0.2743	0.3456	0.5360
3	0.1928	0.1973	0.2122	0.2429	0.3060	0.4746
4	0.1768	0.1809	0.1946	0.2228	0.2807	0.4354
5	0.1654	0.1692	0.1820	0.2083	0.2625	0.4072
6	0.1566	0.1602	0.1723	0.1973	0.2485	0.3855
7	0.1495	0.1530	0.1645	0.1883	0.2373	0.3681
8	0.1436	0.1470	0.1581	0.1809	0.2280	0.3536
9	0.1386	0.1419	0.1526	0.1747	0.2201	0.3414
10	0.1343	0.1375	0.1478	0.1692	0.2132	0.3307
11	0.1305	0.1336	0.1437	0.1645	0.2072	0.3214
12	0.1272	0.1301	0.1400	0.1602	0.2019	0.3131
13	0.1242	0.1271	0.1366	0.1564	0.1971	0.3057
14	0.1214	0.1243	0.1336	0.1530	0.1927	0.2990
15	0.1189	0.1217	0.1309	0.1498	0.1888	0.2929
Steel projectile critical diameter (cm)						
1	0.1466	0.1501	0.1614	0.1847	0.2328	0.3611
2	0.1191	0.1219	0.1311	0.1501	0.1891	0.2933
3	0.1055	0.1079	0.1161	0.1329	0.1674	0.2597
4	0.0967	0.0990	0.1065	0.1219	0.1536	0.2382
5	0.0905	0.0926	0.0996	0.1140	0.1436	0.2228
6	0.0857	0.0877	0.0943	0.1079	0.1360	0.2109
7	0.0818	0.0837	0.0900	0.1031	0.1298	0.2014
8	0.0786	0.0804	0.0865	0.0990	0.1247	0.1935
9	0.0759	0.0776	0.0835	0.0956	0.1204	0.1868
10	0.0735	0.0752	0.0809	0.0926	0.1167	0.1810
11	0.0714	0.0731	0.0786	0.0900	0.1134	0.1759
12	0.0696	0.0712	0.0766	0.0877	0.1105	0.1713
13	0.0679	0.0695	0.0748	0.0856	0.1078	0.1673
14	0.0664	0.0680	0.0731	0.0837	0.1055	0.1636
15	0.0651	0.0666	0.0716	0.0820	0.1033	0.1602

Table B2 Predicted TPS ballistic limits using the revised BLE (equation 2) for Soyuz DM average medium region (type 2)

Aluminum projectile critical diameter (cm)						
velocity (km/s)	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**
1	0.3720	0.3807	0.4095	0.4687	0.5905	0.9160
2	0.3022	0.3092	0.3326	0.3807	0.4797	0.7440
3	0.2676	0.2738	0.2945	0.3371	0.4247	0.6588
4	0.2454	0.2512	0.2701	0.3092	0.3896	0.6043
5	0.2295	0.2349	0.2526	0.2892	0.3644	0.5652
6	0.2173	0.2224	0.2392	0.2738	0.3450	0.5351
7	0.2075	0.2124	0.2284	0.2614	0.3294	0.5109
8	0.1994	0.2040	0.2194	0.2512	0.3165	0.4909
9	0.1924	0.1969	0.2118	0.2425	0.3055	0.4738
10	0.1864	0.1908	0.2052	0.2349	0.2960	0.4591
11	0.1812	0.1854	0.1994	0.2283	0.2876	0.4461
12	0.1765	0.1807	0.1943	0.2224	0.2802	0.4346
13	0.1723	0.1764	0.1897	0.2171	0.2736	0.4243
14	0.1685	0.1725	0.1855	0.2124	0.2675	0.4150
15	0.1651	0.1690	0.1817	0.2080	0.2621	0.4065
Steel projectile critical diameter (cm)						
1	0.2035	0.2083	0.2240	0.2564	0.3231	0.5012
2	0.1653	0.1692	0.1820	0.2083	0.2624	0.4071
3	0.1464	0.1498	0.1611	0.1844	0.2324	0.3605
4	0.1343	0.1374	0.1478	0.1692	0.2132	0.3307
5	0.1256	0.1285	0.1382	0.1582	0.1994	0.3092
6	0.1189	0.1217	0.1309	0.1498	0.1888	0.2928
7	0.1135	0.1162	0.1250	0.1430	0.1802	0.2796
8	0.1091	0.1116	0.1201	0.1374	0.1731	0.2686
9	0.1053	0.1078	0.1159	0.1327	0.1671	0.2592
10	0.1020	0.1044	0.1123	0.1285	0.1619	0.2512
11	0.0991	0.1015	0.1091	0.1249	0.1574	0.2441
12	0.0966	0.0988	0.1063	0.1217	0.1533	0.2378
13	0.0943	0.0965	0.1038	0.1188	0.1497	0.2322
14	0.0922	0.0944	0.1015	0.1162	0.1464	0.2271
15	0.0903	0.0924	0.0994	0.1138	0.1434	0.2224

Table B3 Predicted TPS ballistic limits using the revised BLE (equation 2) for Soyuz DM average thick region (type 3)

Aluminum projectile critical diameter (cm)						
velocity (km/s)	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**
1	0.5026	0.5143	0.5532	0.6332	0.7978	1.2375
2	0.4082	0.4178	0.4493	0.5143	0.6480	1.0051
3	0.3615	0.3699	0.3978	0.4554	0.5738	0.8900
4	0.3316	0.3393	0.3649	0.4178	0.5263	0.8164
5	0.3101	0.3174	0.3413	0.3907	0.4923	0.7636
6	0.2936	0.3005	0.3231	0.3699	0.4661	0.7229
7	0.2803	0.2869	0.3085	0.3532	0.4450	0.6903
8	0.2693	0.2756	0.2964	0.3393	0.4275	0.6631
9	0.2600	0.2661	0.2861	0.3275	0.4127	0.6401
10	0.2519	0.2578	0.2772	0.3174	0.3998	0.6202
11	0.2448	0.2505	0.2694	0.3084	0.3886	0.6027
12	0.2385	0.2441	0.2625	0.3005	0.3786	0.5872
13	0.2328	0.2383	0.2563	0.2933	0.3696	0.5733
14	0.2277	0.2330	0.2506	0.2869	0.3615	0.5607
15	0.2230	0.2283	0.2455	0.2810	0.3540	0.5492
Steel projectile critical diameter (cm)						
1	0.2750	0.2814	0.3027	0.3465	0.4365	0.6771
2	0.2234	0.2286	0.2458	0.2814	0.3545	0.5500
3	0.1978	0.2024	0.2177	0.2492	0.3139	0.4870
4	0.1814	0.1857	0.1997	0.2286	0.2880	0.4467
5	0.1697	0.1736	0.1867	0.2138	0.2693	0.4178
6	0.1606	0.1644	0.1768	0.2024	0.2550	0.3955
7	0.1534	0.1570	0.1688	0.1932	0.2435	0.3777
8	0.1474	0.1508	0.1622	0.1857	0.2339	0.3628
9	0.1422	0.1456	0.1566	0.1792	0.2258	0.3502
10	0.1378	0.1410	0.1517	0.1736	0.2188	0.3393
11	0.1339	0.1371	0.1474	0.1687	0.2126	0.3298
12	0.1305	0.1335	0.1436	0.1644	0.2071	0.3213
13	0.1274	0.1304	0.1402	0.1605	0.2022	0.3137
14	0.1246	0.1275	0.1371	0.1570	0.1978	0.3068
15	0.1220	0.1249	0.1343	0.1538	0.1937	0.3005

Table B4 Predicted TPS ballistic limits using the original BLE (equation 1) for Soyuz DM average thin region (type 1 and type 4)

Aluminum projectile critical diameter (cm)						
velocity (km/s)	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**
1	0.5765	0.5900	0.6346	0.7264	0.9152	1.4196
2	0.3632	0.3717	0.3998	0.4576	0.5765	0.8943
3	0.2772	0.2837	0.3051	0.3492	0.4400	0.6825
4	0.2288	0.2342	0.2518	0.2883	0.3632	0.5634
5	0.1972	0.2018	0.2170	0.2484	0.3130	0.4855
6	0.1746	0.1787	0.1922	0.2200	0.2772	0.4299
7	0.1576	0.1612	0.1734	0.1985	0.2501	0.3879
8	0.1441	0.1475	0.1586	0.1816	0.2288	0.3549
9	0.1333	0.1364	0.1467	0.1679	0.2115	0.3281
10	0.1242	0.1271	0.1367	0.1565	0.1972	0.3058
11	0.1166	0.1193	0.1283	0.1469	0.1850	0.2870
12	0.1100	0.1126	0.1211	0.1386	0.1746	0.2708
13	0.1043	0.1067	0.1148	0.1314	0.1655	0.2568
14	0.0993	0.1016	0.1092	0.1251	0.1576	0.2444
15	0.0948	0.0970	0.1043	0.1194	0.1505	0.2334
Steel projectile critical diameter (cm)						
1	0.3488	0.3570	0.3839	0.4395	0.5537	0.8588
2	0.2197	0.2249	0.2418	0.2768	0.3488	0.5410
3	0.1677	0.1716	0.1846	0.2113	0.2662	0.4129
4	0.1384	0.1417	0.1524	0.1744	0.2197	0.3408
5	0.1193	0.1221	0.1313	0.1503	0.1894	0.2937
6	0.1056	0.1081	0.1163	0.1331	0.1677	0.2601
7	0.0953	0.0975	0.1049	0.1201	0.1513	0.2347
8	0.0872	0.0892	0.0960	0.1099	0.1384	0.2147
9	0.0806	0.0825	0.0887	0.1016	0.1280	0.1985
10	0.0751	0.0769	0.0827	0.0947	0.1193	0.1850
11	0.0705	0.0722	0.0776	0.0889	0.1119	0.1736
12	0.0665	0.0681	0.0732	0.0838	0.1056	0.1639
13	0.0631	0.0646	0.0694	0.0795	0.1001	0.1553
14	0.0600	0.0615	0.0661	0.0757	0.0953	0.1479
15	0.0573	0.0587	0.0631	0.0723	0.0910	0.1412

Table B5 Predicted TPS ballistic limits using the original BLE (equation 1) for Soyuz DM average medium region (type 2)

Aluminum projectile critical diameter (cm)						
velocity (km/s)	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**
1	0.8160	0.8351	0.8982	1.0281	1.2954	2.0093
2	0.5141	0.5261	0.5658	0.6477	0.8160	1.2658
3	0.3923	0.4015	0.4318	0.4943	0.6227	0.9660
4	0.3238	0.3314	0.3564	0.4080	0.5141	0.7974
5	0.2791	0.2856	0.3072	0.3516	0.4430	0.6872
6	0.2471	0.2529	0.2720	0.3114	0.3923	0.6085
7	0.2230	0.2282	0.2454	0.2810	0.3540	0.5491
8	0.2040	0.2088	0.2245	0.2570	0.3238	0.5023
9	0.1886	0.1930	0.2076	0.2376	0.2994	0.4644
10	0.1758	0.1799	0.1935	0.2215	0.2791	0.4329
11	0.1650	0.1688	0.1816	0.2079	0.2619	0.4062
12	0.1557	0.1593	0.1714	0.1962	0.2471	0.3833
13	0.1476	0.1510	0.1625	0.1860	0.2343	0.3634
14	0.1405	0.1438	0.1546	0.1770	0.2230	0.3459
15	0.1342	0.1373	0.1477	0.1690	0.2130	0.3304
Steel projectile critical diameter (cm)						
1	0.4937	0.5052	0.5434	0.6220	0.7837	1.2156
2	0.3110	0.3183	0.3423	0.3918	0.4937	0.7658
3	0.2373	0.2429	0.2612	0.2990	0.3768	0.5844
4	0.1959	0.2005	0.2156	0.2468	0.3110	0.4824
5	0.1688	0.1728	0.1858	0.2127	0.2680	0.4157
6	0.1495	0.1530	0.1646	0.1884	0.2373	0.3681
7	0.1349	0.1381	0.1485	0.1700	0.2142	0.3322
8	0.1234	0.1263	0.1358	0.1555	0.1959	0.3039
9	0.1141	0.1168	0.1256	0.1438	0.1811	0.2809
10	0.1064	0.1088	0.1171	0.1340	0.1688	0.2619
11	0.0998	0.1021	0.1099	0.1258	0.1584	0.2458
12	0.0942	0.0964	0.1037	0.1187	0.1495	0.2319
13	0.0893	0.0914	0.0983	0.1125	0.1417	0.2199
14	0.0850	0.0870	0.0935	0.1071	0.1349	0.2093
15	0.0812	0.0831	0.0893	0.1023	0.1288	0.1999

Table B6 Predicted TPS ballistic limits using the original BLE (equation 1) for Soyuz DM average thick region (type 3)

Aluminum projectile critical diameter (cm)						
velocity (km/s)	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**
1	1.1482	1.1750	1.2638	1.4466	1.8227	2.8272
2	0.7233	0.7402	0.7961	0.9113	1.1482	1.7810
3	0.5520	0.5649	0.6076	0.6955	0.8762	1.3592
4	0.4557	0.4663	0.5015	0.5741	0.7233	1.1220
5	0.3927	0.4019	0.4322	0.4947	0.6233	0.9669
6	0.3477	0.3559	0.3827	0.4381	0.5520	0.8562
7	0.3138	0.3211	0.3454	0.3953	0.4981	0.7726
8	0.2870	0.2938	0.3159	0.3617	0.4557	0.7068
9	0.2654	0.2716	0.2921	0.3343	0.4213	0.6534
10	0.2474	0.2532	0.2723	0.3117	0.3927	0.6091
11	0.2321	0.2376	0.2555	0.2925	0.3685	0.5716
12	0.2191	0.2242	0.2411	0.2760	0.3477	0.5394
13	0.2077	0.2125	0.2286	0.2617	0.3297	0.5114
14	0.1977	0.2023	0.2176	0.2490	0.3138	0.4867
15	0.1888	0.1932	0.2078	0.2378	0.2997	0.4648
Steel projectile critical diameter (cm)						
1	0.6946	0.7109	0.7646	0.8752	1.1027	1.7104
2	0.4376	0.4478	0.4816	0.5513	0.6946	1.0775
3	0.3340	0.3418	0.3676	0.4208	0.5301	0.8223
4	0.2757	0.2821	0.3034	0.3473	0.4376	0.6788
5	0.2376	0.2431	0.2615	0.2993	0.3771	0.5850
6	0.2104	0.2153	0.2315	0.2651	0.3340	0.5180
7	0.1898	0.1943	0.2089	0.2392	0.3013	0.4674
8	0.1737	0.1777	0.1911	0.2188	0.2757	0.4276
9	0.1605	0.1643	0.1767	0.2023	0.2549	0.3953
10	0.1497	0.1532	0.1647	0.1886	0.2376	0.3685
11	0.1404	0.1437	0.1546	0.1769	0.2229	0.3458
12	0.1325	0.1356	0.1459	0.1670	0.2104	0.3263
13	0.1256	0.1286	0.1383	0.1583	0.1994	0.3094
14	0.1196	0.1224	0.1316	0.1507	0.1898	0.2945
15	0.1142	0.1169	0.1257	0.1439	0.1813	0.2812

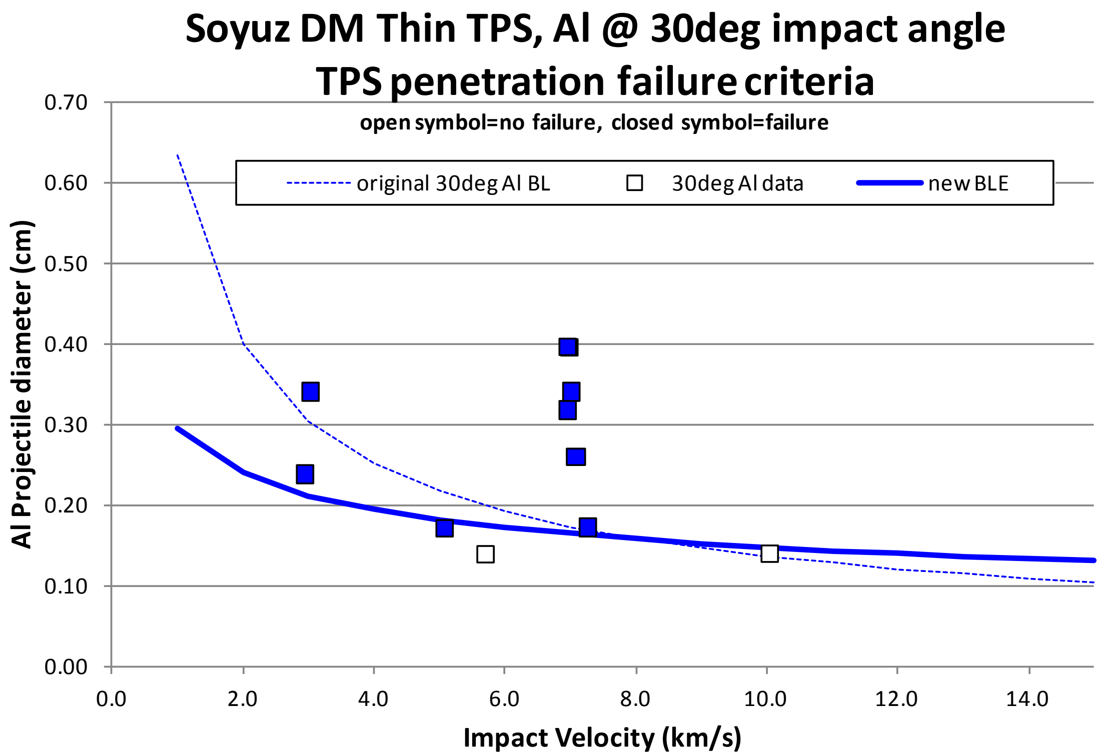


Figure B1. Predicted BLE versus test data for 30 deg impacts by aluminum projectiles on thin TPS (target type 1)

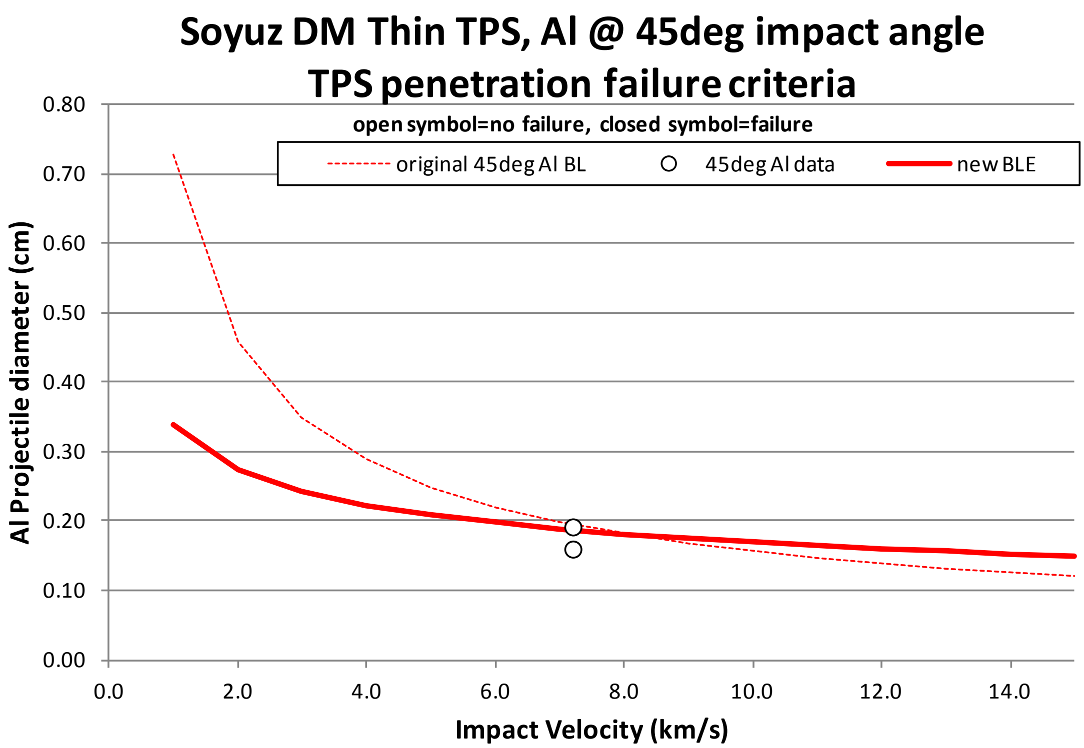


Figure B2. Predicted BLE versus test data for 45 deg impacts by aluminum projectiles on thin TPS (target type 1)

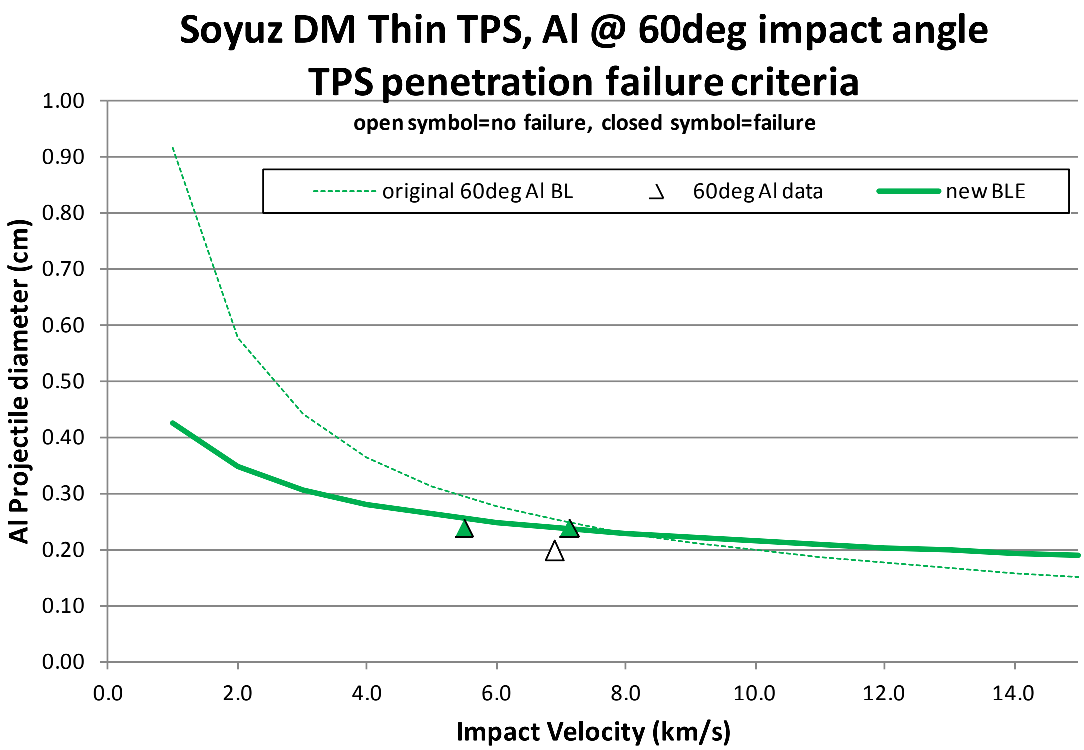


Figure B3. Predicted BLE versus test data for 60 deg impacts by aluminum projectiles on thin TPS (target type 1)

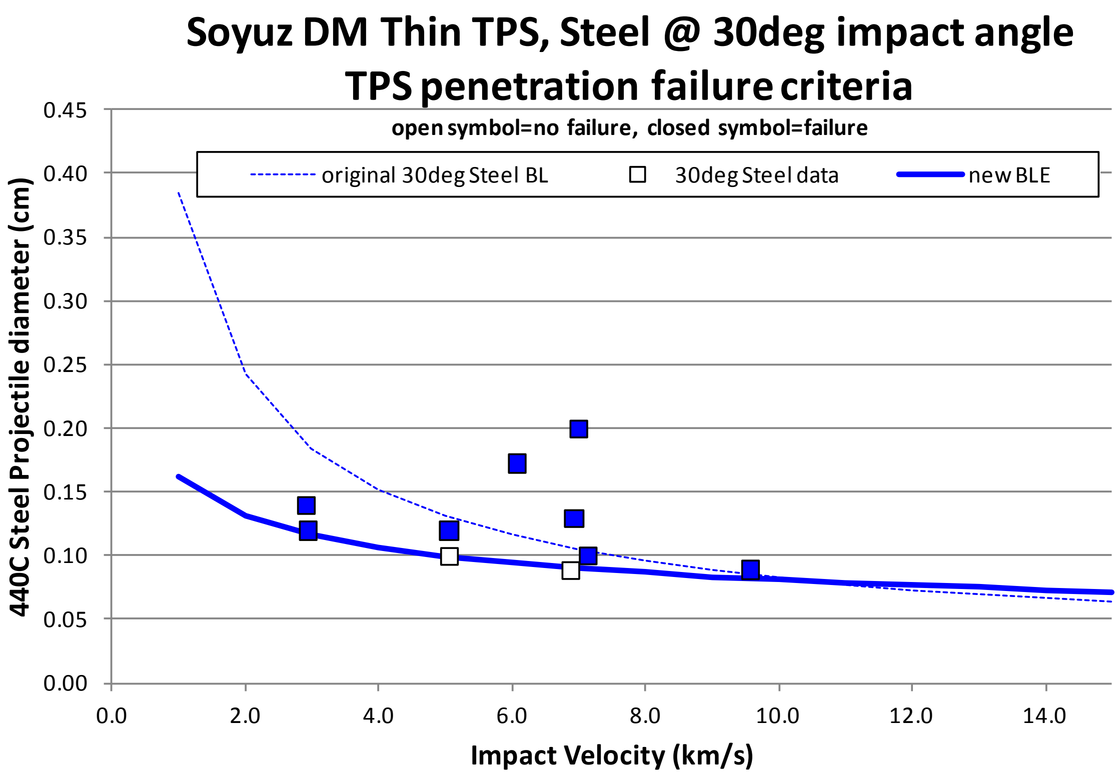


Figure B4. Predicted BLE versus test data for 30 deg impacts by steel projectiles on thin TPS (target type 1)

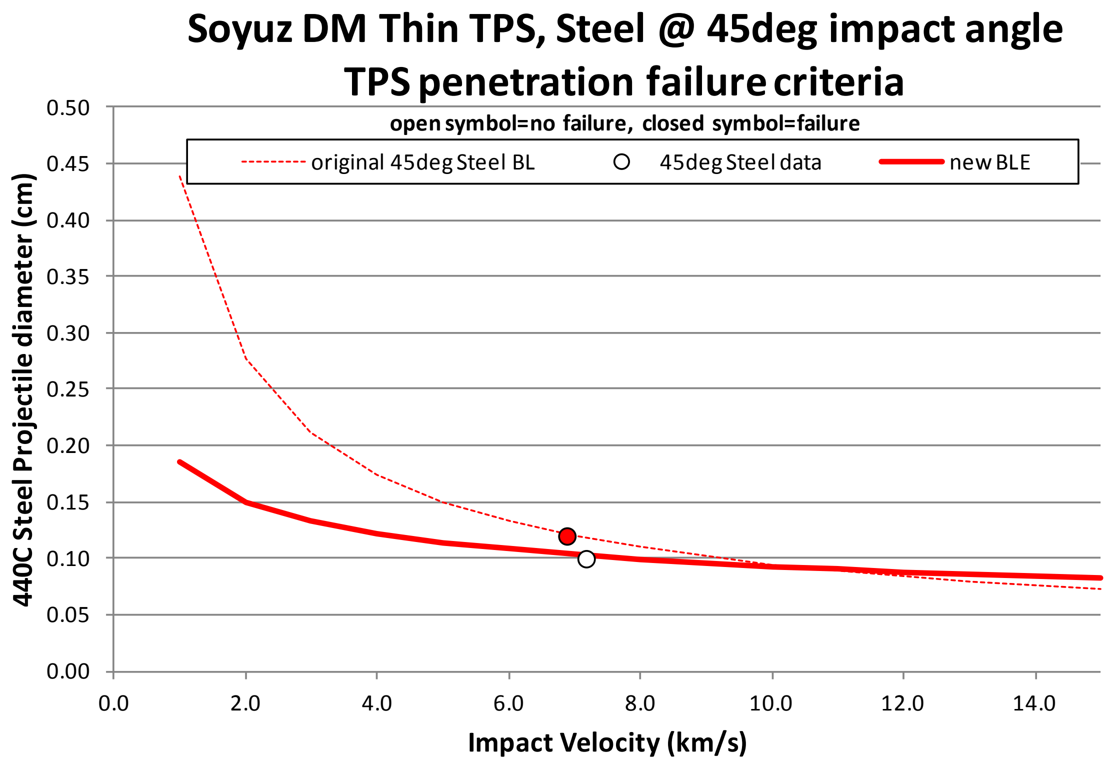


Figure B5. Predicted BLE versus test data for 45 deg impacts by steel projectiles on thin TPS (target type 1)

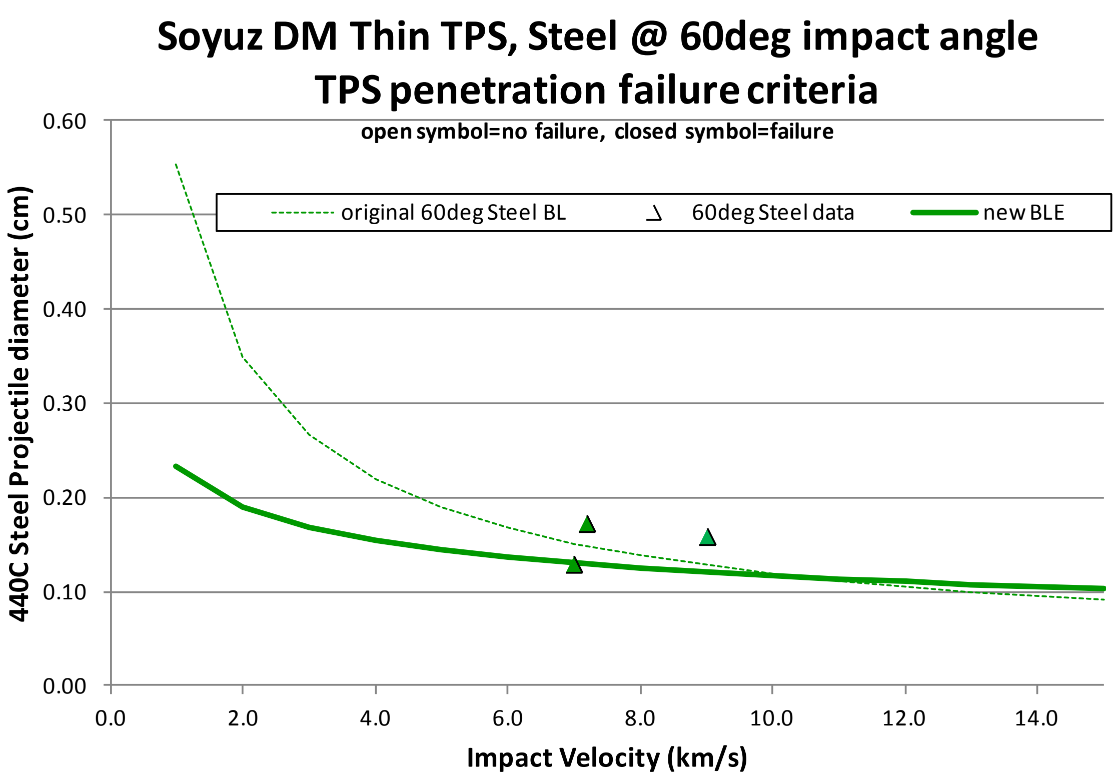


Figure B6. Predicted BLE versus test data for 60 deg impacts by steel projectiles on thin TPS (target type 1)

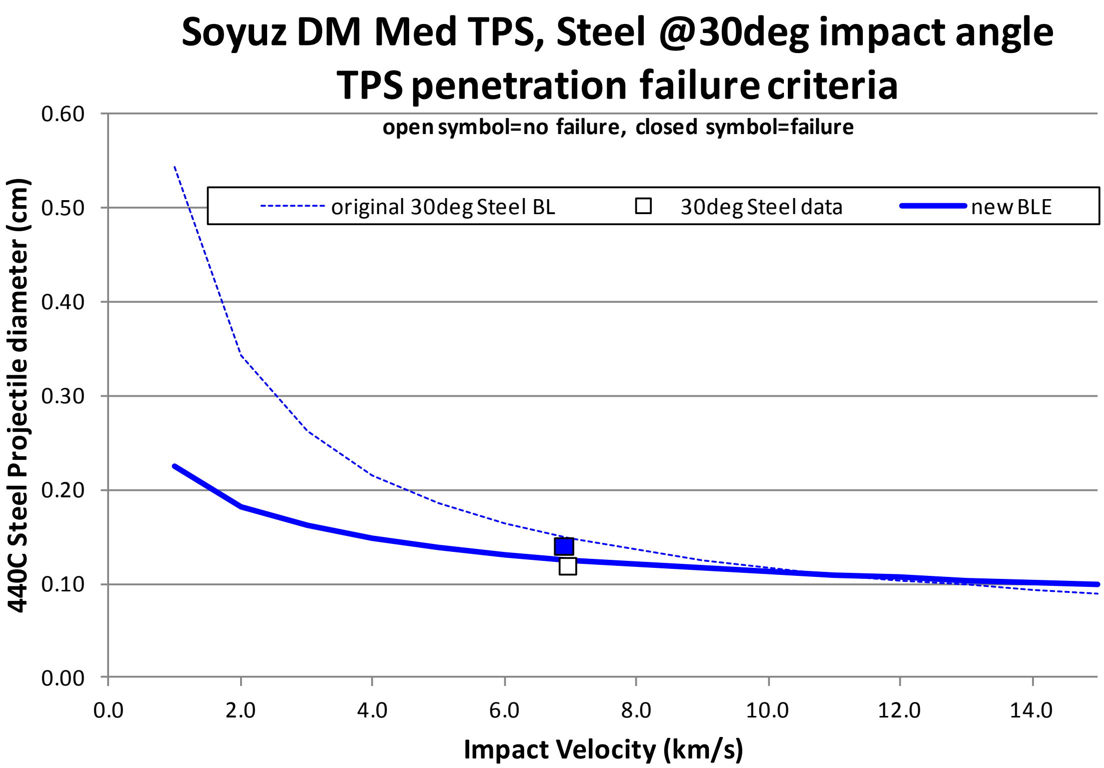


Figure B7. Predicted BLE versus test data for 30 deg impacts by steel projectiles on medium TPS (target type 2)

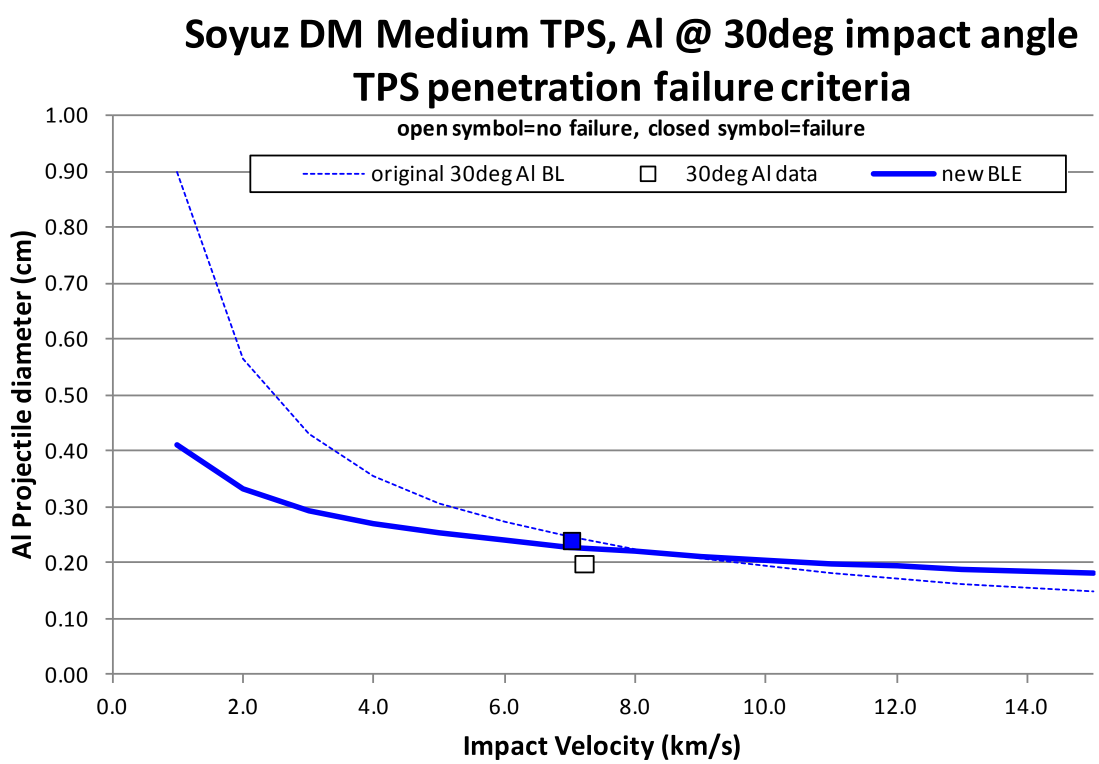


Figure B8. Predicted BLE versus test data for 30 deg impacts by aluminum projectiles on medium TPS (target type 2)

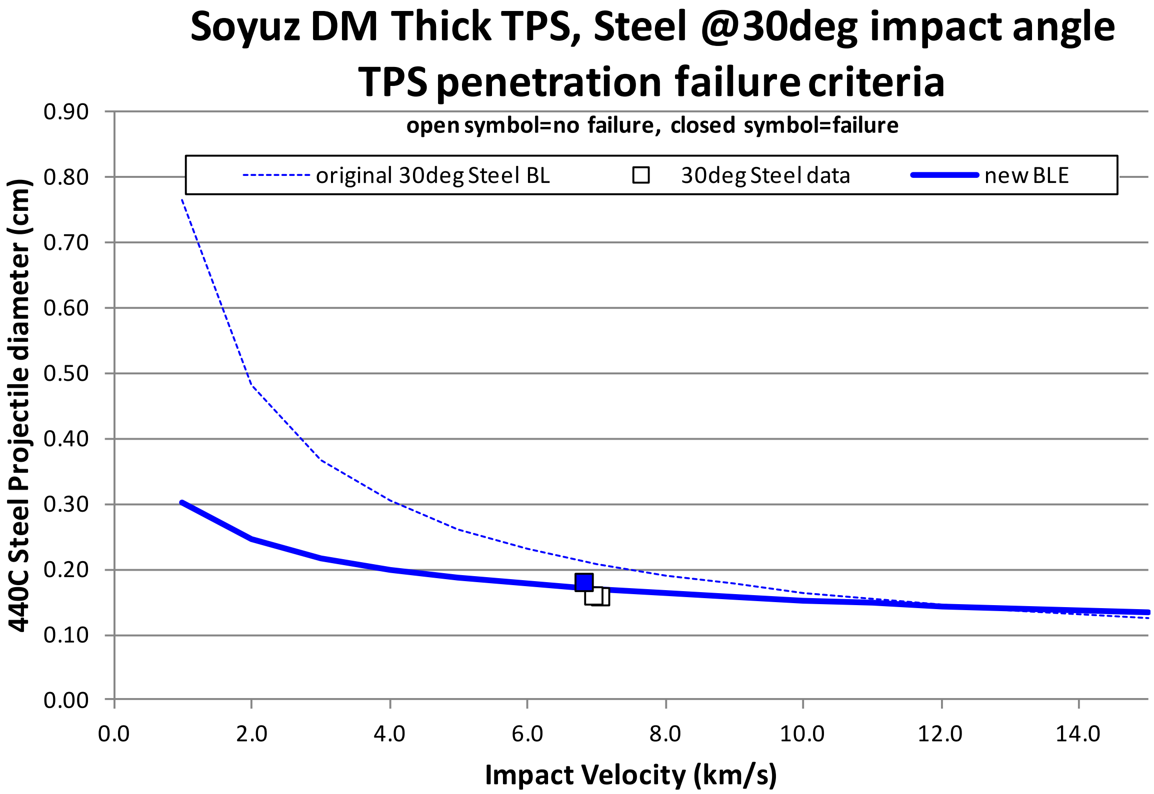


Figure B9. Predicted BLE versus test data for 30 deg impacts by steel projectiles on thick TPS (target type 3)

Predicted Ballistic Limits for Pressure Shell behind TPS

A second failure mode of interest is penetration through the TPS, the low-density insulation behind the TPS substrate, and the aluminum pressure shell. The predicted ballistic limit particle size given in the following tables and figures are based on threshold penetration through the aluminum pressure shell behind the TPS. The predicted ballistic limits were derived from Bumper code calculations provided by J.L. Hyde [6], with a summary of the ballistic limit parameters provided below.

```
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LAST COMMIT DATE: 2012/07/30 12:07:44 STATE OF CURRENT EXE: Modified

RESPONSE MODULE SUMMARY FILE

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NAME OF THE MATERIAL PROPERTIES FILE: mat.prp
MAN-MADE DEBRIS ANALYSIS
ORDEM 3.0 DEBRIS ENVIRONMENT

PROPERTY ID NUMBER = 528
SOYUZ TM DESCENT MODULE
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Table B7 provides predicted pressure shell ballistic limits for the thin TPS region of the Soyuz (target type 1).

Figure B10 illustrates how the impact test data from this report compares to predicted pressure shell ballistic limits for aluminum projectiles impacting on thin TPS target type 1 at 30deg impact angle. The data and predictions match well.

Figure B11 provides a similar comparison between pressure shell ballistic limit prediction and results for steel projectiles impacting at 30deg impact angles on TPS target type 1. Again, data and predictions compare well.

Figure B12 shows the comparison for 60deg impact angles on TPS target type 1. A data point obtained at UDRI [5] was also plotted. The data indicates that the predicted ballistic limits are non-conservative for 60deg impact angles, and will need to be adjusted.

Table B7 Predicted pressure shell ballistic limits for Soyuz DM average thin region (type 1)

Aluminum projectile critical diameter (cm)						
velocity (km/s)	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**
1	1.4582	1.4923	1.6049	1.8372	2.3147	2.3147
2	0.9186	0.9401	1.0110	1.1574	1.4582	1.4582
3	0.7010	0.7174	0.7716	0.8832	1.1128	1.1128
4	0.5787	0.5922	0.6369	0.7291	0.9186	0.9186
5	0.4987	0.5104	0.5489	0.6283	0.7916	0.7916
6	0.4416	0.4519	0.4861	0.5564	0.7010	0.7010
7	0.3985	0.4078	0.4386	0.5021	0.6326	0.6326
8	0.3645	0.3731	0.4012	0.4593	0.5787	0.5787
9	0.3370	0.3449	0.3709	0.4246	0.5350	0.5350
10	0.3142	0.3215	0.3458	0.3958	0.4987	0.4987
11	0.2948	0.3017	0.3245	0.3714	0.4680	0.4680
12	0.2782	0.2847	0.3062	0.3505	0.4416	0.4416
13	0.2637	0.2699	0.2903	0.3323	0.4187	0.4187
14	0.2510	0.2569	0.2763	0.3163	0.3985	0.3985
15	0.2397	0.2454	0.2639	0.3021	0.3806	0.3806
Steel projectile critical diameter (cm)						
1	0.8627	0.8828	0.9495	1.0869	1.3694	1.3694
2	0.5434	0.5562	0.5981	0.6847	0.8627	0.8627
3	0.4147	0.4244	0.4565	0.5225	0.6583	0.6583
4	0.3424	0.3504	0.3768	0.4313	0.5434	0.5434
5	0.2950	0.3019	0.3247	0.3717	0.4683	0.4683
6	0.2613	0.2674	0.2876	0.3292	0.4147	0.4147
7	0.2357	0.2413	0.2595	0.2970	0.3742	0.3742
8	0.2157	0.2207	0.2374	0.2717	0.3424	0.3424
9	0.1994	0.2040	0.2194	0.2512	0.3165	0.3165
10	0.1859	0.1902	0.2046	0.2342	0.2950	0.2950
11	0.1744	0.1785	0.1920	0.2197	0.2769	0.2769
12	0.1646	0.1684	0.1811	0.2074	0.2613	0.2613
13	0.1560	0.1597	0.1717	0.1966	0.2477	0.2477
14	0.1485	0.1520	0.1635	0.1871	0.2357	0.2357
15	0.1418	0.1452	0.1561	0.1787	0.2251	0.2251

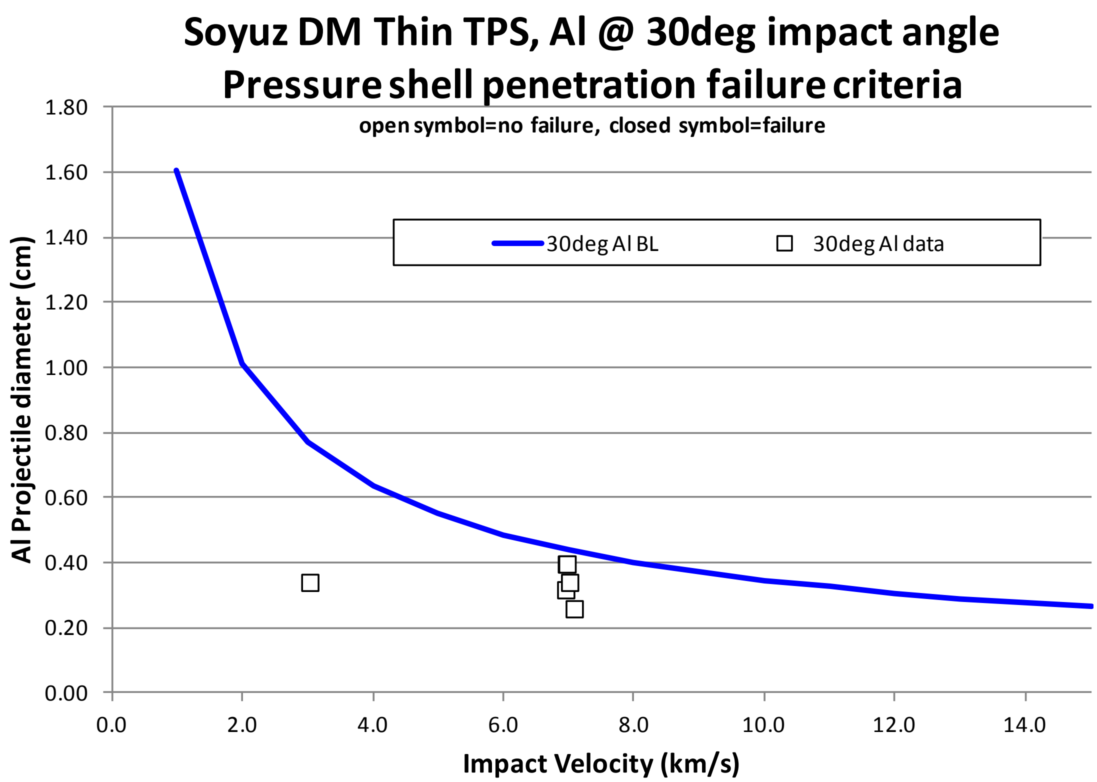


Figure B10. Predicted BLE for perforation failure of the pressure shell behind the TPS versus test data for 30 deg impacts by aluminum projectiles on thin TPS (target type 1)

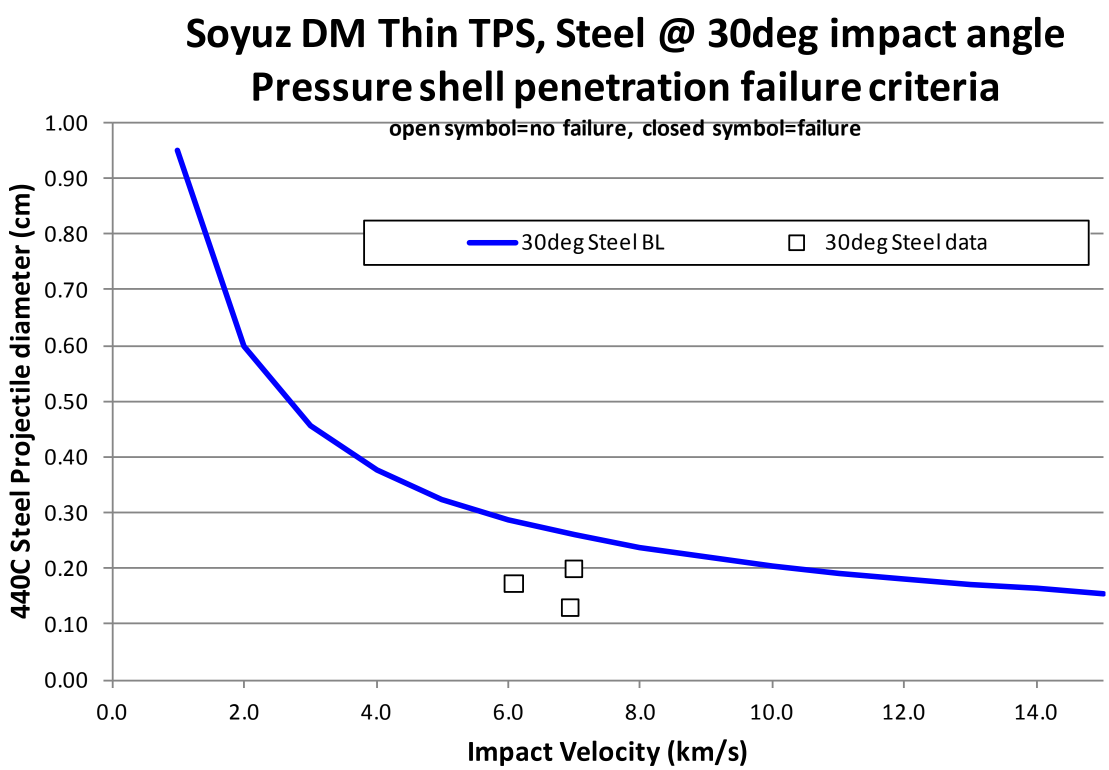


Figure B11. Predicted BLE for perforation failure of the pressure shell behind the TPS versus test data for 30 deg impacts by steel projectiles on thin TPS (target type 1)

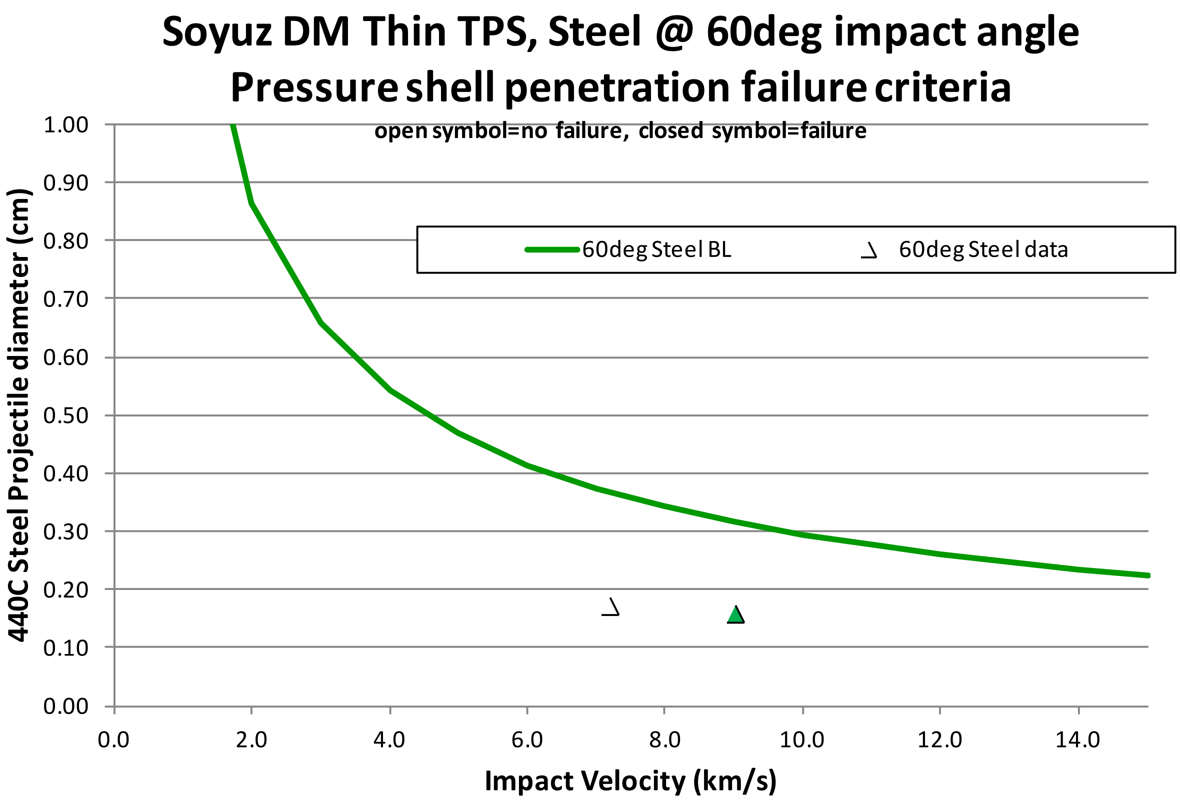


Figure B12. Predicted BLE for perforation failure of the pressure shell behind the TPS versus test data for 60 deg impacts by steel projectiles on thin TPS (target type 1)

Appendix C: Projectile Verification High-Speed Imagery

HITF12283 / Test #1

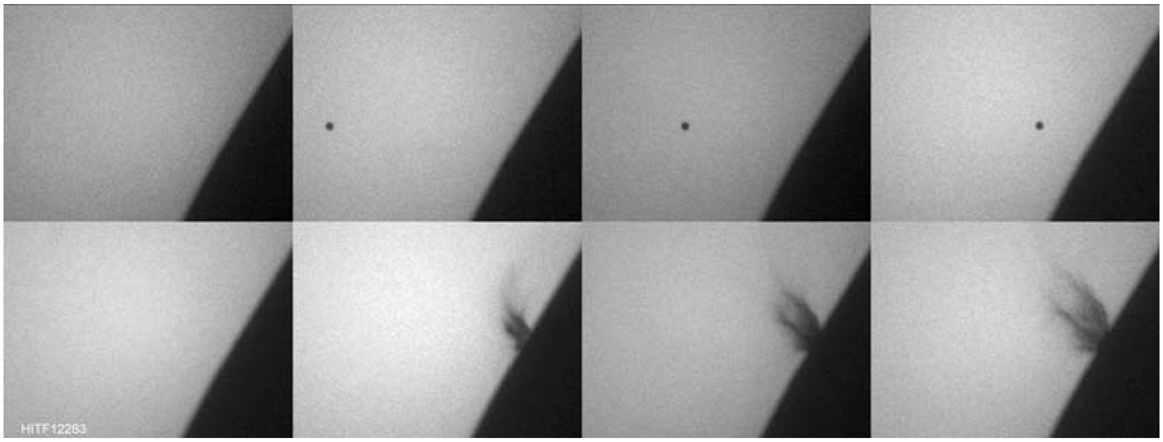


Figure C1 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

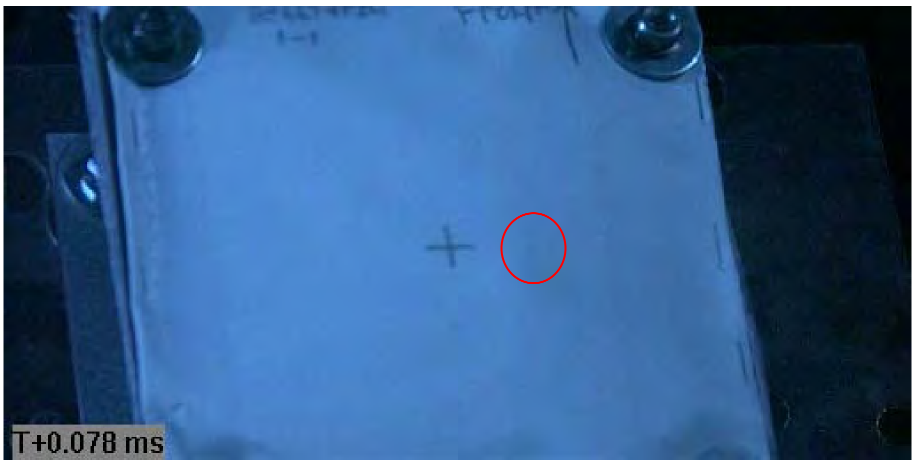


Figure C2 Faint Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

Figure C3 Projectile Impacting Target (via Phantom v711)

HITF12284 / Test #2

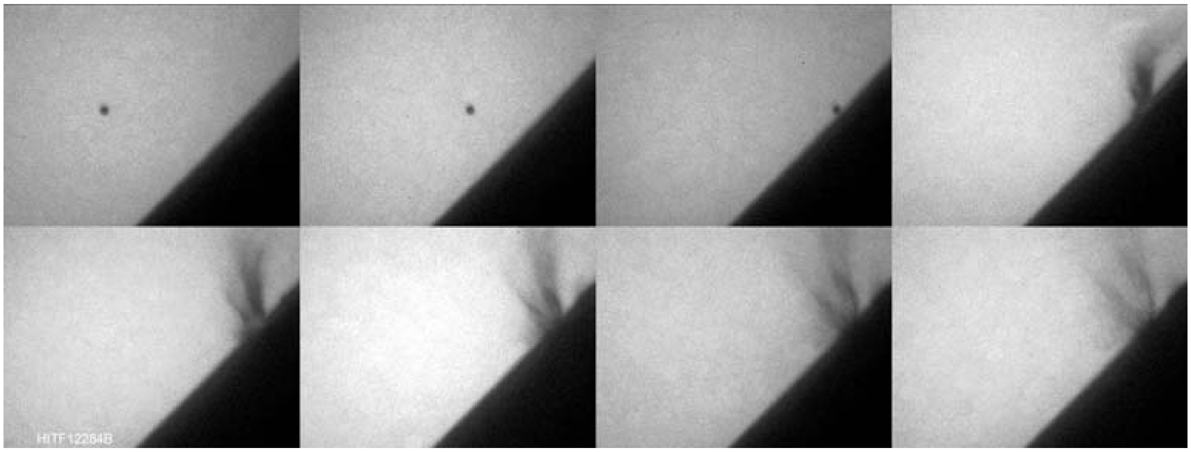


Figure C4 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

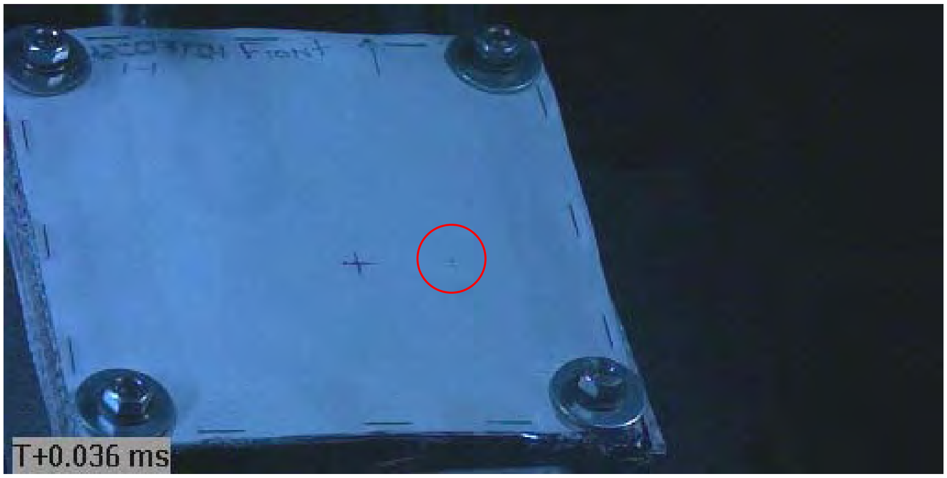


Figure C5 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

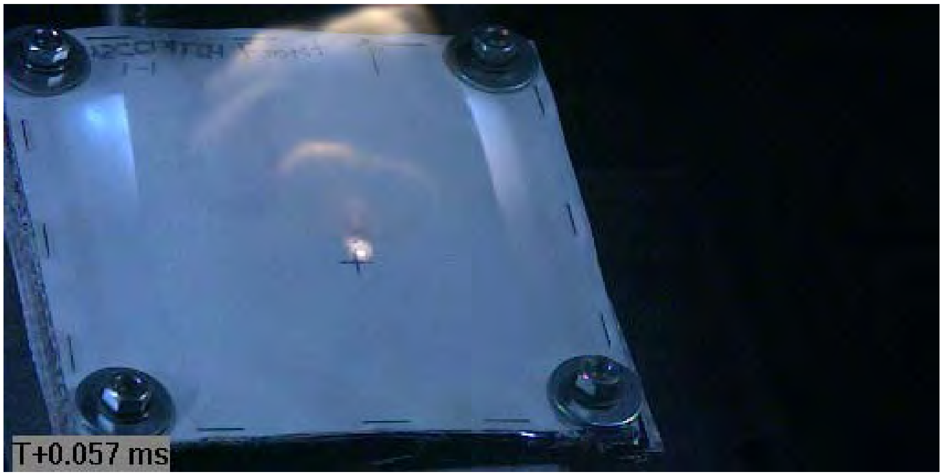


Figure C6 Projectile Impacting Target (via Phantom v711)

HITF12285 / Test #3

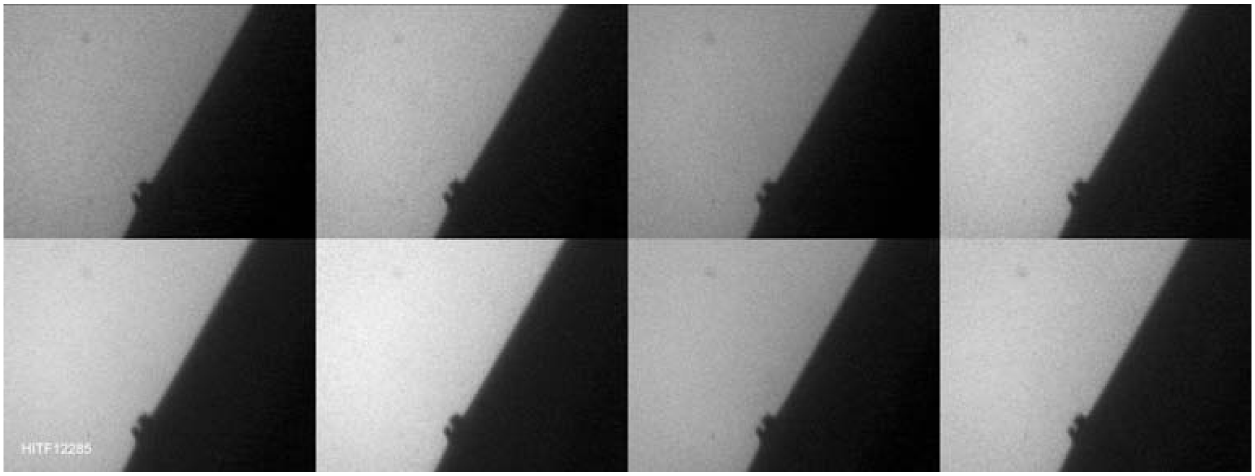


Figure C7 Projectile Not Captured Prior to Impact (via SIMX-8 Camera / projectile impacted before camera triggered)

Figure C8 Projectile Not Captured Prior to Impact (via Phantom v711 / projectile impacted before camera triggered)

HITF12286 / Test #4

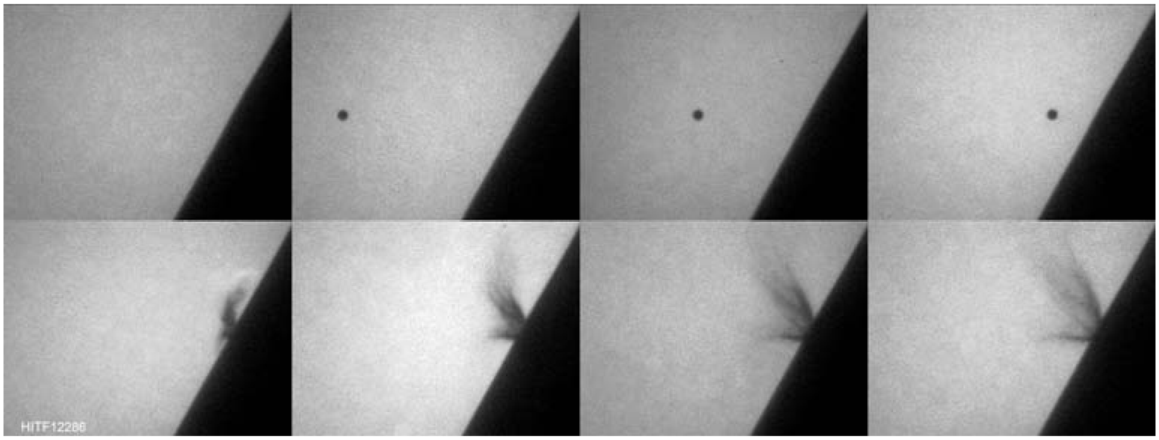


Figure C9 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

Figure C10 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

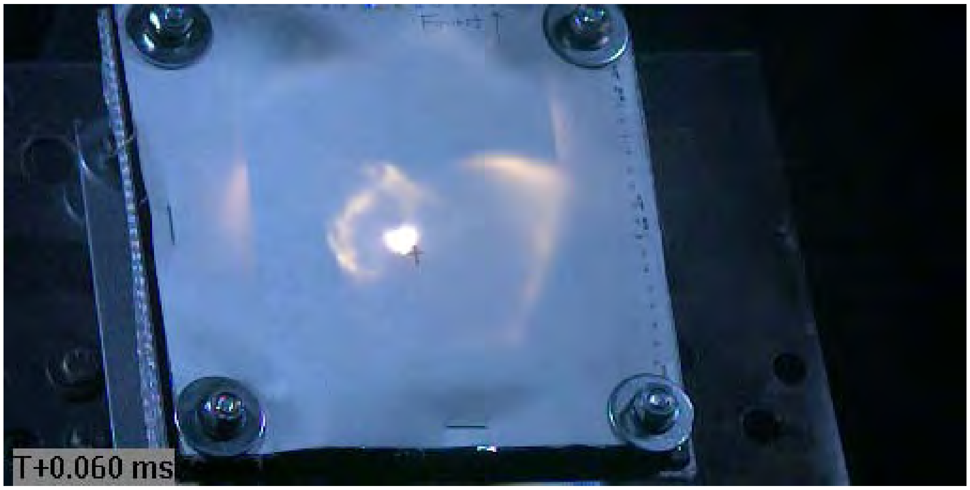


Figure C11 Projectile Impacting Target (via Phantom v711)

HITF12287 / Test #5

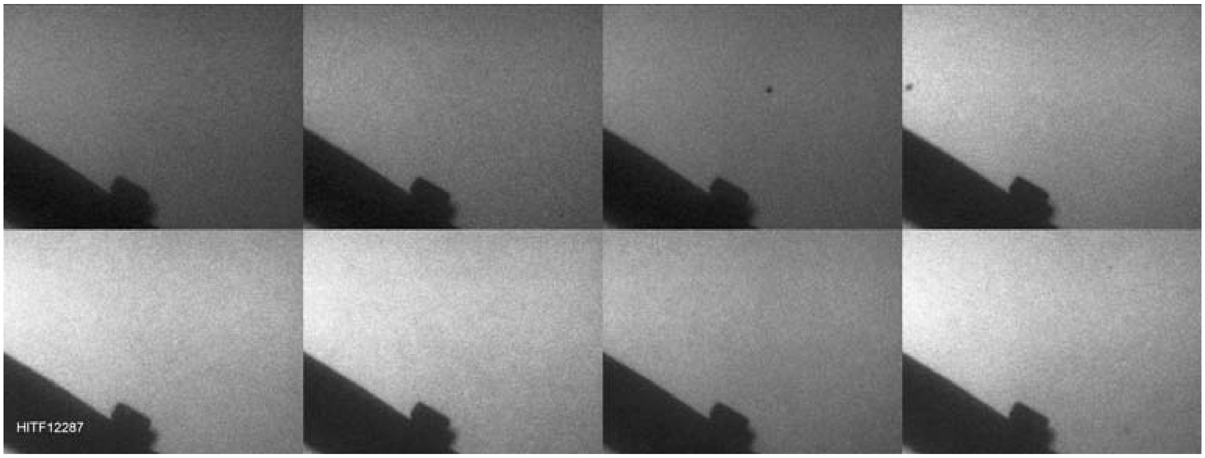


Figure C12 Projectile Captured Prior to Impact (via SIMX-8 Camera)

Figure C13 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

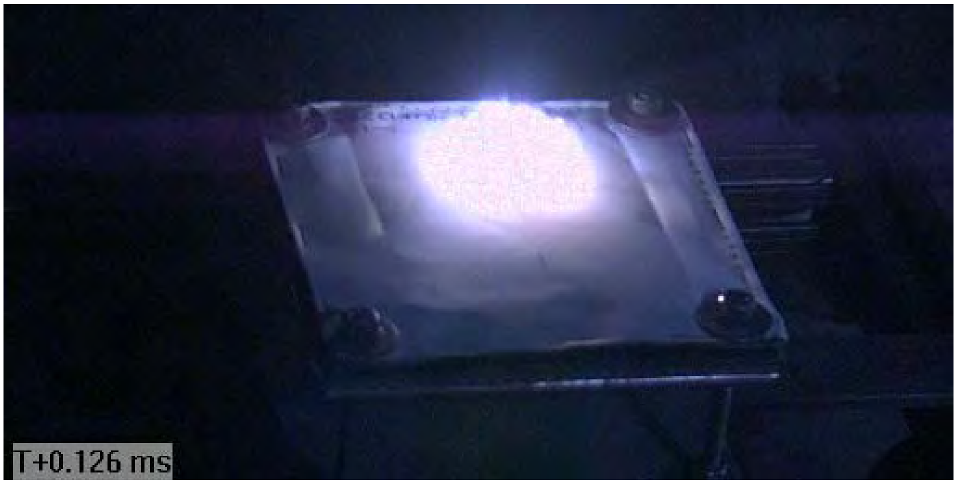


Figure C14 Projectile Impacting Target (via Phantom v711)

HITF12288 / Test #6

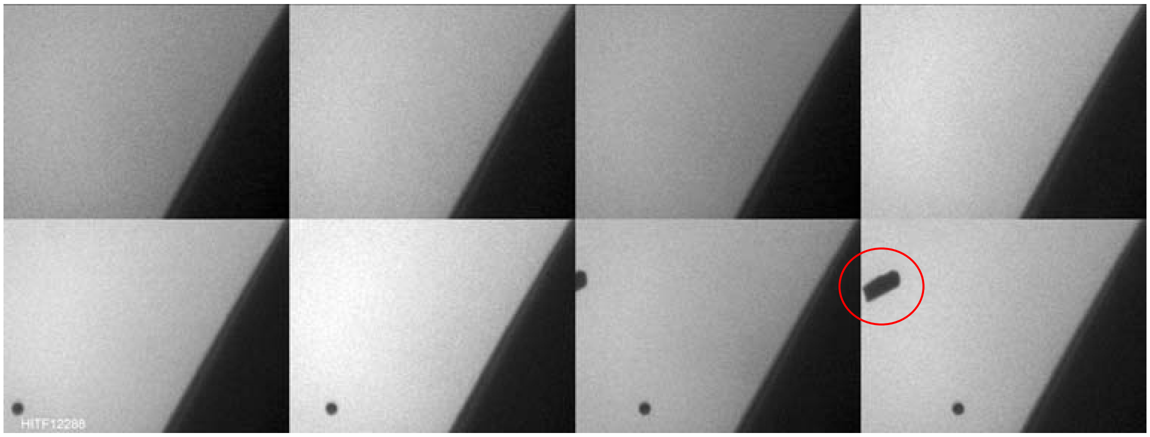


Figure C15 Projectile and Sabot Petal Captured Prior to Impact (via SIMX-8 Camera / sabot petal within red circle)

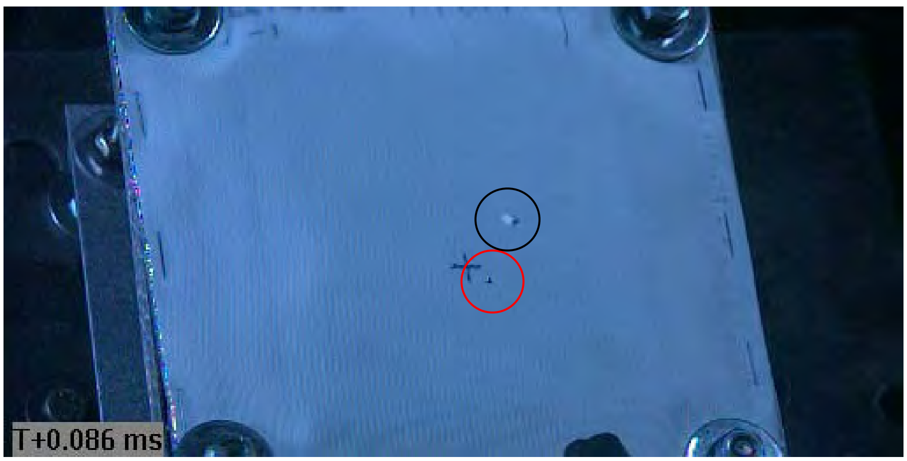


Figure C16 Image of Projectile and Sabot Petal Captured Prior to Impact (via Phantom v711 / projectile within red circle / sabot petal within black circle)

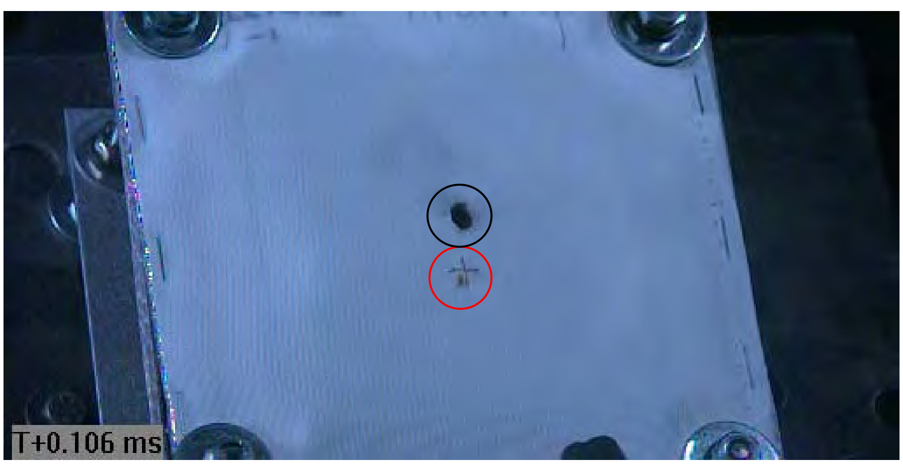


Figure C17 Image of Projectile and Sabot Petal Impacting Target (via Phantom v711 / projectile impact within red circle / sabot petal impact within black circle)

HITF12289 / Test #7

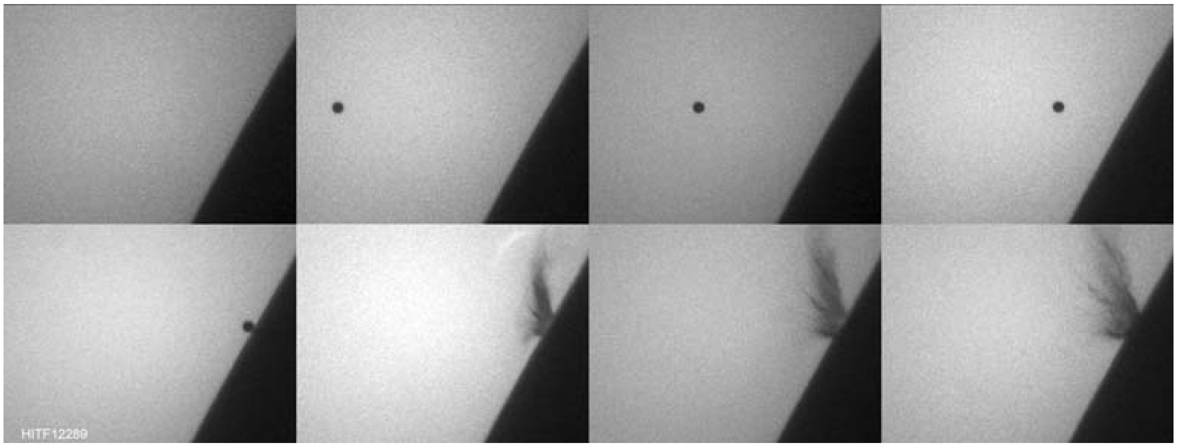


Figure C18 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

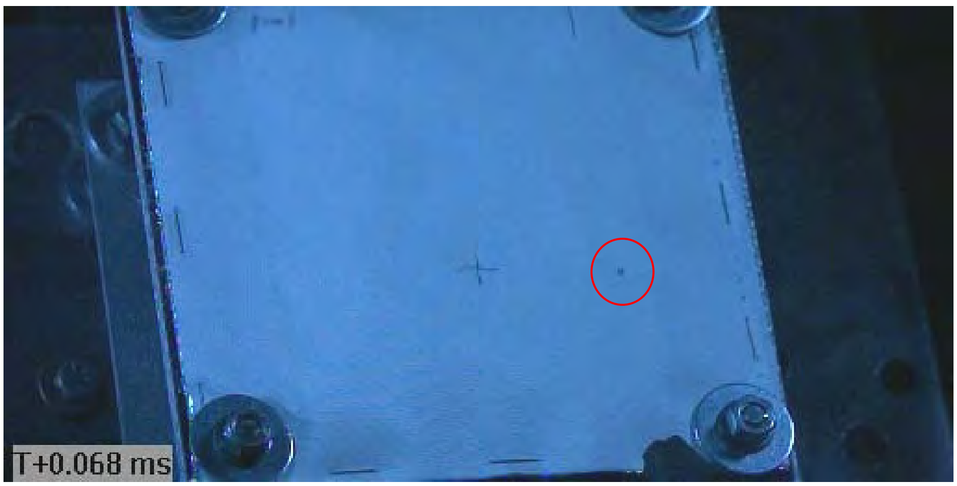


Figure C19 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

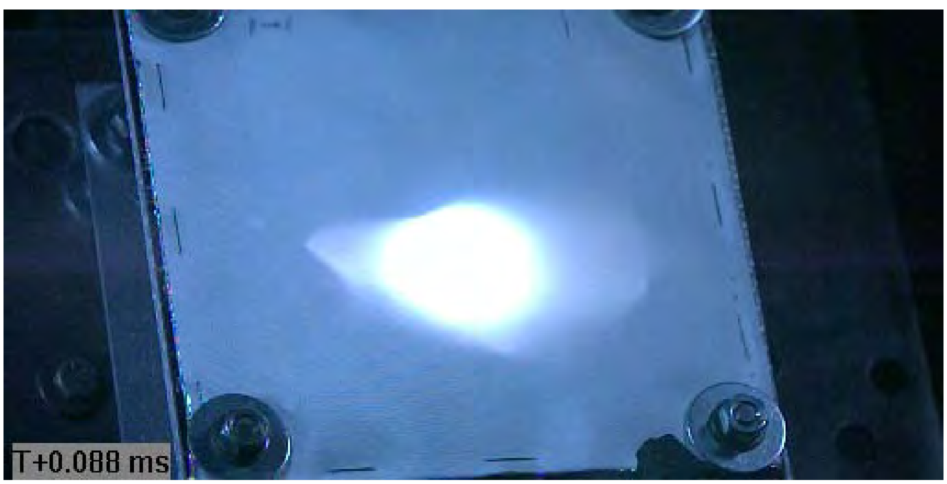


Figure C20 Projectile Impacting Target (via Phantom v711)

HITF12290 / Test #8

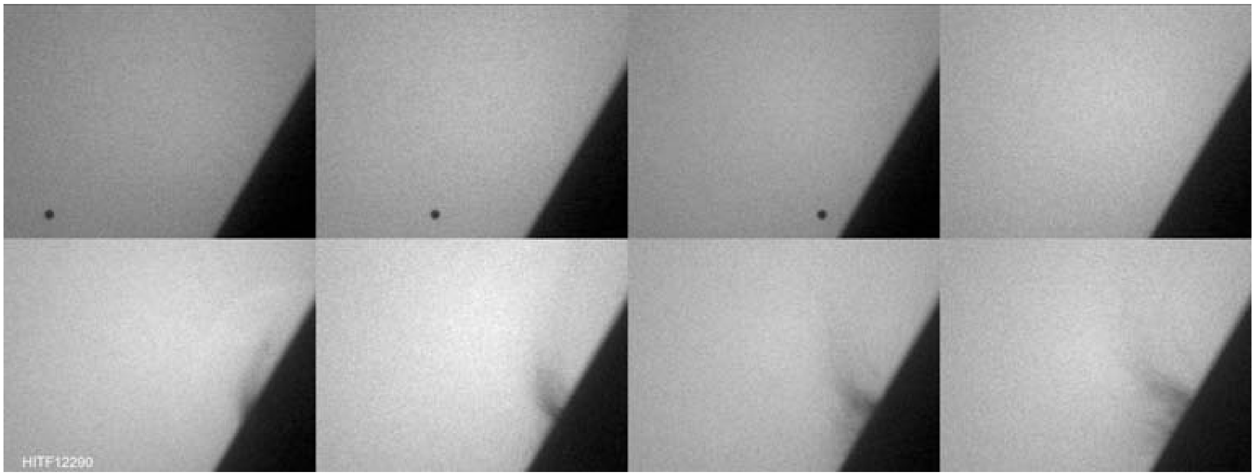


Figure C21 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

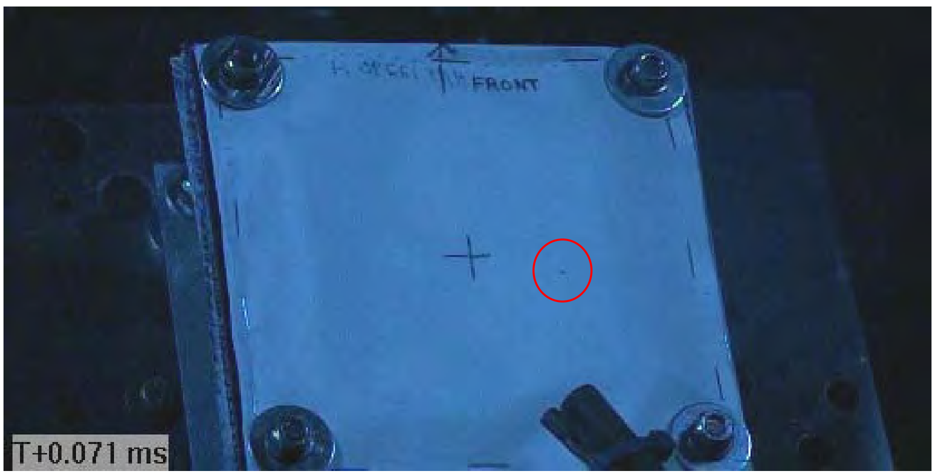


Figure C22 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

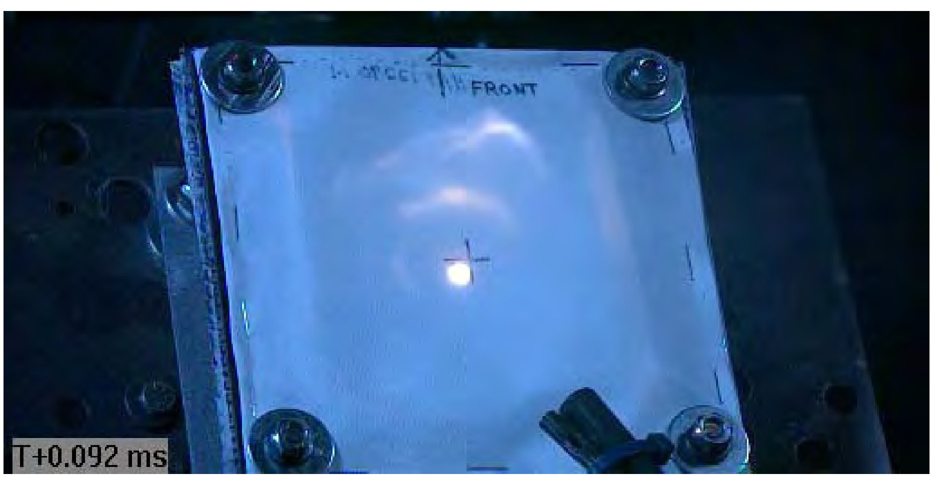


Figure C23 Projectile Impacting Target (via Phantom v711)

HITF12291 / Test #9

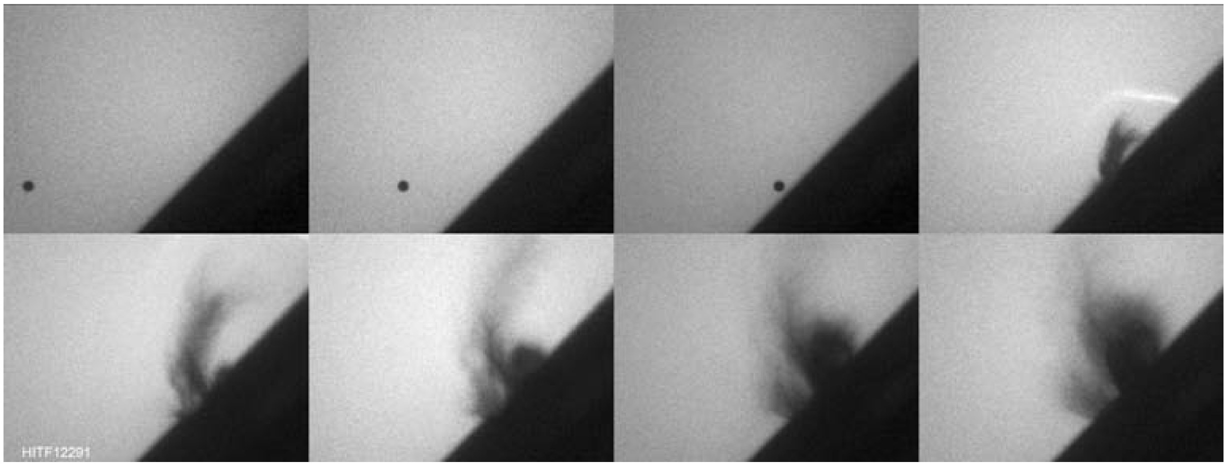


Figure C24 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

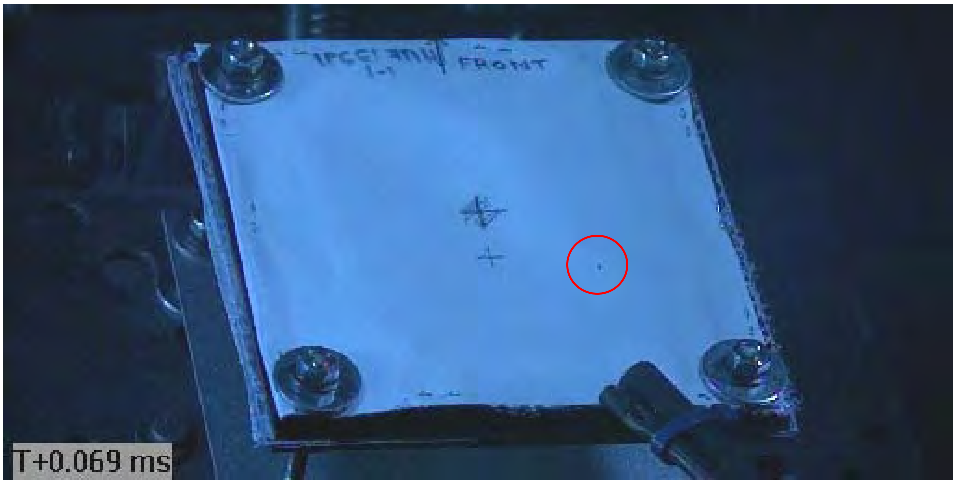


Figure C25 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

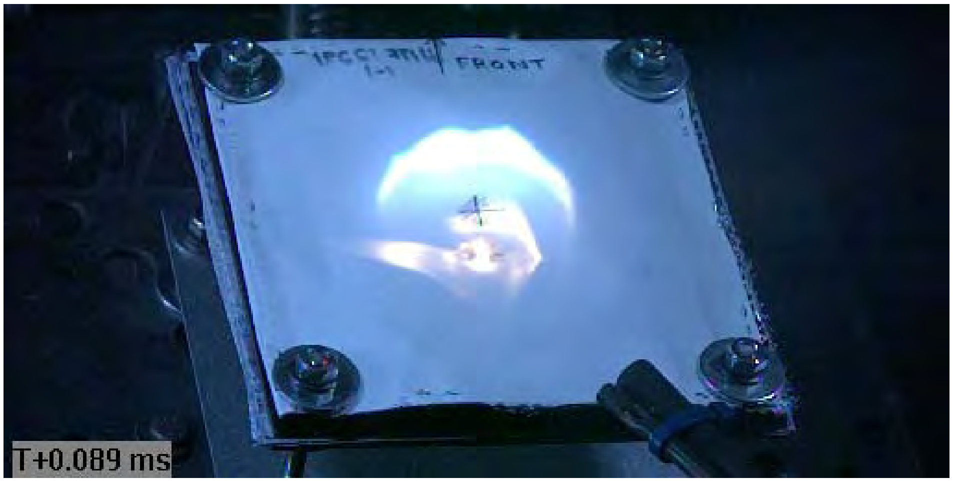


Figure C26 Projectile Impacting Target (via Phantom v711)

HITF12292 / Test #10

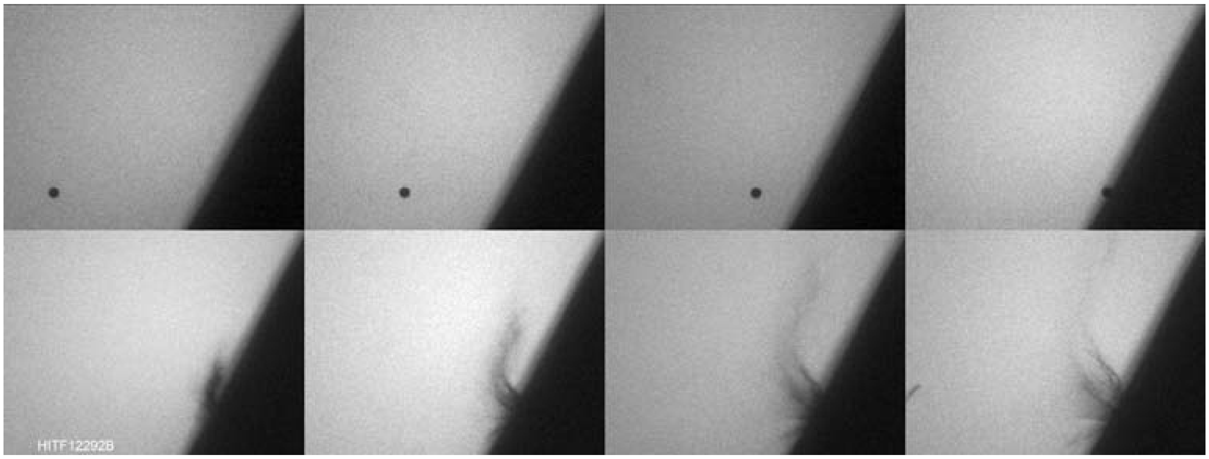


Figure C27 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

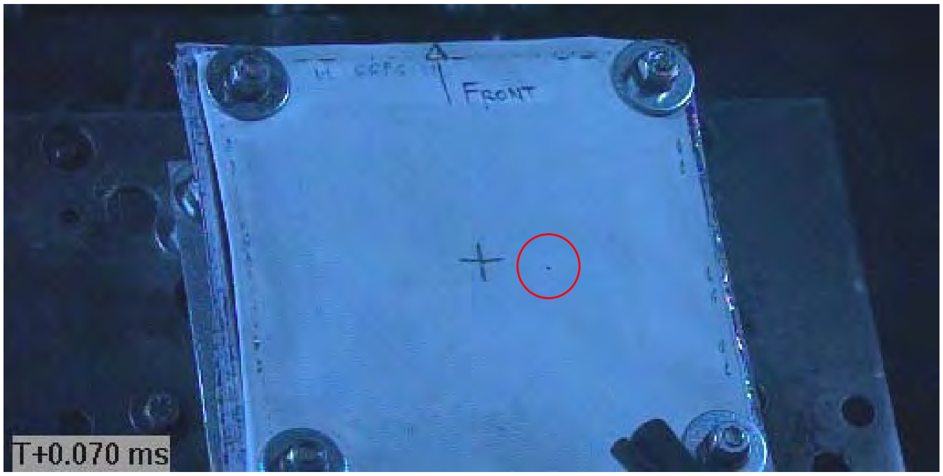


Figure C28 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

Figure C29 Projectile Impacting Target (via Phantom v711)

HITF12293 / Test #11

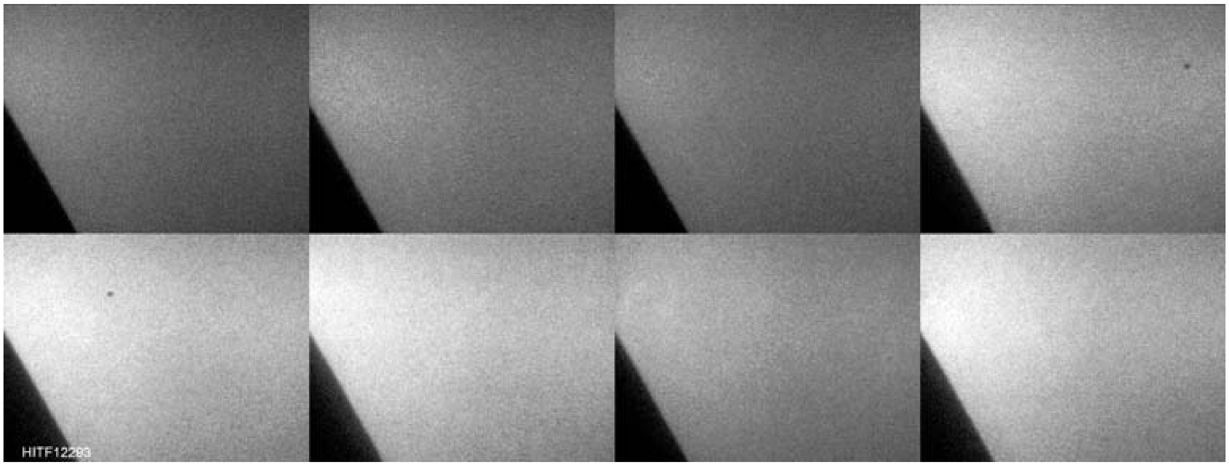


Figure C30 Projectile Captured Prior to Impact (via SIMX-8 Camera)

Figure C31 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

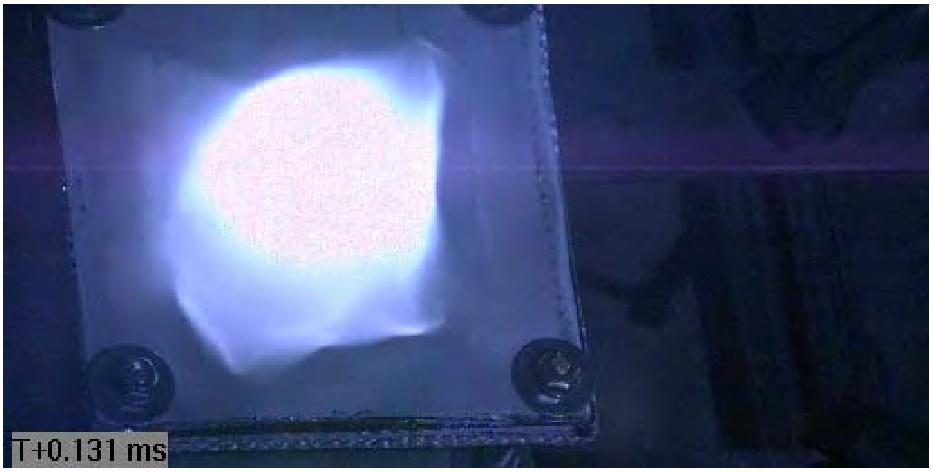


Figure C32 Projectile Impacting Target (via Phantom v711)

HITF12294 / Test #12

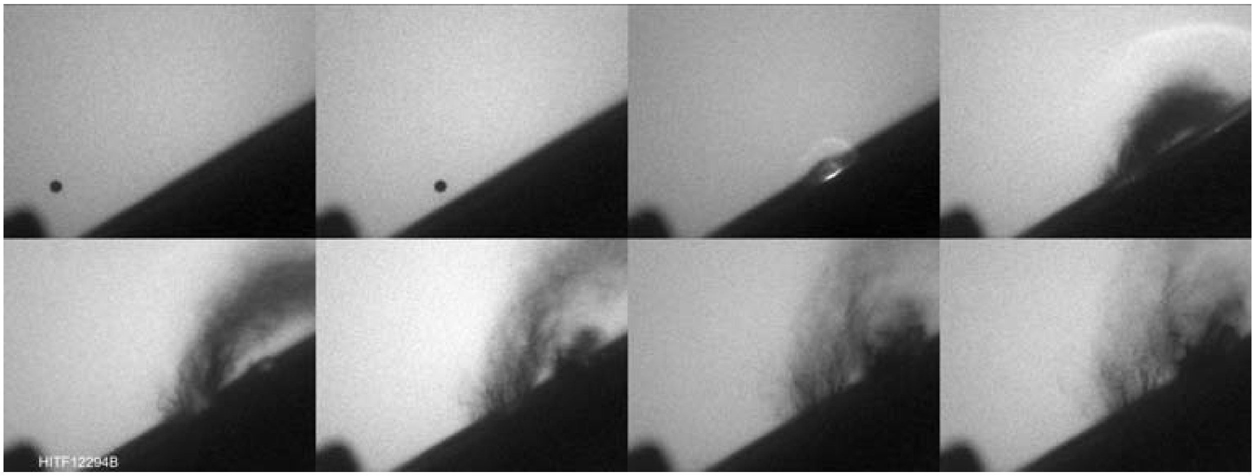


Figure C33 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

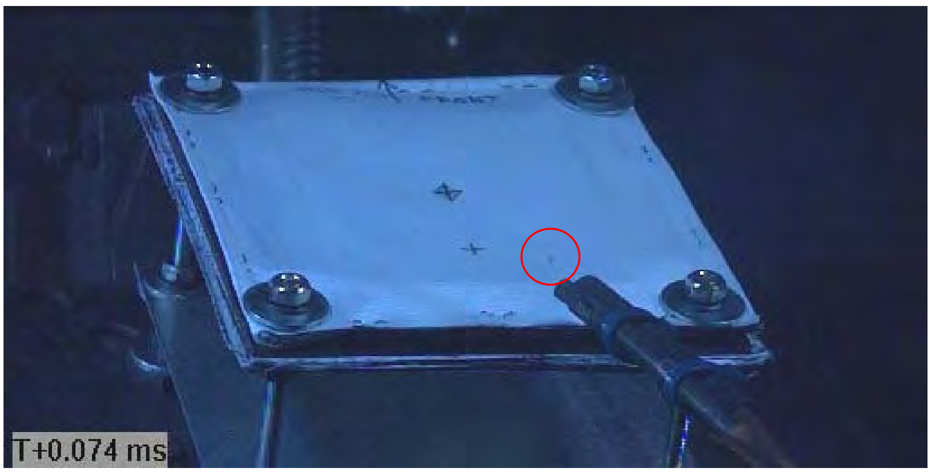


Figure C34 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

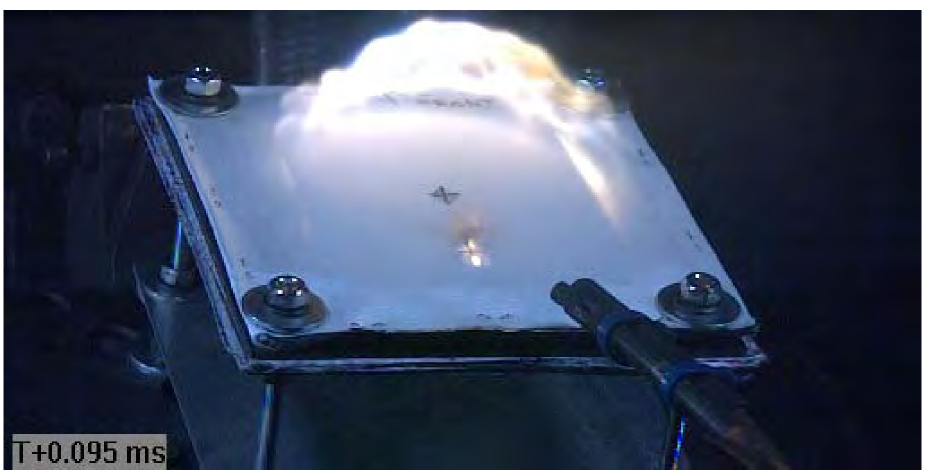


Figure C35 Projectile Impacting Target (via Phantom v711)

HITF12295 / Test #13

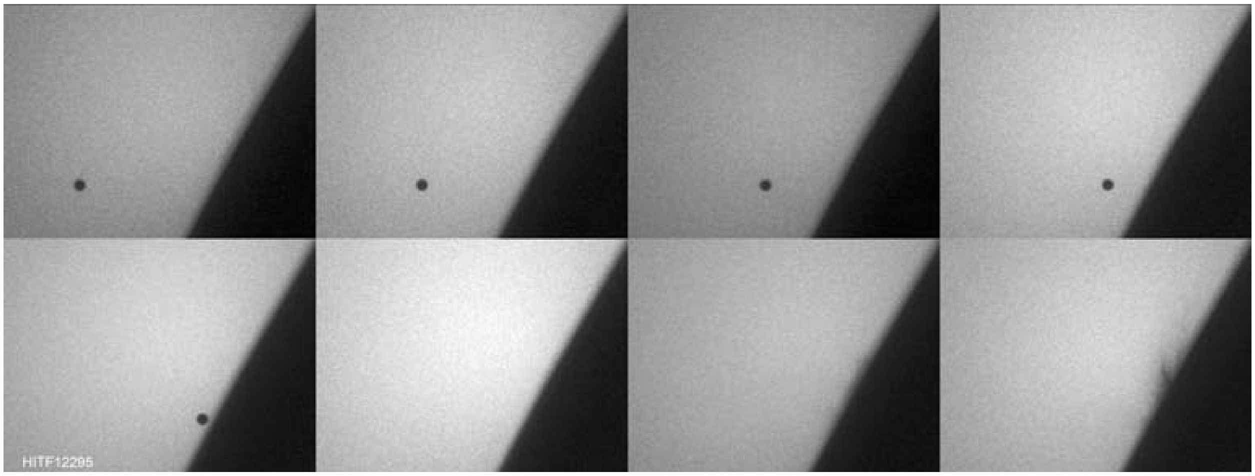


Figure C36 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

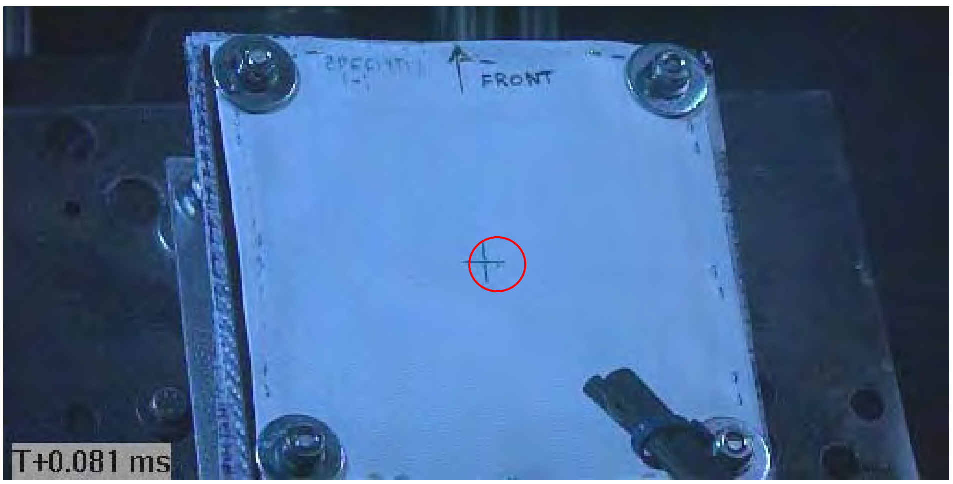


Figure C37 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

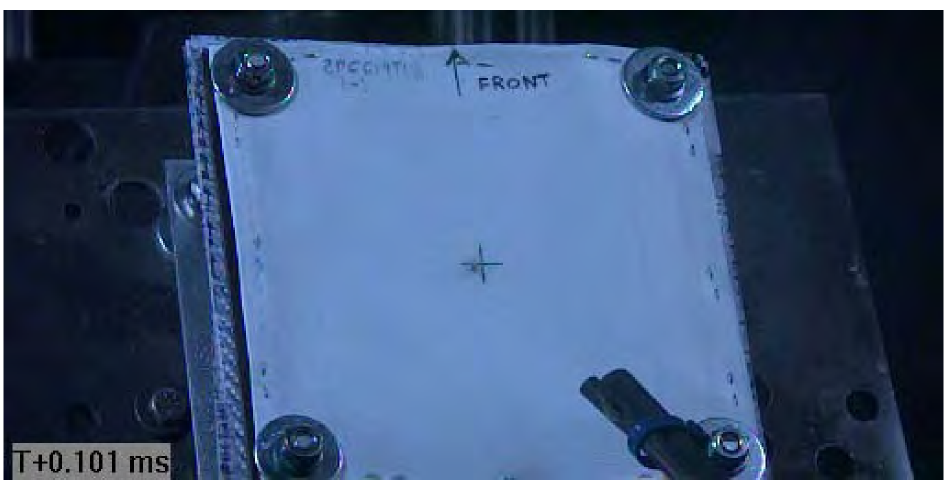


Figure C38 Projectile Impacting Target (via Phantom v711)

HITF12296 / Test #14

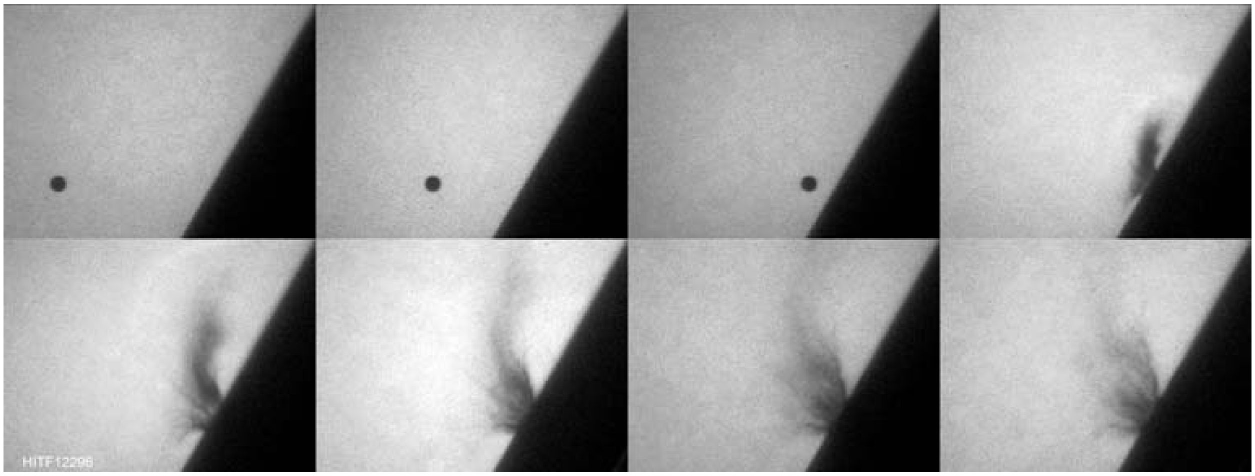


Figure C39 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

Figure C40 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

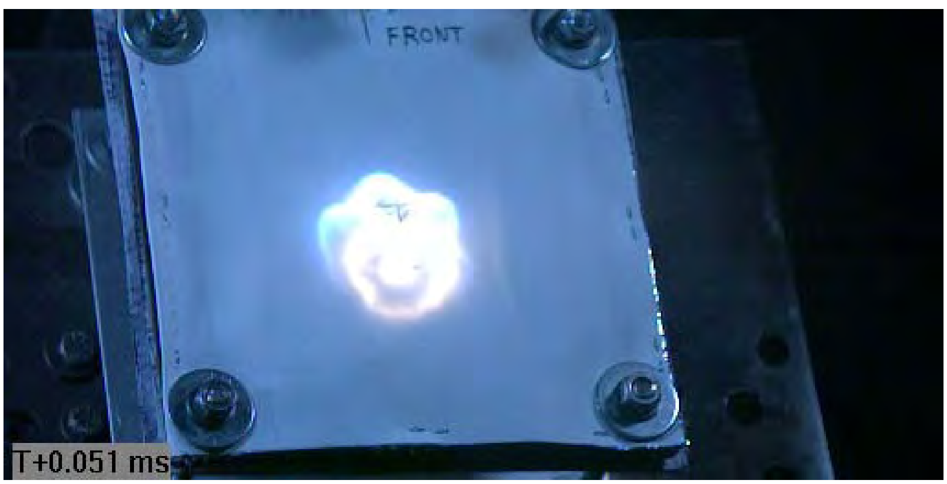


Figure C41 Projectile Impacting Target (via Phantom v711)

HITF12296-B / Test #14-B

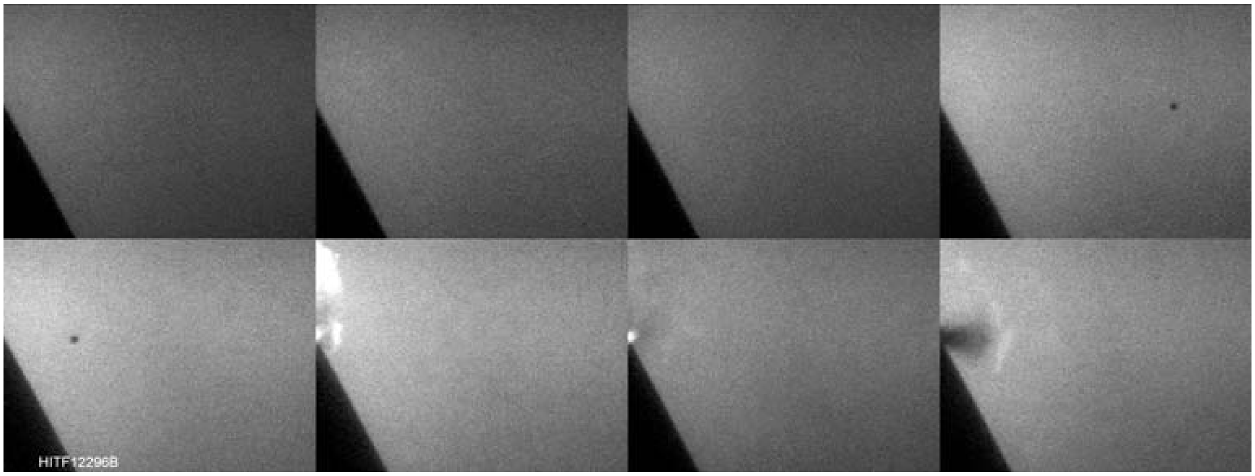


Figure C42 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

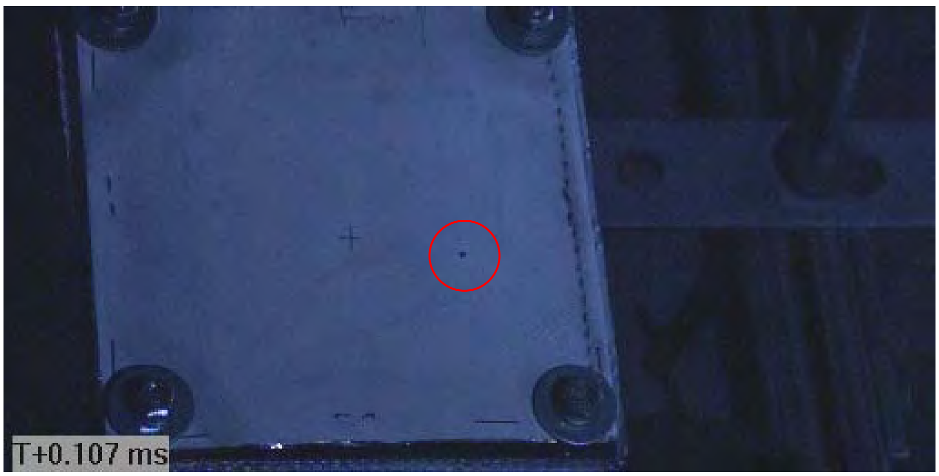


Figure C43 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

Figure C44 Projectile Impacting Target (via Phantom v711)

HITF12297 / Test #15

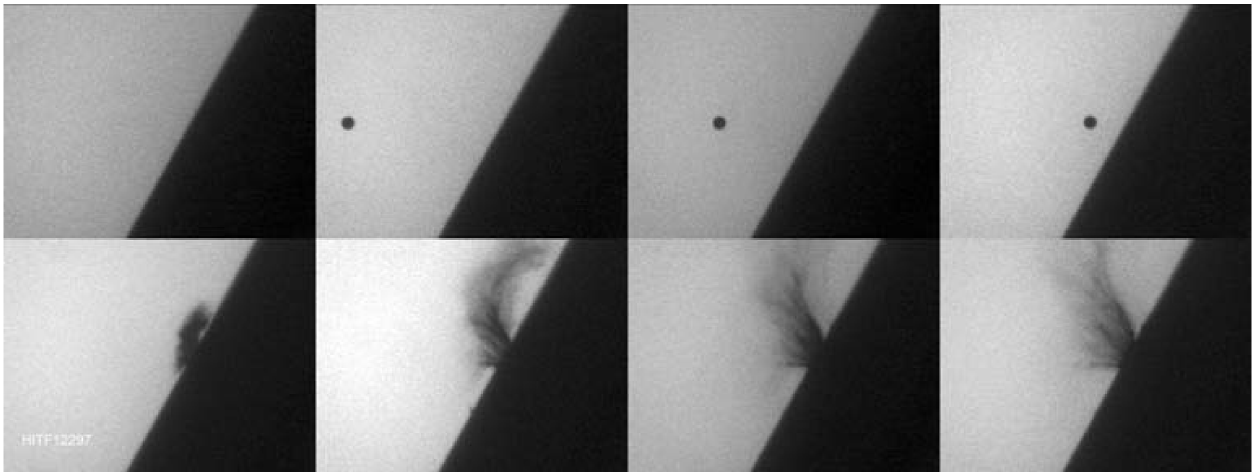


Figure C45 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

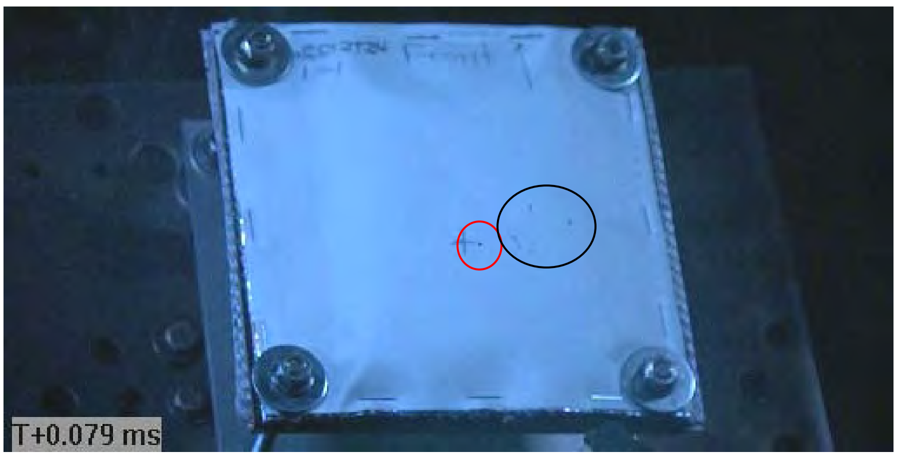


Figure C46 Image of Projectile and Secondary Debris Captured Prior to Impact (via Phantom v711 / projectile within red circle / secondary debris within black circle)

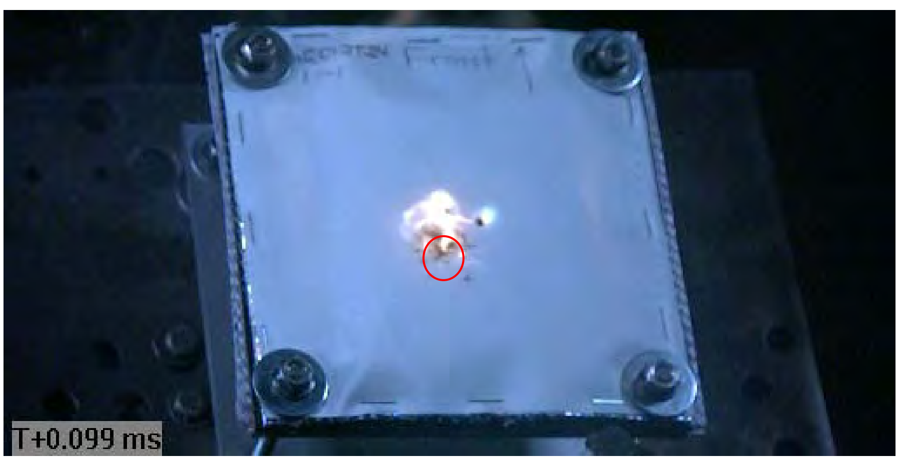


Figure C47 Image of Projectile and Secondary Debris Impacting Target (via Phantom v711 / projectile impacting within red circle, the remaining impacts are secondary debris)

HITF12298 / Test #16

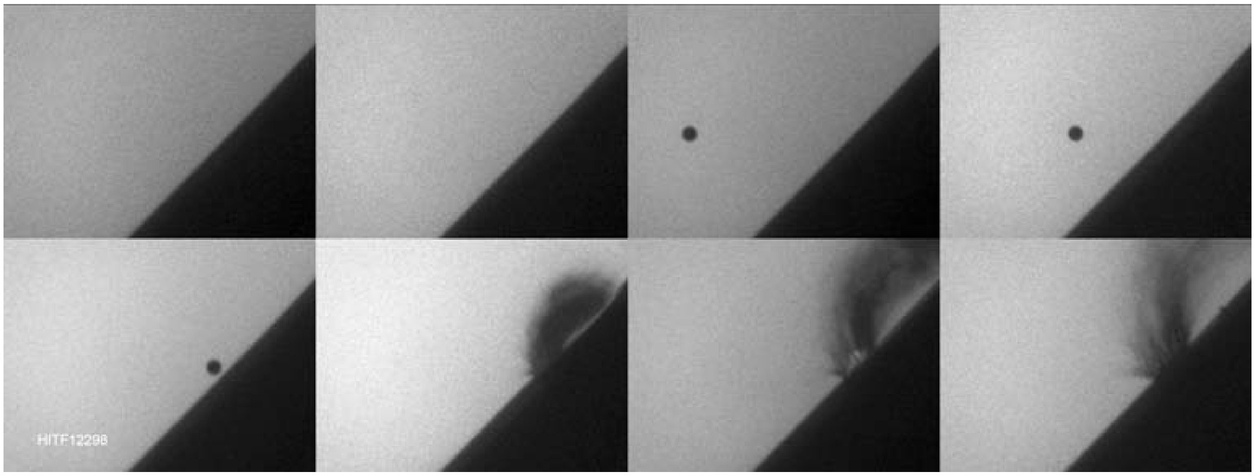


Figure C48 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

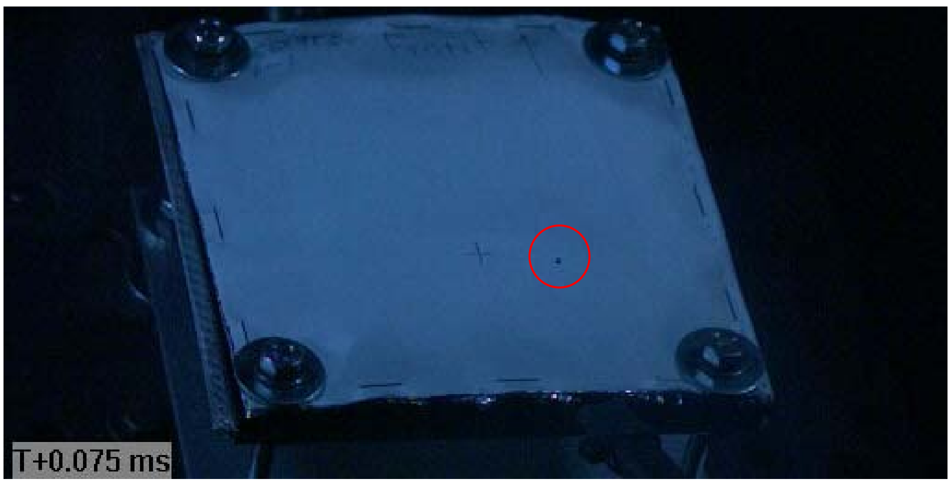


Figure C49 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

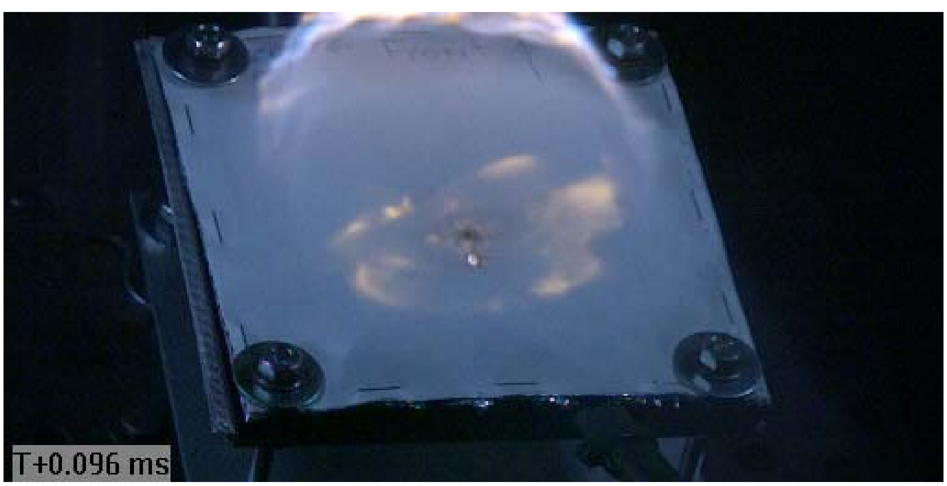


Figure C50 Projectile Impacting Target (via Phantom v711)

HITF12299 / Test #17

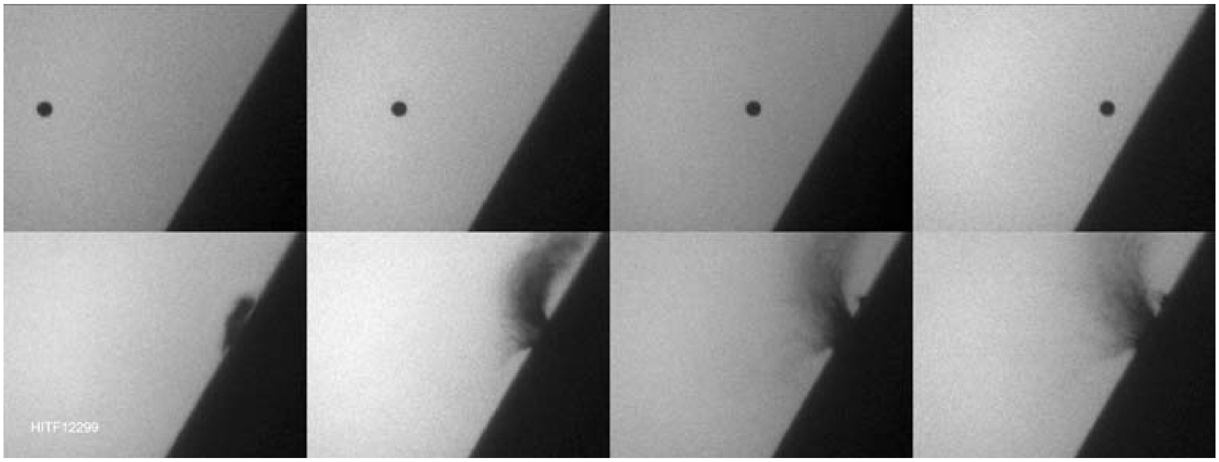


Figure C51 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

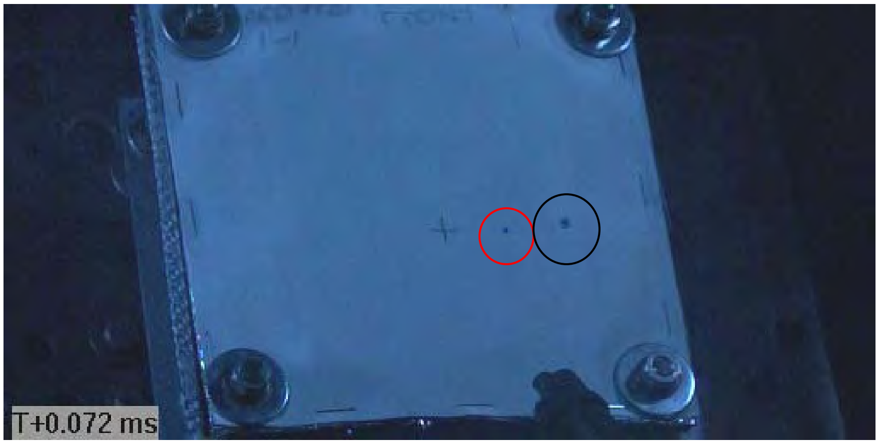


Figure C52 Image of Projectile and Secondary Debris Captured Prior to Impact (via Phantom v711 / projectile within red circle / secondary debris within black circle)

Figure C53 Image of Projectile Impacting Target and Secondary Debris Just Prior to Impacting Target (via Phantom v711 / projectile impacting within red circle / secondary debris within black circle and impacted directly above projectile entry damage)

HITF12300 / Test #18

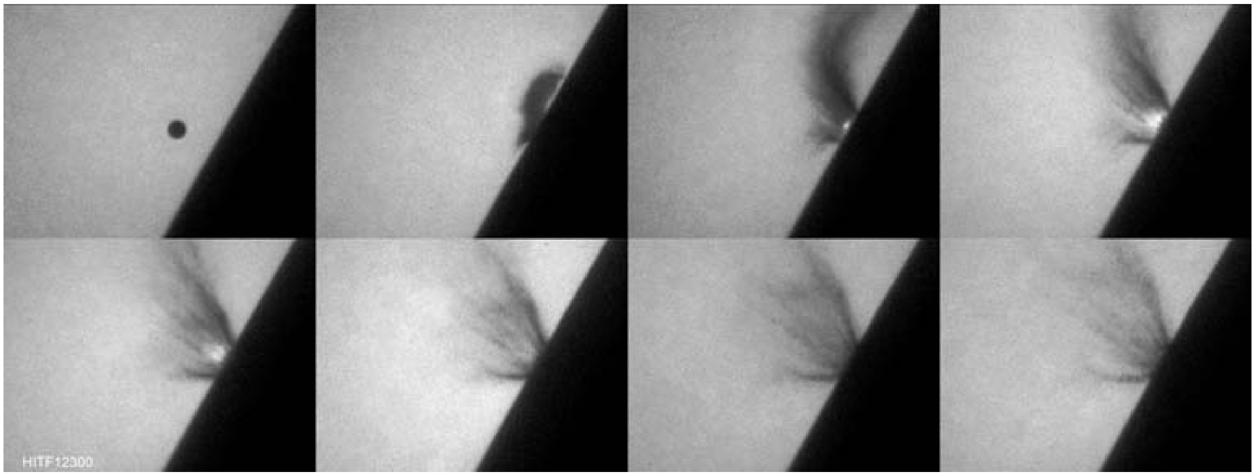


Figure C54 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

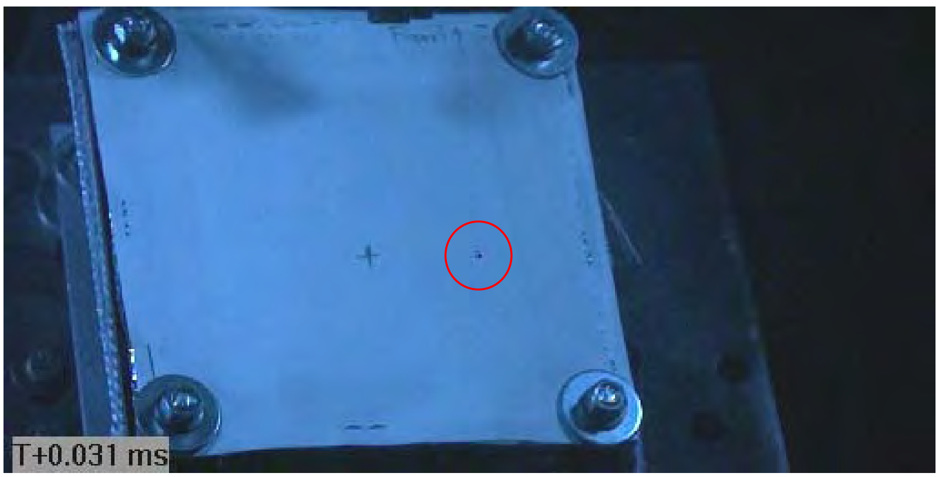


Figure C55 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

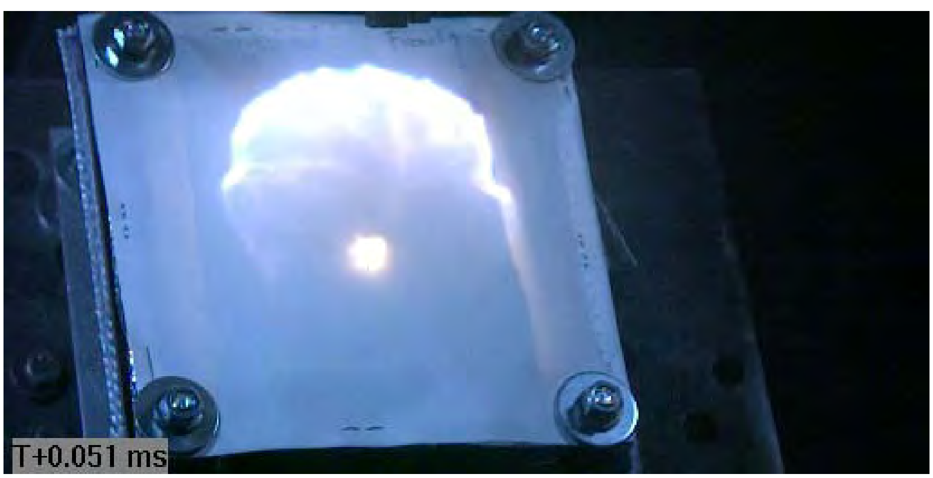


Figure C56 Projectile Impacting Target (via Phantom v711)

HITF12301 / Test #19

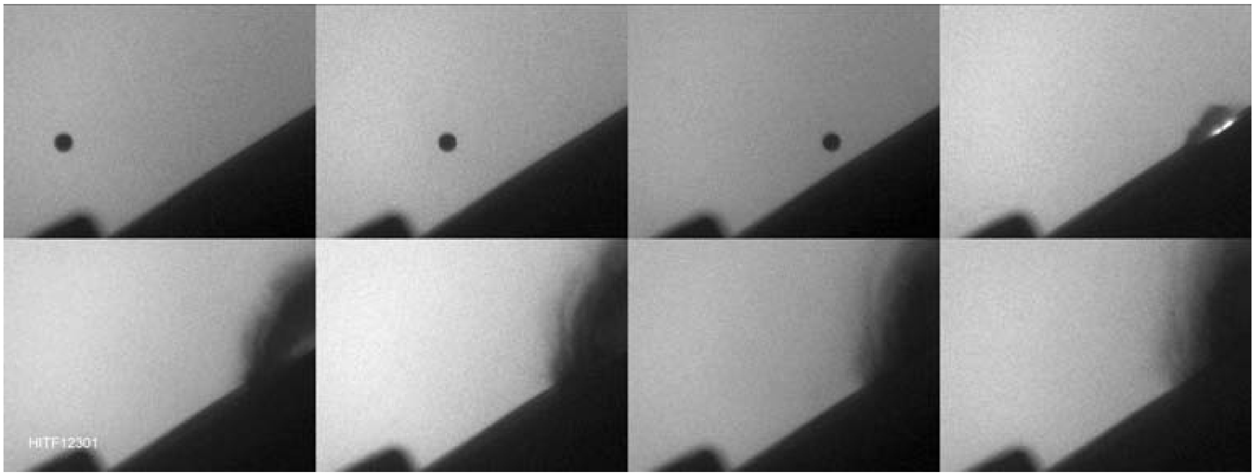


Figure C57 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

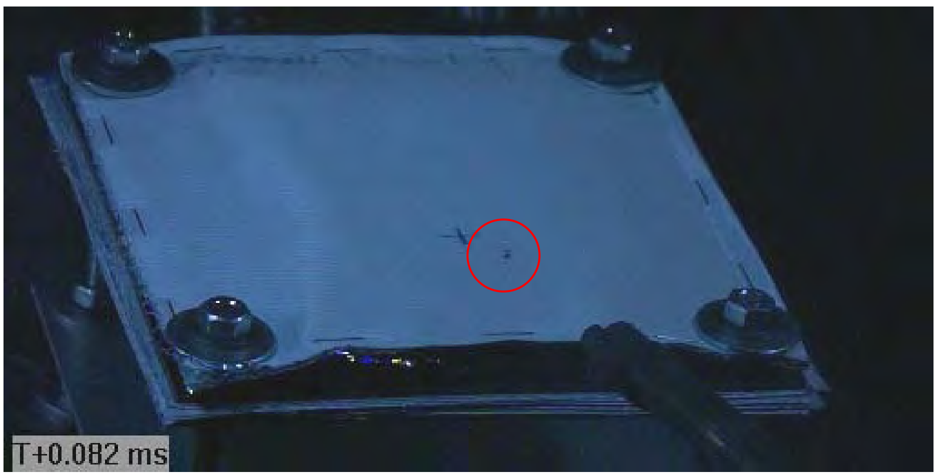


Figure C58 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

Figure C59 Projectile Impacting Target (via Phantom v711)

HITF12302 / Test #20

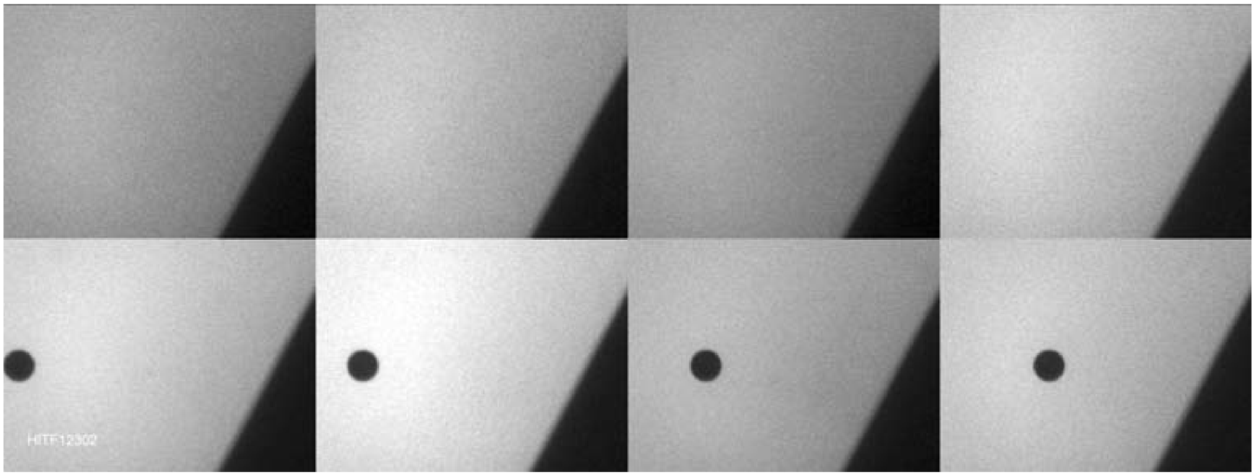


Figure C60 Projectile Captured Prior to Impacting Target (via SIMX-8 Camera)

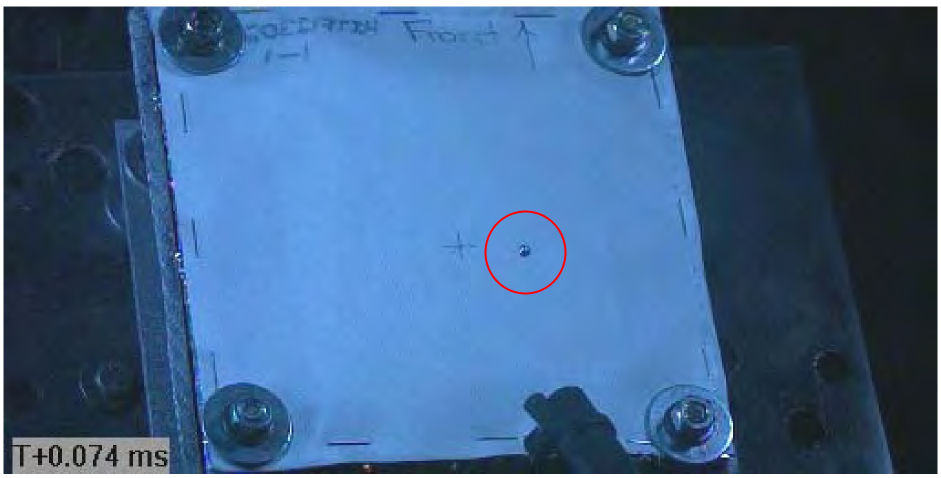


Figure C61 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

Figure C62 Projectile Impacting Target (via Phantom v711)

HITF12303 / Test #21

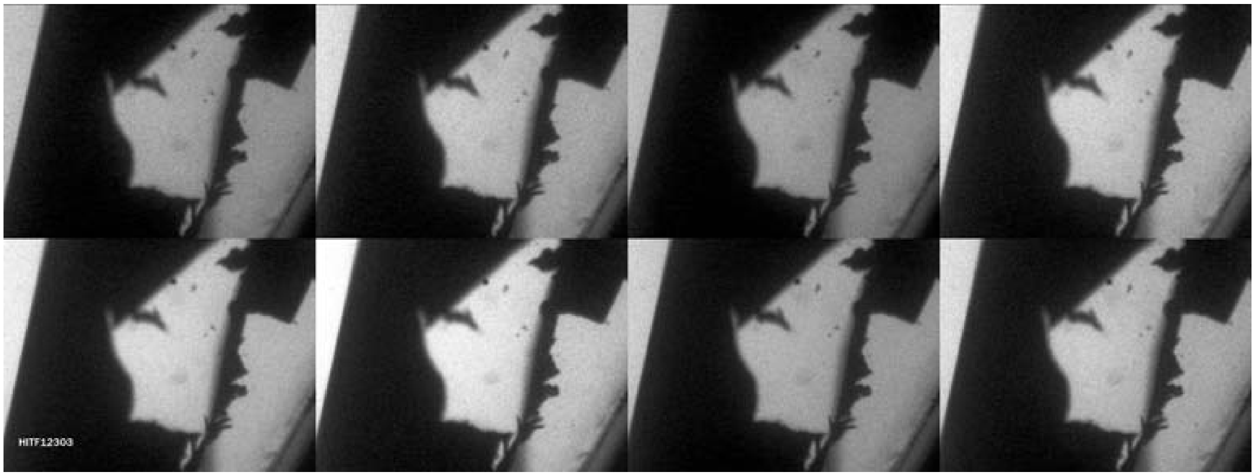


Figure C63 Projectile Not Captured Prior to Impact (via SIMX-8 Camera / camera triggered after impact occurred)

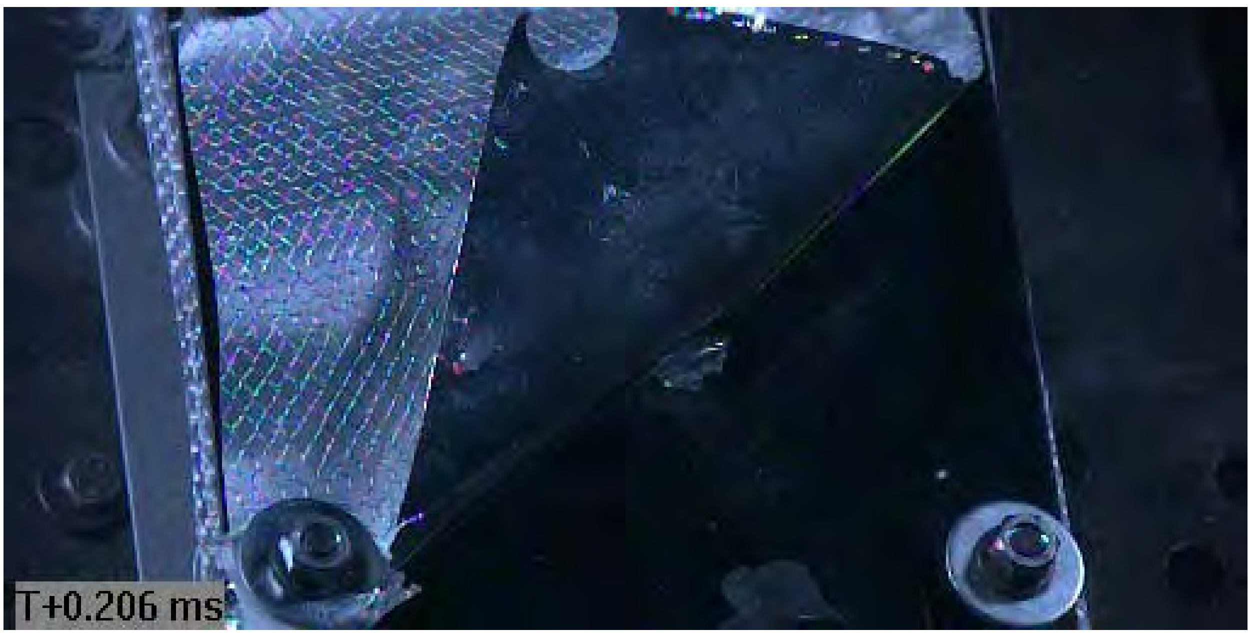


Figure C64 Projectile Not Captured Prior to Impact (Phantom v711 Camera / camera triggered after impact occurred)

HITF12304 / Test #22

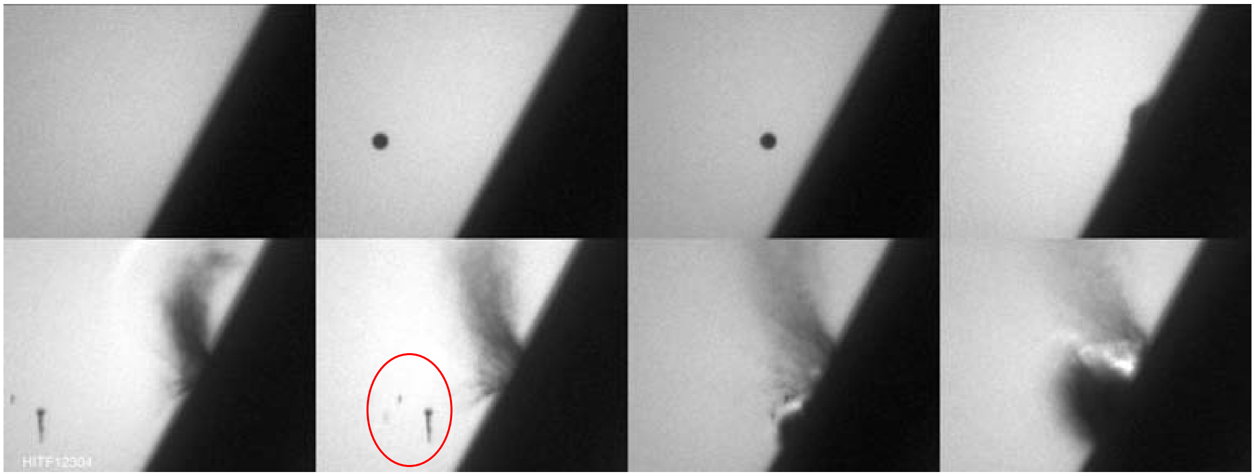


Figure C65 Projectile and Secondary Debris Captured Prior to Impact and Impacting Target (via SIMX-8 Camera / secondary debris within red circle)

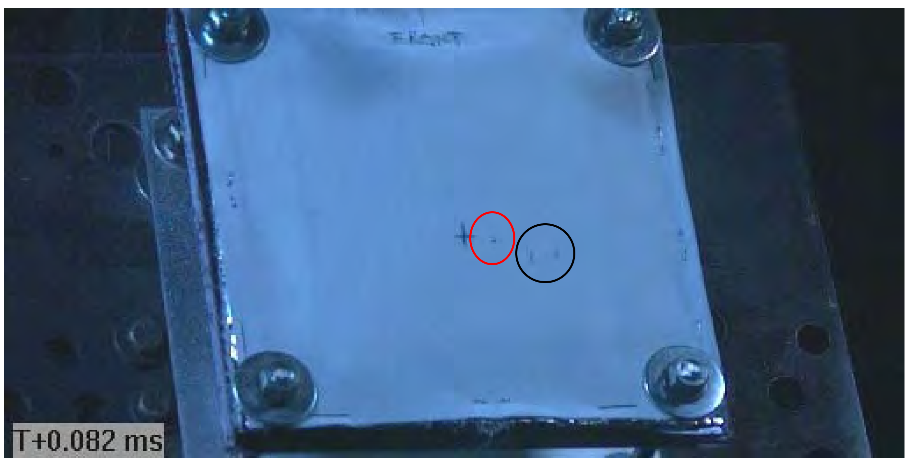


Figure C66 Image of Projectile and Secondary Debris Captured Prior to Impact (via Phantom v711 / projectile within red circle / secondary debris within black circle)

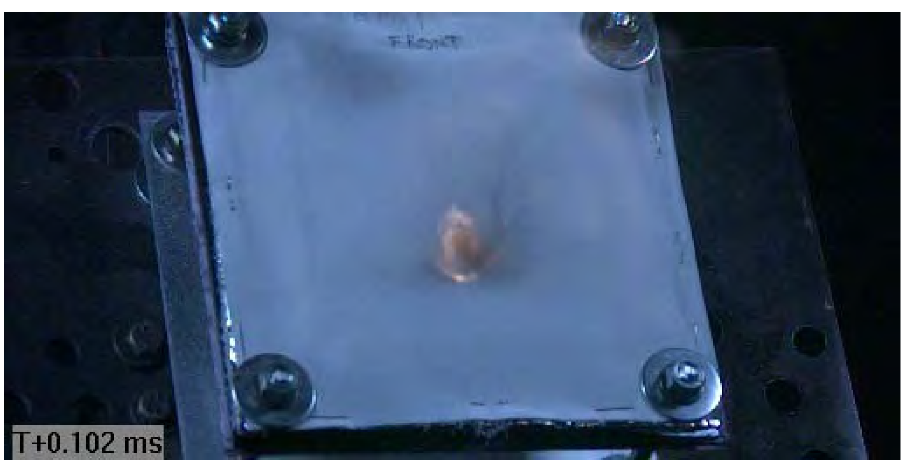


Figure C67 Image of Projectile and Secondary Debris Impacting Target (via Phantom v711)

HITF12305 / Test #23

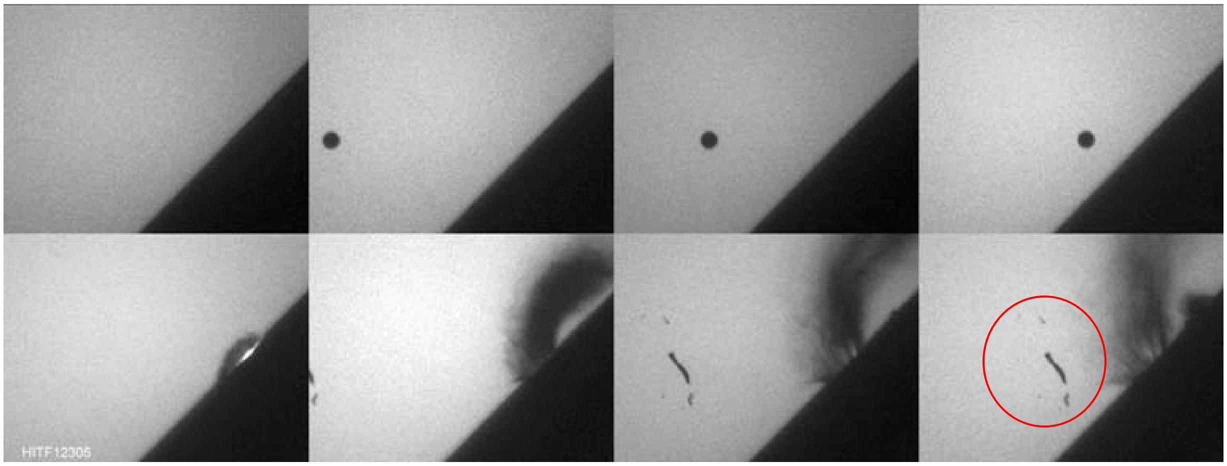


Figure C68 Projectile and Secondary Debris Captured Prior to Impact and Impacting Target (via SIMX-8 Camera / secondary debris within red circle)

Figure C69 Image of Projectile and Secondary Debris Captured Prior to Impact (via Phantom v711 / projectile within red circle / secondary debris within black circle)

Figure C70 Image of Projectile Impacting Target and Secondary Debris Just Prior to Impacting Target (via Phantom v711 / projectile impacting within red circle / secondary debris within black circle and impact directly behind projectile entry damage)

HITF12306 / Test #24

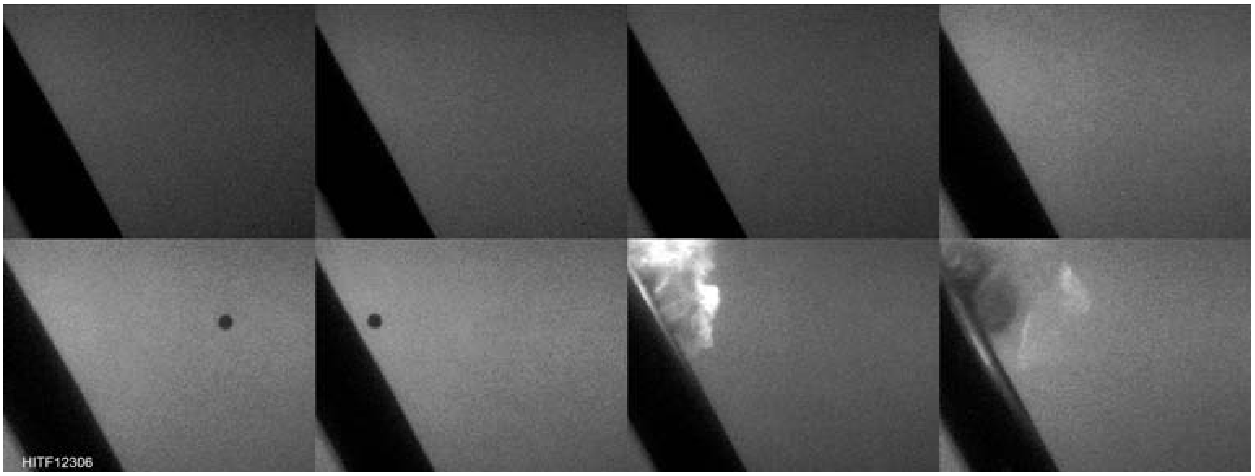


Figure C71 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

Figure C72 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

Figure C73 Projectile Impacting Target (via Phantom v711)

HITF12307 / Test #25

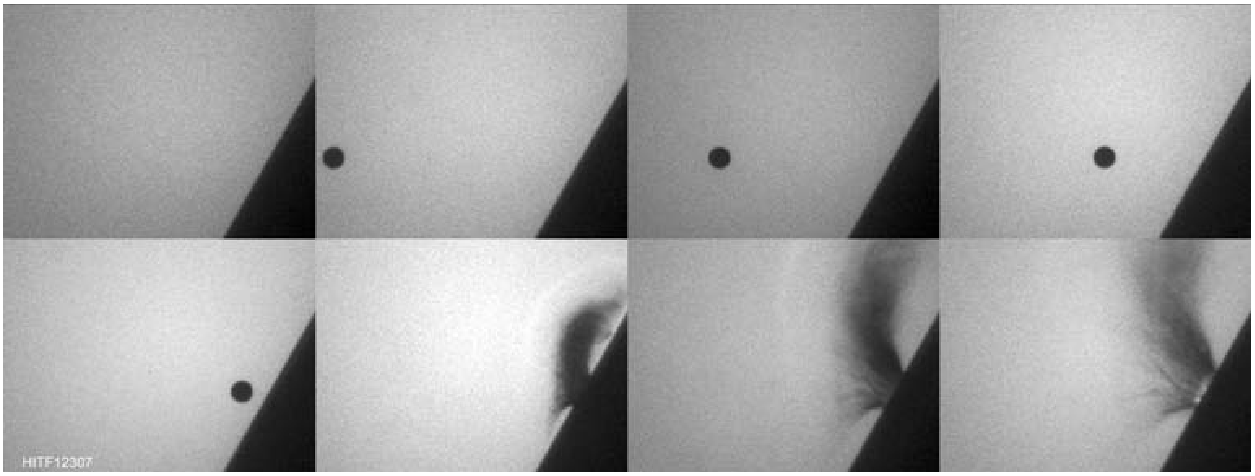


Figure C74 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

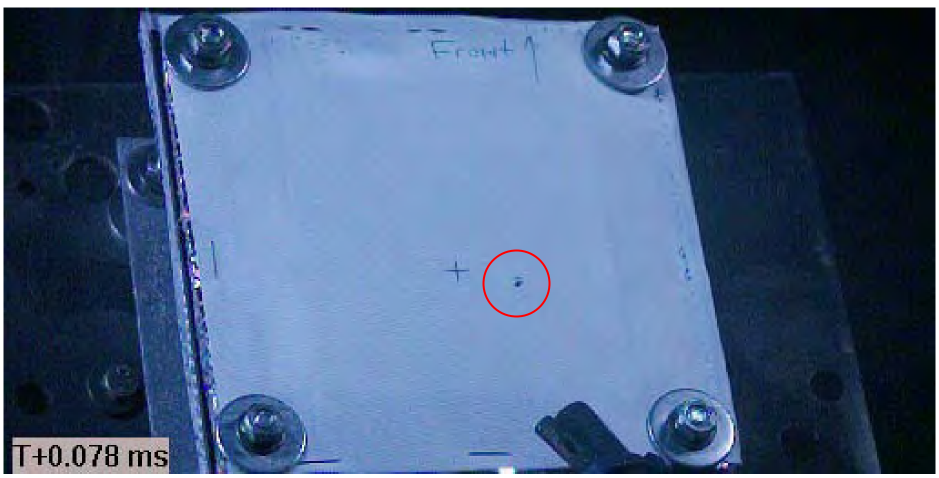


Figure C75 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

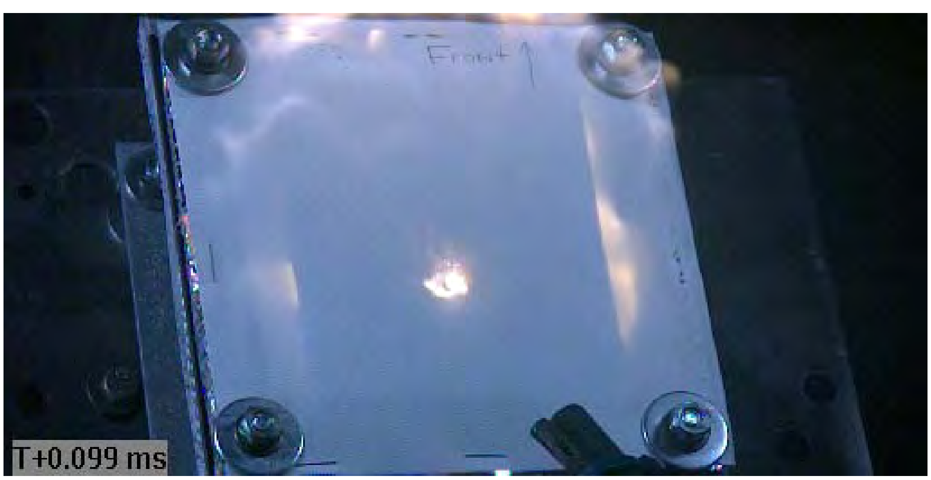


Figure C76 Projectile Impacting Target (via Phantom v711)

HITF12308 / Test #26

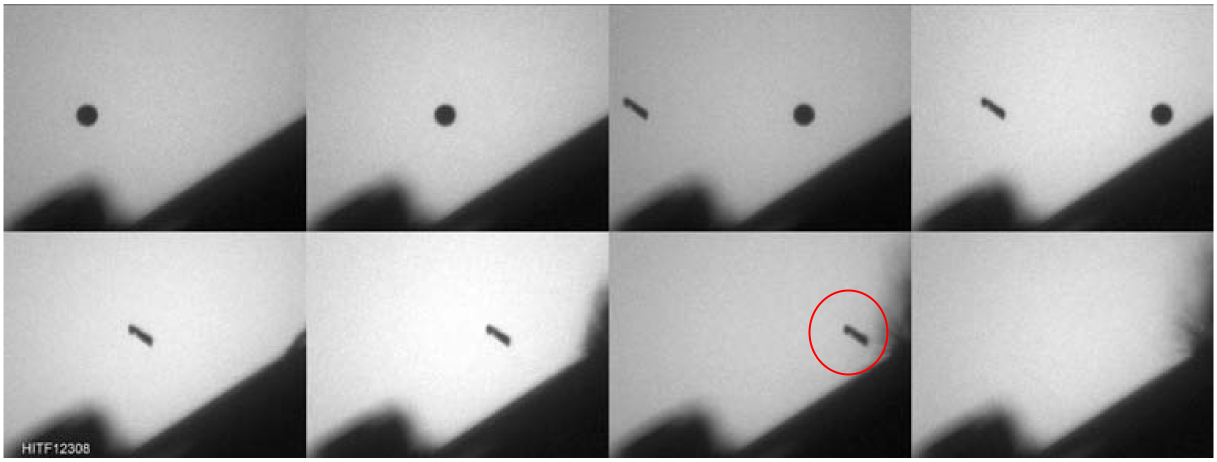


Figure C77 Projectile and Secondary Debris Captured Prior to Impact and Impacting Target (via SIMX-8 Camera / secondary debris within red circle)

Figure C78 Image of Projectile and Secondary Debris Captured Prior to Impact (via Phantom v711 / projectile and secondary debris traveling close to one another)

Figure C79 Image of Projectile and Secondary Debris Impacting Target (via Phantom v711 / the lower impact on the target was the projectile and secondary debris impacted above projectile impact)

HITF12308-B / Test #26-B

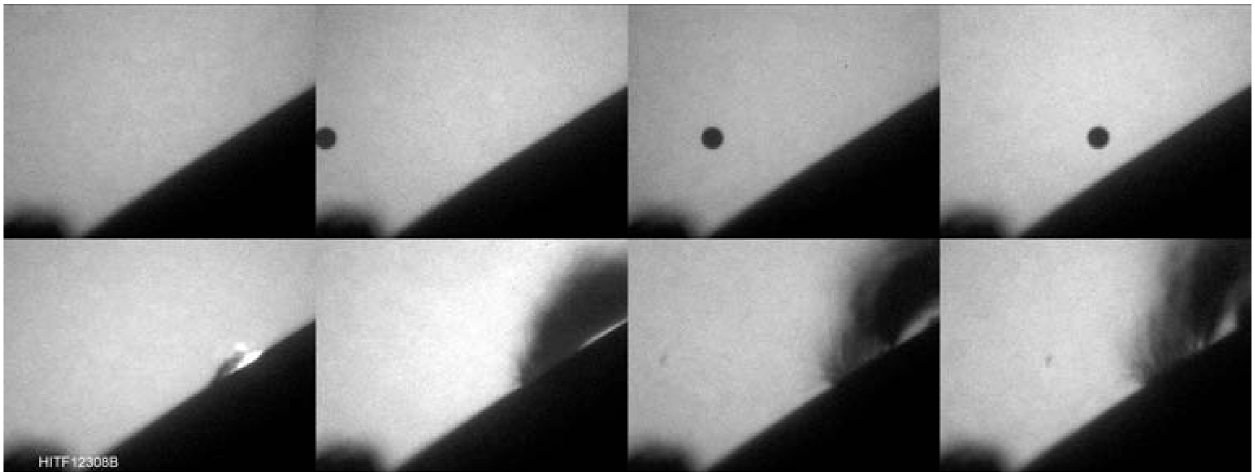


Figure C80 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

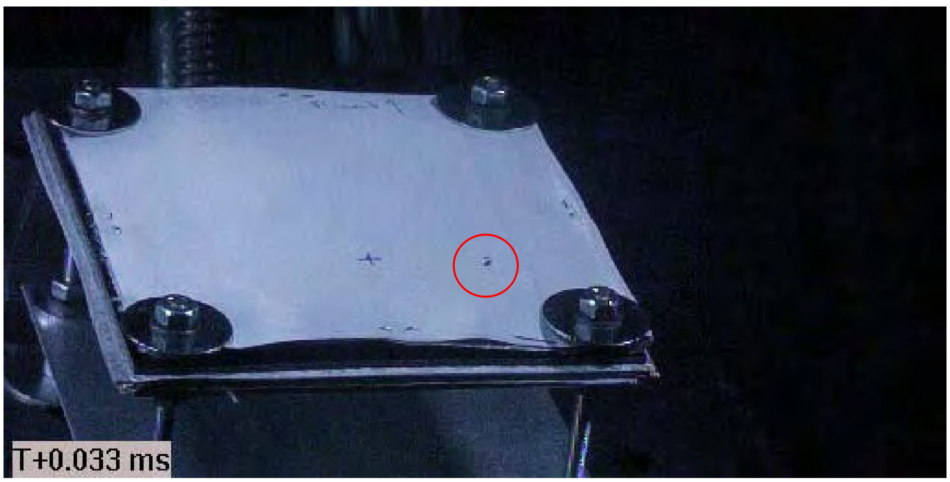


Figure C81 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

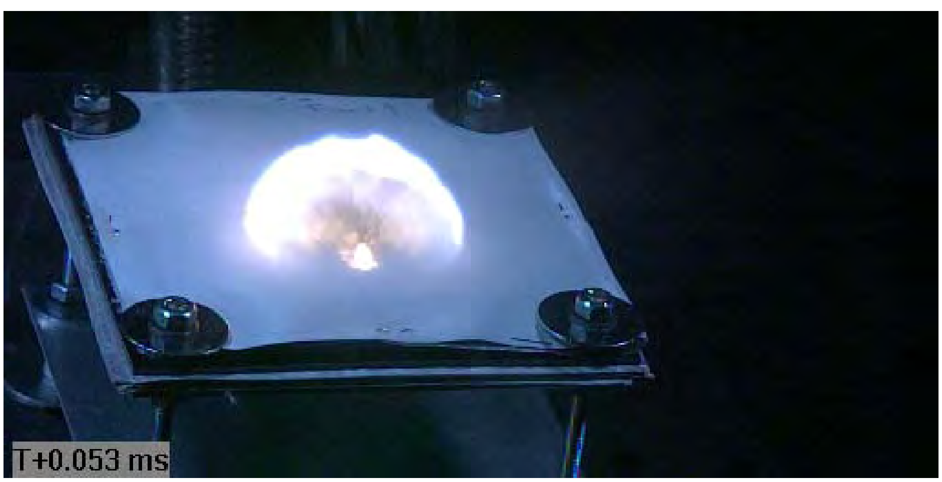


Figure C82 Image of Projectile Impacting Target (via Phantom v711)

HITF12309 / Test #27

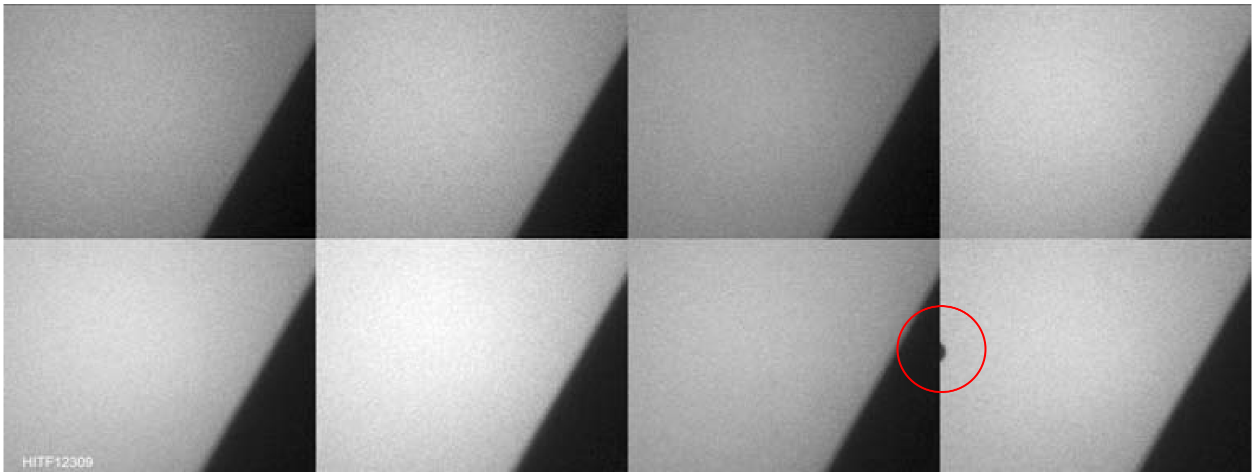


Figure C83 Partial Projectile Captured Prior to Impact (via SIMX-8 Camera / partial projectile within red circle)

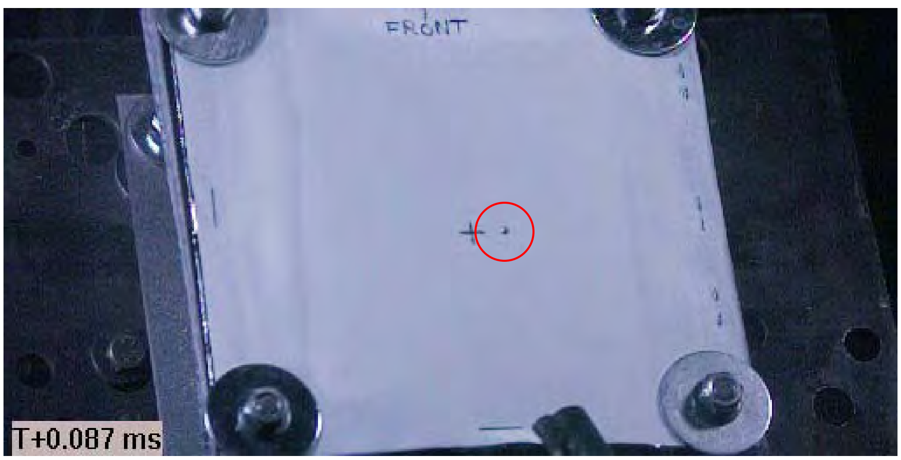


Figure C84 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

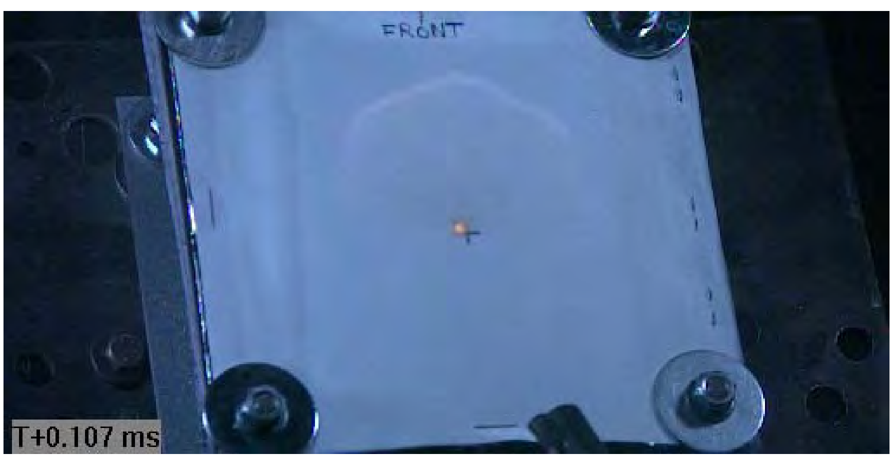
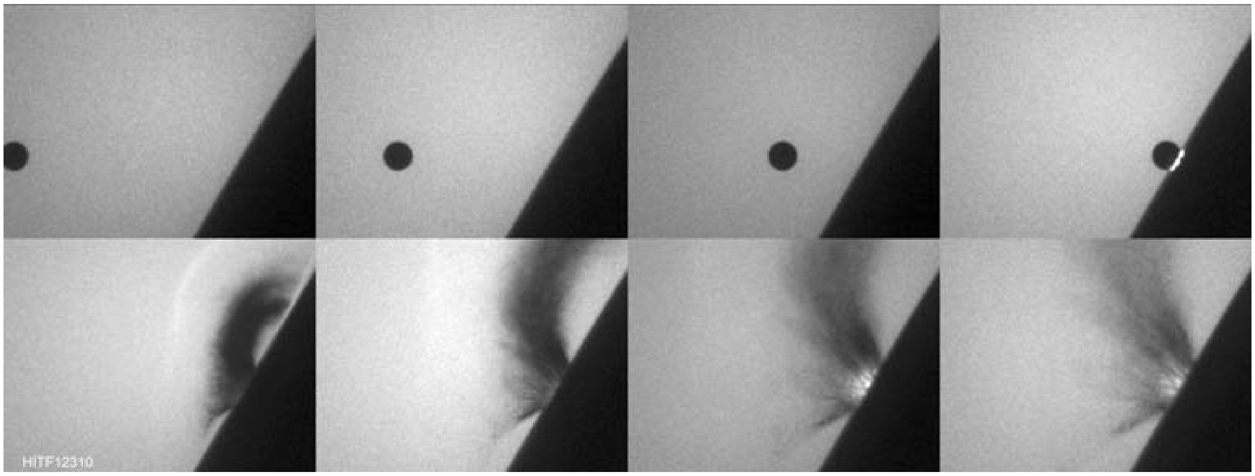


Figure C85 Image of Projectile Impacting Target (via Phantom v711)

HITF12310 / Test #28



C86 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

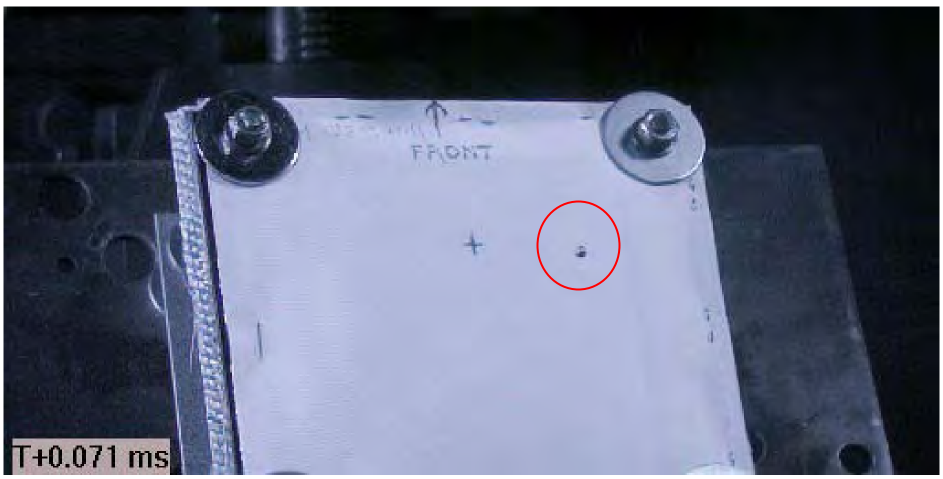


Figure C87 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

Figure C88 Image of Projectile Impacting Target (via Phantom v711)

HITF12311 / Test #29

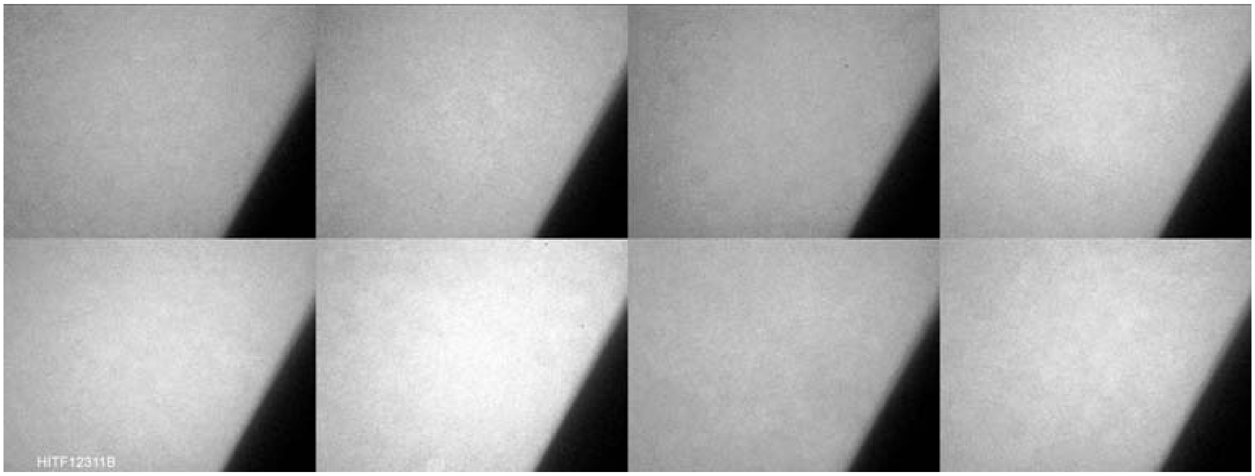


Figure C89 Projectile Not Captured Prior to Impact (via SIMX-8 Camera)

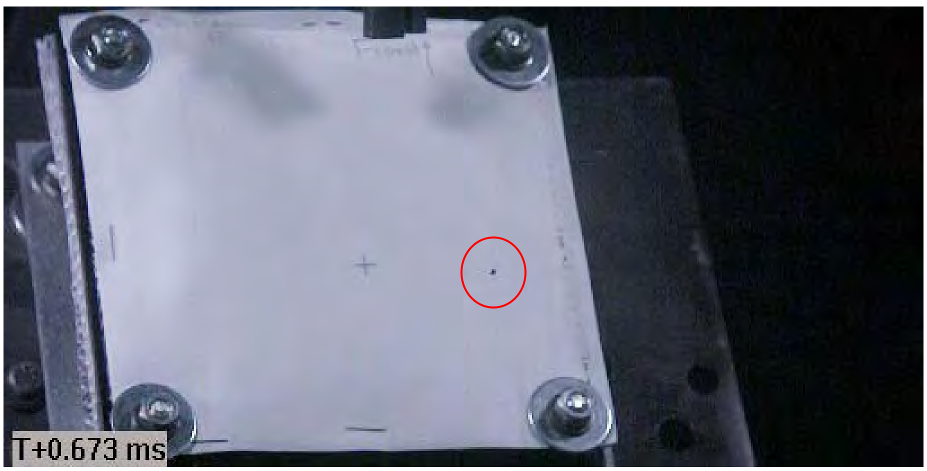


Figure C90 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle out of round)

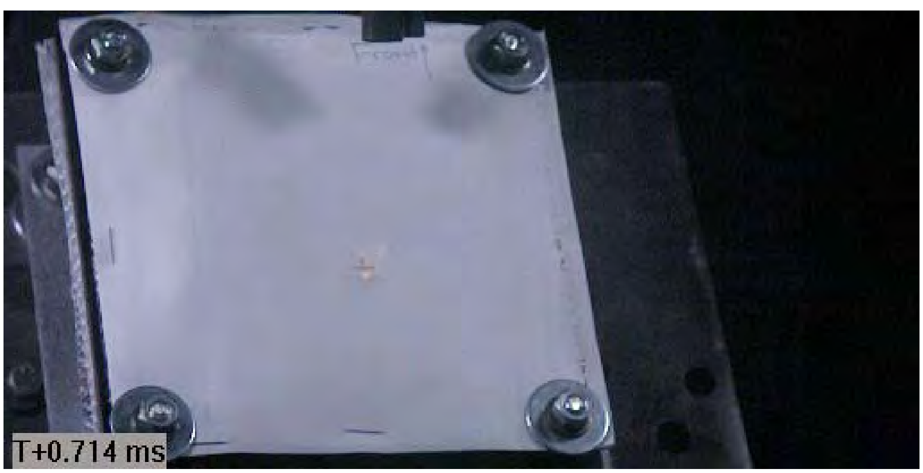


Figure C91 Image of Projectile Impacting Target (via Phantom v711)

HITF12311-B / Test #29-B

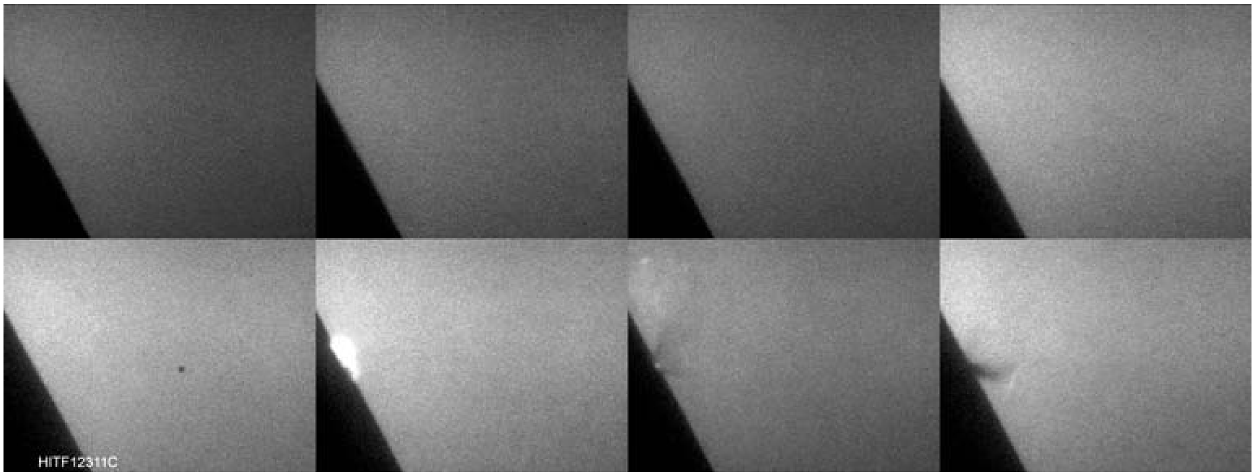


Figure C92 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

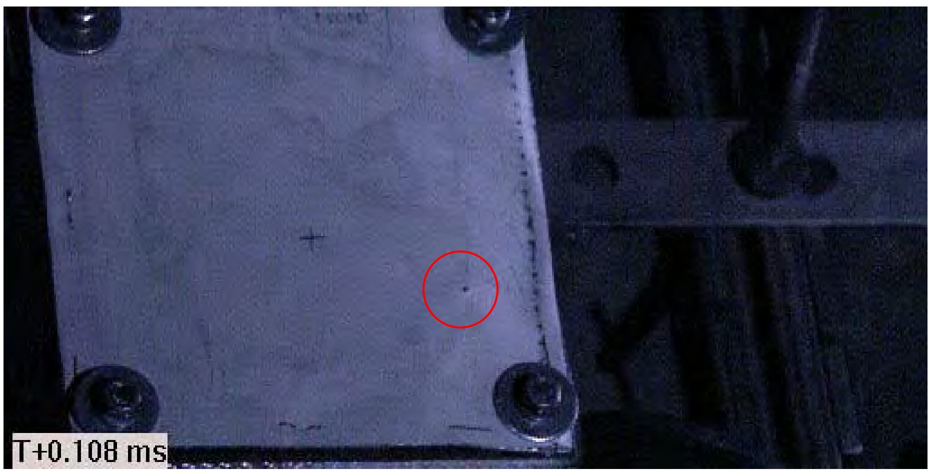


Figure C93 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

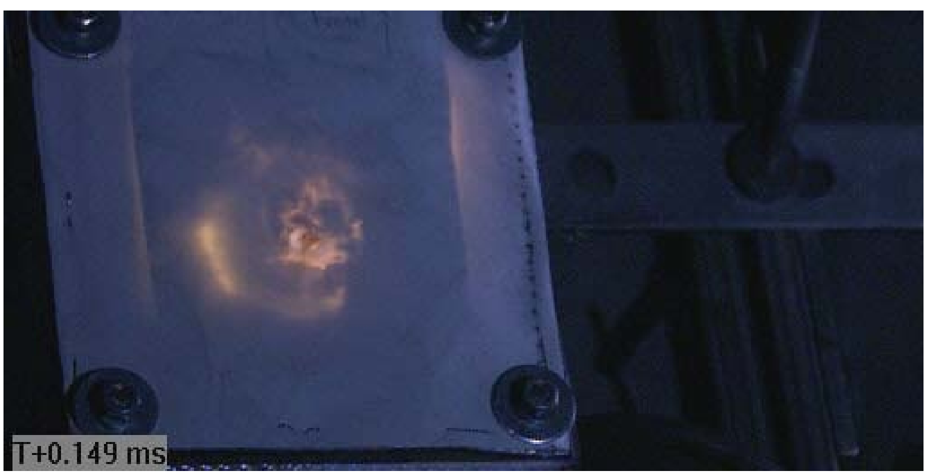


Figure C94 Image of Projectile Impacting Target (via Phantom v711)

HITF12312 / Test #30

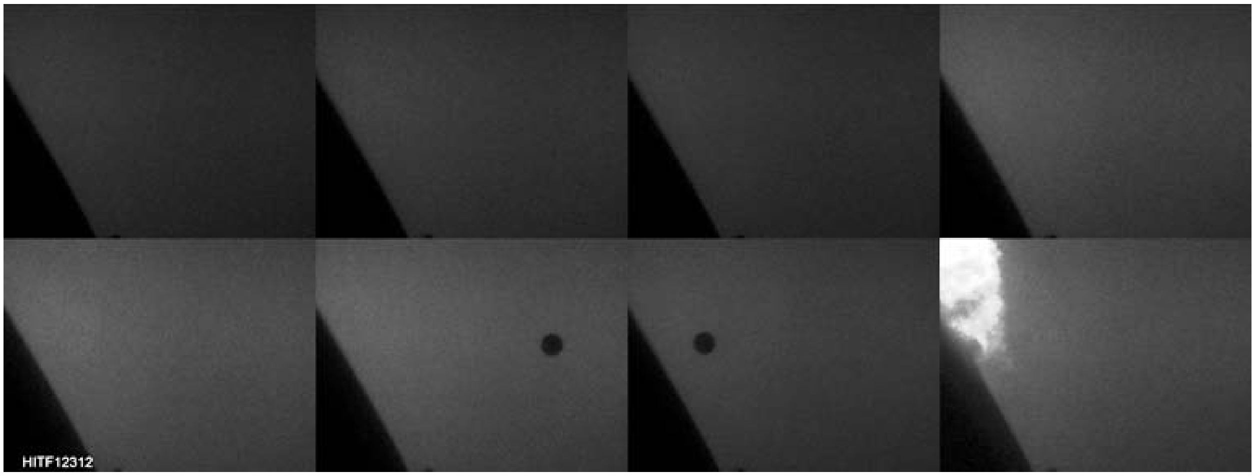


Figure C95 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

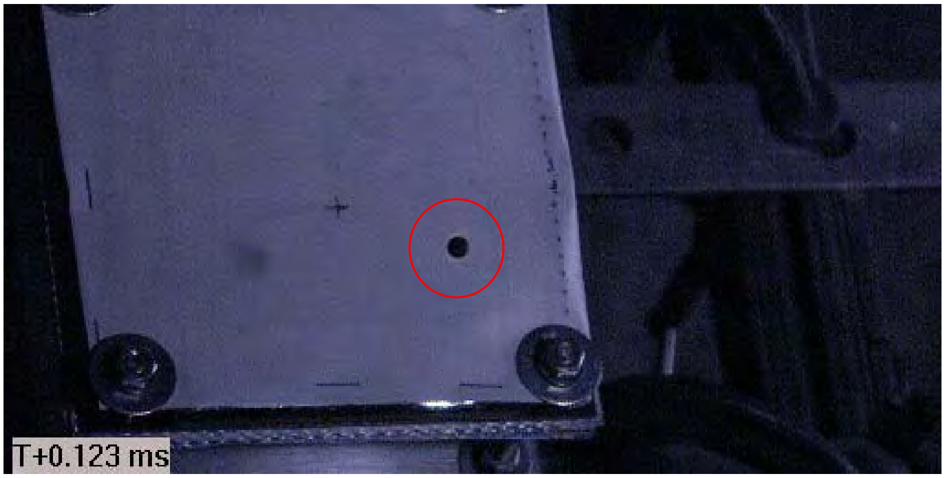


Figure C96 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

Figure C97 Image of Projectile Impacting Target (via Phantom v711)

HITF12313 / Test #31

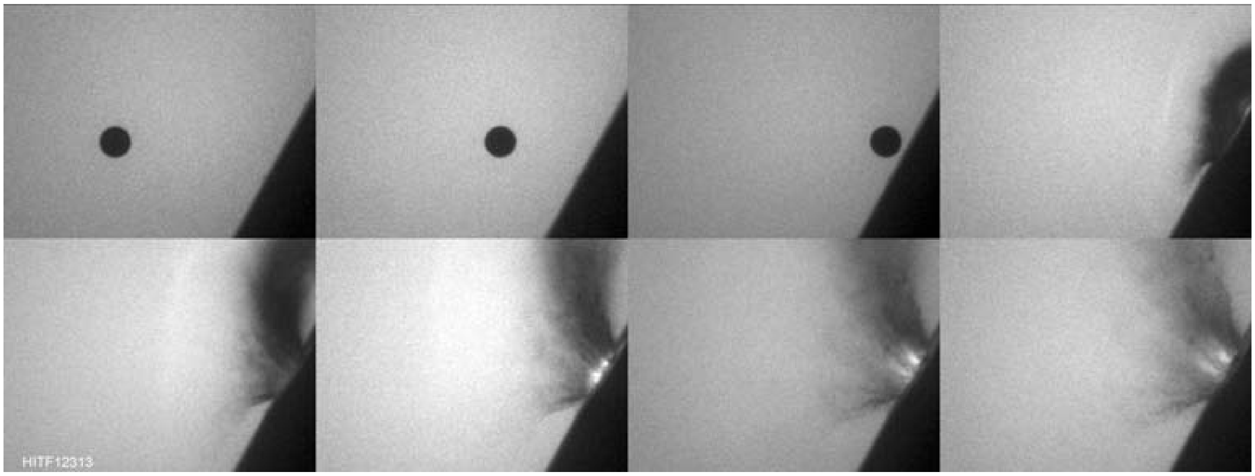


Figure C98 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

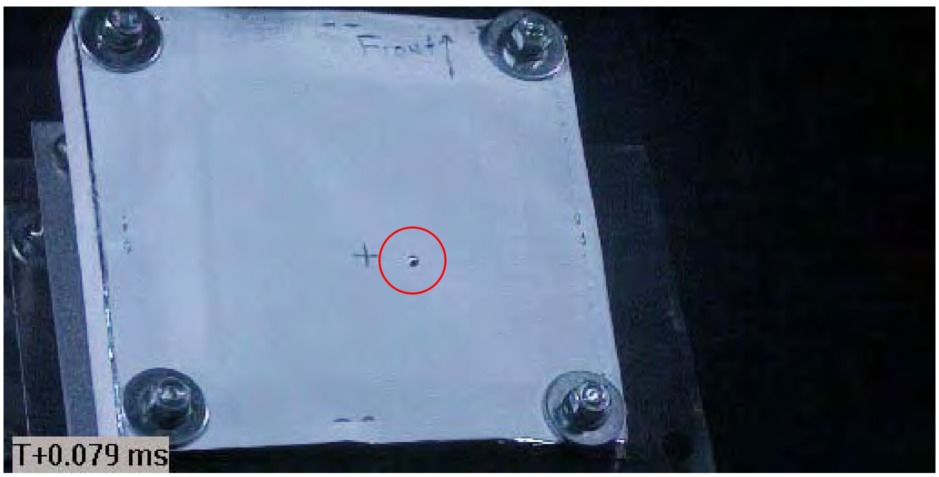


Figure C99 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

Figure C100 Image of Projectile Impacting Target (via Phantom v711)

HITF12314 / Test #32

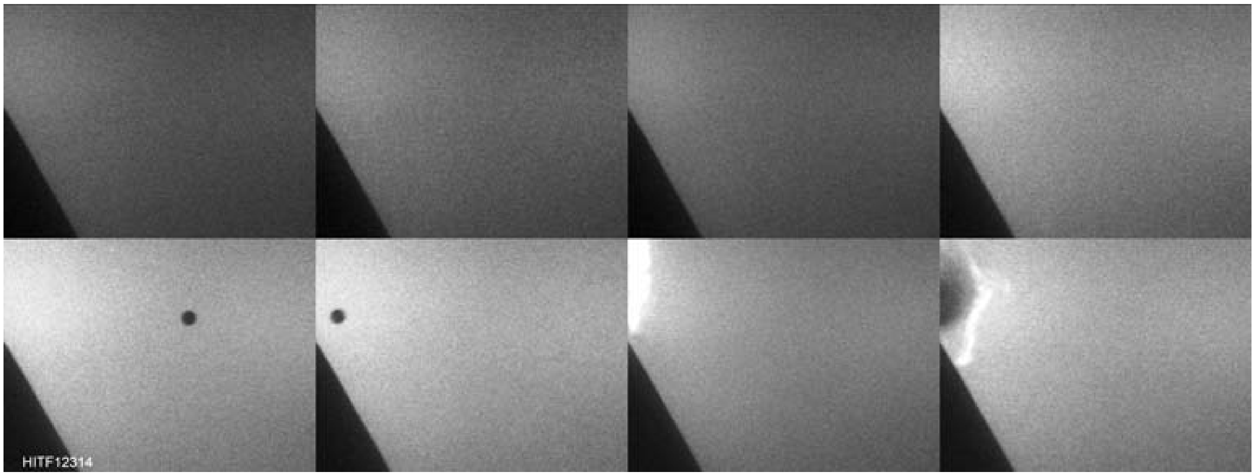


Figure C101 Projectile Captured Prior to Impact and Impacting Target (via SIMX-8 Camera)

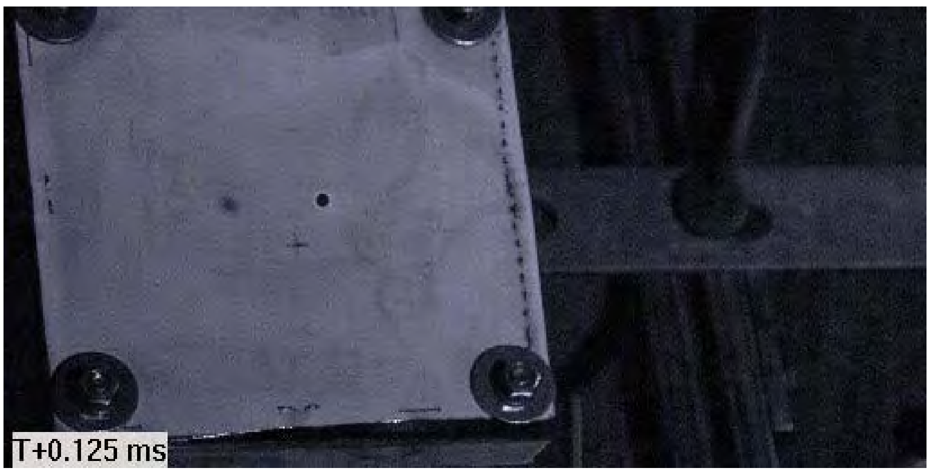


Figure C102 Image of Projectile Captured Prior to Impact (via Phantom v711 / projectile within red circle)

Figure C103 Image of Projectile Impacting Target (via Phantom v711)

Appendix D: NP 504 Substrate and TORLON 5030 Bonding Summary

Table D1 – NP 504 Substrate and TORLON Bonding Summary						
Serial Number	**NP 504 Substrate Pre-Bond Mass (g)**	**TORLON Pre-Bond Mass (g)**	**NP 504 and TORLON Post-Bond Mass (g)**	*****RTV Mass (g)**	******RTV Mass Per Unit Area (cm^2)**	**Comments**
***Type 2 Average Medium Configuration (0.125” thick NP 504 Substrate bonded to 0.049” thick TORLON)**						
1	132.6	45.2	179.8	2.0	0.013	Used in test #4 (HITF12286)
2	132.7	45.9	180.2	1.6	0.010	Used in test #11 (HITF12293)
3	133.0	46.1	180.3	1.2	0.008	Used in test #18 (HITF12300)
4	132.4	46.8	182.1	2.9	0.019	Used in test #25 (HITF12307)
5	131.8	45.7	179.9	2.4	0.016	Not used (spare)
6	132.2	47.9	182.8	2.7	0.017	Not used (spare)
7	132.0	46.2	180.1	1.9	0.012	Not used (spare)
8	131.8	45.6	179.1	1.7	0.011	Not used (spare)
****Type 3 Average Thick Configuration (0.125” thick NP 504 Substrate bonded to 0.187” thick TORLON)**						
9	132.5	120.6	255.0	1.9	0.012	Used in test #29 (HITF12311)
10	132.2	120.9	256.3	3.2	0.021	Used in test #30 (HITF12312)
11	133.2	120.8	256.4	2.4	0.016	Used in test #29-B (HITF12311-B)
12	132.3	120.9	256.4	3.2	0.021	Not used (spare)

*****The NP 504 substrate was cut into a 6” x 6” panel and TORLON was a 4” x 6” panel that was 0.080” thick, the 0.049” thickness on the TORLON was achieved by milling 3” diameter pocket within center of the panel.
** The NP 504 substrate was cut into a 6” x 6” panel and TORLON was a 4” x 6” panel.
***The RTV application was said to have thickness range of 0.004” – 0.007”, which can vary within this range per application.
****The mass per unit area (areal density) was obtained by calculating the RTV mass, using all of the mass per unit areas from each sample provided an average areal density of 0.015 g/cm^2.

Appendix E: NP 504 and TORLON 5030 Property Data Sheets

NORPLEX MICARTA

Global Thermoset Composite Solutions

Sheet Products - Property Comparison

			NP504	MC507U	NP509	NP510A
			Glass Fabric			
			Phenolic	Silicone	Melamine	Epoxy
PHYSICAL PROPERTIES						
Specific Gravity (0.500″)		-	1.85	1.88	1.85	1.85
Rockwell Hardness (0.250″ Build-up)		M Scale	110	100	115	98
Moisture Absorption (0.062″)	Condition D_1-24/23	%	2.00	0.19	0.60	0.10
Flexural Strength (0.062″)	Condition A Lengthwise / Crosswise	psi	55,000 / 50,000	18,500 / 15,400	61,600 / 51,100	65,000 / 52,000
	Condition E-1/150 T150 Lengthwise / Crosswise	psi	-- / --	-- / --	-- / --	29,000 / 26,000
Flexural Modulus (0.062″)	Lengthwise / Crosswise	kpsi	1,800 / 1,400	-- / --	2,000 / 1,700	2,900 / 2,600
Tensile Strength (0.125″)	Lengthwise / Crosswise	psi	42,000 / 34,000	-- / --	44,000 / 34,000	40,000 / 32,000
Izod Impact Strength (0.500″)	Condition E-48/50 Lengthwise / Crosswise	ft-lb/in (notched)	12.00 / 11.00	17.00 / 8.50	12.50 / 8.50	7.90 / 7.30
Compressive Strength (0.500″)	Flatwise	psi	76,000	--	70,000	66,000
Bonding Strength (0.500″)	Condition A	lb	1,500	600	1,900	2,300
	Condition D-48/50	lb	--	--	--	--
Shear Strength (0.062″)	Perpendicular	psi	18,000	--	18,000	21,500
THERMAL PROPERTIES						
Temperature Index[1]	Electrical / Mechanical	°C	140 / 170	170 / 220	-- / 140	130 / 140
Coefficient of Thermal Expansion (0.125″)	X-axis / Y-axis	$″/″/°C \times 10^{-6}$	15.0 / 18.0	-- / --	15.0 / 18.0	10.0 / 13.0
Flammability Rating U.L. 94	Condition A	Class	HB	V-0	V-0	V-0
ELECTRICAL PROPERTIES						
Dissipation Factor (0.062″)	Condition D_1-24/23	-	--	0.002	0.015	0.032
Permittivity (0.062″)	Condition D_1-24/23	-	--	4.34	7.03	4.80
Breakdown Voltage (0.062″)	Condition A	kV	55	55	65	66
	Condition D-48/50	kV	40	34	55	65
Electric Strength (0.062″)	Condition A	V/mil	375	350	450	800
	Condition D-48/50	V/mil	200	--	400	750
Arc Resistance D495 (0.125″)	Condition A	sec	100	240	185	130
Comparative Tracking Index D3638 (0.125″)		V	150	--	600+	300

NOTE a: A double dash (--) indicates that the value has not been determined or is not applicable to the product.
NOTE b: All testing per ASTM D348 unless otherwise noted.

[1] NEMA LI-6: This temperature is a recommendation only and is based upon experience in various applications. The maximum operating temperature is dependent upon the application and should be investigated prior to use.

Torlon® 5030

TYPICAL PROPERTIES OF Torlon® 5030

Property	Test Method[2]	Typical Values[1] U.S. Customary Units Value	Units	SI Units Value	Units
Mechanical					
Tensile strength					
-321°F (-196°C)	D 1708	29.5	kpsi	204	MPa
73°F (23°C)	D 1708	29.7	kpsi	205	MPa
275°F (135°C)	D 1708	23.1	kpsi	160	MPa
450°F (232°C)	D 1708	16.3	kpsi	113	MPa
Tensile elongation					
-321°F (-196°C)	D 1708	4	%	4	%
73°F (23°C)	D 1708	7	%	7	%
275°F (135°C)	D 1708	15	%	15	%
450°F (232°C)	D 1708	12	%	12	%
Tensile modulus					
73°F (23°C)	D 1708	1560	kpsi	10.8	GPa
Flexural strength					
-321°F (-196°C)	D 790	54.4	kpsi	381	MPa
73°F (23°C)	D 790	48.3	kpsi	338	MPa
275°F (135°C)	D 790	35.9	kpsi	251	MPa
450°F (232°C)	D 790	26.2	kpsi	184	MPa
Flexural modulus					
-321°F (-196°C)	D 790	2040	kpsi	14.1	GPa
73°F (23°C)	D 790	1700	kpsi	11.7	GPa
275°F (135°C)	D 790	1550	kpsi	10.7	GPa
450°F (232°C)	D 790	1430	kpsi	9.9	GPa
Izod impact strength					
Notched	D 256	1.5	ft-lb/in	79	J/m
Unnotched	D 256	9.5	ft-lb/in	504	J/m
Shear strength	D 732	20.1	kpsi	140	MPa
Compressive strength	D 695	38.3	kpsi	260	MPa
Compressive modulus	D 695	1150	kpsi	7.9	GPa
Poisson's ratio		0.43		0.43	
Thermal					
Heat deflection temperature					
at 264 psi (1.82 MPa)	D 648	539	°F	282	°C
Flammability Rating[3]	UL-94	94 V-0		94 V-0	
Coefficient of thermal expansion	D 696	9	10^{-6} in/in/°F	16.2	10^{-6} m/m/°C
Thermal conductivity	C 177	2.5	Btu-in/hrft^2°F	0.37	W/mK
Oxygen index	D 2863	51	%	51	%
Electrical					
Dielectric strength	D 149	840	V/mil	32.6	kV/mm
Dielectric constant					
at 1 kHz	D 150	4.4		4.4	
at 1 MHz	D 150	4.2		4.2	
Dissipation factor					
at 1 kHz	D 150	0.022		0.022	
at 1 MHz	D 150	0.050		0.050	
Surface resistivity	D 257	$1x10^{18}$	ohm	$1x10^{18}$	ohm
Volume resistivity	D 257	$6x10^{16}$	ohm-in	$2x10^{15}$	ohm-m
General					
Moisture absorption	D 570	0.24	%	0.24	%
Rockwell hardness	D 785	94		94	
Density	D 1505	0.058	lb/in^3	1.61	g/cm^3

[1]Actual properties of individual batches will vary within specification limits.

[2]Test methods are ASTM unless otherwise noted.

[3]These flammability ratings are not intended to reflect hazards presented by these or any other materials under actual fire conditions.