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Investigations of Near-Edge Ballistic Impacts on Law Enforcement Body Armor

Kirk D. Rice, Amanda L. Forster, Michael A. Riley,
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National Institute of
Standards and Technology
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Materials Measurement Science Division
Material Measurement Laboratory

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U.S. Department of Commerce
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Willie May, Acting Under Secretary of Commerce for Standards and Technology, and Acting Director

Abstract

In 2005 and 2006, two law enforcement officer-involved shootings resulted in injuries to the officers when bullets were not stopped in the officers' body armor. In both cases, the bullets struck the officers' armor quite close to the edge of the ballistic-resistant panel. In each case, the National Institute of Justice (NIJ) and the law enforcement agencies involved had several concerns. Was the armor's response indicative of a serious problem with the armor? Was the armor performance degrading significantly during use? Were similar armors being worn by other law enforcement officers providing the expected level of protection?

The National Institute of Standards and Technology (NIST) investigated how each of the armors performed, including examining the shot panels, performing ballistic testing, and measuring select material properties of samples of ballistic-resistant material from the armors, in order to provide guidance to NIJ. The research effort concluded that in both cases the bullets struck the body armor too close to an edge for the armor to be able to reliably stop the bullet. The results of ballistic testing on one incident armor and a similar armor indicated that the armors appeared to provide sufficient protection when struck by bullets away from the edge, in the region normally tested during compliance testing. Material property testing found that there were some indications of changes to the ballistic-resistant materials due to use, but no indications of significant degradation in the materials.

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Acknowledgments

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The Panama City Beach Police Department and Bureau of Alcohol, Tobacco, Firearms and Explosives assisted with and provided information related to the Panama City Beach armor investigation.

The Tampa Police Department provided extensive information, spare armor, and assistance that made the investigation into the Tampa incident possible.

The National Law Enforcement and Corrections Technology Center assisted with contacting law enforcement agencies, provided information on compliance test results, and provided chain-of-custody for incident armors that were inspected at NIST.

The authors thank all of them for their valuable assistance.

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Disclaimer

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List of Acronyms

ATF Bureau of Alcohol, Tobacco, Firearms and Explosives

ATR attenuated total reflectance

BFS backface signature

CBC Companhia Brasileira de Cartuchos

CPL Certified Products List

CTP Compliance Testing Program

DMTA dynamic mechanical thermal analysis

FBI Federal Bureau of Investigation

FMJ full metal jacket

FTIR Fourier transform infrared spectroscopy

IR Interim Requirements

JHP jacketed hollow point

JSP jacketed soft point

LEOKA Law Enforcement Officers Killed and Assaulted

LSCM laser scanning confocal microscope

MCT mercury-cadmium-telluride

NIJ National Institute of Justice

NILECJ National Institute of Law Enforcement and Criminal Justice

NIST National Institute of Standards and Technology

P-BFS penetration and backface signature

PBO poly(*p*-phenylene benzobisoxazole)

PCB Panama City Beach

PPTA poly(*p*-phenylene terephthalamide)

SAAMI Sporting Arms and Ammunition Manufacturers' Institute

SPSJ soft point semi-jacketed

UHMWPE ultra-high molecular weight polyethylene

UTM universal testing machine

1 Introduction

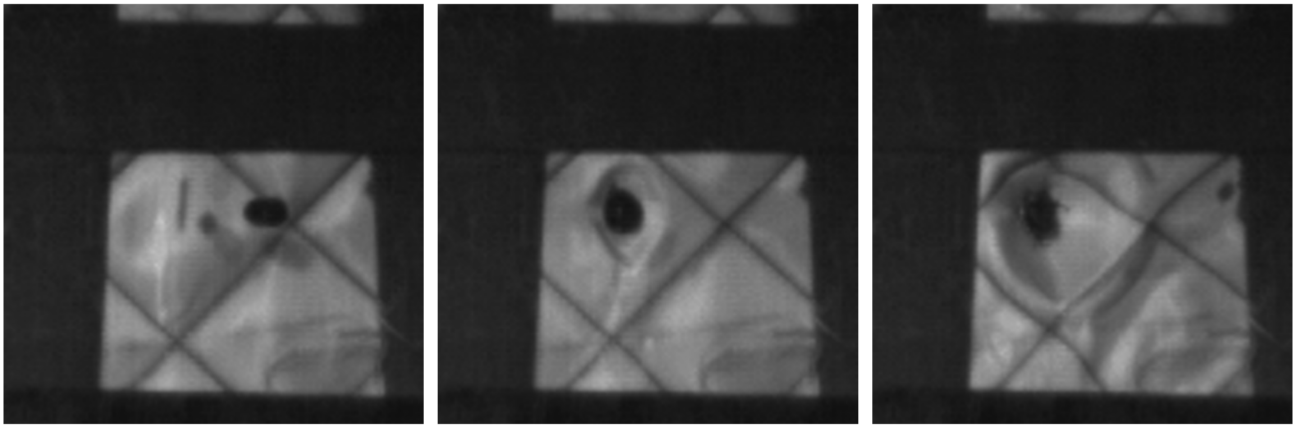
In 2005 and 2006, two law enforcement officer-involved shootings resulted in officer injuries—one fatal [1, 2, 3, 4], one minor [5, 6, 7]—when bullets that struck the officers' body armor were not stopped in the armor. In both cases, the bullets struck the armor close to the edge of the ballistic panel.

In each case, the National Institute of Justice (NIJ) and the law enforcement agencies involved had several concerns: Was the armor's response indicative of a serious problem with the armor? Was the armor performance degrading significantly during use? Were similar armors being worn by other law enforcement officers providing the expected level of protection? For help answering these questions, NIJ requested the assistance of researchers from the National Institute of Standards and Technology (NIST). The following sections summarize the facts relevant to the shooting incidents, the examination of the incident armors, and the testing performed at NIST to better understand the armor performance.

1.1 Background

At the time of the first incident, March 27, 2005, NIST was performing research related to the Department of Justice Attorney General's *Body Armor Safety Initiative* [8, 9, 10, 11], a research effort to examine new and used body armor constructed from poly(*p*-phenylene benzobisoxazole) (PBO) due to concerns about whether the armor maintained acceptable ballistic performance. Findings from the research determined that PBO, as it was then used in soft body armor models, exhibited signs of degradation, which led to declines in ballistic resistance. In order to understand the cause and extent of the PBO degradation, NIST used ballistic testing [10, 11] and a variety of material property test methods, including tensile testing of yarns and fibers [9, 11, 12, 13], Fourier transform infrared spectroscopy (FTIR) [11, 13], and laser scanning confocal microscopy [13]. These techniques were utilized in the current effort to understand if the materials in the two armors had changed and if material degradation had contributed to the armor response.

The current research effort also focused on understanding how the proximity of the bullet impact to the edge of the ballistic panel influenced the armor response. It is generally well understood that soft, fabric-based body armor cannot reliably stop bullets near the edges of the ballistic panel. The earliest versions of the NIJ performance standard for law enforcement body armor, National In-



(a) Prior to Impact (b) Cone Forming (c) Cone Fully Formed

Figure 1.1: Example of Armor Deformation During Ballistic Impact.

stitute of Law Enforcement and Criminal Justice (NILECJ) Standard–0101.00 [14] and NILECJ Standard–0101.01 [15], both required that all test impacts be at least "5 cm (2 in)" from the edge of the armor. In 1985, the second revision of this standard, NIJ Standard–0101.02 [16], increased the minimum distance to the edge to "7.6 cm (3 in)" for the purpose of improving test consistency. This requirement remained the same through the third revision, NIJ Standard–0101.03 [17] and fourth revision, NIJ Standard–0101.04 [18], which was the current standard at the time of this investigation.

Ideally, when a bullet strikes a fabric body armor the force from the bullet deforms the armor in the shape of a cone, as can be seen in the photographs in Figure 1.1. This cone will grow until either the bullet is stopped or the armor fails. When a bullet impacts fabric body armor close to the edge, a number of undesirable responses may occur. If the growing cone reaches the edge of the ballistic-resistant material, the edge of the cone may collapse and allow the bullet to slide off of the armor. If the bullet remains in the armor, the deformation may be much greater than for a similar impact that occurs at standard test distances from the edge. In addition, fabric armor relies on material away from the point of impact to constrain the relative movement of individual yarns. When the impact occurs close to the edge of the woven fabric there may not be sufficient material to keep the weave intact; yarns will separate from the weave, allowing the projectile to pass through layers without breaking the yarns. This can effectively reduce the number of layers of material involved in stopping the projectile and allow it to perforate the remaining layers.

1.2 Armor Materials

As described in the following sections, both of the incident armors described in this report were constructed primarily of woven para-aramid fabric. Para-aramid material, more formally known as poly(*p*-phenylene terephthalamide) (PPTA), was used in the first modern ballistic-resistant body armors, and remains one of the most common materials for this application, along with ultra-high molecular weight polyethylene (UHMWPE).

There are two common brands of para-aramid material used in body armor: Kevlar, manufactured by DuPont [19] and Twaron, manufactured by Teijin Aramid [20]. These two products appear quite similar, and their differences are difficult to distinguish, even through analysis of their material properties.

Of the two armors investigated in this report, one was constructed from Twaron, based on information provided by the armor manufacturer, but the material in the other one was not definitively determined.

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2 Details of the Incidents

The law enforcement officer-involved shootings were reported both in the press and on-line sources. As described below, additional details of the incidents were determined from conversations and correspondence with the police agencies and personnel involved in the criminal investigations.

The first incident occurred in Panama City Beach, Florida. After an officer of the Panama City Beach (PCB) Police Department was fatally shot, the police agency contacted NIJ and requested assistance to understand why the officer's armor had failed to protect him. NIJ requested that NIST provide technical assistance, and NIST agreed to inspect the incident armor to attempt to gain a better understanding of the armor performance.

The second incident occurred in Tampa, Florida. After media reports of an officer from the Tampa Police Department being wounded during a shooting, NIJ was concerned with how the armor was reported to have performed, whether there was a safety issue for other officers using this model of armor, and whether this incident could provide information that could improve future armor testing standards. NIJ contacted the police agency and requested permission to inspect the incident armor. The police agency was eager to collaborate, and not only provided the incident panel to NIST, but the back panel of the same armor and an additional armor, which allowed a more detailed study of the ballistic performance.

2.1 Panama City Beach Shooting

The first incident occurred on March 27, 2005, in Panama City Beach, Florida [1, 2, 3, 4]. An officer with the Panama City Beach Police Department was shot and killed during a traffic stop. This incident was summarized by the Federal Bureau of Investigation (FBI) in the 2005 *Law Enforcement Officers Killed and Assaulted* (LEOKA) [1]:

> "Around 10:30 p.m. on March 27, a 34-year-old sergeant with the Panama City Beach Police Department was shot and killed during a traffic stop. The 6-year veteran of law enforcement pulled over a vehicle for unspecified reasons and obtained the driver's license, registration, and proof of insurance. A check of the information revealed that the man's license had been revoked. The officer returned

Figure 2.1: Strike Face (Front) of Panama City Beach Armor Ballistic Panel.

> to the vehicle to place him under arrest. However, as the officer approached the vehicle, the man produced a 9 mm semiautomatic handgun and shot the officer at close range twice in the chest; a third shot missed and hit a passing car. The two bullets that struck the victim officer penetrated his protective vest (body armor failure), and he died at the scene."

The language in the last sentence of the FBI LEOKA report on this incident represents a simple factual assessment of the situation – that the officer's body armor did not stop the two bullets that struck it; however, the LEOKA report does not consider whether it was reasonable to expect the armor to stop the bullets in this specific case. A common concern is that reported armor failures could undermine law enforcement officers' faith in their armor, potentially leading to reduced wear rates. Representatives from NIST, NIJ, and the law enforcement agency all recognized that in this case it was important to understand why the armor performed the way it did, so that any deficiencies related to the design or materials could be addressed, and so that the law enforcement agency would have a clear understanding of why the armor was perforated.

Although it was not documented in writing, it was understood from discussions with law enforcement personnel that the officer was leaning over to look into the vehicle at the time he was shot. The bullets impacted his armor high up on the left shoulder, between the neck scoop and where the armor terminates for the left arm. This can be observed in the photograph of the strike face of the armor panel in Figure 2.1.

The officer was wearing a NIJ type IIA body armor that had been tested and found to be compliant with the NIJ Standard–0101.03 [17] in July 1995. It had been listed on the NIJ Certified Products List (CPL) with the model number MON-IIA+LSC [21]. This armor model was manufactured by Second Chance Body Armor, Inc. and sold under their "Monarch" line.

From the serial number (11961572) on the label (Figure 2.2) of the officer's front ballistic panel (Figure 2.1), the armor was apparently manufactured in November 1996. At the time of the incident on March 27, 2005, the armor would have been approximately 8 years, 4 months old.

The label (Figure 2.2) also indicated that the armor was manufactured as part of lot number 1701; and the size designation was "22 x 15", which was the manufacturer's notation for describing a panel with a side-to-side width of approximately 559 mm (22 in) across the widest section of the armor panel, and a maximum top-to-bottom length of approximately 381 mm (15 in) from the top edge of the armor panel near the shoulder to the bottom edge. Measurements made as part of the subject examination confirmed the width of the armor panel as 559 mm (22 in) and the height as 378 mm (14.9 in). The distance from the bottom of the neckline to the bottom edge of the panel was 327 mm (12.9 in).

From communications with personnel from the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF), NIST learned that the firearm used in this incident was a 9 mm Luger (9 x 19 mm) caliber [22], Taurus Millennium Pro with a barrel length of 82.6 mm (3 ¼ in) [23]. Law enforcement personnel reported that two different bullets were believed to have perforated the front panel of the armor. One bullet was described as a full metal jacket (FMJ) bullet made by Companhia Brasileira de Cartuchos (CBC), a Brazilian ammunition manufacturer. CBC manufactures two bullets of this general type: one having a mass of 7.5 g (115 gr), and the other having a mass of 8.0 g (124 gr) [24]. It is not known which of these were involved. The other bullet was described as a Federal Hydra-Shok jacketed hollow point (JHP) manufactured by Federal Premium Ammunition. There are three bullets of this general type made by Federal, each having a different mass, 8.0 g (124 gr) [25], 8.7 g (135 gr) [26], or 9.5 g (147 gr) [27]. It is not known which of these were involved. It is our understanding that one each of these two bullet types were involved in the shooting.

When the MON-IIA+LSC armor model was originally tested for compliance with NIJ Standard–0101.03 [17], the two test threats used were a 8.0 g (124 gr) Remington 9 mm Luger [22] FMJ bullet with a speed between 332 m/s (1090 ft/s) and 347 m/s (1140 ft/s), and a 10.2 g (158 gr) Remington .357 Magnum [22] jacketed soft point (JSP) bullet with a speed between 381 m/s (1250 ft/s) and 393 m/s (1290 ft/s). Bullet speeds were measured at a location 2.0 m (6.5 ft) to 2.5 m (8.2 ft) in front of the armor. The test specimens were tested in both the wet and dry conditions. While additional information and extensive studies would be necessary to definitively understand how the tested bullets compared to those involved in the shooting incident, it appears that the CBC FMJ bullet was likely to be similar to, but possibly traveling at a higher speed than, the 9 mm Luger test bullets used in the NIJ standard test. The Federal Hydra-Shok JHP bullets had significantly different construction, but the speed would have been similar to or slightly less than [25, 26, 27] the 9 mm Luger test bullets. The actual speed that these bullets would have obtained when fired from the incident firearm was not investigated as part of this study.

The CBC cartridge specifications [24] list a speed at 16 m of 385 m/s (1263 ft/s) for the 7.5 g (115 gr) bullet and 370 m/s (1214 ft/s) for the 8.0 g (124 gr) bullet; however, these appear to be based on a 508 mm (20 in) barrel, rather than the standard 101.6 mm (4.00 in) test barrel [22].

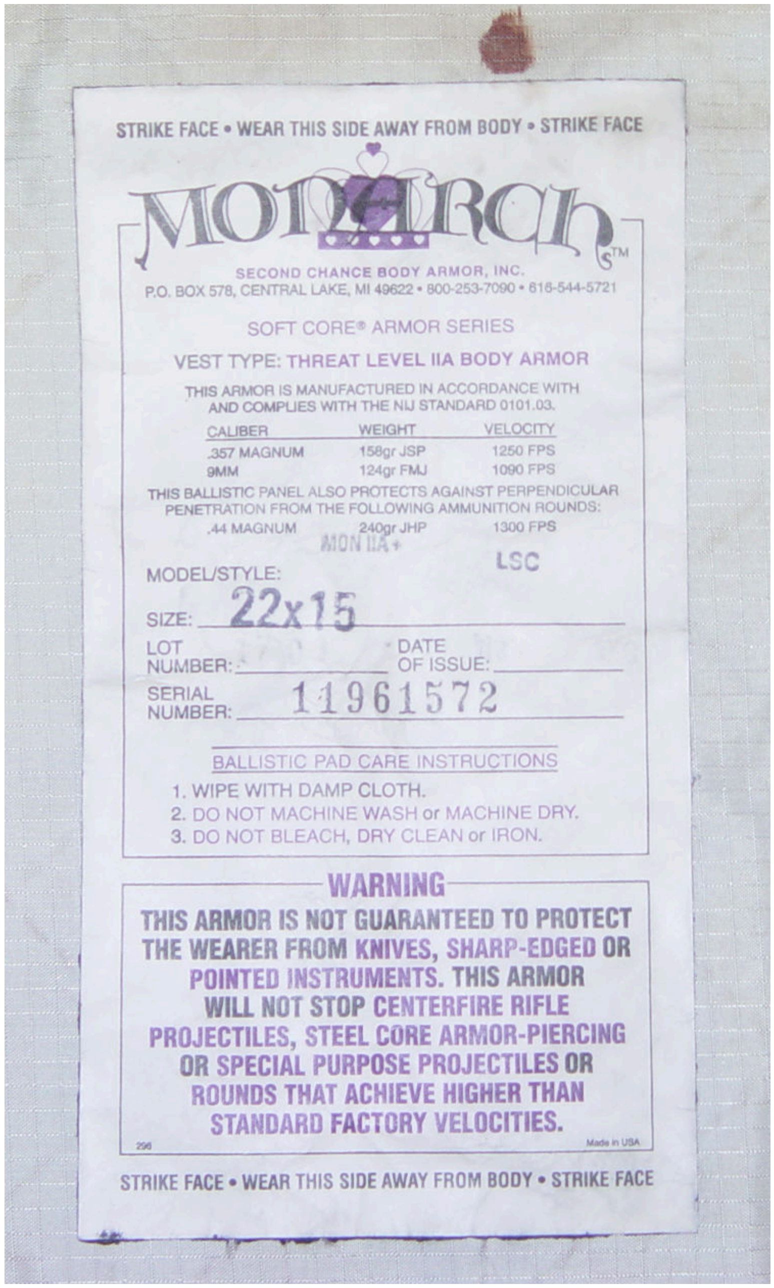


Figure 2.2: Panama City Beach Armor Ballistic Panel Label.

2.2 Tampa Shooting

At approximately 1:30 a.m. on May 26, 2006, in Tampa, Florida an officer of the Tampa Police Department was shot by an assailant who had been stopped for suspicion of driving on a suspended license [5, 6, 7]. As the officer approached the stopped vehicle the assailant opened fire with a .357 Magnum revolver, firing five shots before driving away. Upon seeing the imminent attack, the officer took evasive action, and only one of the five shots struck him. The bullet struck the officer, and "...slid below Wilkinson's badge, stabbed through a notebook in his breast pocket and punctured his bullet-resistant vest" [6]. Another article reported that "The bullet pierced Wilkinson's shirt, a spiral note pad and the vest before lodging in the fleshy part of his chest..." [5]. As described in news reports [7, 5], the officer required only minor surgery, and was released from the hospital the same day as the shooting.

Four days after the shooting, NIST personnel discussed the incident in a telephone conversation with a representative of Tampa Police Department. The NIST personnel explained that there was great interest in this incident to understand the cause of the apparent armor penetration so that assessments could be made regarding whether the safety of other officers might be jeopardized, and whether information relevant to this incident might support future body armor standards-setting activities. A few days later, NIJ sent official correspondence to the Chief of the Tampa Police Department requesting that he confirm the facts describing the incident and that his agency continue to support the NIJ examination of this matter. The correspondence also requested access to the incident body armor as well as other samples of body armor, and it extended an invitation to the agency to accompany the armors and observe testing at NIST. The Tampa Police Department responded with official correspondence confirming the facts that had been established in this incident, and requested NIJ's assistance "in having the body armor the officer was wearing tested by an independent laboratory" and assessing whether "the body armor purchased by the Tampa Police Department performs to the specifications represented by the manufacturer."

The Tampa Police Department reported that they visually inspected the incident armor five days after the shooting. A week later, representatives of the body armor manufacturer were permitted access to the armor so that they could visually inspect and photograph it. A representative of the Tampa Police Department confirmed that nothing beyond simple handling, visual inspection, and photographing of the exterior of the body armor was permitted during these examinations.

The officer was wearing a NIJ type II body armor that had been tested and found to be compliant with the NIJ Standard–0101.04 [18] in April 2003. It had been listed on the NIJ CPL with the model number 329-MON-II 301230 [28]. This armor model, like the armor in the Panama City Beach incident, was manufactured by Second Chance Body Armor, Inc. and sold under their "Monarch 329" line. After Second Chance Body Armor, Inc. was sold to Armor Holdings in 2005, Second Chance Armor, a subsidiary of Armor Holdings, continued to manufacture this armor model. When NIJ added the 2005 Interim Requirements (IR) [29] to the armor compliance requirements, Armor Holdings submitted a declaration that the armor model met these requirements. At the time of the incident, the model was listed on the NIJ CPL as 2005 IR compliant.

The label on the incident armor panel, shown in Figure 2.3, indicates that the body armor was manufactured on March 14, 2005. The label also confirms that the armor panel is from lot 1357. The serial number of the incident ballistic panel is AL03559416, which indicates that it was manufactured in Second Chance Body Armor's Geneva, Alabama facility. The Tampa Police Department reported that their records indicated that the body armor was issued to the officer in May 2005.

The armor panel label describes the armor size as 201715. Following the sizing convention that the manufacturer was using at that time, which allows both the front and back panels to be labeled the same even if they are quite different sizes, the interpretation of size 201715 is that the front panel is approximately 508 mm (20 in) wide at the widest point, the back panel is approximately 432 mm (17 in) wide at the widest point, and both panels are approximately 381 mm (15 in) high. The height is measured from the bottom edge to the highest point on the panel, so the height from the bottom of the neck cut-out to the bottom of the panel will generally be 38 mm (1.5 in) to 51 mm (2.0 in) less.

After the assault on the officer, the assailant reportedly emptied the spent casings on the road while fleeing, and then reloaded. The ammunition that is believed to have been used by the assailant was manufactured by CBC (according to the head stamp on the casings), and marketed outside Brazil as Magtech Ammunition. Based on cartridges that were still in the revolver's cylinder, a partial box of ammunition in the assailant's truck, and the bullet surgically extracted from the officer's torso, the bullet type was determined to be a .357 Magnum [22] 10.2 g (158 gr), soft point semi-jacketed (SPSJ) flat nose. This type of bullet is shown in Figure 2.4. The manufacturer specifications for the Magtech ".357 Magnum 158 SPSJ Flat" cartridge [30] lists the muzzle velocity as 376 m/s (1235 ft/s) when fired from a standard 102 mm (4.0 in) velocity barrel [22].

The firearm used in this incident was a Ruger Security-Six, a six-shot revolver [31], having a 70 mm (2 ¾ in) barrel. A photograph of the incident firearm, provided by the Tampa Police Department, is shown in Figure 2.5. The serial number of the revolver was 155-39321, which indicates that the firearm was likely manufactured in 1979 [32]. Since the barrel length of this revolver is significantly less than the standard velocity barrel length used by Magtech to determine the typical muzzle velocity, it is likely that the actual bullet speed from this revolver was less than the manufacturer specified 376 m/s (1235 ft/s) [30]. The Tampa Police Department, as described in Section 4.1.2, reported to NIST that the estimated incident bullet speed was 344 m/s (1130 ft/s), based on tests performed at their crime laboratory.

This model of revolver was manufactured with a number of different barrel lengths, including 70 mm (2 ¾ in), 102 mm (4 in), and 152 mm (6 in).

The incident bullet type is very similar to that used in the NIJ standard test for type II armor, which is a .357 Magnum, 10.2 g (158 gr), jacketed soft point bullet with a flat nose [18], and manufactured by Remington. The NIJ standard specifies the measured bullet speed for this type of bullet to be 436 m/s $\pm$ 9.1 m/s (1430 ft/s $\pm$ 30 ft/s), so the body armor should have had a large safety margin for the similar incident bullet, which, based on the Tampa Police Department's investigation, would have impacted the body armor at a speed approximately 90 m/s (300 ft/s) slower than the speed specified in the NIJ standard.

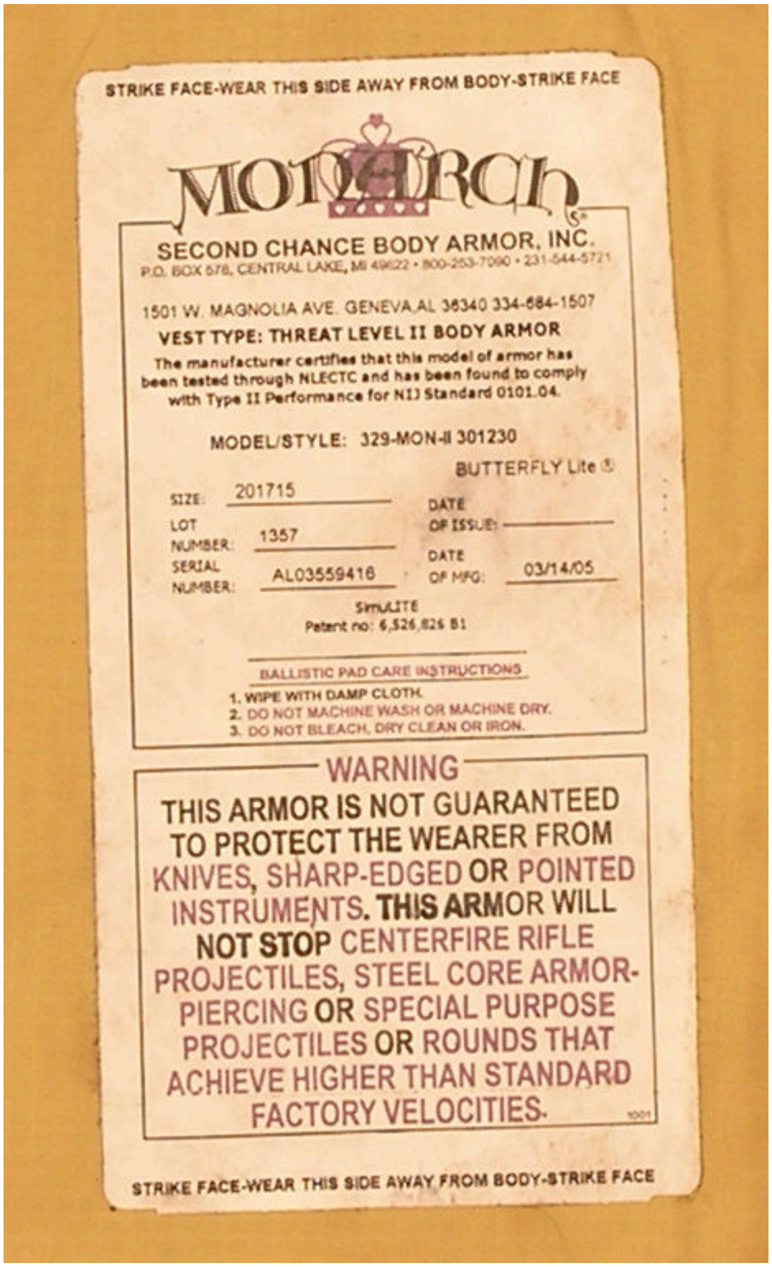


Figure 2.3: Tampa Armor Ballistic Panel Label.

Figure 2.4: Bullet of the Type Used in the Tampa Shooting.
From Magtech Product Specification [30]

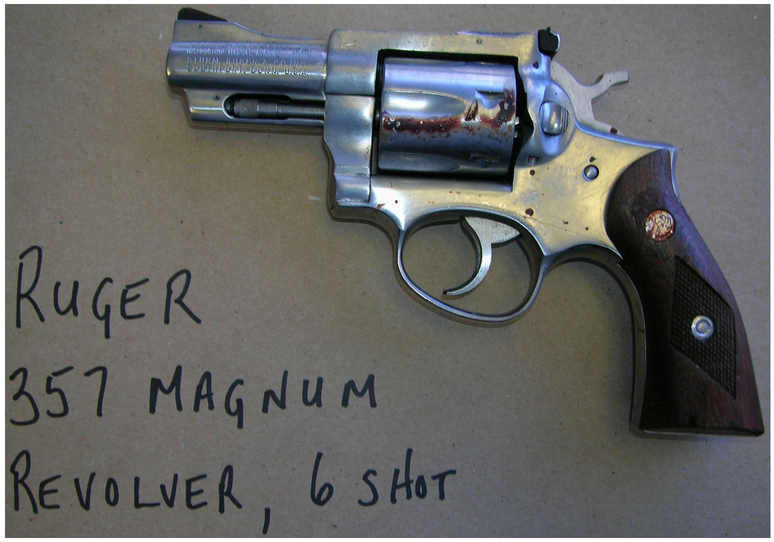


Figure 2.5: Firearm used in the Tampa Shooting.
Photograph provided by Tampa Police Department

The armor carrier is a close fitting garment that contains the armor panel. Most carriers are constructed so that the armor panel can be easily removed for cleaning.

According to a representative of the Tampa Police Department, the bullet struck in the center of the officer's left breast pocket, passed through the center of a small spiral bound notepad in that pocket, and entered the body armor. Given how a uniform shirt fits over the armor carrier, this meant the bullet struck the body armor approximately 32 mm (1.25 in) from the armor panel edge near the lower left underarm area. The location where the bullet perforated the armor carrier can be seen in Figure 2.6. Since the bullet struck at a wide angle, with the direction of flight angled outward toward the edge of the armor panel, the bullet exited near the edge of the armor panel and entered the officer's torso somewhere between his left breast and underarm. The location where the bullet exited from the armor can be seen in the photograph in Figure 2.7.

Figure 2.6: Front of Tampa Armor with Bullet Entry Hole Indicated.
Photograph provided by Tampa Police Department

Figure 2.7: Body Side of Tampa Armor with Bullet Exit Hole Visible on Left Edge.
Photograph provided by Tampa Police Department

3 Examination of the Armors

NIST researchers were given opportunities to examine each of the incident armors, including cutting the panel covers and inspecting the ballistic-resistant material. These examinations were intended to assess whether the ballistic-resistant material inside the ballistic panels was perforated, and whether the reason(s) for each armor's performance could be determined.

At the time of the visual inspection, material samples were extracted from each incident panel. These samples were later subjected to a variety of material property tests, which are described in more detail in Section 5. The following sections detail the observations from the visual examination of each of the incident armor ballistic panels.

3.1 Panama City Beach Armor

A visual examination of the front panel of the armor was made by NIST researchers. The initial examination showed that both bullets struck the incident armor high on the ballistic panel, on the narrow portion of the armor panel that extends up toward the officer's left shoulder. This can be seen in the photograph in Figure 2.1.

The ballistic panel was removed from the armor carrier, and it was noted that the ballistic panel was inserted into the carrier in the correct orientation. This was verified by the manufacturer's label, shown in Figure 2.2, which was affixed to the ballistic panel and mostly legible. The label on the incident panel clearly indicated that the labeled side was intended to be worn as the *Strike Face*, facing away from the body, and the visual inspection verified that the bullets struck this side of the panel covering. For some armor types, the orientation of the panel is critical, because the order of the layers of ballistic-resistant material leads to different ballistic resistance depending on which side of the ballistic panel a bullet strikes.

The NIJ Standard and Compliance Testing Program (CTP) require that all production armor be clearly labeled, with the label indicating the armor model number, a unique serial number, the proper orientation, and other information; however, many of the labels become damaged or illegible after years of use.

The location of the entry holes on the ballistic panel cover may be seen in Figure 3.1. These two bullet impact locations will be described as *neck-side* and *arm-side*, because one shot was located close to the armor edge nearer to the neck, while the other shot was located closest to the armor edge nearer to the arm. The visual examination also revealed that both bullets exited the body side of the armor panel covering. The damage to the body side of the ballistic panel can be seen in the photograph in Figure 3.2.

Figure 3.1: Entry Holes on Upper Left Shoulder of Panama City Beach Incident Panel.

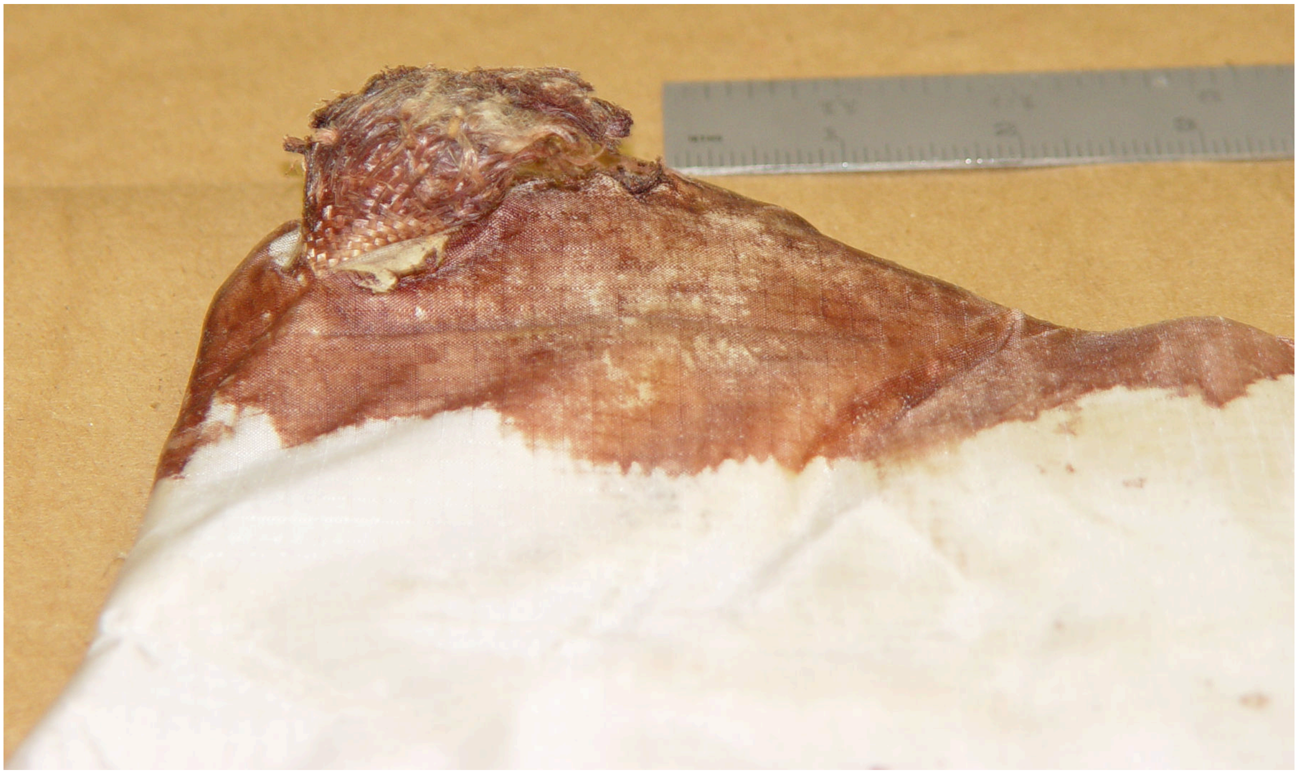


Figure 3.2: Exit Holes on Upper Left Shoulder of Panama City Beach Incident Panel.

The back of the incident panel revealed that the neck-side hole appeared to be relatively clean, with no indication of any material extruding out the back of the panel. The arm-side hole revealed a significant amount of extrusion, with a large tuft of ballistic fibers protruding, as can be observed in Figure 3.2. The extruded fiber lengths were generally between 13 mm (0.5 in) and 25 mm (1.0 in). The fibers formed a tightly clustered tuft of approximately 25 mm (1.0 in) diameter. The lack of any material extrusion from the neck-side hole suggests that little to no ballistic-resistant material was engaged by the bullet that perforated that location. When a perforation occurs in a typical laboratory test, ballistic-resistant material is driven rearward, causing some extrusion of the material through the armor panel cover and rupture of the panel cover. Evidence of ballistic-resistant material extrusion from the arm-side hole is an indicator that the bullet was engaged by the armor, but there appears to have been very little material available and a typical deformation cone would not have been able to form.

The cover was removed and the ballistic-resistant material was examined, both to understand where the bullets struck the material and whether the armor was properly constructed.

The ballistic panel was constructed from 22 layers of woven para-aramid fabric. The yarn count of the weave was measured to be approximately 8.7 by 9.8 yarns/cm (22 by 25 yarns/in). All layers were oriented with the weave direction running left-to-right across the panel and top-to-bottom. From the strike face of the panel, the first eleven layers (layers 1-11) were stitched together with a diamond quilt pattern, with each row of stitches approximately 32 mm (1.25

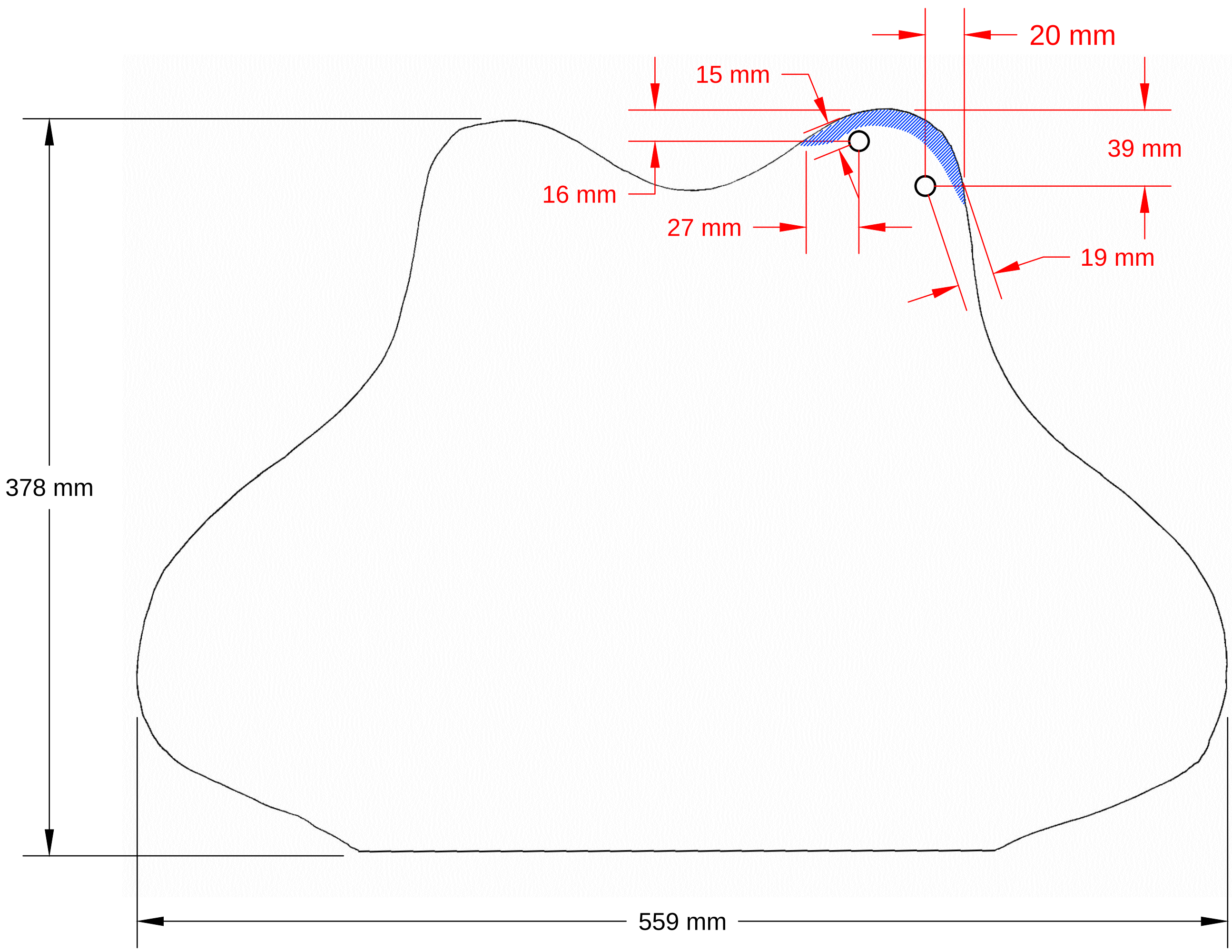


Figure 3.3: Sketch of Bullet Entry Locations on Panama City Beach Incident Panel.
(Blue hatch indicates approximate area of weave unraveling on undamaged shoulder.)

in) apart. The next eleven layers (layers 12-22) were stitched together with a box pattern, again with each row of stitches approximately 32 mm (1.25 in) apart. These two 11-layer packs were then stitched together with four vertical full-length stitches spaced approximately 25 mm (1.0 in) apart, and centered about the vertical center line of the panel. All stitches appeared to be para-aramid thread. This construction matched the construction details that were recoded at the time the armor model was tested for compliance to the NIJ body armor standard [21].

Measurements were made to characterize the position of the two bullet impact locations relative to the edge of the armor panel cover. The estimated dimensions are shown graphically on an approximate outline of the armor panel in Figure 3.3 and can be observed in the photograph in Figure 3.4. All distances measured to a bullet hole were referenced to the approximate center of the entrance hole.

The arm-side hole was located a horizontal distance of approximately 20 mm (0.79 in) from the edge, and a vertical distance of approximately 39 mm (1.5 in)

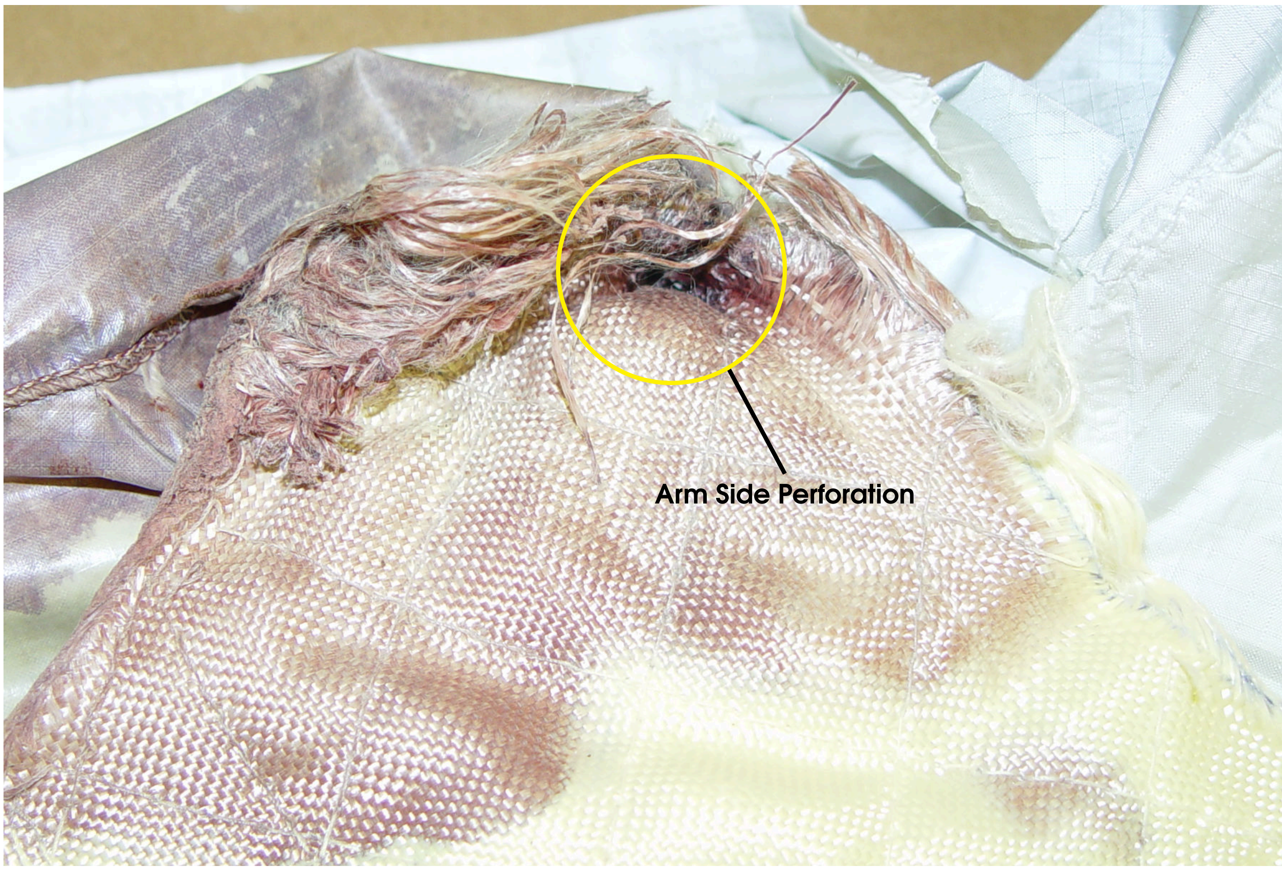


Figure 3.4: Damaged Area of Panama City Beach Incident Panel with Cover Removed.

down from the top edge. Due to the curvature of the armor in this region, the distance to the nearest edge was approximately 19 mm (0.75 in), in a direction approximately 30° to 40° up from horizontal. This hole is visible to upper center (right side of ballistic-resistant material) of the photograph in Figure 3.4

The neck-side hole was located a horizontal distance of approximately 27 mm (1.1 in) from the edge, and a vertical distance of approximately 16 mm (0.63 in) down from the top edge. Because of the curvature of the armor in this region, the distance to the nearest edge was approximately 15 mm (0.59), in a direction approximately 20° from vertical.

When woven ballistic-resistant materials similar to those used in this ballistic panel are cut, there is often an unraveled edge of 2 mm to 6 mm (0.08 in to .25 in) that occurs along straight edges. This occurs because the yarns running along the edge are not locked in place by adjacent yarns. Around tight curves, the extent of unraveling can be larger because there is even less material to hold the shorter length yarns in the weave. In the incident ballistic panel, the unraveled edge on the opposite shoulder strap region of the panel (the one not struck by the bullets) was approximately 10 mm, as shown in Figure 3.5. This suggests that similar unraveling, which was noted around the perimeter of the armor panel in the shoulder region that was struck by the bullets, may have been pre-existing and not the result of the bullet impact.

Both shots were found to have engaged very little ballistic-resistant material that would have been bound together through the fabric weave and stitching used to construct the armor panel. Figure 3.4 shows how little ballistic-resistant material there was between the arm-side hole and the edge of the panel. A close examination of the arm-side hole revealed that the edge of the ballistic panel, proximal to the impact location, buckled and was extruded through the body side of the armor panel cover, allowing the bullet passage. The exact location of the neck-side hole in the ballistic-resistant material was difficult to determine with certainty, although it appears to have passed through the frayed and unraveled yarns at the extreme edge of the armor panel.

The incident panel was deconstructed by removing the quilt stitching and through-stitching (the vertical stitching holding the two 11-layer packs together) from the lower 100 mm to 125 mm (4 in to 5 in) of the armor panel. The partially deconstructed panel is shown in the photograph in Figure 3.6. Full-length pieces of fabric, approximately 100 mm (4 in) wide, were cut from layers 1, 6, 11, 12, 17, and 22, where the strike face was designated layer 1 and the body-side layer was designated layer 22. The ballistic panel with sample material removed is shown in the photograph in Figure 3.7 and an example of one of the material samples being prepared for storage is shown in the photograph in Figure 3.8. Once the fabric samples were taken, individual yarns were extracted from the fabric samples. Material property tests performed on these yarns are described in Section 5.

One additional observation from the inspection of the ballistic panel concerned the body side of layer 22. Some *bronzing*, i.e. a slight brownish cast to the otherwise bright yellow para-aramid, of the body side of this layer of the ballistic-resistant material was observed. The other side of this same fabric layer did not exhibit any discoloration. Para-aramid fabrics can suffer degradation due

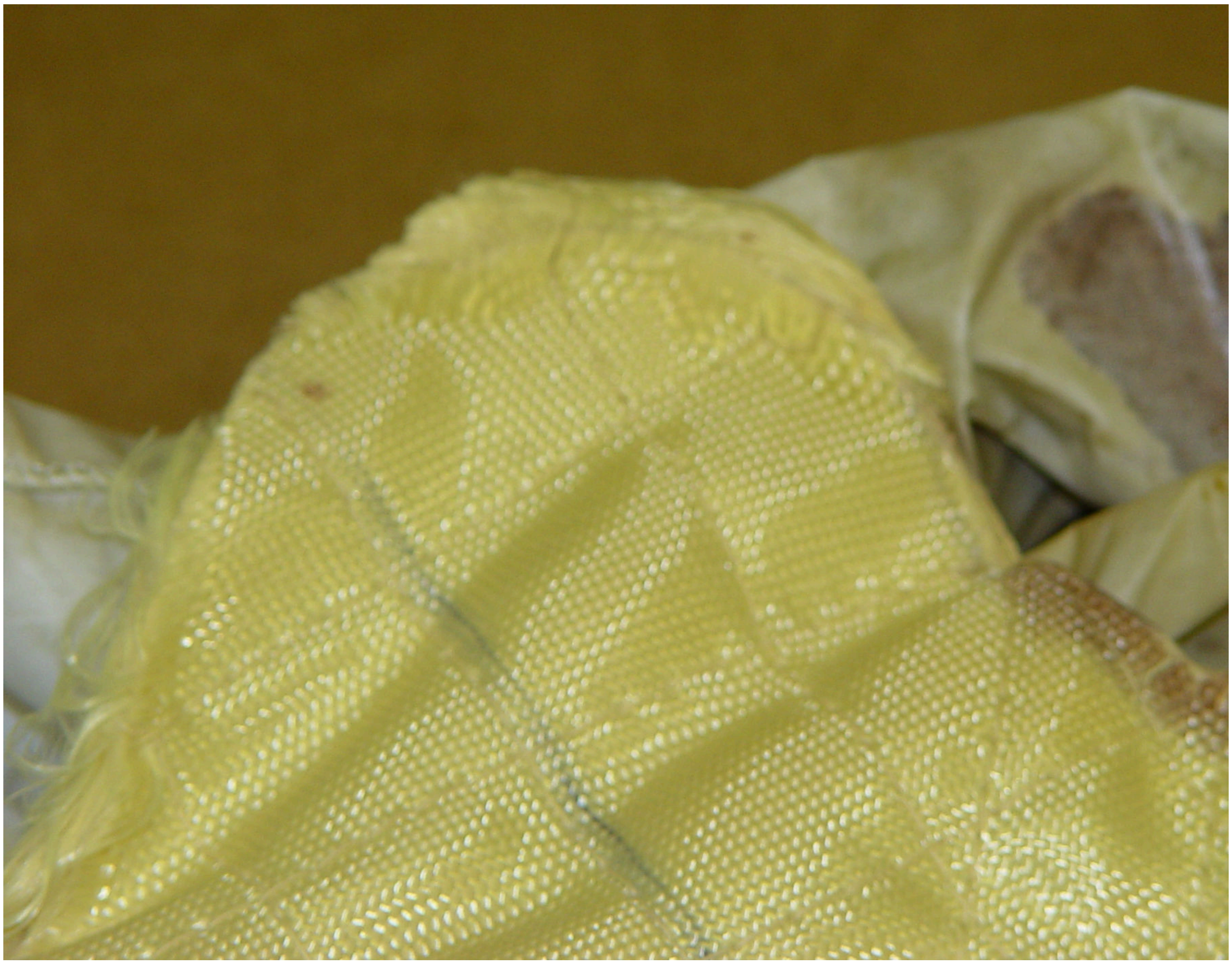


Figure 3.5: Unraveled Material on Panama City Beach Incident Panel Right Shoulder.

Figure 3.6: Panama City Beach Incident Panel with Stitching Removed.

to a number of factors. Discoloration, as observed, is likely to be due to moisture or light exposure [33]. Because only one side of the fabric layer is slightly discolored, light exposure is strongly suspected. This limited discoloration is a curiosity; however, NIST did not investigate this phenomenon further, since the chemical and physical analysis did not show any significant difference between this layer and the other layers.

Generally, shots located very near an edge are unlikely to be stopped, simply because there is not enough ballistic fabric surrounding the impact location [34, 35]. This appears to be the condition that lead to the perforations in this incident. The bullets that struck the armor engaged very little ballistic fabric, because they struck the armor panel at the extreme edge. There is no reasonable expectation that a conventional armor panel can perform satisfactorily when impacted in this region; therefore, the perforation of the armor at this location is not surprising.

3.2 Tampa Armor

About one month after the shooting incident, a representative of the Tampa Police Department visited NIST, bringing with him the incident body armor and an additional, similar armor. Several other representatives from NIJ and industry, including a representative of Second Chance Armor, Inc., were in attendance.

The armor was examined in a fume hood and detailed photographs were taken during the course of the examination. Initial inspection of the armor

Figure 3.7: Panama City Beach Incident Panel with Sample Material Extracted.

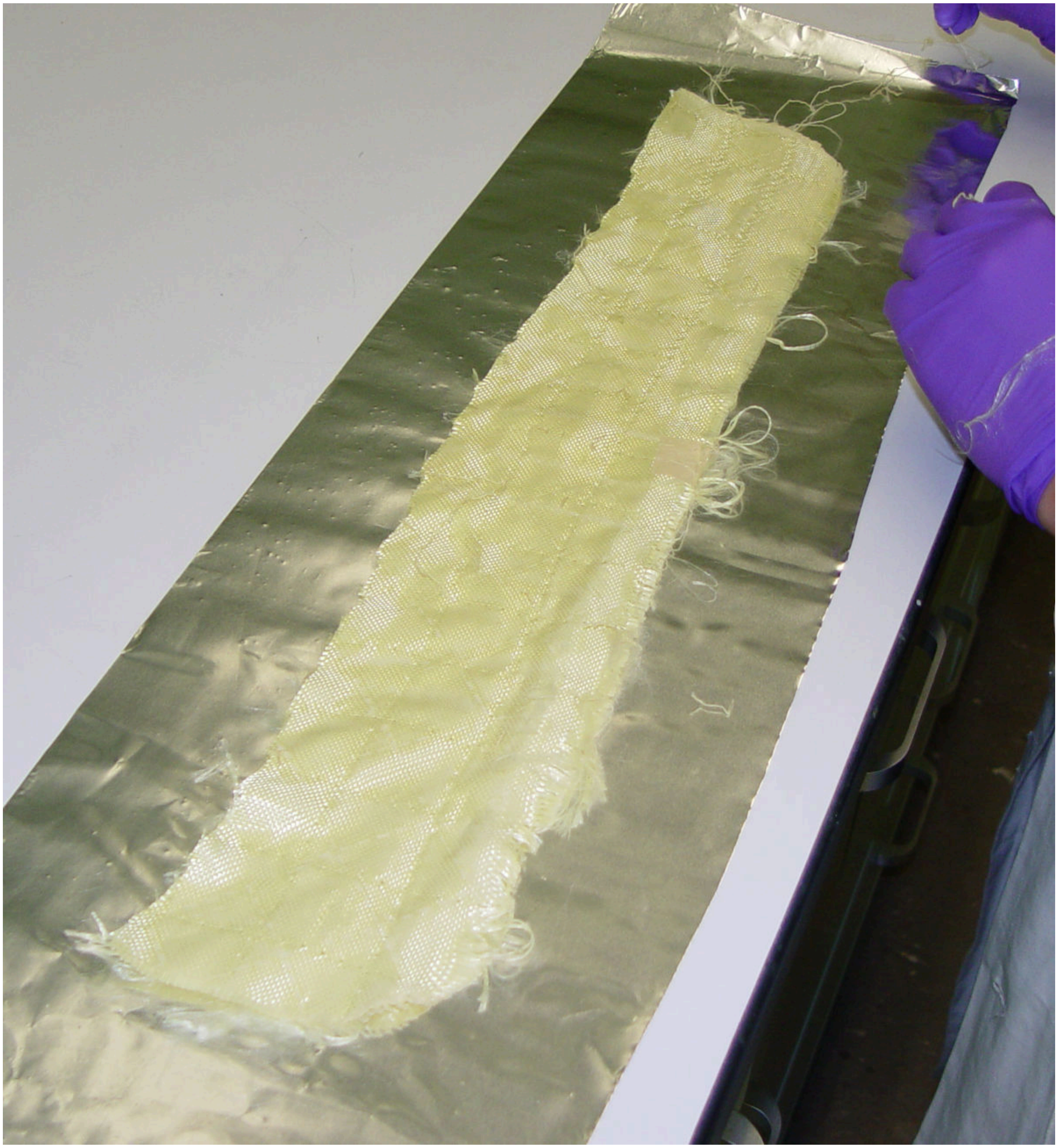


Figure 3.8: Example of Sample Material from Panama City Beach Armor.

Figure 3.9: Body Side of Tampa Incident Panel with Bullet Exit Hole on Left Edge.

indicated that the ballistic panel had not been cut open and that the interior ballistic-resistant materials did not appear to have been manipulated. The armor appeared to have been well preserved from the time of the incident.

A photograph of the ballistic panel, removed from its carrier, but still encased in the panel covering, is shown in Figure 3.9. The body side is facing up in this picture, so the bullet impact location is on the left side in the photograph. After this photograph was taken, the armor panel covering was cut open to remove the armor panel from the armor panel covering for further examination of the bullet impact location.

The ballistic panel consisted of 26 layers of plain-woven para-aramid fabric. The armor manufacturer reported that the material was Twaron, manufactured by Teijin Aramid [20]. The pick (yarn) count of the weave was measured to be approximately 8.7 by 9.4 yarns/cm (22 by 24 yarns/in). The fabric layers were held together by a great deal of stitching: layers 1 through 13 were stitched together with a 32 mm (1.25 in) diamond quilt pattern, and layers 14 through 26 were stitched together with a 32 mm (1.25 in) box quilt pattern. All quilt stitching appeared to use para-aramid threads. The 26 layers of the two quilted packs were fastened together with four full-length vertical stitches at the right and left sides, and two full-length vertical stitches at the center, for a total of 10 full-length vertical stitches. These construction details matched those that had been recorded when the armor model was certified to the NIJ standard [28].

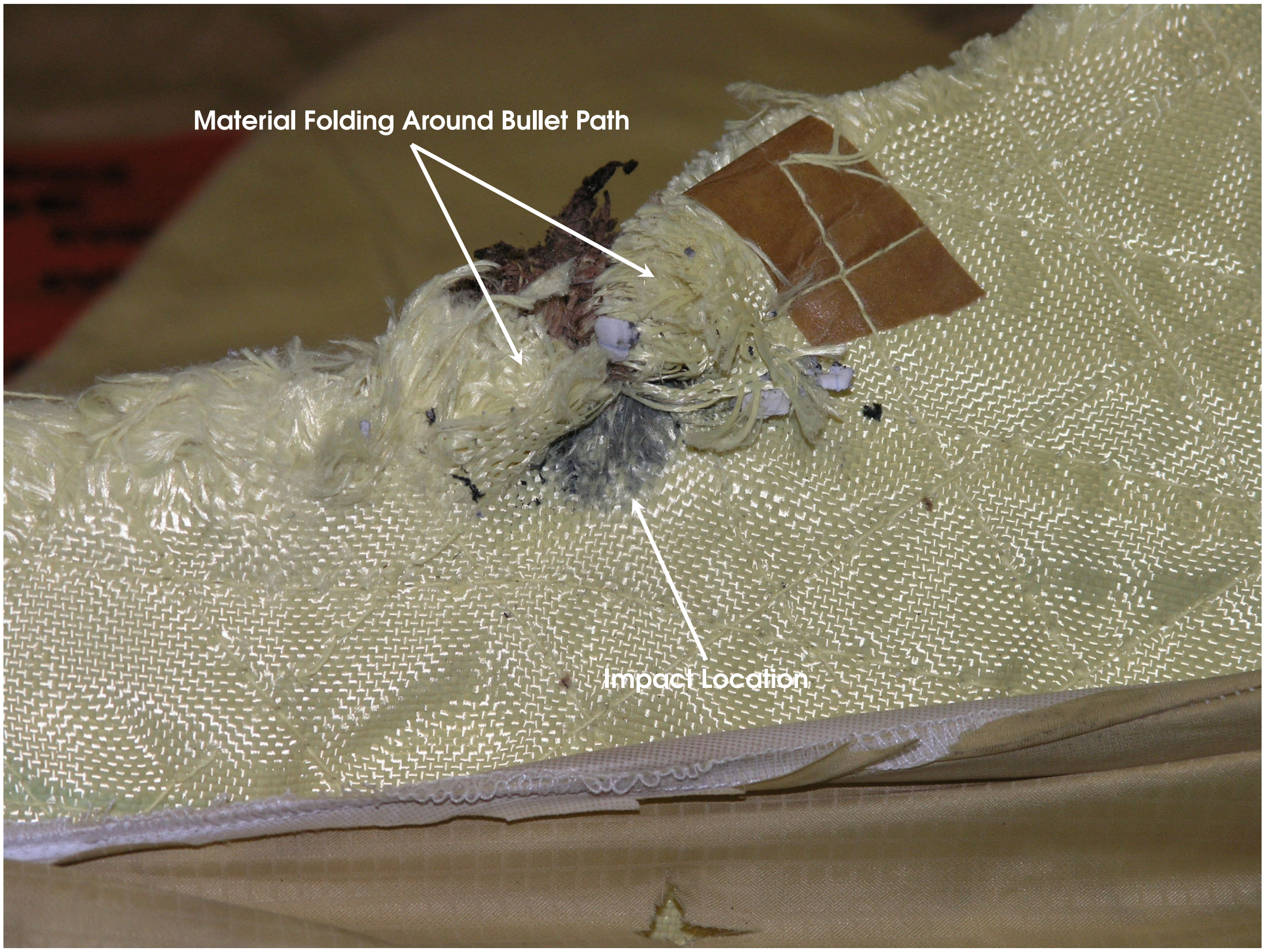


Figure 3.10: Strike Face of Ballistic Material Showing Bullet Path and Damage.

Close-up photographs of the bullet impact location on the strike face and the body side of the armor panel, with the panel cover removed, are shown in Figures 3.10 and 3.11. The body side does not indicate much about the bullet impact location, but the strike face shows that the ballistic-resistant material deformed inward while the material immediately above and below the bullet impact location deformed outward and folded around the impact site. The folds created in the armor panel over the bullet impact location are visible in the photograph (Figure 3.10). These folds create what appears to be a channel through the armor panel. This type of behavior has been observed in other armor testing with near-edge shots.

Figures 3.12 and 3.13 show the strike face (layer 1), with the ballistic-resistant material pulled flat to expose the bullet impact location. As shown in the photographs, only a small amount of woven material was available to stop or deflect the bullet at the bullet impact location. In Figure 3.13, the first layer of the ballistic-resistant material (the strike face) is separated from the underlying layers to expose the location where the bullet contacted the armor. Penetration into the first few layers is to be expected, and this type of damage is typical of

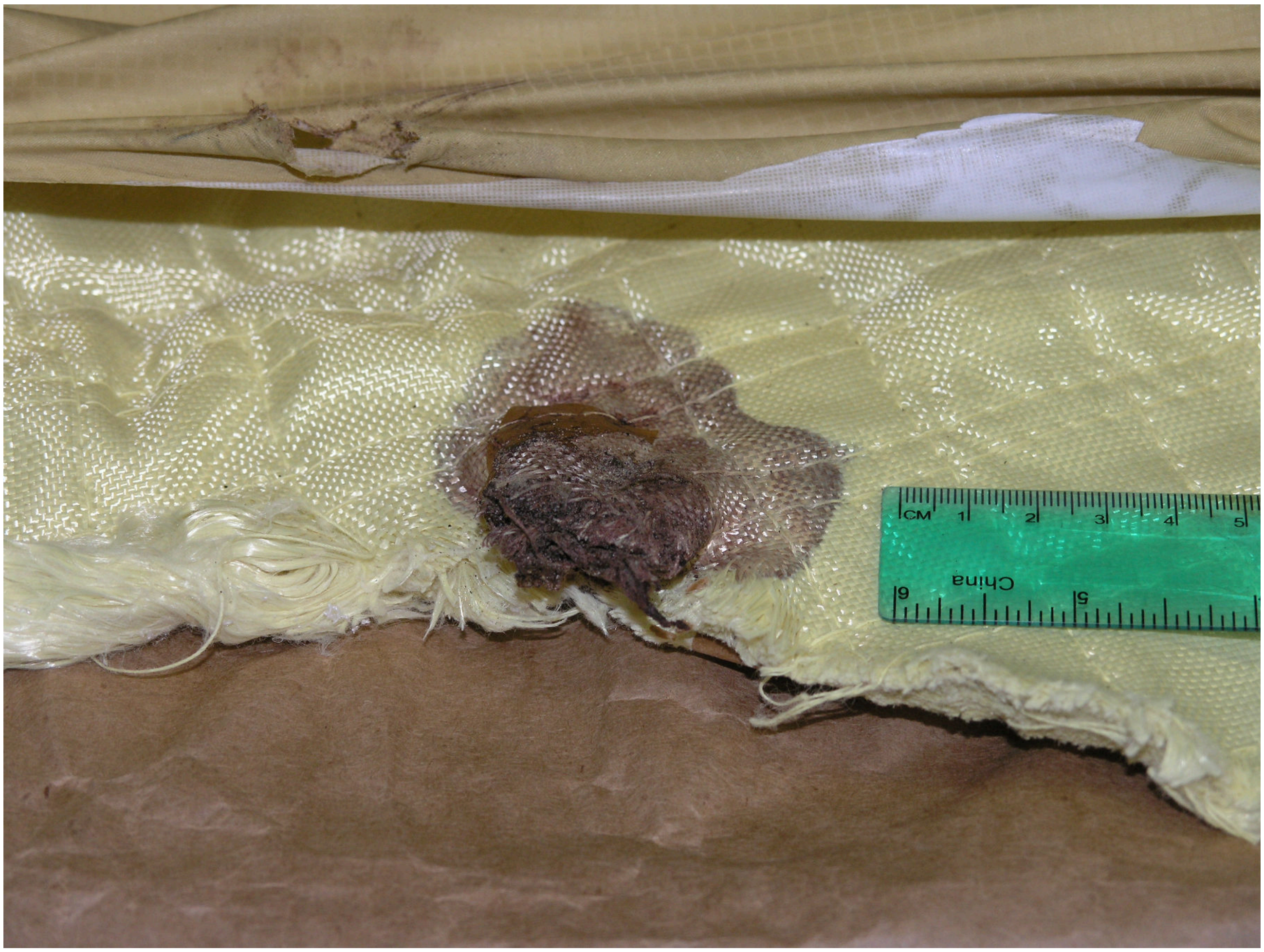


Figure 3.11: Body Side of Tampa Ballistic Material at Bullet Impact Location.

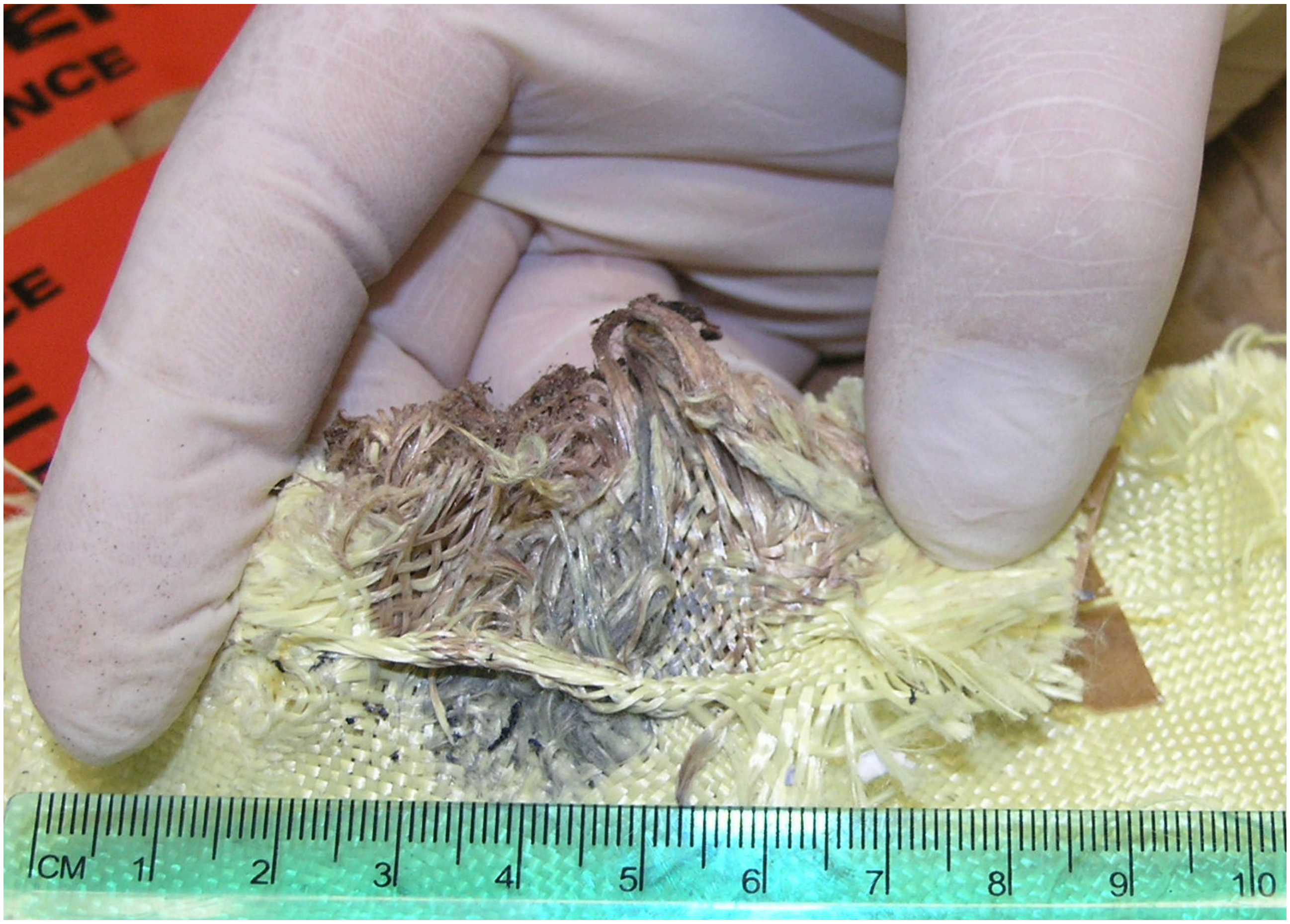


Figure 3.12: Incidence Location on Tampa Ballistic Material (Layer 1 on top).

bullet impacts during armor testing. Since the bullet was a jacketed soft point, the lead core is exposed on the nose of the bullet, which produces the blackened markings on the materials, indicating the bullet path.

During the examination of the armor, some quilt stitching was removed in order to examine the interior layers of the ballistic panel. The photograph in Figure 3.14 shows the second layer of the incident armor from the strike face side. Layer 1 is folded back to expose layer 2. In this and subsequent photographs where upper fabric layers are folded back, the edges of those upper layers can be seen under the transparent green scale. The arrow points to a distortion in the fabric that indicates where the bullet went through, although no yarns appear to have been broken by the bullet. This situation appears to be common in near-edge shots, where the edge of the armor panel buckles due to a lack of material to stop the bullet.

The next two photographs (Figures 3.15 and 3.16) show layers 3 and 4 of the incident armor, respectively. Layer 3 shows a small distortion in the weave where the bullet went through, but this is not visible in layer 4 (see arrows). The bullet appears to have slipped out of the edge of the armor around layer 2 or 3, wounding the officer.

The final photograph (Figure 3.17) of the incident armor shows layer 5.

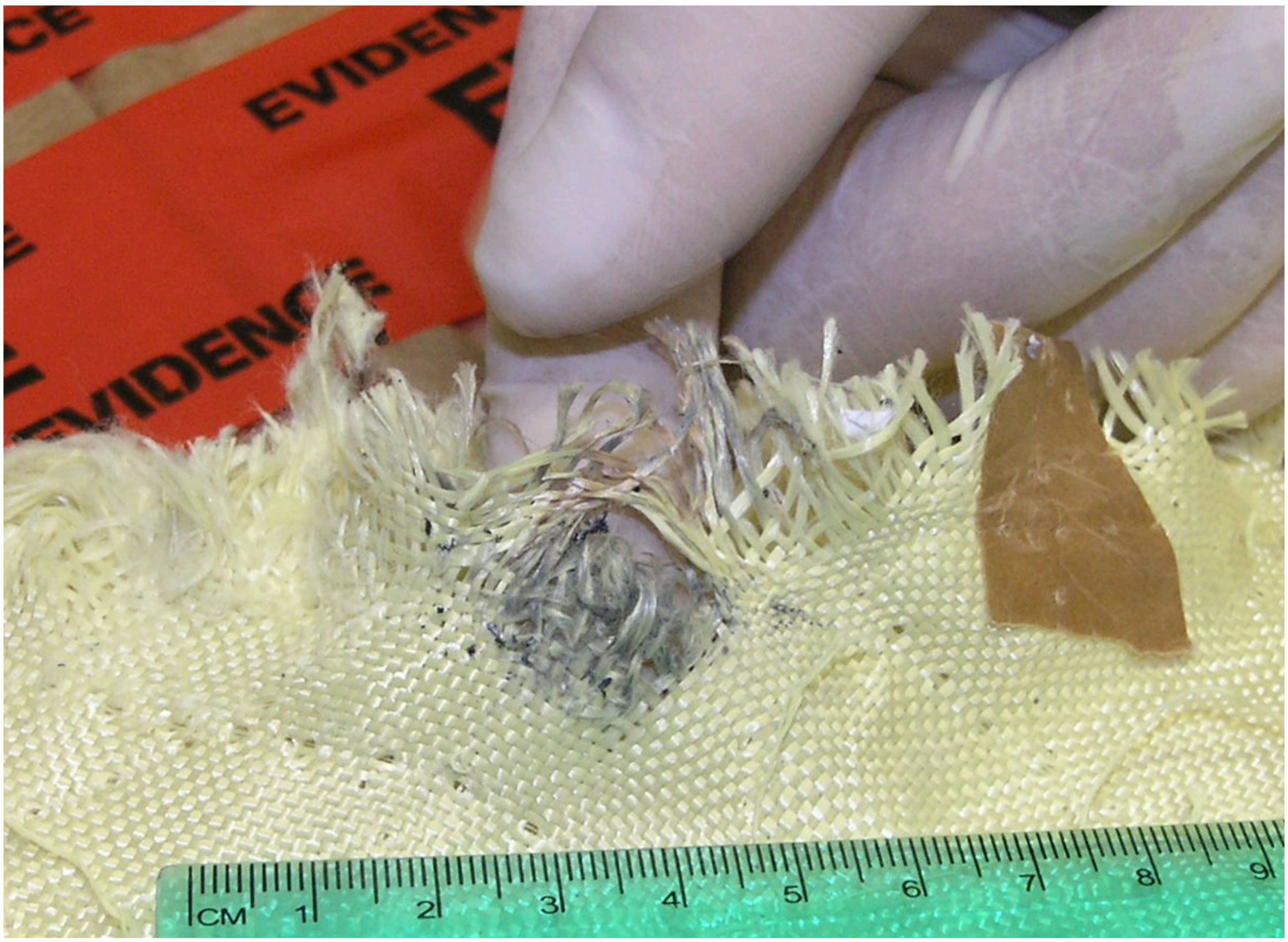


Figure 3.13: Incidence Location on Layer 1 of the Tampa Ballistic Material.

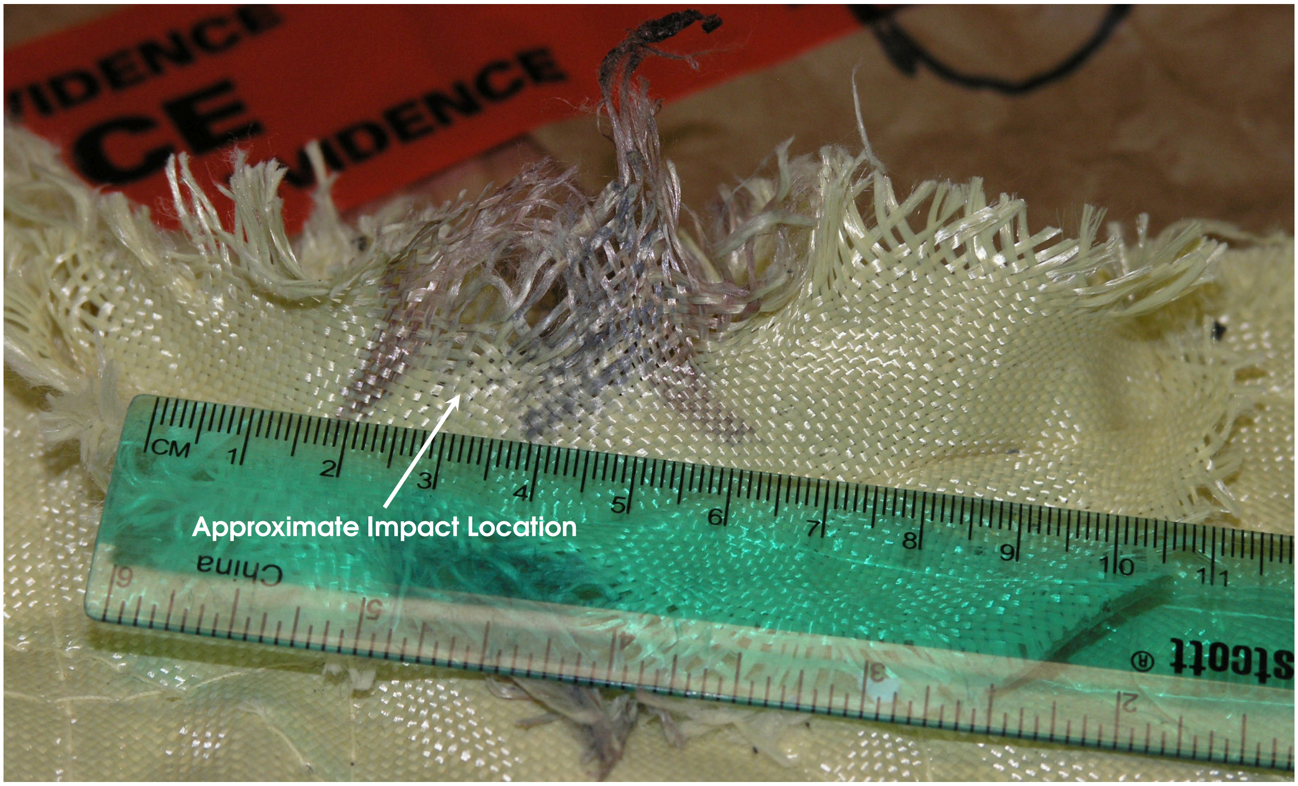


Figure 3.14: Incidence Location on Layer 2 of the Tampa Ballistic Material.

There appears to be little distortion of this layer, indicating that the bullet had likely exited through the edge of the armor panel before it reached this layer. From these observations, it appears that this near-edge, angled shot, simply slid out of the armor between layers, due to the angle and close proximity to the edge, without perforating or damaging most of the layers of ballistic-resistant material.

The visual examination also confirms, by the absence of singed fibers and powder residue, that neither a contact shot nor a near contact shot occurred in this incident. One press article reported that the attack occurred at "point blank" [7]; however, a Tampa Police Department representative reported that the officer stated the shot was fired from a distance of approximately 3 feet. This confirmation, and the lack of any contradictory physical evidence, indicates that this incident was not a *contact shot*, which can be more penetrative.

As described above and noted in some of the press articles [7, 5], the officer who was shot had carried a small spiral-bound notepad (top bound) in his left breast pocket. The bullet perforated the notepad prior to striking the body armor. A probe was inserted through the bullet hole in the notepad to estimate the angle of impact. As shown in the photograph in Figure 3.18, the bullet appears to have struck the notepad at an angle of approximately 30° from the perpendicular.

Body armor that was tested to NIJ Standard–0101.04 [18] was assessed for ballistic resistance to within 76.2 mm (3.0 in) of any edge, but most impacts at this distance to the edge were perpendicular to the surface of the armor panel

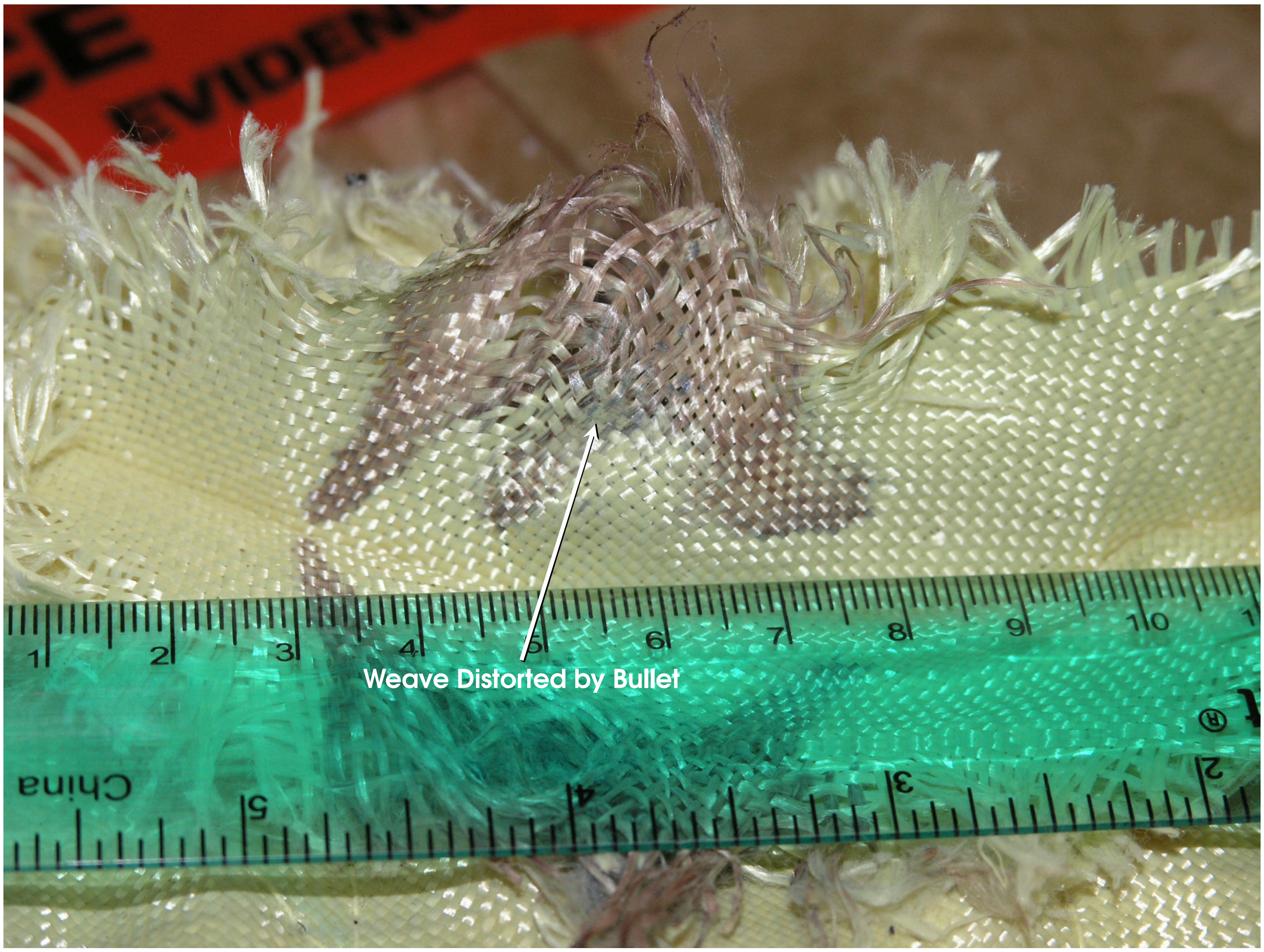


Figure 3.15: Incidence Location on Layer 3 of the Tampa Ballistic Material.

Figure 3.16: Incidence Location on Layer 4 of the Tampa Ballistic Material.

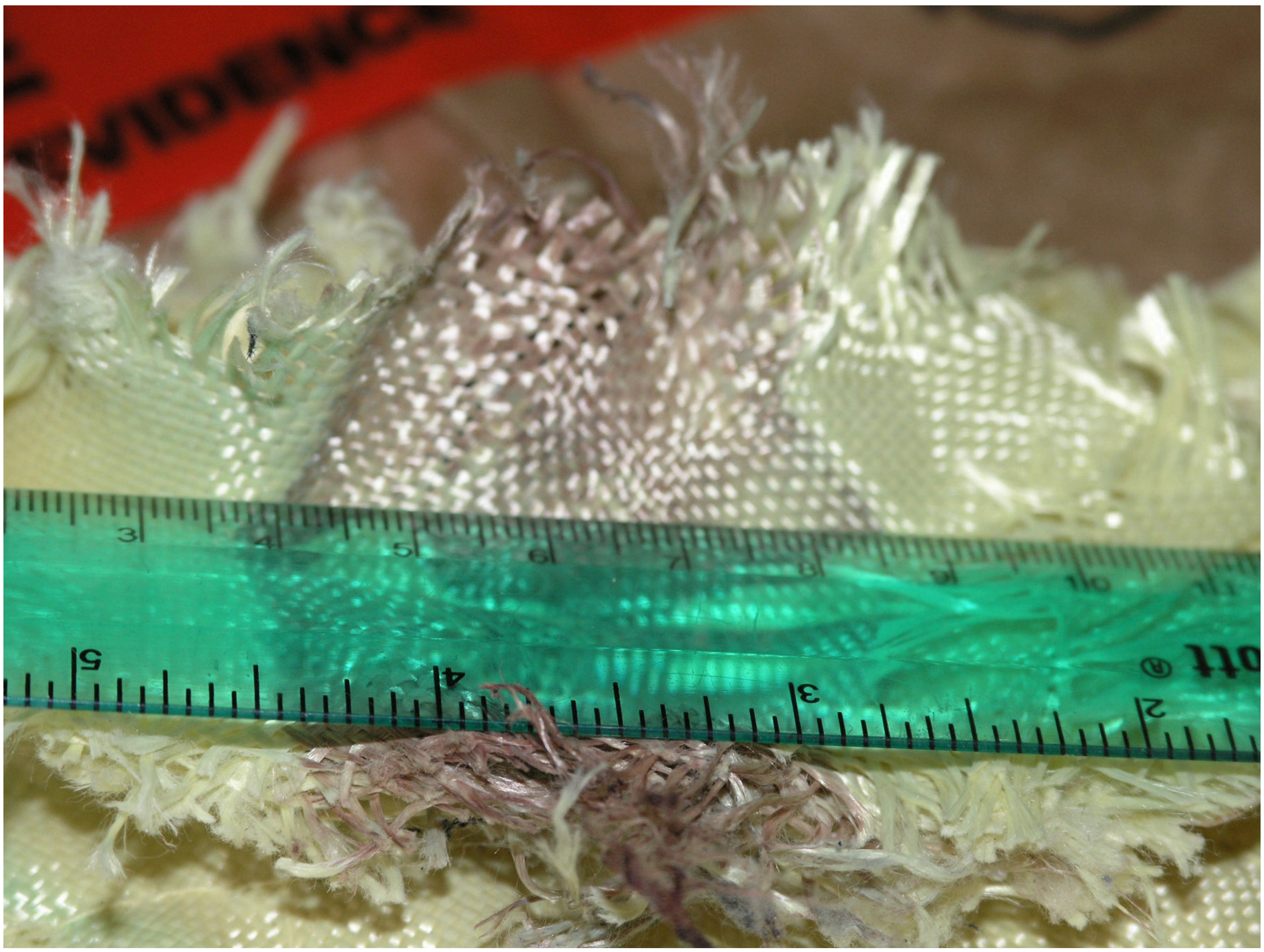


Figure 3.17: Incidence Location on Layer 5 of the Tampa Ballistic Material.

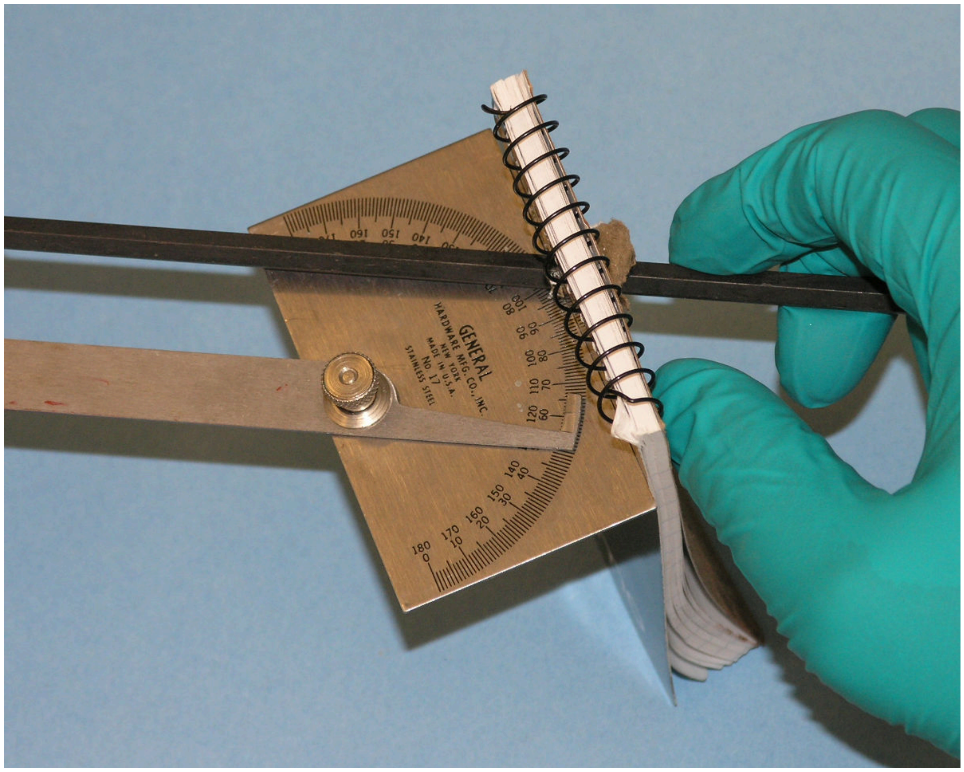


Figure 3.18: Estimation of Impact Angle from Tampa Officer's Notebook.

(0° angle according to standard convention for measuring the angle of incidence). The armor was also tested with angled shots at 30° from the perpendicular [18]; however, the angled shots are generally targeted at locations farther from the edge of the armor and they are always angled inward, away from the nearest edge.

4 Ballistic Testing

A variety of ballistic tests were performed to gain a better understanding of why the Tampa Police Department armor performed as it did, and to assess whether similar armors that were still in use could be expected to perform acceptably. No ballistic testing was performed as part of the Panama City Beach Police Department armor investigation.

The ballistic testing described in the following sections was performed for two primary purposes: first, to determine if the damage observed with the incident armor could be reproduced in the laboratory; and, second, to attempt to verify whether other Tampa Police Department armors were still capable of providing an acceptable level of ballistic protection. The ballistic testing included .357 Magnum bullets fired at either the estimated incident bullet speed or at the NIJ Standard–0101.04 test speed [18].

4.1 Tampa Armor

The Tampa Police Department provided two sets of body armor: the model 329 Monarch armor worn by the officer when he was shot, and a similar female armor model that was also from the 329 Monarch armor line. These armors were both tested at NIST, along with some additional armors of similar construction.

4.1.1 Testing with Near-Edge Impacts

The first step of the ballistic testing was to attempt to reproduce the observed damage, using a similar piece of armor, the same bullet type, a similar bullet speed, and a similar impact angle.

At the time this testing was performed, an estimate of the incident bullet speed was not yet available from Tampa Police Department. Instead, a fresh box of Magtech .357 Magnum 10.2 g (158 gr) SPSJ ammunition [30] was used, and cartridges were fired from three different revolvers in the NIST ballistic laboratory. The firearm involved in the shooting incident was not available; however, another revolver of the same model, Ruger Security-Six [31], was available, but with a longer barrel: 102 mm (4.0 in) instead of a 70 mm (2 ¾ in). In addition, two Smith and Wesson revolvers were available, both with shorter barrels: 89 mm (3 ½ in) and 64 mm (2 ½ in). Twelve cartridges were fired from each firearm, and the average bullet speed was found to be nearly proportional to the

Table 4.1: Test Firearms used to Estimate Incident Bullet Speed.

Firearm Manufacturer	Model	Barrel Length		Average Speed		Standard Deviation	
Ruger	Security-Six	102 mm	(4.0 in)	338.3 m/s	(1110 ft/s)	17.4 m/s	(57 ft/s)
Smith and Wesson	27-2	89 mm	(3.5 in)	310.6 m/s	(1019 ft/s)	14.6 m/s	(48 ft/s)
Smith and Wesson	19-3	64 mm	(2.5 in)	284.4 m/s	(933 ft/s)	14.3 m/s	(47 ft/s)

All firearms are .357 Magnum caliber revolvers.

All ammunition was Magtech .357 Magnum 10.2 g (158 gr) SJSP commercial cartridges. [30]

barrel length. The firearms and the average bullet speeds obtained are listed in Table 4.1. Based on these results, the speed of the bullet involved in the assault on the officer was estimated to be approximately 291 m/s (954 ft/s). For testing purposes, a target bullet speed of 290 m/s (950 ft/s) was selected.

During the armor testing, all cartridges were fired from a universal receiver, with a 101.6 mm (4.0 in), Sporting Arms and Ammunition Manufacturers' Institute (SAAMI) standard .357 Magnum barrel [22]. To achieve the target bullet speed, cartridges were handloaded using Magtech .357 Magnum 10.2 g (158 gr) SJSP bullets, new Remington brass cartridge cases, and 0.70 g (10.8 gr) of Accurate Arms #7 smokeless propellant. With this propellant load, the average speed of the test bullets was 288 m/s (946 ft/s) with a standard deviation of 5.2 m/s (17 ft/s).

Additional armor specimens of the same model as the Tampa incident armor were not readily available, so a similar armor model was used. The selected armor panel was a Second Chance Body Armor, Inc., Monarch, model MON-II+T-LSC 791210. This armor was of similar construction to the Tampa Police Department armor, but it had two more layers of ballistic-resistant material. Since the armor models are not the same, only limited conclusions can be drawn from these test results, but the tests provide an indication of whether the response observed in the Tampa shooting incident might be typical of angled, near-edge shots.

Four test shots were fired at this armor, which was mounted on a clay block that had been prepared according to the requirements of NIJ Standard–0101.04 [18]. All four shots were targeted at locations 25.4 mm (1.0 in) from the edge of the armor. Two shots were fired perpendicular to the armor surface (0° angle of incidence), and two were fired at 30° angles from perpendicular. The 30° angle shots were intended to reproduce the incident shot; therefore, the shots were angled outward, away from the center of the armor, instead of inward as they would be angled during a standard test. The shot locations can be seen in the photograph in Figure 4.1, which shows the armor panel mounted on the clay block immediately after the fourth shot.

The first two shots were fired at the edge of the *wings*, the portion of the armor that wraps around the wearer's waist. Both of those shots were fired at 0° angles; the first at the left edge of the panel, the second at the right edge. Both bullets were successfully stopped, but the impacts produced backface signatures (BFS) of 48 mm and 58 mm, respectively, which exceeded the NIJ Standard–

Figure 4.1: Near-edge Impact Test Armor Mounted on Clay Block.

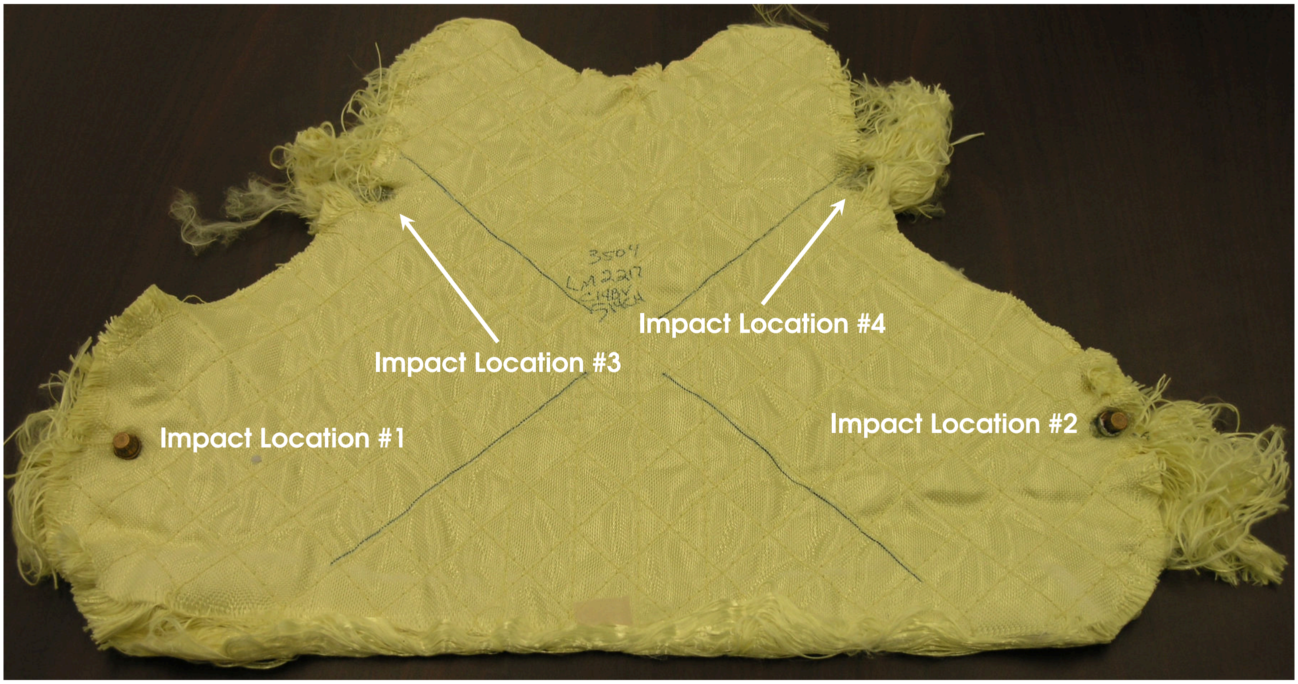


Figure 4.2: Ballistic Resistant Material from Near-edge Impact Test Armor.

0101.04 limit of 44 mm [18]. The ballistic panel, after completion of all four shots, is shown with the cover removed in the photograph in Figure 4.2. The two bullets from shots 1 and 2 are visible, having been captured by the first few layers of the ballistic-resistant material. The excessive BFS results are not surprising, because BFS tend to increase as the distance to the nearest edge of the ballistic-resistant material decreases. Prior research has proposed that impacts nearer to the edge engage less of the mass of the ballistic-resistant material, which, due to the conservation of momentum, results in a greater kinetic energy in the armor immediately after impact [36]. This larger initial kinetic energy translates to greater armor deformation and deeper indentations in the clay backing material. Since both of the impact locations were at approximately one-third the minimum shot-to-edge distance specified in the NIJ Standard–0101.04 test [18], it is not reasonable to expect that the armor would meet the standard performance requirements at these locations.

While the limited prior research and observations of test results both provide evidence that BFS depths will increase as the distance to the nearest edge decreases, there is a need for further research to provide a better understanding of how the armor responds during near-edge impacts and how the BFS depth is influenced by the proximity to the edge.

The third and fourth shots were fired at the left and right edges of the chest area of the panel, at locations that were similar to the location of the incident shot, and at an angle of 30°. Both bullets damaged the outer layers of the armor, caused the ballistic-resistant material to fold over into the BFS cavity, and exited the armor into the clay without perforating the back layers. The fourth shot, in particular, appeared to do little damage to the material, primarily bending back the panel. The damaged caused by both bullets is visible in the photograph in Figure 4.2, while a close-up of the fourth impact location can be seen in the photograph in Figure 4.3.

Although the BFS of the two 0° shots exceeded the BFS limit of 44 mm, and the two 30° shots slid out of the armor, the performance of this used armor is not surprising. This armor model, like most concealable body armors, was

Figure 4.3: Shot Location 4 on Near-edge Impact Test Armor.

not designed to stop shots close to the edge; moreover, for any soft body armor, reliably stopping a shot that strikes close to an edge while angled toward that edge will be considerably more difficult than stopping perpendicular impacts that occur toward the center of the armor. Since the tested armor model was not the same model as the Tampa Police Department armor, only limited conclusions about the incident armor performance can be drawn from these test results. The test results, however, do provide an indication that the response observed in the incident body armor may be typical of angled, near-edge shots.

4.1.2 Testing of Incident Armor Front Panel

Further testing was performed using the incident armor and an additional, similar armor from Tampa Police Department. The purpose of these tests was to determine if the angle of impact was critical to the observed response, and if the armor model was still capable of providing an acceptable level of protection. The first step was to test the incident armor with near-edge shots to determine if the angle was critical to the response. Then the same panel was subjected to a limited number of shots with the Magtech bullet at the estimated incident speed, but at standard test distances from the edges, for the purpose of assessing whether the armor could reliably stop such bullets. The back panel was tested with a ballistic limit test to determine if the response had significantly changed from the baseline ballistic limit estimated as part of the original NIJ Standard–0101.04 [18] compliance test. Finally, a limited penetration and backface signature (P-BFS) test series was performed on a similar armor panel to determine if the Tampa Police Department armors of this model would still meet the NIJ performance requirements.

Before these tests were performed, the Tampa Police Department reported that they had tested spare Magtech cartridges, which were recovered from the suspect's vehicle, in the revolver used in the assault on the officer and determined that the estimated bullet speed was 344 m/s (1130 ft/s). This speed is 54 m/s (176 ft/s) higher than the value estimated based on the measured speeds from other .357 Magnum revolvers, as reported in Section 4.1.1 and Table 4.1. The difference between the speed measured from the incident firearm and that estimated in the NIST laboratory may have been due to different propellant loads between ammunition lots, or due to different conditions of the firearms. The reason for this difference was not investigated, but the Tampa Police Department estimate for the speed of the bullet involved in the assault on the officer was used for all further testing. To achieve the new target bullet speed, the hand load was adjusted to 0.82 g (12.6 gr) of Accurate Arms #7 powder, with Remington cartridge cases and Magtech .357 Magnum, 10.2 g (158 gr) SPSJ bullets. This configuration achieved an average speed of 354 m/s (1160 ft/sec) with a standard deviation of 13.6 m/s (44.6 ft/s).

4.1.2.1 Influence of Shot Angle

To assess whether the shot angle (angle of incidence) was critical to how the armor performed during the incident, two shots were fired at near-edge locations on the front armor panel of the incident armor. Both shots were fired perpendicular to the armor (0° angle). The first was fired at a location on the upper right of the armor panel, essentially a mirror image of the shot that wounded the officer, but not angled outward. The second was fired at a location near the edge of the right wing of the armor. These shot locations can be seen in the photograph in Figure 4.4

The first bullet impacted the armor on target, approximately 25 mm to 32 mm (1.0 in to 1.3 in) from the edge of the panel. The armor successfully stopped this impact, which produced 45 mm (1.77 in) BFS. The photographs in Figures 4.5 and 4.6 show where the armor was impacted by the bullet, labeled as "1st Edge Shot", and the resulting damage to the body side of the armor panel. While this BFS exceeds the limit in the NIJ standard, as noted above, the standard test does not require impacts this close to the edge of the armor, and the depth of BFS indentations tend to increase significantly when the shot-to-edge distance is reduced.

The second bullet impacted the armor closer to the edge, approximately 19 mm (0.75 in) from the edge. The bullet damaged the first few layers of the ballistic-resistant material, before the edge of the armor collapsed and the bullet exited through the side of the armor. A careful examination of the damage showed that less than seven layers were damaged, and that the mode of damage appeared to be similar to the shot that wounded the officer. This impact location was closer to the edge of the armor than either the prior test bullet impact location or the incident bullet impact location; moreover, this impact location, near the edge of the right wing, was in an area where there is minimal surrounding material to prevent the edge of the armor from folding over. Again, the location where the second bullet struck the ballistic panel, labeled as "2nd Edge Shot", and the damage to the body side of the ballistic panel can be seen in Figures 4.5 and 4.6.

These two test shots cannot conclusively prove that the armor's response to the shot that wounded the officer was due entirely to the angle of the shot or its proximity to the edge, but they do provide an indication that these likely were significant factors influencing the response. The incident armor would have been more likely to stop and capture the bullet if the incident shot had either struck perpendicular to the armor, struck farther from the nearest edge, or both.

4.1.2.2 Verification of Performance

The next step of the testing was intended to determine if the front panel of the incident armor was capable of reliably stopping threats similar to the incident shot when the point of impact was consistent with the locations normally tested during the NIJ standard tests. Since the incident armor panel was smaller than the standard test specimen size and three bullet impacts had already damaged the edges of the panel, the testing was limited to three additional impacts. These shots were placed at approximately the #1, #4, and #6 locations described in NIJ Standard–0101.04 [18]. These locations correspond to the center of the upper chest, the right side of the lower chest, and the left center of the abdomen, respectively. These target locations can be seen in the photograph in Figure 4.4, where they are labeled "3" through "5" (indicated as the 1st through 3rd BFS shots). All shots were placed at least three inches from the edge of the armor

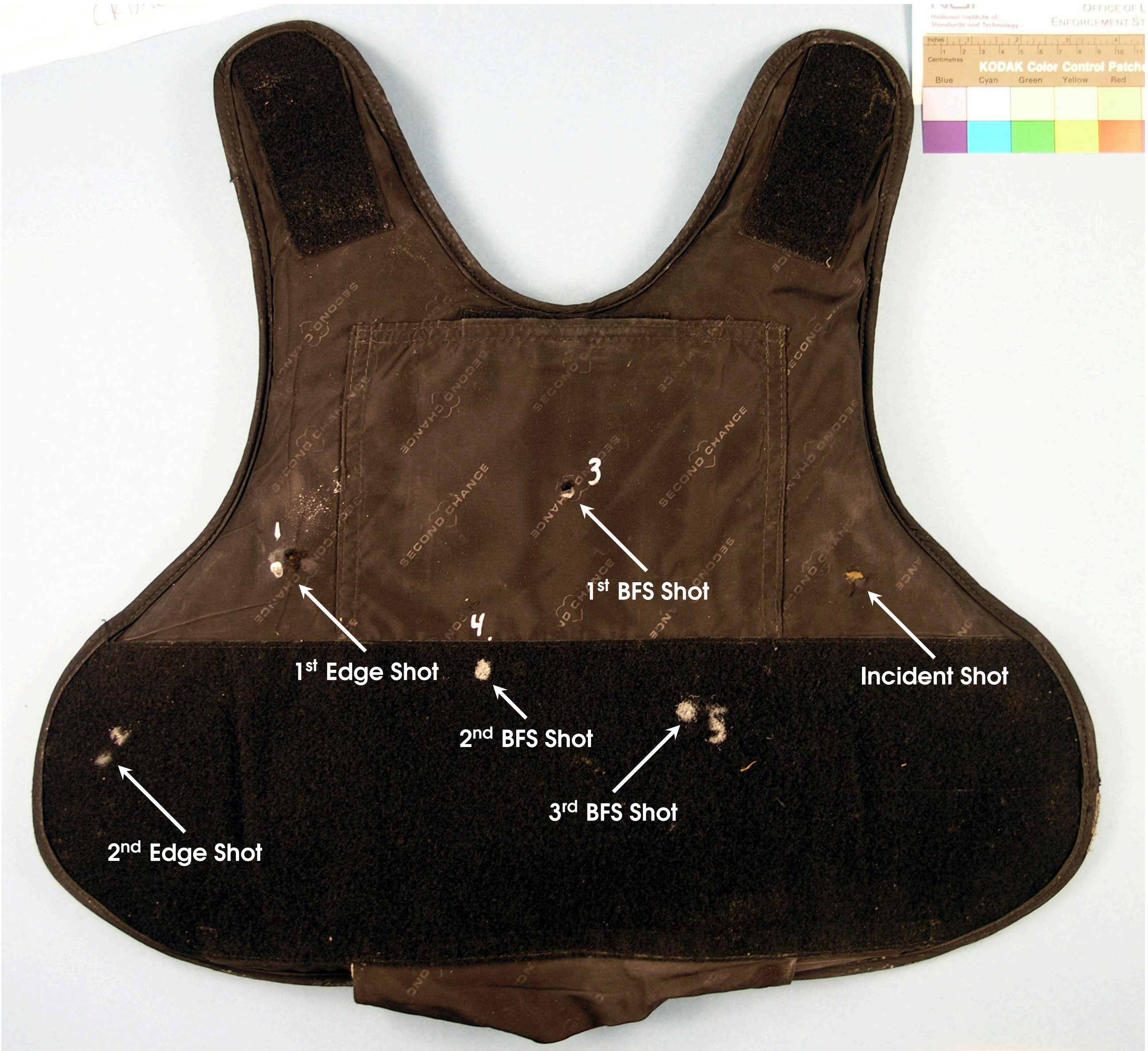


Figure 4.4: Tampa Incident Armor, Strike Face, Post Testing.

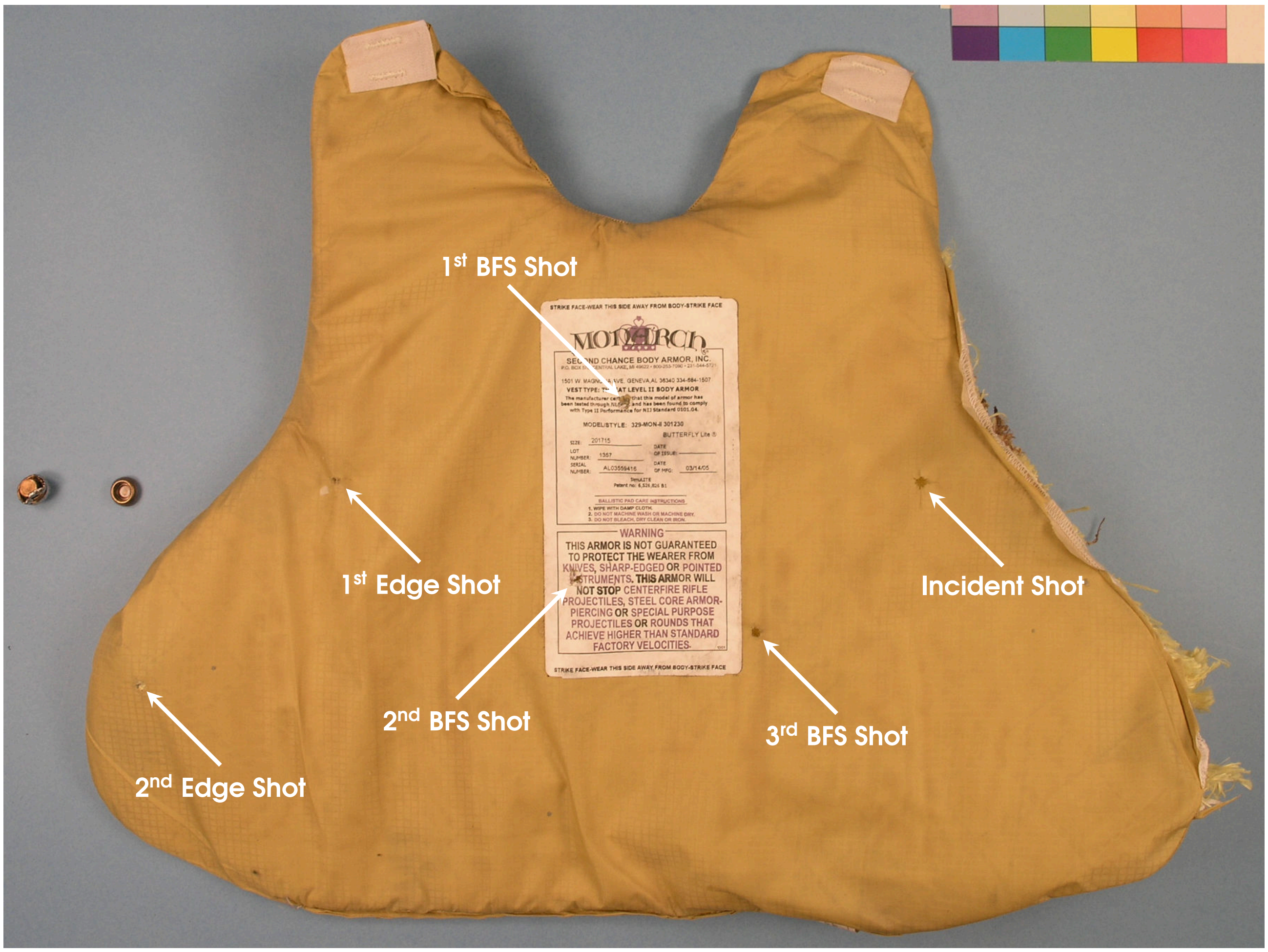


Figure 4.5: Tampa Incident Panel, Strike Face, Post Testing.

Figure 4.6: Tampa Incident Panel, Body Side, Post Testing.

panel, and at least two inches from all other shots. The shot placed at the #4 location (2^{nd} BFS Shot) was fired at a 30° angle toward the center of the armor. All cartridges consisted of Magtech .357 Magnum, 10.2 g (158 gr) SPSJ bullets hand loaded as described in Section 4.1.2, above, to produce speeds similar to what the Tampa Police Department crime laboratory reported.

The armor successfully stopped all three bullets. As listed in Table 4.2, the depth of the BFS indentations were measured for the two 0° angle shots, and they were 45 mm and 42 mm, respectively. These results imply that the armor was capable of safely stopping threats such as the one fired at the officer, provided that the bullet impacted the armor away from the edges; however, there is a limit on what can be confidently stated about these results.

The individual shots of a ballistic test series, such as the one described here and the P-BFS test series described in NIJ Standard–0101.04 [18], can be considered to be Bernoulli trials [37], and a complete test series can then be considered to be a Bernoulli experiment. The results of such testing can then be modeled using the binomial distribution [37, 38], and the *binomial proportion confidence interval* can be used to assess the quality of the estimated mean probability, and to estimate the range of values that can be expected to include the actual mean probability of a single shot perforating the armor. Since this testing is intended to assure the safety of the armor, the one-sided, lower confidence limit represents the lowest probability that can be expected to include the actual mean probability of a perforation at a selected confidence level. In general, there are a variety of methods that can be used to estimate the confidence limits [39, 40, 41], but for safety critical applications, such as this, the Clopper-Pearson, or *exact*, method [39, 38] is appropriate, because it uses the binomial distribution as the basis of the estimation and the resulting estimated limits are conservative.

Using this approach, the estimated mean probability of a single shot being stopped is 100 %, based on three out of three shots stopped during the ballistic test; however, by the exact method, the one-sided, lower confidence limit is estimated to be 36.8 % with 95 % confidence, or 68.2 % with 68.3 % confidence. In other words, these limited test results provide 95 % confidence that the true probability of the armor stopping a single shot at the test speed may be as high as 100 % or as low as 36.8 %. Significant additional testing would be necessary to improve this estimate.

For comparison, the NIJ Standard–0101.04 [18] certification test for soft armor required that the test items stop 24 shots with each of two types of test bullet. The results for a single bullet type (24 stops in 24 shots) corresponds to a one-sided, lower confidence limit of 88.3 % with 95 % confidence. If the results with both bullet types, 48 stops in 48 shots, are combined, the estimated one-sided, lower confidence limit is 94.0 % with 95 % confidence.

The results from testing three shots on a single armor panel do not provide nearly the same level of confidence in the armor performance as a full compliance test; however, with the limited materials available for testing there was no practical way to reach the same probabilities and levels of confidence as the compliance test. Based on these limited results, there was no evidence that the armor was unsafe to use.

As described above, the Tampa Police Department provided a spare armor

Table 4.2: Summary of P-BFS Test Results.

Shot	Location	Bullet	Speed	Result	Notes
Incident Armor Front Panel					
1	Edge of upper right chest	Magtech .357 Mag 10.2 g (158 gr) SPSJ	332 m/s (1089 ft/s)	Stop (45 mm BFS)	Impact 32 mm (1.25 in) from edge
2	Edge of right wing	Magtech .357 Mag 10.2 g (158 gr) SPSJ	368 m/s (1206 ft/s)	Edge collapsed, bullet slid off edge	Impact 19 mm (0.75 in) from edge
3	NIJ Shot 1	Magtech .357 Mag 10.2 g (158 gr) SPSJ	338 m/s (1109 ft/s)	Stop (45 mm BFS)	
4	NIJ Shot 4	Magtech .357 Mag 10.2 g (158 gr) SPSJ	366 m/s (1201 ft/s)	Stop	Shot at 30° angle
5	NIJ Shot 6	Magtech .357 Mag 10.2 g (158 gr) SPSJ	358 m/s (1175 ft/s)	Stop (42 mm BFS)	
Spare Armor Front Panel					
Shot	**Location**	**Bullet**	**Speed**	**Result**	**Notes**
1	NIJ Shot 1	Remington .357 Mag 10.2 g (158 gr) JSP	422 m/s (1385 ft/s)	Stop (53 mm BFS)	Low bullet speed
2	NIJ Shot 2	Remington .357 Mag 10.2 g (158 gr) JSP	430 m/s (1411 ft/s)	Stop (45 mm BFS)	
3	NIJ Shot 5	Remington .357 Mag 10.2 g (158 gr) JSP	428 m/s (1404 ft/s)	Stop	Shot at 30° angle
4	NIJ Shot 3	Remington 9 mm Luger 8.0 g (124 gr) FMJ	357 m/s (1171 ft/s)	Stop (40 mm BFS)	Low bullet speed
5	NIJ Shot 4	Remington 9 mm Luger 8.0 g (124 gr) FMJ	366 m/s (1201 ft/s)	Stop	Shot at 30° angle
6	NIJ Shot 6	Remington 9 mm Luger 8.0 g (124 gr) FMJ	362 m/s (1188 ft/s)	Stop (35 mm BFS)	

of a similar age to the incident armor; however the two armors were not the same model. The spare armor that was provided was a Second Chance Body Armor model 329-MON-II FEM 306020. This model was a female variant that had similar construction to the incident armor, model 329-MON-II 301230. The two models were constructed with the same material and weave, and the stitch patterns of the back panels were identical. There were, however, some stitching variations in the front panel designs, with additional stitches added to the female variant.

The front panel of the spare armor was tested with an abbreviated version of the NIJ Standard–0101.04 [18] P-BFS test. During a complete compliance test of a Type II armor model to the requirements of NIJ Standard–0101.04, eight armor panels are tested, each with six shots from one of two test bullet types at a specified speed. Four panels are tested with one of the test bullet types and four are tested with the other. Since only a single armor panel was available for this test, three shots of each of the two bullet types were used to test the panel. The shot locations can be seen in the photograph in Figure 4.7.

The panel was first tested with three shots of the NIJ Standard–0101.04 Type II .357 Magnum test cartridge – a Remington 10.2 g (158 gr) JSP bullet with a measured speed of 436 m/s ± 9.1 m/s (1430 ft/s ± 30 ft/s). These shots were fired at the #1, #2, and #5 locations, as described in NIJ Standard–0101.04 [18]. As in the standard test, the shots at the #1 and #2 locations were fired perpendicular (0° angle) to the armor, while the shot at the #5 location was fired at a 30° angle. As listed in Table 4.2, the armor successfully stopped all three shots; however, the measured BFS depths of the perpendicular shots were 53 mm and 45 mm, respectively. The results of these shots can be viewed in the photographs in Figures 4.8 and 4.9.

The panel was then tested with three shots of the NIJ Standard–0101.04 Type II 9 mm Luger test cartridge – a Remington 8.0 g (124 gr) FMJ bullet with a measured speed of 367 m/s ± 9.1 m/s (1205 ft/s ± 30 ft/s). These shots were fired at the #3, #4, and #6 locations. The shots at the #3 and #6 locations were fired perpendicular (0° angle) to the armor, while the shot at the #4 location was fired at a 30° angle. The armor successfully stopped all three bullets, and the BFS depths of the perpendicular shots were 40 mm and 35 mm, respectively. Again, the results of these shots can be viewed in the photographs in Figures 4.8 and 4.9.

These results provide evidence, albeit with limited confidence, that the armor is still capable of stopping the NIJ standard threats. The two .357 Magnum BFS measurements of 53 mm and 45 mm would not be acceptable for an armor specimen being tested for compliance to NIJ Standard–0101.04 [18]; however, the spare Tampa Police Department armor panel had been worn for a considerable time and, most importantly, the size of the panel was significantly smaller than the standard test size. While BFS measurements that exceed the standard limit are not desirable, they are not unexpected when testing smaller armor panels.

4.1.3 Ballistic Limit Testing

Additional ballistic testing was undertaken to assess whether the armor ballistic performance had degraded significantly, and whether the armor appeared to have a sufficient safety margin. The back panel of the incident armor was tested with

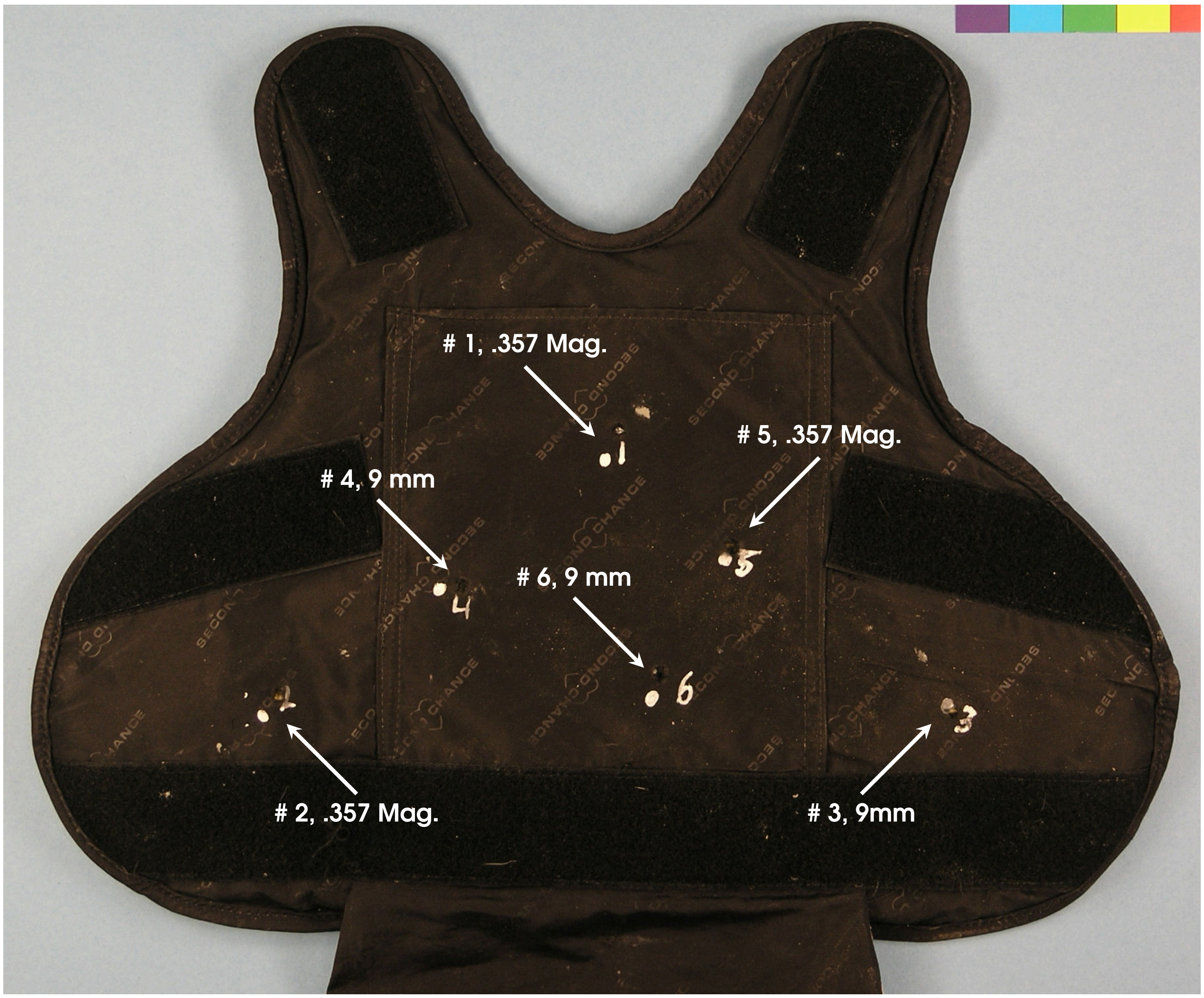


Figure 4.7: Tampa Spare Armor, Strike Face, Post Testing.

Figure 4.8: Tampa Spare Panel, Strike Face, Post Testing.

Figure 4.9: Tampa Spare Panel, Body Side, Post Testing.

a standard V_{50} ballistic limit test, to determine if the speed at which half of the shots with a particular bullet would perforate was sufficiently greater than the standard test speeds, and whether the V_{50} appeared to have changed significantly from the estimate obtained during the compliance test.

The V_{50} ballistic limit test is intended to subject body armor to unrealistically high bullet speeds in an attempt to induce armor failure by bullet perforation. Since the behavior depends on the bullet type, the NIJ Standard–0101.04 [18] required that the ballistic limit tests be conducted using 9 mm Luger 8.0 g (124 gr) FMJ bullets manufactured by Remington. By estimating the speed at which half of the bullets will perforate the armor, insight can be gained about whether the armor has a significant safety margin, and, when comparable test results on new armors are available, whether the ballistic resistance has changed significantly.

The V_{50} ballistic limit test on the back panel of the incident armor, shown in the photograph in Figure 4.10, was conducted according to the methods and requirements of NIJ Standard–0101.04 [18]. All cartridges were hand loaded using new Remington .357 Magnum cartridge cases, Accurate Arms #2 propellant, and Remington 9 mm Luger, 8.0 g (124 gr) FMJ bullets. The cartridges were fired out of a special universal receiver barrel that has a .357 Magnum chamber and a 254 mm (10 in) barrel with SAAMI standard 9 mm Luger rifling [22]. This configuration with the .357 Magnum chamber and 9 mm barrel allows the 9 mm bullets to be fired at much higher speeds than can normally be achieved with a standard 9 mm Luger cartridge, while maintaining the other standard flight characteristics for the bullet.

The V_{50} ballistic limit test consisted of twelve shots, listed in Table 4.3, ranging in speed from 480 m/s (1575 ft/s) to 522 m/s (1713 ft/s). Of these, the speeds of ten impacts (five stops and five perforations) were within 38 m/s (125 ft/s) of each other, between 489 m/s (1604 ft/s) and 522 m/s (1713 ft/s), and these ten impacts were used to calculate an estimated V_{50} value of 507 m/s (1663 ft/s) according to the requirements of NIJ Standard–0101.04 [18] and MIL–STD–662F [42]. The high stop speed was 506 m/s (1658 ft/s) and the low perforation speed was 502 m/s (1649 ft/s). A plot of the ballistic limit test series is shown in Figure 4.11.

The V_{50} ballistic limit test results were also analyzed by using the maximum likelihood method to fit the complete set of results to a logistic model [43, 44]. This analysis estimated the V_{50} to be 507 m/s (1662 ft/s). This method also allowed the goodness of the results to be estimated through an analysis of confidence intervals on the model fit. The 68.3 % confidence levels for the V_{50} were estimated to be 503 m/s (1651 ft/s) and 511 m/s (1677 ft/s), and these are shown in Figure 4.11. The twelve test shots were insufficient to allow the confidence intervals to be estimated at the 95 % level, which is to be expected, since the twelve shots represent a relatively small set of data for this type of analysis.

These V_{50} results compare favorably to the original V_{50} estimates obtained on new armor panels during NIJ Standard–0101.04 [18] compliance testing. The compliance test results estimated the front panel V_{50} to be 506 m/s (1661 ft/s) and the back panel V_{50} to be 498 m/s (1634 ft/s) [28]. These estimates were calculated using the MIL–STD–662F [42] method, as required by NIJ Standard–0101.04 [18]. The average compliance V_{50} was therefore 502 m/s (1648 ft/s),

Figure 4.10: Incident Armor Back Panel used for Ballistic Limit Test.

Table 4.3: Summary of Ballistic Limit Test Results.

Incident Armor Back Panel

Shot Number	Charge Weight		Measured Speed		Result	Used for V_{50} Estimate
1	0.60 g	(9.2 gr)	480 m/s	(1575 ft/s)	Stop	No
2	0.64 g	(9.9 gr)	512 m/s	(1680 ft/s)	Perforation	Yes
3	0.60 g	(9.3 gr)	489 m/s	(1604 ft/s)	Stop	Yes
4	0.63 g	(9.7 gr)	502 m/s	(1649 ft/s)	Perforation	Yes
5	0.60 g	(9.2 gr)	481 m/s	(1578 ft/s)	Stop	No
6	0.62 g	(9.5 gr)	496 m/s	(1627 ft/s)	Stop	Yes
7	0.64 g	(9.9 gr)	514 m/s	(1686 ft/s)	Perforation	Yes
8	0.62 g	(9.6 gr)	502 m/s	(1647 ft/s)	Stop	Yes
9	0.65 g	(10.1 gr)	520 m/s	(1706 ft/s)	Perforation	Yes
10	0.63 g	(9.7 gr)	506 m/s	(1658 ft/s)	Stop	Yes
11	0.66 g	(10.2 gr)	522 m/s	(1713 ft/s)	Perforation	Yes
12	0.64 g	(9.8 gr)	506 m/s	(1658 ft/s)	Stop	Yes
		Estimated V_{50}:	507 m/s	(1663 ft/s)		

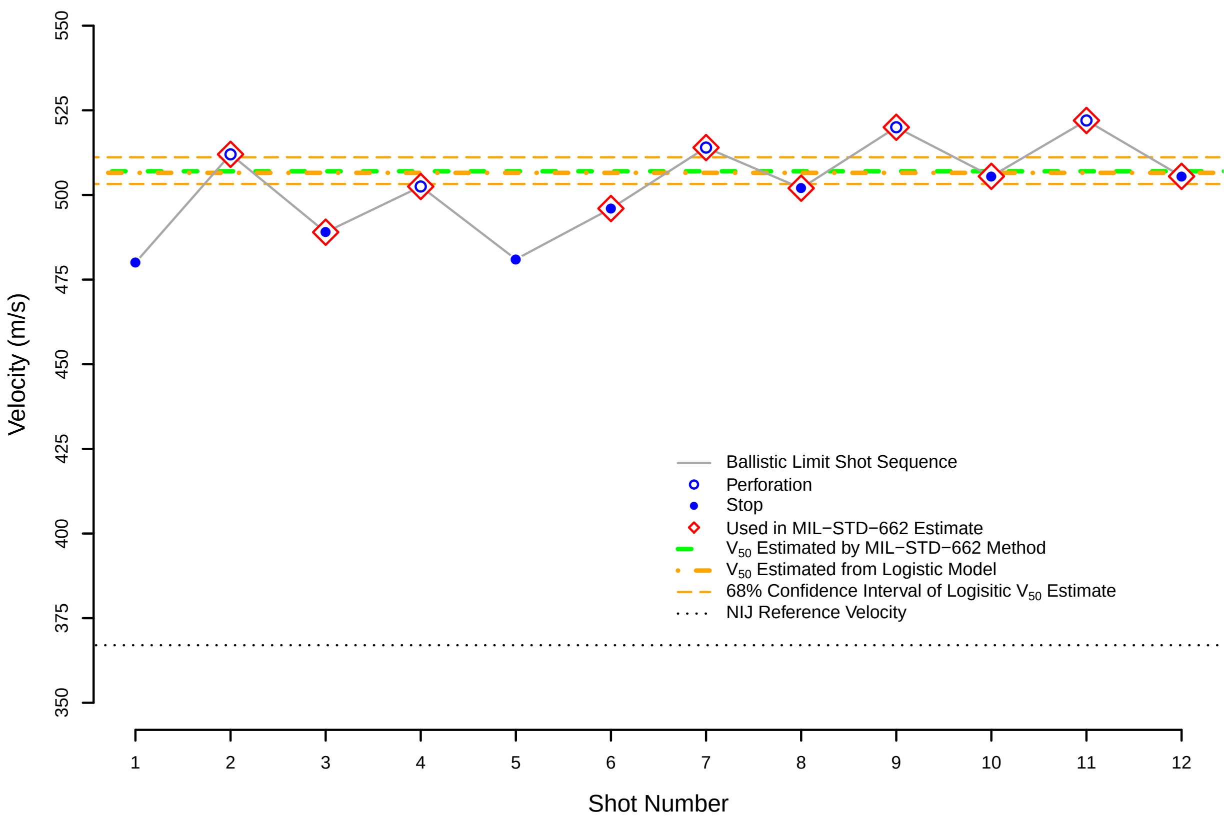


Figure 4.11: Ballistic Limit Shot Sequence and Test Results.

which is slightly less than the estimated V_{50} of 507 m/s (1663 ft/s) for the incident armor back panel. This result provides evidence that the ballistic resistance of the incident armor had not degraded while in use.

5 Measurement of Material Properties

Past research at NIST [12, 13, 45, 46, 47] identified several analytical techniques that were particularly effective for assessing the degradation of ballistic-resistant materials, including tensile testing of yarns, dynamic mechanical thermal analysis (DMTA) of fibers, confocal microscopy, and Fourier transform infrared spectroscopy (FTIR). These techniques have all shown promise for use in characterizing chemical and mechanical degradation of high-strength fabric materials, and were used extensively in the investigation into the issues with PBO body armor [9, 10, 11]. All of these techniques require the removal of samples of the ballistic-resistant fabric from the body armor panel.

Tensile testing is performed to determine the amount of stress required to break the yarns that make up the ballistic-resistant material. A decrease in the amount of stress required to break a yarn indicates a loss of strength. Entire yarns may be tested in a universal testing machine (UTM), or single fibers may be tested using a DMTA in transient mode.

The yarn tests reported herein were performed in accordance with ASTM D2256-02, *Standard Test Method for Tensile Properties of Yarn by the Single Strand Method* [48], using an Instron Model 4482 test frame equipped with a 500 N (110 lb) capacity load cell, and pneumatic yarn and cord grips. The grip jaw separation was 80 mm (3.1 in), giving a gage length of 254 mm (10 in), and the cross-head speed was 23 mm/min (0.9 in/min).

The single fiber tests were performed using a TA Instruments RSA III, a DMTA equipped with transient testing capability. All specimens were tested in tension mode using a 25 mm gage length, a 20 mN to 29 mN pretension force, and a constant extension rate of 0.01 mm/s. Using this method, the standard uncertainty of the measured tensile strengths is typically $\pm$ 9 %.

Confocal microscopy is a type of microscopy that uses lasers to look beneath the surface of a fiber to provide a three dimensional picture of the fiber. By moving the focal plane in the z-direction, a series of two dimensional images (optical slices) are obtained. These images are then digitally stacked to obtain a three dimensional image. These pictures can be used to look for physical signs of degradation or wear such as increases in surface roughness and pitting. The confocal microscopy was performed using a Zeiss Model LSM510 reflection laser scanning confocal microscope (LSCM). The incident laser wavelength is 543 nm, and the z-direction step size was 0.1 μm using a 150x objective. The confocal microscopy images presented are two dimensional projections of the three

Table 5.1: Tensile Testing Results for the Panama City Beach Incident Armor.

Layer Designation	Mean Strain at Break (%)	Standard Deviation (%)	Standard Error of the Mean (%)	Mean Stress at Break (GPa)	Standard Deviation (GPa)	Standard Error of the Mean (GPa)
Woven Kevlar 29	1.16	0.43	0.19	1.678	0.604	0.270
Layer 1, strike face	1.44	0.41	0.18	2.091	0.697	0.312
Layer 6	0.59	0.40	0.16	0.829	0.578	0.236
Layer 11	1.03	0.47	0.21	1.494	0.757	0.339
Layer 12	0.72	0.52	0.21	1.024	0.830	0.339
Layer 17	1.01	0.24	0.12	1.509	0.435	0.217
Layer 22, body side	1.27	0.27	0.13	1.928	0.558	0.279

dimensional images.

FTIR spectroscopy can be used to determine whether or not the chemical structure of the ballistic-resistant material has changed. Some changes in the chemical structure of the material correlate to strength loss, and can be an early warning sign of degradation. The FTIR spectroscopy was carried out using a Nicolet Nexus FTIR, which was equipped with a mercury-cadmium-telluride (MCT) detector and a SensIR Durascope attenuated total reflectance (ATR) accessory with a dry air purge. Consistent pressure on the samples was applied using the force monitor on the Durascope. FTIR spectra were recorded in the spectral range between 4000 cm^{-1} and 700 cm^{-1} at three different locations on each yarn, and were averaged over 128 scans. Spectral analysis, including subtraction, was performed using a custom software program developed at NIST that is designed to catalog and analyze multiple spectra.

5.1 Panama City Beach Armor

As described in Section 3.1, material samples were extracted from the Panama City Beach incident armor. Yarn and fibers from these samples were then analyzed using DMTA and FTIR analysis.

Single fibers were separated from the yarns, and tensile testing was performed using a DMTA. Up to ten fibers from each of layers 1, 6, 11, 12, 17, and 22, as described in Section 3.1, were tested to determine fiber breaking strength. The exact composition of the ballistic-resistant material used in the incident body armor is not known; however the FTIR analysis and construction details provided by the NIJ CTP database indicate that the material is a para-aramid. All specimens were compared to samples taken from woven DuPont Kevlar 29 fabric. It is not known if the para-aramid material in the incident armor was Kevlar or Twaron. These results are presented in Table 5.1.

As indicated by the results shown in Table 5.1, some layers of the incident armor had lower average strain at break and lower average breaking stress than the woven Kevlar 29 sample; however, when the standard deviations and the sample sizes are taken in consideration, there does not appear to be significant differences between them. The mean stress at break of the fibers sampled from two layers were greater than that of the woven Kevlar 29, and only the fibers

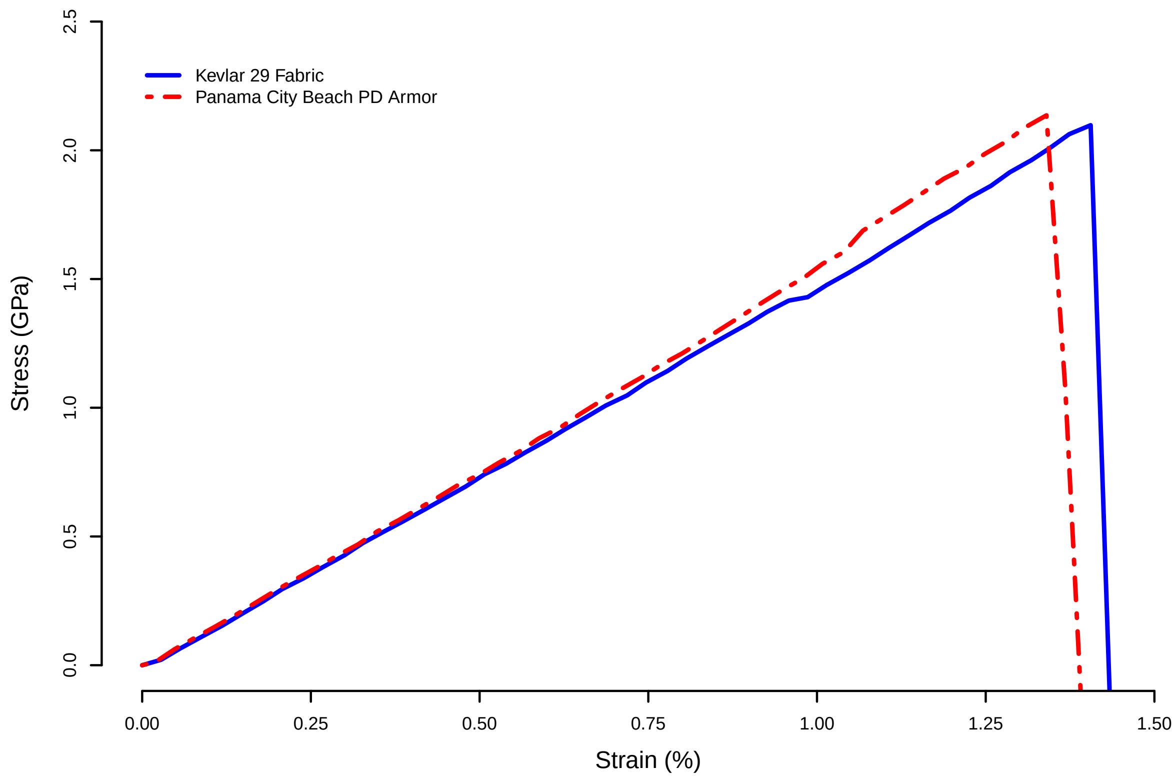


Figure 5.1: Stress-Strain Response of Representative Material Samples from PCB Armor.

from layers 6 and 12 had a significantly lower mean stress at break ($P = 0.05$). If the body armor were significantly degraded, the yarns extracted from the armor would be markedly weaker than those extracted from the woven Kevlar 29 fabric. The differences found between the two samples, however, are not large enough to conclude that there was any significant degradation in the tensile properties of the yarns in the incident armor.

The profiles of the breaking strength curves were also compared, and there did not appear to be any significant differences between the two. An example comparison can be seen in Figure 5.1.

Other yarns extracted from the incident armor were analyzed using FTIR, as described above. All spectra were baseline corrected and normalized using the aromatic C-H deformation peak at 894 cm^{-1}. Again, these results were inconclusive. Using this sensitive technique, some differences were noted between samples taken from woven Kevlar 29 fabric, which was used as the baseline, and samples extracted from the body armor; however, the differences were not sufficient to say authoritatively whether they were a result of degradation or just due to inherent variability in the two materials. Since no new or unworn samples from the same ballistic-resistant material lot was available for analysis, it was not possible to say whether the differences observed were a result of degradation or if they were always present in the body armor.

Table 5.2: Comparison of Tensile Test Results from Tampa Armor.

Panel and Layer	Mean Tensile Strength (GPa)	Standard Deviation (GPa)	Strength Change (%)
Incident Armor Layer 5	1.67	0.033	-2.91
Incident Armor Layer 20	1.65	0.059	-4.07
Control Armor Layer 5	1.72	0.056	–
Control Armor Layer 20	1.72	0.054	–

5.2 Tampa Armor

All three of the techniques described above were applied to the study of the Tampa incident armor. After the ballistic testing described in Section 4 was completed, material samples were extracted from layer 5 and layer 20 of the incident panel. Material samples were also extracted from the same layers of a new, never worn body armor of the same model, that was supplied to NIST by Second Chance Armor, Inc. The samples extracted from the new armor were used as control samples for the purpose of estimating how much the properties of the materials in the incident armor may have changed.

5.2.1 Tensile Testing

Yarn samples were extracted from the selected layers of both the incident armor and the control armor. Each of the extracted yarns were approximately 381 mm (15 in) long and had an estimated linear density of 880 denier. Prior to tensile testing, each yarn was twisted to 157 turns/m (4 turns/in) using a laboratory twisting device. Ten replicates from each layer were tested to failure in the UTM.

As shown in Table 5.2, the tensile strength of samples taken from the incident armor were only slightly different from the samples taken from the control armor. The incident panel yarns had an average tensile strength of 1.66 GPa, while the control armor yarns had an average tensile strength of 1.72 GPa. While these results show a slight degradation of 3 % to 4 % in the incident armor, it is difficult to know if this is an actual difference, simply a lot to lot variation in the material used to make the two armors, or variation due to the limitation of the test method. Based on the standard deviations associated with each set of results, the change in strength is not statistically significant. In past cases where significant degradation was observed, yarn strength had dropped by approximately 30 %, so the loss of tensile strength in the incident armor, if comparison to the control armor is valid, is not significant. This supports the earlier ballistic findings that there was no evidence that the armor was significantly degraded.

5.2.2 Confocal Microscopy

Confocal microscopy was used to characterize the surface morphology of fibers taken from both the incident armor panel and the control armor, which is described in Section 5.2. Figures 5.2 and 5.3 show some representative micrographs of fibers extracted from the control armor and the Tampa incident panel, respectively.

The micrographs show that the fibers from the unworn armor (Figure 5.2) tended to have a much smoother surface than the fibers from the incident armor (Figure 5.3). There is, however, no evidence of severe mechanical damage in the incident armor, such as would be characterized by deep pitting or kink bands. The minor surface roughness and pitting in the incident armor appears to be consistent with minor mechanical damage due to normal wear. These confocal microscopy results indicate that there does not appear to be significant mechanical damage or excessive wear in the incident armor.

Additional confocal micrographs were taken of fibers extracted from the area that was struck by the bullet during the assault on the officer. These micrographs did not provide any evidence that material at the bullet impact location was any different than material elsewhere on the armor panel. They did, however, provide some indication that material in this area remained intact, and that some of the lead material from the bullet was left behind on the fibers, as can be seen in Figure 5.4.

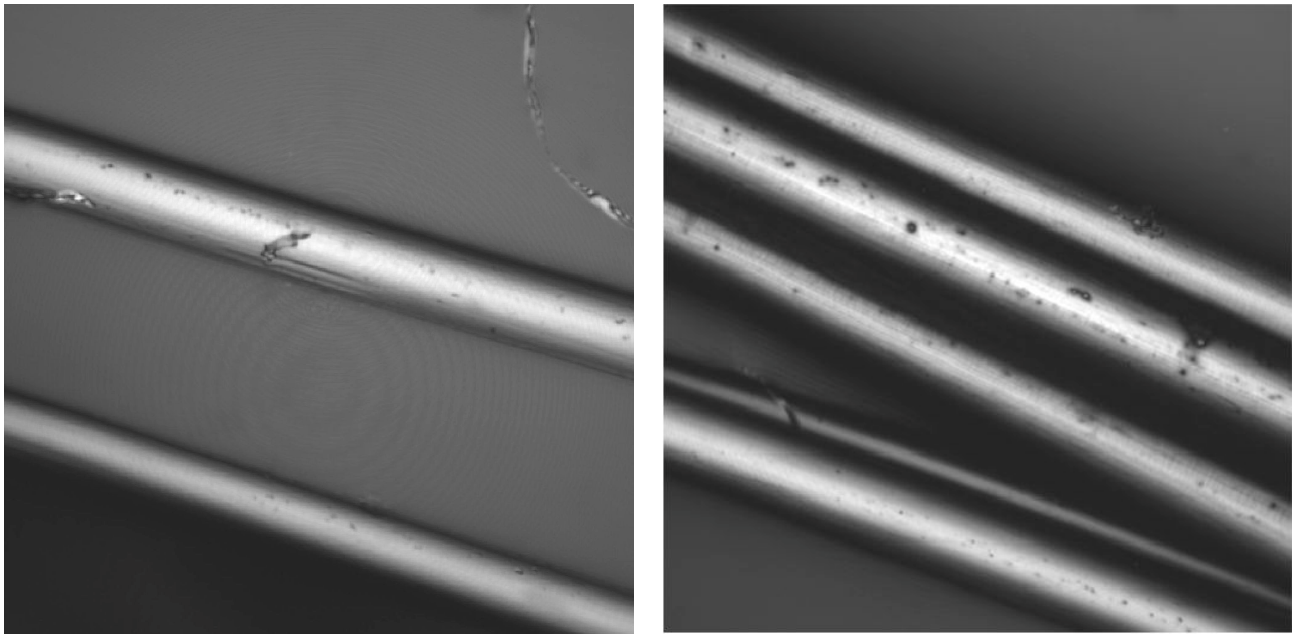
5.2.3 Infrared Spectroscopy

Fourier transform infrared spectroscopy (FTIR) was used to look for evidence that the chemical structure of the ballistic-resistant material in the incident armor was changing or degrading. Again, both the incident armor panel and the control armor, described in Section 5.2, were assessed, and the spectra taken from the control armor were assumed to represent the *new condition*.

All spectra were baseline corrected and normalized using the aromatic C-H stretch peak at 863 cm^{-1}.

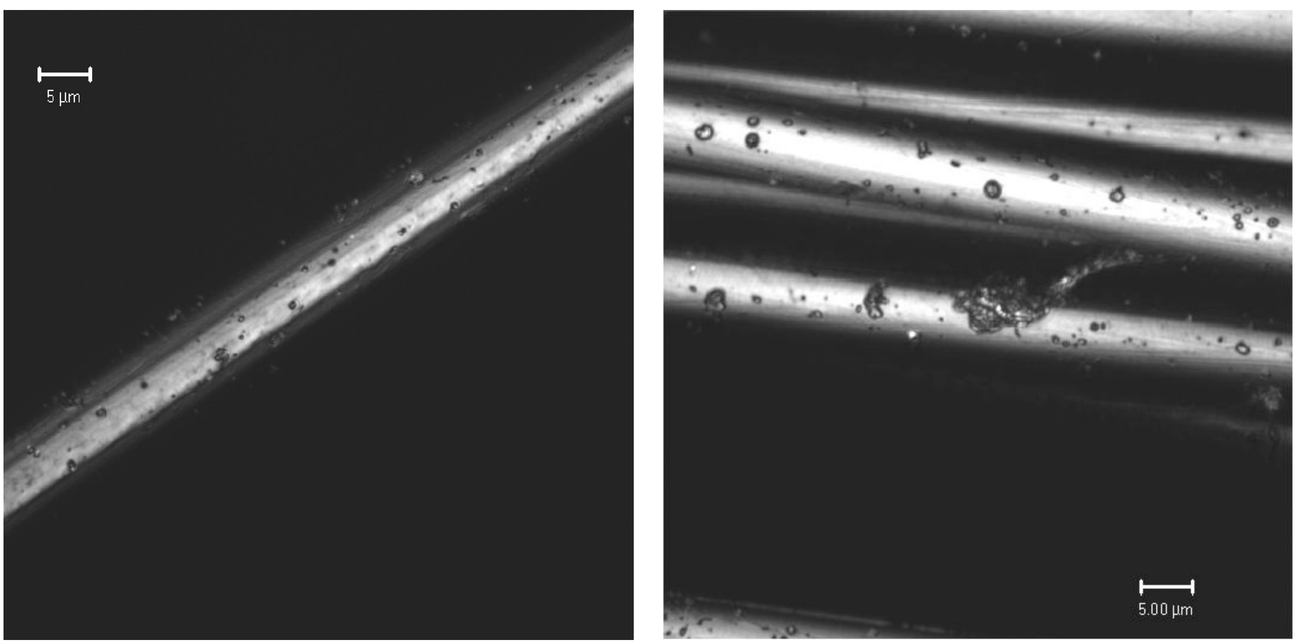
The result of this comparison is shown in Figure 5.5. Peaks that point downward from zero (negative peaks) indicate parts of the spectra that are less prominent or missing from the incident armor as compared to the control armor. Peaks that point upward from zero (positive peaks) indicate parts of the spectra that are more prominent or new in the spectra of the incident armor as compared to the control armor.

The peaks that are missing from the incident armor correspond to a breakdown of part of the material's chemical structure called an amide linkage. These peaks may be indicative of degradation in the incident armor. The positive peaks, however, do not correspond to the breakdown products expected when amide linkages disappear. The missing amide peaks may be attributed to slight batch to batch differences in the material for the two armors, or may be due to changes or rearrangement of impurities in the chemical structure of the material. While these results are interesting from a scientific perspective, there is no clear evidence to support chemical degradation of the incident armor.



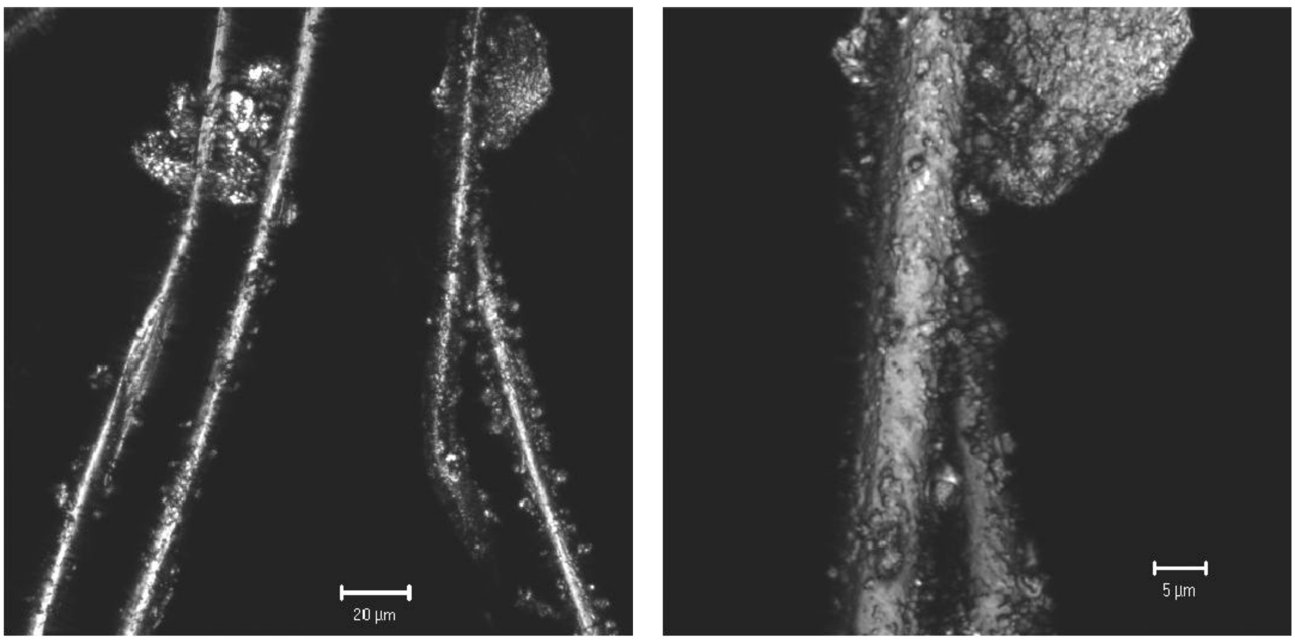
(a) 1st Example (b) 2nd Example

Figure 5.2: Confocal Micrographs of Control Armor Fibers, 150x Magnification.



(a) 1st Example (b) 2nd Example

Figure 5.3: Confocal Micrographs of Tampa Incident Armor Fibers, 150x Magnification.



(a) 50x Magnification (b) 150x Magnification

Figure 5.4: Confocal Micrographs of Material Sampled from the Bullet Impact Location.

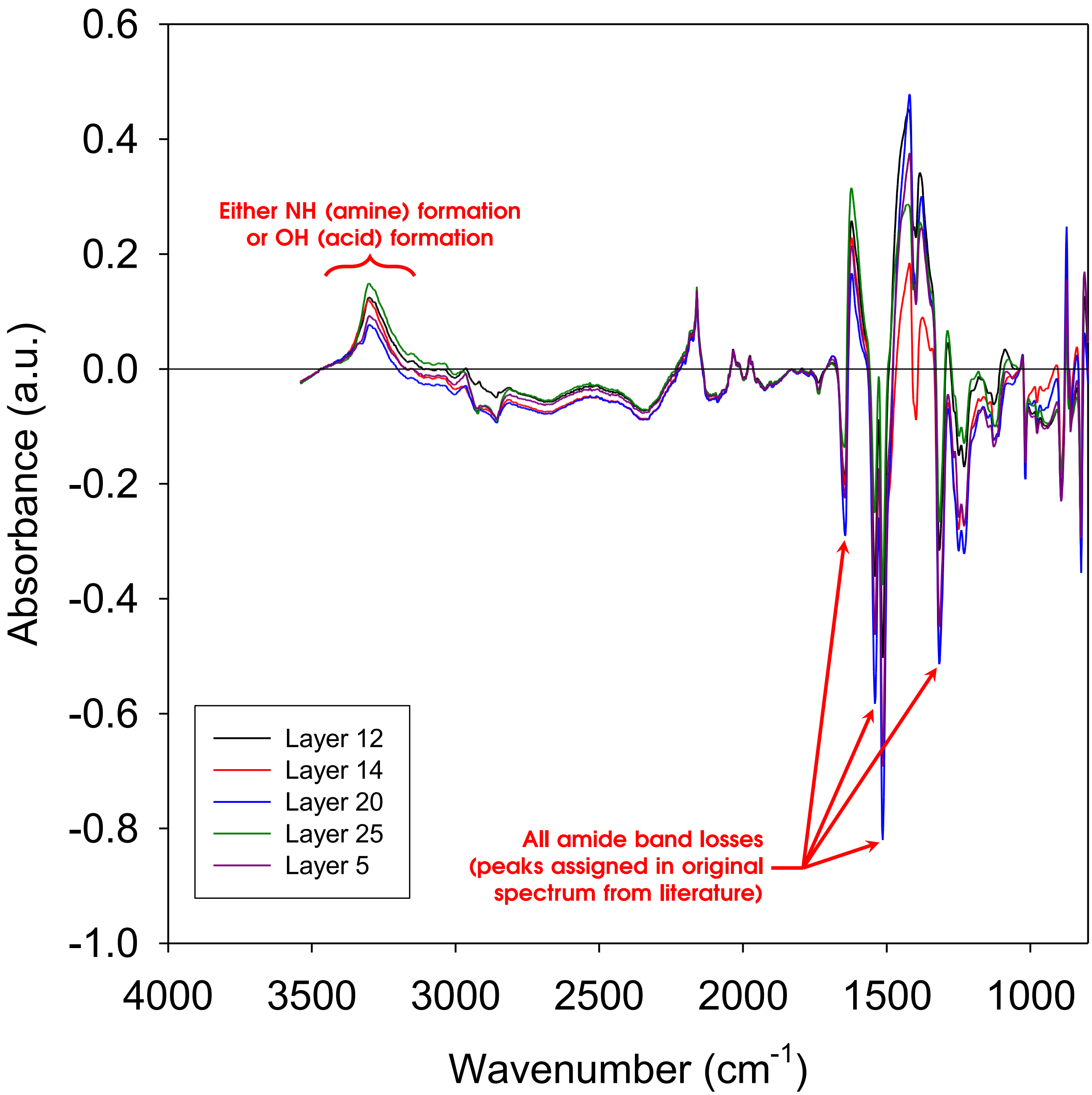


Figure 5.5: Difference Spectrum: Tampa Incident Vest minus Control Vest.

6 Summary of Observations and Conclusions

In these two cases of officer-involved shootings with near-edge bullet impacts, both the law enforcement agencies involved and NIJ had good reasons to be concerned about the safety of the armors, including whether the armor response was an indication of a serious problem with the armor, whether the armor performance was degrading significantly during use, and whether similar armors being worn by law enforcement officers were providing the expected level of protection. To address these concerns, NIST investigated how each of the armors performed. As described above, the shot panels were examined, ballistic testing was performed on one incident armor and several similar armors, and select material properties of ballistic-resistant material extracted from the armors were analyzed.

The results of this work indicated that, in both cases, the bullets struck the body armor too close to an edge for the armor to be able to reliably stop the bullet. The ballistic testing indicated that the Tampa Police Department armor appeared to be capable of providing sufficient protection when struck by bullets away from the edge. The material property testing found indications of differences between the armor materials and the reference materials, but no indications of significant degradation in the armor materials.

6.1 Panama City Beach Shooting

The shots that perforated the Panama City Beach incident body armor engaged very little ballistic fabric, because they struck the armor panel at the extreme edge where there is no reasonable expectation that the armor panel will perform satisfactorily. Chemical and physical analysis of this armor did not detect any significant degradation in the ballistic-resistant materials; this analysis, however, was hindered by a lack of detailed information about the materials used in the armor and by not having a similar, unworn armor available to be used as a reference. This made it difficult to develop a good baseline to which the results could be compared.

6.2 Tampa Shooting

The results of the Tampa Police Department body armor examination, and the analysis of samples of ballistic-resistant material extracted from the armor, indicated that there was no evidence of significant degradation of the material in the incident body armor, although it shows normal signs of wear. NIST reported to NIJ that if the incident armor was representative of the level of wear common with other armors in use in Tampa, then there were no indications of performance issues related to wear.

The ballistic testing results indicate that the response observed during the assault on the officer was due to the impact location being quite near the edge of the panel, combined with the angle of impact of the shot. Based on the laboratory response of the incident armor and the spare Tampa Police Department armor, armors of similar construction and levels of use appear to be capable of stopping the NIJ standard test threats.

The results of the ballistic analysis, tensile testing, and confocal microscopy all indicate that the incident armor performance and materials appeared to be similar to what would be expected of a new armor of the same design. The infrared spectroscopy results were not as clear, and more research would be necessary to better understand why the fiber chemistry appears to be slightly different. These results, however, do not indicate that the ballistic-resistant material had degraded while in use.

From these results, NIST researchers concluded that there was no indication of serious degradation in the Tampa incident armor, and that the armor performance during the shooting incident was most likely due entirely to how close the bullet struck to the edge of the armor and the angle at which it struck.

6.3 Final Conclusions

Based on the results of the armor examinations, ballistic testing, and material properties testing, the law enforcement agencies involved and NIJ had confidence that there were no safety issues with similar armors that were still in use. There remained, however, the issue of how well armors could be expected to perform when bullets impact close to an edge.

As described above, it is unreasonable to expect soft, fabric based armors to reliably stop bullets impacting very close to the edge of the ballistic-resistant material. There is, however, an expectation by law enforcement that the armor will provide reasonable protection, even in areas that may not be tested during certification tests. The dilemma presented by these two seemingly opposing views is due primarily to expectations that testing protocols should be repeatable and reproducible, and that test outcomes should also be reliable. Yet, as demonstrated in the ballistic tests described in this report, armor response (test outcomes) for near-edge shots is inherently more variable and sensitive to test conditions, even when the test conditions are well controlled. Implementation of near-edge shot locations for certification tests poses a significant risk factor for the armor manufacturing industry due to the consequences of failing a test. As a reasonable tradeoff between competing risks, standardized ballistic testing protocols typically specify a minimum shot-to-edge distance, which excludes from ballistic assessments some amount of surface area around the perimeter of the armor panel. An unfortunate consequence of excluding this area is that some may perceive that the *only* portion of the armor panel that provides, or is expected to provide, adequate protection is the central area of the armor panel, which is located inside the boundary created by the shot-to-edge distance offset.

Recognizing this, and informed by the findings from the near-edge assessments described here, the revised body armor standard, NIJ Standard–0101.06 [49], which was published in 2008, reduced the minimum test shot-to-edge distance for some test bullets to 51 mm (2.0 in) from the 76 mm (3.0 in) requirement in some earlier revisions of the standard [16, 17, 18]. This reduced shot-to-edge distance applies to all rifle bullets and to the lighter bullet type from the each pair of handgun bullet types – the 9 mm Luger [22] 8.0 g (124 gr) FMJ and the .357 SIG [22] 8.1 g (125 gr) FMJ bullets. The minimum shot-to-edge distance for the heavier of each pair of handgun bullet types – the .40 S&W [22] 11.7 g (180 gr) FMJ, the .357 Magnum [22] 10.2 gr (158 gr) JSP, and the .44 Magnum [22] 15.6 g (240 gr) SJHP bullets – remains at 76 mm (3.0 in). The revised standard also requires that the first three shots fired at each soft armor panel during a P-BFS test impact the test specimen between the minimum shot-to-edge distance and the minimum shot-to-edge distance plus 19 mm (0.75 in) [49].

As noted above in Section 4.1.1, the size of the BFS tends to increase as the distance to the nearest edge decreases. The heavier bullets also tend to produce greater BFS responses. During the drafting of the revised standard, there were concerns that moving the impact locations of the heavier bullets closer to the edge, when combined with other changes being made to the testing requirements, could lead to armor designs that were much heavier than those necessary to pass the earlier standard.

These revised requirements would likely not have prevented the outcomes that occurred in the two incidents described above, but they are intended to increase the area that is tested and found to provide reliable protection. Moreover, they provide some assurance that shots that impact near the shot-to-edge limit are less likely to cause the armor to buckle and allow the bullet to slide off, as occurred in the Tampa shooting. Further improvements could involve modified test protocols for near-edge shots, and failure criteria that consider both the sensitivity of armor responses to test conditions and the probabilistic nature of armor responses to near-edge impacts.

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7 References

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