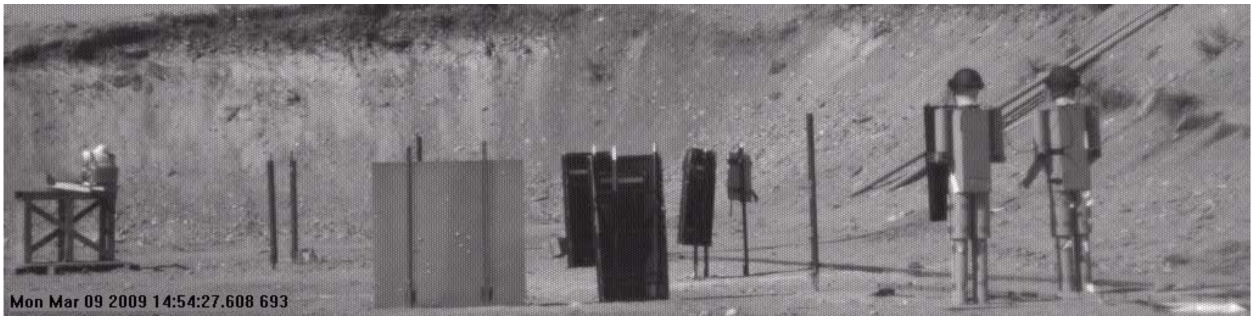


WPSTC
Weapons & Protective Systems Technologies Center
*A Criminal Justice Technology Center of Excellence*

# SUICIDE BOMBER BALLISTIC SHIELD STAND-OFF TESTING

## Summary Report

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**The National Institute of Justice**

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# PREFACE

**Validity of the Threat**

During the past several years, The National Bomb Squad Commanders Advisory Board (NBSCAB) in conjunction with the National Tactical Officers Association (NTOA) has been discussing joint bomb squad/SWAT operations. These two groups further discussed a situation in which a Person Borne Improvised Explosive Device (PBIED) is worn by an incapacitated suicide bomber. In this scenario, the PBIED has to be approached by a bomb technician for a manual render safe. SWAT members would, in some instances, (if the bomber appears incapacitated or dead) need to provide protection to the bomb technician. The groups voiced concern over how close could the team get, and still be safe? NBSCAB and NTOA agreed that a series of tests needed to be conducted, and the following questions would need to be addressed:

1. Will standard tactical shields, in particular the NIJ IIIA, offer any protection from the blast and fragmentation effects of a PBIED?
2. At what point does the shield become a damage mechanism when subjected to the forces of overpressure?
3. At what distance is the responder safe from an IED from overpressure and shrapnel?

**Explosive Choice**

The Technical Support Working Group (TSWG) Capping report titled, "Person Borne Improvised Explosive Device Study" was used as a guideline for construction of the IED's and also for selection of the explosives. This report cited Home Made Explosives (HME) and stolen commercial explosives as most likely to be used for a PBIED in the United States.

HME was ruled out, for several reasons:

- *HME manufacturing is hazardous under any circumstance and there are many different mixtures to choose from.*
- *Manufacturing would have added time and additional cost.*
- *HME varies in detonation velocity from one batch to another.*
- *The same batch of the HME mixtures of Triacetone Triperoxide (TATP) or Hexamethylene Triperoxide Diamine (HMTD)can break down and lose detonation velocity in a short period of time. Any particular batch of HMTD or TATP could perform at a lesser detonation velocity on the following day. Test results would be inconsistent.*

According to information obtained from local explosive retailers in 2008, Ammonium Nitrate and Fuel Oil (ANFO) is the most commonly used commercial explosive in the



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United States, with dynamite in a distant second place. Dynamite is more conducive than ANFO for a PBIED vest bomb, and was therefore chosen to construct the explosive devices. Ultimately DYNO Nobel, Unigel dynamite was the product selected. Unigel has a detonation velocity of 14,100 feet per second (*according to the DYNO Nobel, "Trench Blasting with Dynamite" publication).*

From a historical perspective, dynamite is a good choice as it has been used by radical and anarchist groups in this country and abroad on numerous occasions.

- *On May 17th, 1927, the Bath Consolidated School in Michigan was destoyed with dynamite.*
- *During the late 1960's and early 1970's, dynamite was used by the FALN in New York and Chicago during a bombing campaign.*
- *Again, in the 1960's and early 1970's, an explosive magazine in Colorado was broken into, and dynamite IED's were used in a series of bombings throughout Colorado.*
- *In the early 1990's, Eric Robert Rudolph used gunpowder in his first bomb at the Olympic festival in Atlanta, his second and third devices however were made with stolen dynamite.*
- *The explosive used in the March 2004 Madrid train bombings was "goma – 2," a gelatinous dynamite.*

**Explosive Weight**

The amount of explosives used for the simulated PBIED were chosen from ATF/TSWG/NGIC/FBI information regarding Explosive/Terrorist Threat Stand-Off publications for first responders. This handheld card contains 10 possible IED's/containers that may be used as PBIED's or LVIED's and the amount of explosives these various containers could hold. Also listed are recommendations for safe evacuation distances. Two of the listed items are a suicide belt and a suicide vest. The "Suicide Belt Bomb," according to the card has a maximum explosive capacity of 10 pounds. The "Suicide Vest Bomb," has a maximum explosive capacity of 20 pounds. This information was the determining factor for the explosive weights used during the test.

**Fragmentation**

To determine the type of fragmentation to use in the testing, the "Person Borne Improvised Explosive Device" study was referenced. The report noted that loose fragmentation would be taped, glued or placed in a bag and attached to the explosive (shrapnel). The report also noted that the explosives could be placed into pipes (the explosion would cause the pipe to become fragments).

The shrapnel option was chosen for the test series in order to get the best spread pattern. It was decided to attach ¼" hexagonal nuts to duct tape, then cover the nuts with another layer of tape and secure them to the explosives. The ¼" hexagonal nuts were chosen as



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they are readily available for purchase at any hardware store. They were hand placed in rows on most of the IED's, as that configuration produced the best spread pattern.

**Extra Shields, Ballistic Vests and Helmets**
After several tests had been conducted, a large fragmentation spread pattern was noted. Researchers decided to add SWAT helmets to both Ironmen, and to place helmets on the ground to collect more data. Finally, a ballistic vest was added to an Ironman without the shield for additional information regarding it's ability to protect a first responder. The helmets and ballistic vest came from another Applied Research project, and were new or used only once before.

**Disclaimer**
This report is not intended as procurement guidance. The equipment used was not manufactured or intended to protect against this threat. They were manufactured and tested to protect against handgun threats. Many of the pieces of equipment used in this project were not new and were previously used in unknown circumstances. The intent of this report is to provide information for tactics, training, and policy as it relates to person borne IEDs, first responders, and their equipment.

The "Test Plan," was approved by NIJ and NBSCAB at a Board meeting.


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## SUICIDE BOMBER – BALLISTIC SHIELD STAND-OFF TESTING

## SUMMARY REPORT

### 1.0 Introduction

The threat from suicide bombers is increasing in the U.S. First responders may have to deal with suicide bombers in congested urban settings, and therefore a safe approach distance between the suicide bomber and first responders needs to be established. The goal of this initial shield testing effort was to try to determine the minimum safe distance between a first responder, most likely law enforcement personnel, with a standard ballistic shield, and a suicide bomber if the bomber were to detonate his explosives.

Initially, overpressure loads generated by the explosion were the main focus of the test effort. However, after a few tests shrapnel damage became the main concern and additional efforts were quickly undertaken to try to capture as much information on this dangerous environment as possible.

During this test series, different lethal/injury measurements were made at various distances from representative explosive charges. The measurements were: blast overpressure, fragment penetration, whole body acceleration, blunt trauma from pressure loading and the shield being driven into law enforcement personnel. These injury measurements were all taken simultaneously by self-contained blast lethality mannequins called Ironman. The data from Ironman was then analyzed to determine lethality/casualty probabilities for law enforcement personnel at different distances from different size explosive charges. Also, high speed video measurements performed by the University of Denver (DU) were used to determine shrapnel velocities. Plywood witness panels were attached to Ironman and were used to help define shrapnel injury levels. Finally, these analyses were condensed down to investigate preliminary safe distance criteria.

### 2.0 Approach

In order to define the minimum safe distance between law enforcement personnel and suicide bombers, various lethal insults were measured on simulated law enforcement personnel during detonation of an explosive charge (with and without shrapnel) worn by a bomber. Two blast mannequins, called Ironman, were used to measure blast overpressure, fragment penetration, whole body acceleration, and blunt trauma that can be caused by the ballistic shield itself. The Ironman mannequins are standing human substitutes that simultaneously measure all four lethality insults described above. The Ironman mannequins were placed where responding officers would face the greatest threat from an explosion of a PBIED. One Ironman held a representative ballistic shield and the other Ironman did not have a shield. This was done in order to determine the ability of the shield to protect an officer, and to determine any negative effects that the shield has on the officer holding the shield. The Ironman without the shield would show the hits and overpressure readings of an unprotected officer in a similar situation.

Free field pressures were measured by MARS (Measure Air blast Remote Station) probes. MARS provided additional pressure data and backed up the data collected by the Ironman. High speed video cameras were used to photograph the flight of shrapnel and the shrapnel impacts on witness panels. This data was used to later determine the velocities of the shrapnel. Shrapnel packs were constructed using 1/4" steel hexagon nuts secured to duct tape laid out in 8" by 18" (approximate) configurations, this single layer was then over laid by more duct tape, which was then attached to the outside of the explosive (Shot 12 was an exception where two of the shrapnel packs were used). The explosives were cartridges of dynamite and detonation cord, constructed to meet the 10 lb suicide belt bomb and the 20 lb suicide vest bomb described in the terrorist threat publications.

The regular and high speed video cameras also captured the individual Ironman responses to the overpressure and shrapnel from the blast. The slow speed video data was used in comparison with Ironman's instrumentation responses to validate the Ironman data.

Interaction of the blast wave with the simulated bomber's torso has been noted on previous suicide bomber test efforts. Therefore, to ensure proper bomber torso interaction with the blast wave, i.e. to provide a realistic lethality blast field, a new ballistic gelatin "suicide bomber" torso was fabricated by the personnel from the University of Denver and used for each test, see Figure 1.

**Figure 1 Gelatin Suicide Bomber Torso**

The Department of Defense (DOD) blast pressure prediction computer program COMWEP was run to determine the initial stand-off distance of the Ironman blast mannequins and the explosive amount for the first two tests. The initial stand-off distance was set to produce an overpressure environment on both Ironman units that was roughly at the lethality threshold. For all tests, both Ironman systems were set the same distance from the charge and were placed 12” apart. Then, based on the lethality data from both Ironman systems, the free field pressure data and the video data, the stand-off distance was increased to try to find the edge of the lethal zone (from shrapnel).

## 3.0 Methodology

The purpose of these tests was to determine the probability of lethality or injury to law enforcement personnel during an encounter with a suicide bomber. Twelve tests and one calibration test were conducted for this initial investigation. The two instrumented Ironmen blast dummies were always set the same distance from the suicide bomber and were oriented so that they saw approximately the same blast and shrapnel environment, facing toward the explosive charge. One Ironman experienced the blast environment while holding a Minuteman III-A ballistic shield. This shield is a folding ballistic shield, manufactured by Patriot 3 for handgun protection only. The other Ironman experienced the blast environment without a shield. The Ironman without the shield provided lethality/injury data to define the safe stand-off distance without the shield. The Ironman with the shield provided lethality/injury data to define the safe stand-off distance with the shield. Comparison of the two data sets provided an indication of the effectiveness of the shield tested in this harsh ballistic environment. In future efforts, other shields and protection systems could be tested to determine their effectiveness in reducing the blast environment effects.

### 3.1 Instrumentation

As stated earlier, the main instrumentation system used in this test effort was the two Ironman blast mannequins, but MARS probes and high speed video cameras were also used to gather additional data. Figure 2 shows the general layout of the test area for this test series.

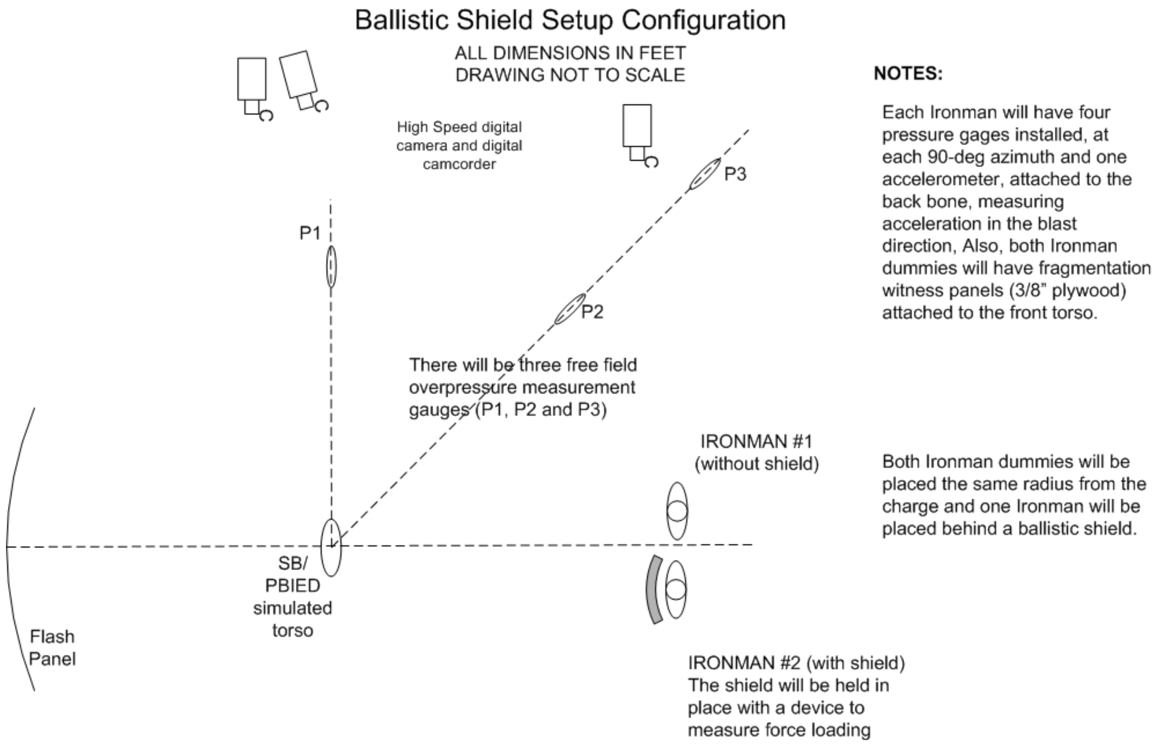


**Figure 2 General Layout of Test Arena for Shield Testing**
**("Dimensions in feet," refers to the distances in each test)**

### 3.1.1 Ironman

The Ironman mannequin is designed to have the same height, weight, and body shape (gas dynamically similar for blast wave interaction) as a 50 percentile male. This design will help to achieve a body interaction with the pressure wave and shrapnel, as well as a whole body response similar to that of law enforcement personnel in the suicide bomber environment.

As stated earlier, the purpose of the Ironman blast mannequins was to field data measurement systems that could gather the required lethality/injury information while responding accurately to the different loadings from the blast. During testing both Ironman systems were located the same distance from the explosive charge and always 12" apart (shoulder to shoulder). Both systems were placed facing the charge so that they would be in the same overpressure and fragmentation blast environment.


**Figure 3 Ironman Blast Mannequins Ready for Testing**

The Ironman without the ballistic shield measured the blast overpressure at four azimuths (sides): 0 deg (front), 90 deg (left side), 180 deg (back), and 270 deg (right side). The systems used to measure the overpressure effects to Ironman were the Endevco, model 8530C-50, and the Kulite, model XTL-190-50A, pressure transducers. These systems were used interchangeably in both Ironman units. These transducers are designed to operate in the 0-50 psi range. However, they can accurately record pressures up to 100 psi. The transducers were installed in a nylon sleeve (to reduce Ironman skin vibration effects). The transducer was then installed in the skin of Ironman so that the face of the transducer and the sleeve were flush with the exterior surface of Ironman's skin. In addition a PCB model J352C04 accelerometer was threaded onto the front face of the 2"x2" square tubular steel back bone of both Ironman units. For the first three tests, the accelerometers were hard mounted directly to the steel back bone. Unfortunately, in this configuration the accelerometers also measured Ironman's ringing steel response to the blast wave. In order to reduce the ringing steel effect, and procure accurate measurements for the remainder of the tests series, the accelerometers were attached to a rubber mount that was placed onto the back bone.

The five transducers in Ironman (four pressures and one accelerometer) were then connected to five on-board miniature data acquisition systems or miniDAS's developed by ARA several years ago. The measured data was then stored on flash cards by the miniDAS's. Upwards to 120 events could be recorded on each flash card. Both Ironman systems were fitted with Lithium Ion batteries that powered all of the onboard data systems for more than eight hours. At the end of each test day the batteries were fully recharged.

Once the trigger was received, the data systems recorded for ~ 550 milliseconds at a sample rate of, one million samples/second while the data recorders used 16 bit resolution. It took roughly 10 seconds for the data recorders to store the data and recycle themselves to be ready for the next event. The result of this effort was five laboratory quality data time histories per explosive event.

The Ironman holding the shield had the same five data channels as the Ironman without the shield. Additionally, this Ironman was fitted with two more data channels. The added data channels measured the load imparted to both fore-arms from the blast pressure (overpressure) effect impacting the ballistic shield. Therefore, the Ironman carrying the shield had seven onboard data channels. In this Ironman, the normal Ironman forearm was replaced with a high strength steel roller bearing sleeve system (see Figure 4). A load cell was also integrated into each forearm.

**Figure 4 Photo Depicts Roller Bearing Sleeve Fore-Arm System**

The new forearm was designed so that the load cell would only experience forces exerted on the shield by the overpressure forcing the forearm straight back into the body. As well as the force moving forward, out away from the body. This forearm was designed to take all of the other load vectors imparted to the shield and convert them to this one dimensional motion.

Initially, the maximum estimated blast pressure load:

**pressure x shield area = blast pressure load**

was calculated to be about 20,000 lbs of force. Therefore, the roller bearing forearms were designed to react to the worst case scenario where all of the force was perpendicular to the forearm. For example, a maximum side load of ~20,000 lbs or a side load of ~10,000 lbs on each arm. However, preliminary test information indicated that instead of the worst case load a lower load was actually being generated so a more sensitive load cell was obtained to measure forces on the forearm. The MLP-1K load cell (1,000 lb nominal load) was used for all of the data presented in this report. Further, the forearm was designed with an adjustable length so that the preload into the load cell could be fine tuned. Finally, a tubular steel frame was fabricated and bolted to the new Ironman forearms, see Figure 5, and the ballistic shield was then strapped to this tubular frame.

**Figure 5 Photo Depicts Ballistic Shield Attachment System**

The front torsos of both Ironman units were fitted with 3/8" plywood panels. These panels were used to measure shrapnel penetration on both Ironman systems to assist in providing an indication of injury. The left and right edge of the plywood panels were beveled to match the contour of Ironman's sides so as not to interfere with gas dynamic flow around Ironman. The front pressure transducer mounts in both Ironman systems were fixed so that the face of the transducer was roughly flush with the exterior surface of the plywood. Also, the plywood panels were set slightly off the steel Ironman skin to minimize the effects of the steel skin on fragment penetration. Starting with Test 4, both Ironman systems also had ¾" plywood panels attached to the units upper and lower leg sections. During the preceding four tests, there had been numerous shrapnel hits to the legs that could not be quantified for injury. With the addition of the plywood to the legs, additional data provided an indication of shrapnel penetration lethality for the remainder of the test series. Wood panels were not attached to the Ironman arms because of the possibility of altering the blast wave measurements with the torso.

After the first shrapnel test, it was determined this was a more serious threat than was originally anticipated. A decision was made to add standard ballistic gear to the Ironman mannequins that may be worn by first responders at a suicide bomber incident. Helmets (F6 PASGT and ROTHCO LII) with face shields were added to both Ironman units, starting with Test 4. Also, ballistic vest body armor (PACA ESII-T Tests 4 – 8 or PACA 04-ES-IIIA Tests 9 - 12) was added to the Ironman with no shield. The Ironman head forms used in these tests were a silicon "skin" over a steel spherical skull, see Figure 6. These head forms captured fragments and provided an indication of tissue penetration depth.

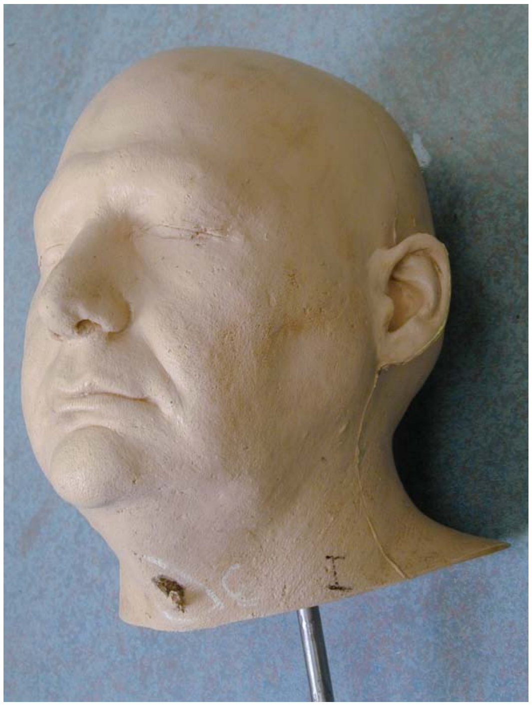

**Figure 6 Ironman Silicone "Skin" Over Steel Sphere Head Form**

### 3.1.2 MARS probes

The free field pressures were recorded by MARS probes. MARS probes consist of hollow aluminum horizontal legs attached to an aluminum base plate. A swiveling clamp is attached to the base and a telescopic aluminum pole is inserted into the base clamp. A sintered nylon splitter plate is clamped to the top of the telescopic pole and the free field pressure gage is installed into the splitter plate (see Figure 7). In previous test efforts the transducer cable simply ran down the aluminum pole to the data recorders, which were attached to the base plate. On occasion, however, flying debris from the explosive charges, etc. severed the transducer cable. So for these ballistic shield tests the back of the transducer was enclosed in a metal sleeve and the cabling ran down inside of a Teflon tube jacketed by a woven stainless steel braid.

**Figure 7 Measure Air blast Remote Station (MARS) Probes**

MiniDAS data recorders similar to those used in Ironman were also used in the MARS probes. The MARS probe data was stored on flash cards and over 100 separate events could be recorded on the probe before the data boxes had to be opened and data downloaded. Once the trigger was received the data system recorded for ~ 500 milliseconds at a sample rate of a million samples/second using 16 bit resolution. It took roughly 10 seconds for the MARS probe data recorders to store the data and recycle themselves to be ready for the next event. In order to protect the data systems in the MARS probes, the data recorder was protected by a spun aluminum dome.

Before each test event each MARS probe was carried to the predetermined location and positioned. The splitter plate was lined-up with the charge so that the pressure transducer face was perpendicular to the blast wave and therefore would measure the incident or side-on pressure wave from the blast. The height of the pressure transducers for all of the MARS probes was set at ~ 1 meter above the ground for all events. The distance from the explosive to the three MARS probes varied during the tests, but Table 1 contains the distances for all tests. For the first several tests, the MARS probe distances were correlated with the Ironman distances from the suicide bomber, but as distances increased between the suicide bomber charge and Ironmen, the MARS probe remained approximately fixed in order to provide a repeatable measure of the pressure field from the explosive.

### 3.1.3 High Speed Video Cameras

As stated earlier, high speed video cameras were set to photograph both shrapnel trajectories from the surface of the suicide bomber explosive vest and the response of both Ironman systems to the blast. DU personnel positioned and operated the cameras. For most tests one high speed video camera was used. For several of the tests another high speed video camera became available so two cameras were used to gather data. The cameras were set to capture the response of both Ironman units. These cameras photographed both the response of the Ironman holding the SWAT shield and the response of the unprotected Ironman. The data from these cameras were used to verify the response data that was recorded internally by Ironman. To better distinguish Ironman movement, the cameras were set to keep the picture as bright as possible, using available lighting. The cameras were also adjusted to maintain as high a frame rate as possible.

The cameras also had to cover the area of the arena where flash panels were purposely placed to be impacted by shrapnel. This way the cameras could accurately determine shrapnel trajectory and record the impacts on the flash panels. This impact information was used for the analysis which aided in determining shrapnel velocities during the testing process.

Other video cameras were used to capture each overall test event. Numerous pre and post still photographs were taken to document shrapnel damage.

### 3.1.4 Break Wire Trigger

In order to start all of the remote data systems simultaneously, a single trigger pulse had to be sent out to all recorders. For this test series, break wire trigger systems were predominantly used. A break wire trigger system uses a fine wire wrapped around the explosive charge, and this wire is connected to a small electronics box that sends out an electrical pulse the instant the fine trigger wire is broken by the blast pressure wave from the detonating explosive. In this test series, typically one master wire ran out of the electronic trigger box to one MARS probe, from there other wires connected to master wire ran out to each of the other recording systems: one wire to each Ironman and one to each of the remaining MARS probes. On most of these tests a separate break wire trigger box was used for the video cameras. When the explosion broke the trigger wires the trigger boxes sent a signal out to start all the data recording systems.

Three different trigger methods were tried during the tests. The initial off-the-shelf break wire trigger system produced an electrical pulse, but the pulse was not clean and this caused trigger problems with the miniDAS's resulting in several missed triggers. A piezo-crystal trigger was tried next. This system produced an electrical pulse when the blast wave hit the crystal. This system had problems consistently generating enough energy to trigger all of the miniDAS's. Finally, a new trigger system was built that used the break wire concept, similar to the original trigger system, this system produced a signal that consistently activated all of the miniDAS's properly. This system was used for the remainder of the tests.

### 3.2 Data Analysis

Twelve tests were conducted with one calibration test, see Table 1. Table 1 provides information on charge weight, shrapnel weight, and distances from the chest of the suicide bomber to the Ironman units. The Mars probes and other shrapnel targets were added later in the test program. For each test, the top of the suicide bombers shoulders were set at approximately the same height as the shoulders of the Ironman units. The suicide bomber had dynamite taped to both the front and back of the torso, see Figure 8. For the shrapnel tests the pack of shrapnel was taped only to the front of the torso, see Figure 9. The testing was conducted at the University of Denver's test range east of Denver, Colorado during February and March of 2009.

**Figure 8 PBIED Torso with Ten Pounds of Explosives**


**Figure 9  Suicide Bomber Torso with Twenty pounds of Explosives and Shrapnel**

As stated earlier, the data recorded during this test series included:  Blast overpressure, shrapnel penetration, whole body acceleration, and blunt trauma potentially caused to the simulated responder (Ironman) when the ballistic shield reacts to impact from overpressure forces caused by the blast.

Although, not initially planned, bio-hazard data was also generated by roughly mapping the post explosion foot print of the gelatin that was distributed from the suicide bomber torso as a result of the blast.  *(No map or diagram drawn, gelatin was plotted.)*

Table 2 provides the initial peak shock pressure and peak upper spine acceleration on both Ironman units.  This table also shows aft (into Ironman) and forward (away from Ironman) arm forces for the Ironman holding the shield and peak incident shock pressures in the free field from the MARS probes.

The four pressure measurement tools on both Ironman units were used to determine blast lung and ear injury.  The acceleration data was used to determine whole body acceleration injury and the forearm load cells were used to determine forearm fracture injury.  The 3/8" plywood panels on the front of both Ironman units were used to help determine shrapnel injury to the chest area.  The ¾" plywood panels on both Ironman legs were used to help determine the lethality probability from shrapnel hits to the legs. The high speed video data captured by the University of Denver were used by DU personnel to determine shrapnel velocities.

Figure 10 shows an example of the pressure data recorded by the Ironman without the ballistic shield and Figure 11 shows an example of the pressure data recorded by Ironman with a shield. Both charts show readings from a test where no shrapnel was used. The noise spikes on Figure 11 appear roughly at the same time on most of the channels, even though the recorders are virtually independent. One hypothesis for the spikes is that the explosively launched gelatin from the suicide bomber torso was ionized and somehow causes the instrumentation noise spikes as the chunks went flying past the transducers.

Further, the pressure data appears to be somewhat modified from pressures generated by ideal spherical "point" charges. The pressure time histories on this test program seem to have additional characteristics (peaks) not normally associated with free field explosive detonations. The perceived cause for much of this difference is that the explosive charges were made up of a number of individual sticks of dynamite. There was one configuration containing approximately 10 lbs. of explosives that made one row of dynamite around the torso. The second configuration consisted of approximately 20 lbs. of explosives, which made two overlapping rows surrounding the torso. The high speed video often showed at least two distinct blast waves emanating from the suicide bomber (probably one from the front and one from the rear), which is consistent with the spread-out pressure time histories recoded during these tests.

Further, the pressure field around Ironman also seemed somewhat distorted from the expected pressures. It is likely that the flight of both the numerous hex nuts (shrapnel) and the gelatin "bits" from the bomber contributed to unexpected and additional pressure peaks in the recorded pressure time histories.

As expected, the ballistic shield modified the pressure environment measured on the Ironman torsos. The pressure transducer on the chest of the Ironman with the shield never measured a shock wave and the maximum overall pressure was much lower on the Ironman with the shield. For the example in Figures 10 and 11, the maximum pressure on the chest dropped from 36 psi (without shield) to 7.5 psi (with shield). For the Ironman without the shield, the initial shock pressure on both the right and left sides of the torso was usually about ½ the peak reflected pressure on the front of the chest. This is consistent with the expected pressure ratio (1/2) between the incident (Ironman sides) and the total reflected pressure (Ironman chest). However, following the initial shock peak pressure on the sides of Ironman, the pressure continued to build up to the maximum side pressure. This phenomenon is probably due to the pressure field flow and pressure wave reflections between the torso and the arms.

The typical effect of the shield on the pressures on the torso sides was to reduce the maximum torso side pressures (in Figures 10 and 11 the maximum side pressure dropped from ~35.7 psi to ~ 23 psi). The effect of the shield on the pressures on the back of the torso was to increase the pressure (in Figures 10 and 11 the maximum pressure on Ironman's back increased from ~ 12.5 psi to ~13.5 psi) for the Ironman holding the shield. It appears that the shield altered the pressure field flow around the subject and created this increased pressure.

Lastly, Figure 12 and Figure 13 show examples of force data applied to the forearms of the Ironman holding the shield and upper spine acceleration, respectively. Both of these measures generally decreased with distance.

**Table 1 Test Matrix**

| Suicide Bomber Shield Test Matrix | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Test** | **Charge** | **Dist. from Bomber** | **Dist. Between** | **Shrp** | **Dist. Bomber to** | **Dist. Bomber to** | **Dist. Bomber to** | **Dist. To** | **Dist. To** | **Dist. To** | **Dist. To** | **Dist. To** | **Dist. To** |
| **#** | **Wt** | **To Ironmen** | **Ironmen** | **Weight** | **1st Front MARS** | **2nd Front MARS** | **Side MARS** | **1st Helmet** | **2nd Helmet** | **Vest** | **Shield 1** | **Shield 2** | **Shiel d 3** |
| | *(lb)* | *(ft)* | *(ft)* | *(lbs)* | *(ft)* | *(ft)* | *(ft)* | *(ft)* | *(ft)* | *(ft)* | *(ft)* | *(ft)* | *(ft)* |
| 1 | 9.7 | 15 | 1 | na | 15 | 30 | 15 | na | na | na | na | na | na |
| 2 | 20.3 | 20 | 1 | na | 20 | 35 | 20 | na | na | na | na | na | na |
| 3 | 10.1 | 20 | 1 | 2.97 | 20 | 35 | 20 | na | na | na | na | na | na |
| 4 | 10.1 | 20 | 1 | 3.53 | 20 | 35 | 20 | na | na | na | na | na | na |
| 5 | 10.1 | 25 | 1 | 3.64 | 20 | 35 | 20 | na | na | na | na | na | na |
| 6 | 10.1 | 25 | 1 | 3.92 | 20 | 35 | 20 | 15 | 20 | na | na | na | na |
| 7 | 10.6 | 30 | 1 | 3.98 | 20 | 35 | 20 | 15 | 20 | na | na | na | na |
| 8 | 21.2 | 35 | 1 | 4.72 | 20 | 35 | 20 | 20 | 25 | 25 | na | na | na |
| 9 | 10.6 | 35 | 1 | 3.34 | 20 | 35 | 20 | 20 | 25 | 25 | na | na | na |
| 10 | 10.6 | 60 | 1 | 4.22 | 20 | 34 | 20 | 20 | 25 | 35 | na | 35 | 49’ 4” |
| cal | 5.08 (TNT) | 60 | 1 | na | 20 | 34 | 20 | na | na | na | na | na | na |
| 11 | 10.6 | 60 | 1 | 4.29 | 24.7 | 39.6 | 20 | 35 | na | 35' 8" | 24’ 7” | 35’ 11” | 50’ 2” |
| 12 | 21.2 | 60 | 1 | 7.94 | 24.7 | 39.6 | 20 | 35 | na | 35' 7" | 24’ 4” | 35’ 9” | 50’ 2” |

**Table 2 Test Data**

| Suicide Bomber - Shield Test Data | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Test #** | | **Ironman No Shield** | | **Ironman with Shield** | | | | | | **Free Field Pressure** | **Free Field Pressure** | **Free Field Pressure** |
| | **Distance** | **Peak Shock** | **Max Upper Spine** | **Peak Shock** | **Max Upper Spine** | **Left Arm** | | **Right Arm** | | **Front of Bomber** | **Front of Bomber** | **Side of bomber** |
| | **Ironmen to explosive charge** | **Pressure** | **Acceleration** | **Pressure** | **Acceleration** | **Force** | | **Force** | | **First** | **Second** | |
| | *(feet)* | *(psi)* | *(g)* | *(psi)* | *(g)* | *(lbf)* | | *(lbf)* | | *(psi)* | *(psi)* | *(psi)* |
| | | | | | | *Forward* | *Aft* | *Forward* | *Aft* | | | |
| 1 | 15 | 23.8 | hm | ? | hm | ? | ? | ? | ? | 13 | 5.2 | ? |
| 2 | 20 | 36.2 | hm | 17 | hm | 55 | 750 | ? | ? | 17 | 6 | ? |
| 3 | 20 | 30.6 | hm | 12 | hm | 291 | 567 | 231 | 453 | 10.6 | 3.7 | 9.2 |
| 4 | 20 | 21.8 | 6.4* | 12.1 | 46.7 | 139 | 394 | 37 | 543 | 9.1 | 4.1 | 8.9 |
| 5 | 25 | 14.1 | 6.0* | ? | ? | ? | ? | ? | ? | ? | ? | ? |
| 6 | 25 | 13.5 | 6.1* | 7.3 | 31.7 | 168 | 523 | 175 | 387 | 10 | 3.5 | 9 |
| 7 | 30 | 4 | 6.0* | 5.3 | 22.7 | 269 | 565 | 196 | 633 | 10.9 | 3.5 | 9.3 |
| 8 | 35 | 6.5 | 6.6* | 5.1 | 28.2 | 407 | 671 | 230 | 435 | 20.2 | 5.4 | ? |
| 9 | 35 | 7.9 | 6.3* | 5.4 | 12 | 28 | 138 | 56 | 200 | 9.5 | 3.3 | 9.5 |
| 10 | 60 | 2.2 | 7.2* | 0.75 | 9.5 | 120 | 64 | 36 | 57 | 10.6 | 4.6 | 9.3 |
| Cal | 60 | 2.5 | 6.6 | 1 | 4.6 | 4 | 24 | 7 | 44 | 8.4 | 3.6 | 6.5 |
| 11 | 60 | 1.6 | 6.5 | 1.2 | 6.3 | 12 | 24 | 75 | 61 | 10 | 4.5 | 10.5 |
| 12 | 60 | 3.6 | 13.2 | 2.5 | 18.9 | 140 | 123 | 48 | 102 | 15.2 | 5.8 | 15.9 |
| | | | | | | | | | | | | |
| * Saturated | | | | | | | | | | | | |
| hm = hard mount<br>?=data trigger issues | | | | | | | | | | | | |

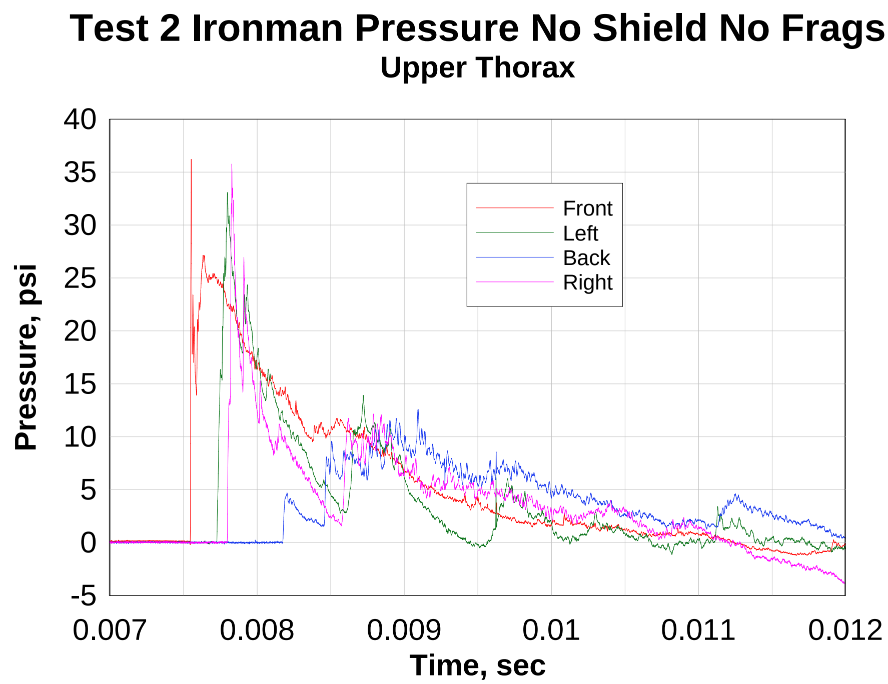


**Figure 10. Example Pressure Time History Ironman without Shield**

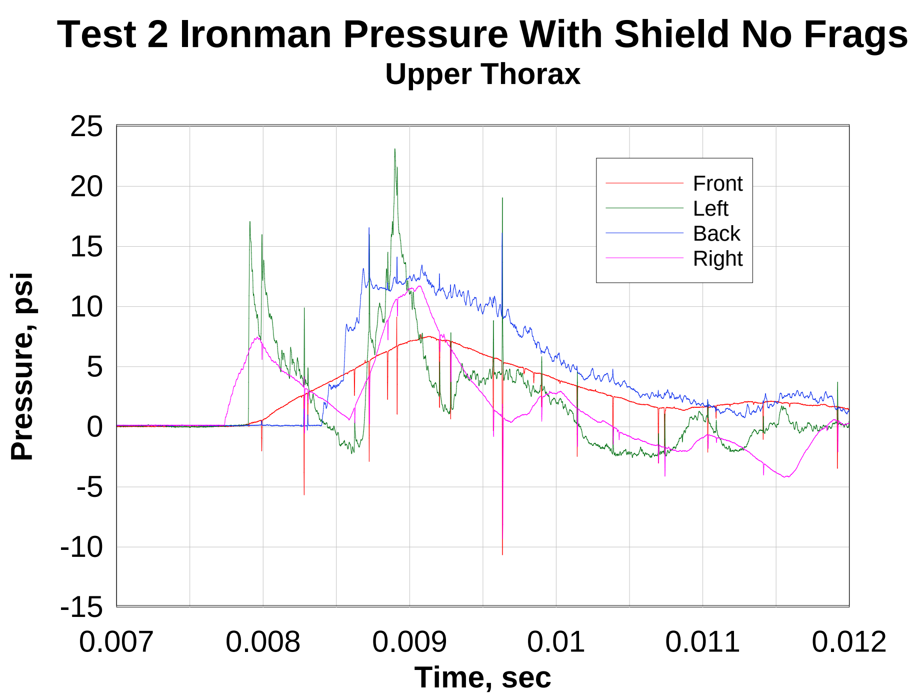


**Figure 11. Example Pressure Time History Ironman With Shield**

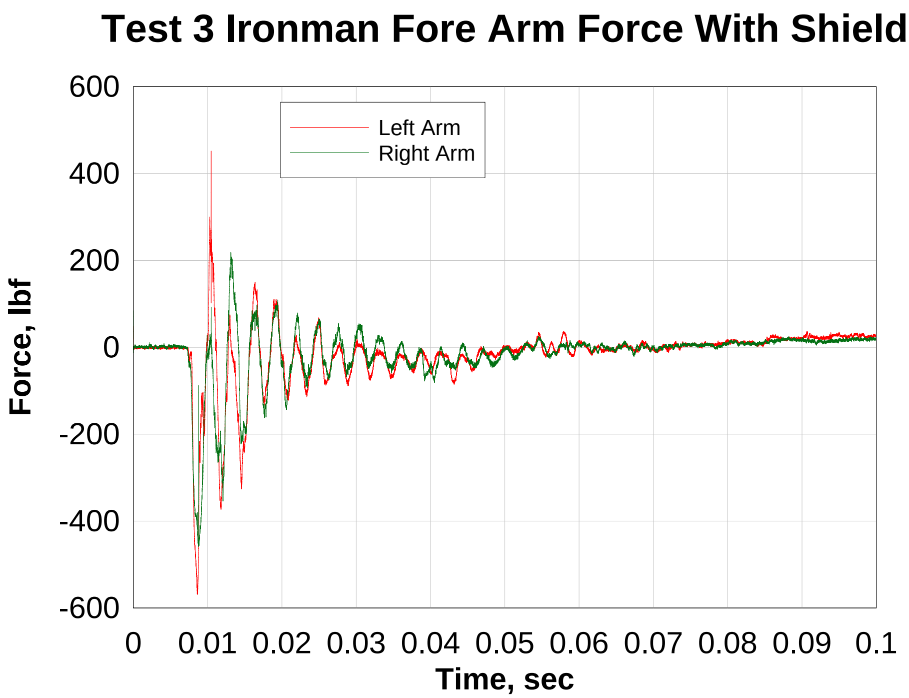


**Figure 12. Example of Arm Force Loads from Shield**

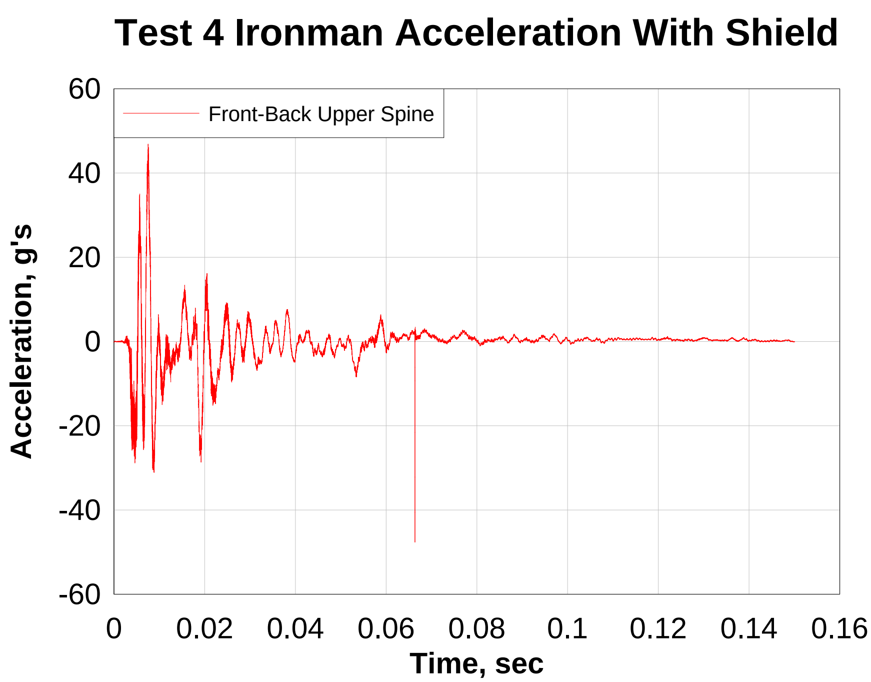


**Figure 13 Example of Ironman Upper Spine Acceleration**

Figure 14 shows two example shrapnel packs, which were assembled by personnel from the University of Denver. The shrapnel packs, one with the hex nuts dropped onto the tape, and the other with the nuts placed singularly onto the tape in a straight line gave very different performances. Placed one at a time, the shrapnel performed better giving a better spread pattern. Table 3 provides information on the shrapnel hits and penetration data to the shields and Ironman units. Figure 15 shows both Ironman units with all of the added shrapnel witness panels and ballistic gear (helmets, face shields and ballistic vest).

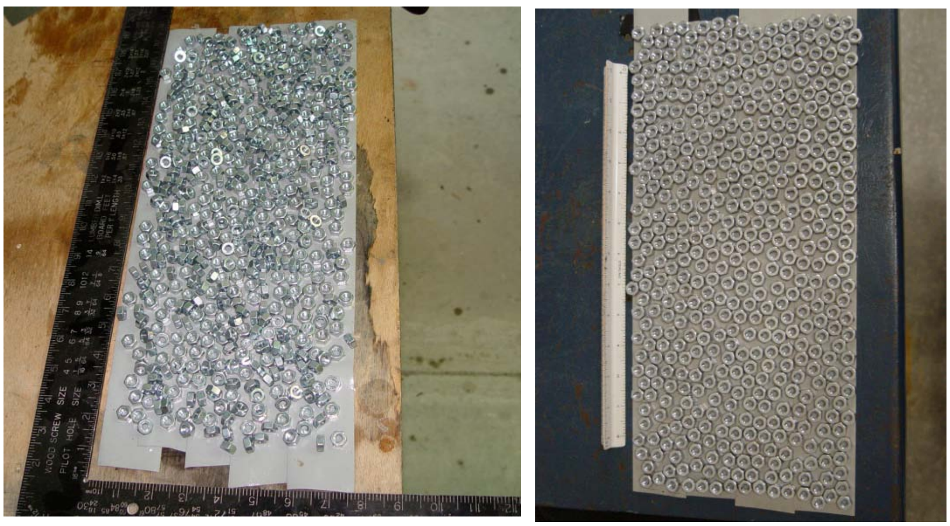

**Figure 14 Two Examples Fragmentation Packs**

Figures 16, 17 and 18 show general shrapnel damage to Ironman, the head form and the arms with silicone hand forms. The silicone head form allowed simulated tissue penetration from the shrapnel and then impact to the stainless steel simulated skull. Further, the head form captured the shrapnel for later examination. Lastly, Figure 18 shows the severe damage to the simulated hand tissue and the simulated bones (10 gauge copper wire) from shrapnel impact.

During testing the steel neck stem on the Ironman holding the shield was bent and on Test 7 the ¼” pipe nipple (frangible neck member) was finally sheared off from shrapnel impact to the face shield and head. In future testing, the forces applied to the head (neck strain gages) should be recorded in order to determine potential resulting lethality/injury levels from this loading.

**Table 3  Fragmentation Penetration Data**

| Ironman Fragment Data | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Test Number** | **Ironman No Shield** | | | | | | **Ironman With Shield** | | | | | |
| | *Face Shield* | *Right Arm* | *Torso* | *Left Arm* | *Right Leg* | *Left Leg* | *Face Shield* | *Right Arm* | *Torso* | *Left Arm* | *Right Leg* | *Left Leg* |
| **1** | na | na | na | na | na | na | na | na | na | na | na | na |
| | | | | | | | | | | | | |
| **2** | na | na | na | na | na | na | na | na | na | na | na | na |
| | | | | | | | | | | | | |
| **3** | 0 | 1 pen hand | 1 pen | 1 pen hand | 1 dent | 2 dent | 1 npen head | 1 dent | 1 dent/ts | 1 dent | 1 dent | 0 |
| | | | | 1 dent | | | | | 1 npen/ts | | | |
| **4** | 0 | 2 dent | 1 npen* | 0 | 3 pen | 1 pen | 0 | 0 | 0 | 0 | 4 pen | 2 pen |
| | | | | | | | | | | | 1 pen/ts | 2 pen/ts |
| **5** | 0 | 0 | 1 dent | 2 dent | 1 pen | 0 | 0 | 0 | 0 | 0 | 2 pen | 1 npen |
| | | | | | | | | | | | | |
| **6** | 1 npen | 0 | 2 pen | 2 dent | 1 pen | 1 pen | 3 npen | 1 dent | 1 pen/ts | 3 dent | 1 pen | 1 pen |
| | 1 pen head | | 1 dent | | | | 1 pen/ts head | | 2 dents/ts | | | |
| **7** | 0 | 0 | 1 dent | 1 dent | 0 | 0 | 1 npen | 1 dent/ts | 2 pen/ts | 1 dent | 1 pen | 2 npen/ts |
| | | | | | | | 2 pen/ts head | | | | | |
| **8** | 0 | 4 pen* | 1pen/v*** | 2 dent | 1 pen | 1 npen | 0 | 1 dent/ts | 1 dent/ts | 1 dent | 1 dent | 1 pen |
| | | | 1npen/v | | | 2 pen | | | 2 pen/ts* | | | |
| | | | | | | | | | | | | |

**npen = damaged but not penetrated**
**pen = penetrated**
**dent = Ironman steel skin dented**
**/ts = thru shield**
**/v = thru vest**
***penetration thru shield**
****dent wood panel behind vest**
*****penetration thru wood and  steel**

**Ironman Fragment Data , continued**

| Test Number | Ironman No Shield | | | | | | Ironman With Shield | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Face Shield* | *Right Arm* | *Torso* | *Left Arm* | *Right Leg* | *Left Leg* | *Face Shield* | *Right Arm* | *Torso* | *Left Arm* | *Right Leg* | *Left Leg* |
| **9** | 0 | 0 | 1 pen | 0 | 0 | 3 pen | 0 | 0 | 0 | 0 | 2 pen | 1 npen |
| | | | | | | | | | | | 1 pen/ts | 1 pen |
| **10** | 0 | 0 | 1 pen | 0 | 1 pen | 1 pen | 0 | 0 | 0 | 0 | 2 pen | 1 pen |
| | | | | | | | | | | | | |
| **Cal** | na | na | na | na | na | na | na | na | na | na | na | na |
| | | | | | | | | | | | | 1 npen |
| **11** | 0 | 0 | 1 pen<br>1 pen/v* | 1 dent | 0 | 1 npen | 1 pen/ts head | 0 | 0 | 0 | 2 pen | 1 pen |
| | | | 2npen/v | | | 1 pen | | | | | | |
| **12** | 0 | 0 | 0 | 0 | 2 pen | 1pen | 1 npen | 0 | 0 | 0 | 2pen | 0 |
| | | | | | | | | | | | | |

**npen= damaged but not penetrated**
**pen= penetrated**
**dent= Ironman steel skin dented**
**/ts = thru shield**
**/v = thru vest**
*** penetration thru steel**
**** dent wood panel behind vest**
***** penetration thru wood and steel**

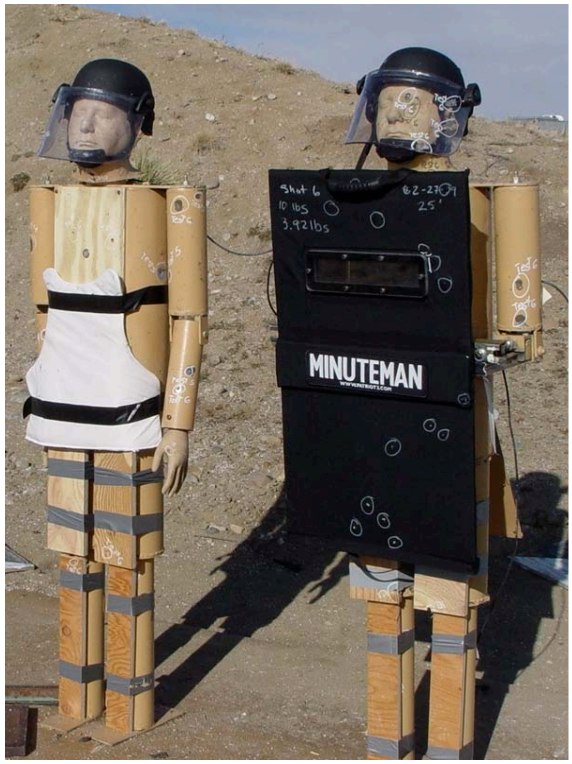


**Figure 15 Ironman with Ballistic Vest after Shot 6**

**Figure 16 Example General Fragmentation Damage to Ironman**

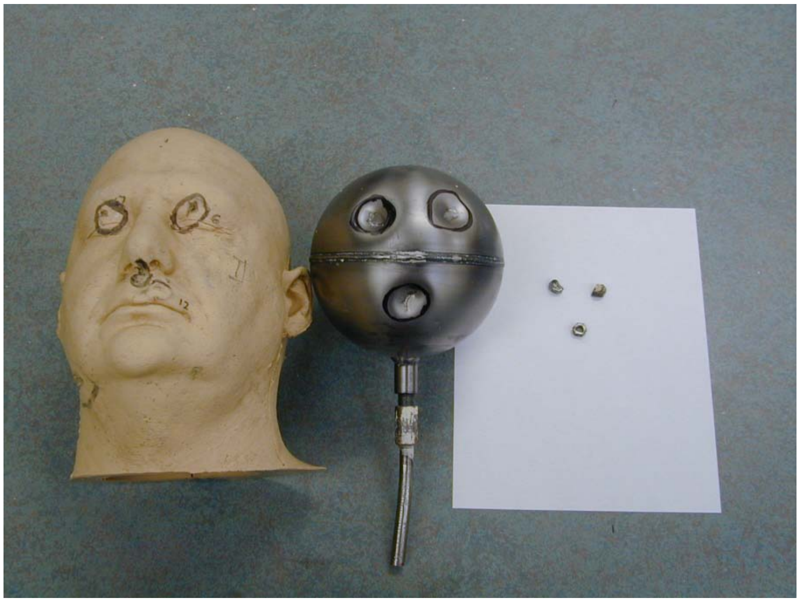

**Figure 17 Example Fragmentation Damage to Ironman Head Form**

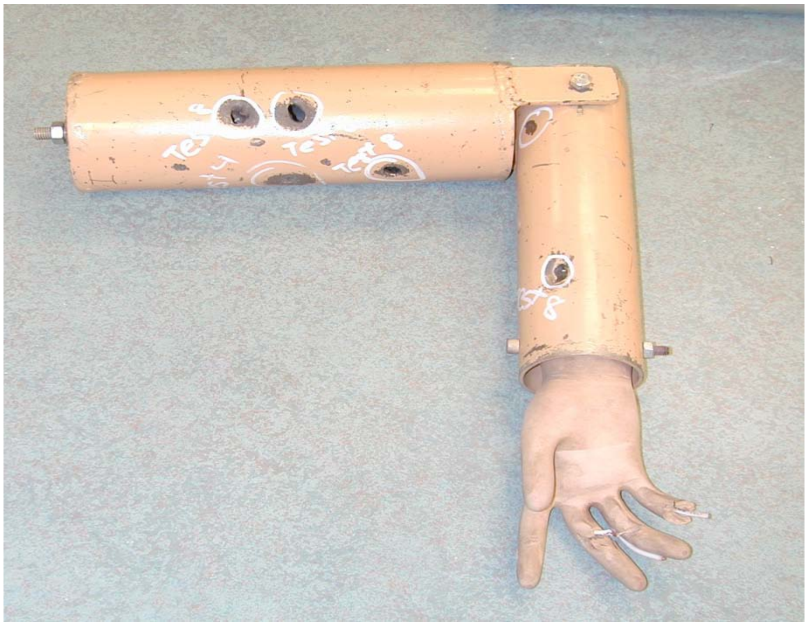

**Figure 18 Example Fragmentation Damage to Ironman Arms and Hand Form**

During the test program it became apparent that the shrapnel hazard from the suicide bomber was quite severe, so additional targets were added to the test environment. Helmets with face shields were put on both Ironman units in order to investigate how much protection this gear actually provided. Additional helmets (ROTHCO II and F6 PASGT) were placed on the ground closer to the bomber than the Ironman units in order to provide helmet impact data at closer ranges. Also, ballistic armor vests (PACA ESII-T

Tests 4 - 8 and PACA 04-ES-IIIA Tests 9 - 12) were added to investigate shrapnel damage and penetration from the hexagonal nut packs. One vest (actually the ballistic element from a vest) was taped to the front of the torso of the Ironman with no shield and one vest was taped to a ¾" plywood panel and secured to a pole. Additional shields where added for the last three shots (Body Bunkers, Model 2448 and Model 1936 both made by Pro-Tech Armored). Figures 19 – 23 show pictures of the additional shrapnel hits and penetrations to the targets. Table 4 provides the fragment penetration data for the added fragment targets.

Table 5 contains shrapnel data; fragment mass, fragment number, average fragment velocity, minimum fragment velocity, and maximum fragment velocity. The NEW in Table 5 refers to the Net Explosive Weight (NEW) formula. Interestingly, the calibration test had a NEW of 5.08 lbs and the predicted NEW from peak overpressure measured on the MARS probes and range to the probes, using hemispherical air burst simulation (required because of the ballistic gelatin torso back plane), was close at ~5.9 psi.

The data in Table 5 is from the University of Denver and was derived from the high speed video data.

**Figure 19 Helmet Fragmentation Target in Field Testing**

**Figure 20 Example Helmet Fragmentation Damage**

**Figure 21 Fragment Impact Points on Ballistic Vest**

**Figure 22 Rear View Exhibiting Penetration of Ballistic Vests and Plywood Panel**

**Figure 23  Back of the Ballistic Vest Exhibiting Penetrations**

**Table 4 Fragmentation Penetration Data – Additional Targets**

| **Added Helmet-Vest Shrapnel Data** | | | | |
|---|---|---|---|---|
| **Test** | **Distance to Helmet** | **Helmet** | **Distance to Vest** | **Vest** |
| | **(ft)** | **(hits)** | **(ft)** | **(hits)** |
| 1 | na | na | na | na |
| 2 | na | na | na | na |
| 3 | na | na | na | na |
| 4 | na | na | na | na |
| 5 | na | na | na | na |
| 6 | 15-20 | 1 npen | na | na |
| 7 | 15-20 | 1 npen | na | na |
| 8 | 20-25 | 1 npen | 25 | 2 pen* |
| | | 4 pen | | 4 pen** |
| 9 | 20-25 | 0 | 25 | 1 npen |
| | | | | 1 pen** |
| 10 | 20-25 | 0 | 35 | 1 npen |
| | | | | 2 pen** |
| cal | na | na | na | na |
| 11 | 35 | 2 pen | 35'8" | 2 npen |
| 12 | 35 | 1 pen | 35'7" | 1 pen* |
| | | | | 4 pen** |
| | | | | |
| pen = penetration | | | | |
| npen = no penetration | | | | |
| * penetration only 3/4" plywood | | | | |
| ** penetration vest and 3/4" plywood | | | | |

**Table 5 Fragment Data (from DU)**

| | | Shrapnel Velocities -DU High Speed Video | | | | | |
|---|---|---|---|---|---|---|---|
| **Test** | **NEW** | **Frag. Wt.** | **~No. Frag.** | **Velocities Measured at:** | **Average Frag. Velocity** | **Minimum Frag. Velocity** | **Maximum Frag. Velocity** |
| | *(lb)* | *(lb)* | | *(ft)* | *(ft/sec)* | *(ft/sec)* | *(ft/sec)* |
| 1 | 9.7 | nf | nf | nf | nf | nf | nf |
| 2 | 20.3 | nf | nf | nf | nf | nf | nf |
| 3 | 10.1 | 2.97 | 424 | ? | ? | ? | ? |
| 4 | 10.1 | 3.53 | 504 | * | * | * | * |
| 5 | 10.1 | 3.64 | 520 | 1758 | 2466 | 1758 | 3376 |
| 6 | 10.1 | 3.92 | 560 | 1507 | 1864 | 1507 | 2220 |
| 7 | 10.6 | 3.98 | 569 | 1950 | 2268 | 1950 | 2768 |
| 8 | 21.2 | 4.72 | 674 | 2592 | 2843 | 2592 | 3024 |
| 9 | 10.6 | 3.34 | 477 | na | ** | ** | ** |
| 10 | 10.6 | 4.22 | 603 | 1455 | 1718 | 1455 | 1947 |
| Cal | 5.08 | nf | nf | nf | nf | nf | nf |
| 11 | 10.6 | 4.29 | 613 | 1657 | 1831 | 1657 | 2071 |
| 12 | 21.2 | 7.94 | 1134 | 1894 | 2272 | 1894 | 2681 |

nf = no fragmentation
?=No data due to trigger issue
*=No flash panel installed
**=High speed Camera triggered late.

## 4.0 Lethality/Injury Results

Lethality/injury analyses were performed on the Ironman data and the shrapnel data. These analyses described the change in potential injury versus distance from the suicide bomber. Finally, potential "safe" distances were investigated. No safe distance from shrapnel was determined during this test series.

### 4.1 Pressure

Overpressure injuries to the lungs and ears can be an issue for a first responder and a SWAT officer if they are too close to the blast. To assess the risk of lung injuries, the four data sensors (discussed on page 11) from the Ironman mannequins were analyzed using the Injury 8.1 software developed by L3[1]. Injury 8.1 estimates the total work applied to the torso by the overpressure wave and correlates that metric to the risk of lung injury. The analysis of the overpressure data shows the peak pressure on Ironman varied from 36 to 2 psi for standoff distances from 20 to 60 feet respectively. The pressures

[1] Kan KK, Ho KH, Chan PC (2003) Use of INJURY on Thermobaric Blast Waves. Defense Threat Reduction Agency Contract; No. ICWA 02-01.

evaluated using the Injury code showed the probability of lung injury is negligible when a shield is used. When the shield was not used, a slight increase in the risk of lung injury was detected, but only at the shortest standoff.

While the risk of lung injury was negligible for these tests, the probability of ear drum rupture was significant for standoff distances less than 30 feet. To estimate the risk of eardrum rupture for an unprotected ear, the pressure data was compared against the published James curves.[2] Table 6 shows the percent risk of the ear drum rupture for each test.

**Table 6  Risk of Injury Results**

| Test | Standoff | Lung Injury | Ear Drum Rupture |
|---|---|---|---|
| 1 | 15 | Low | ? |
| 2 | 20 | Low | High |
| 3 | 20 | Low | High |
| 4 | 20 | Low | High |
| 5 | 25 | Low | ? |
| 6 | 25 | Low | High |
| 7 | 30 | Low | Moderate |
| 8 | 35 | Low | Moderate |
| 9 | 35 | Low | Moderate |
| 10 | 60 | Low | Low |
| cal | 60 | Low | ? |
| 11 | 60 | Low | Low |
| 12 | 60 | Low | Low |

?=data missing

## 4.2 Acceleration

Spinal acceleration data varied from 47 to 6 g and was collected to estimate the risk of injuries resulting from whole body dynamic motion. For this analysis, the 3-ms clip criterion from the automotive community was employed.[3] Using this criterion, injury is predicted to be probable if, during the event, the acceleration trace rises above 60g for more than 3ms. The results of the acceleration data analysis for this test series indicate the risk of injury from whole body motion was low for all standoff distances. In fact, neither Ironman was ever knocked over during the entire test series.

[2] James DJ, Pickette VC, Burdette, KJ Cheesman A (1982) The Response of the Human Eardrum to Blast: Part 1. The Effect of the Eardrum of a “Short” Duration “Fast” Rising Pressure Wave. Joint AWRE/DCE Report No. 04/82 Atomic Weapons Research Establishment, Aldermaston, Berkshire, England 1982.

[3] NHSTA (1997) Federal Motor Vehicle Safety Standards: Occupant Crash Protection, Code of Federal Regulations 49 CFR 571.208.

### 4.3 Blunt Impact

Ironman was configured to simulate a person rigidly holding the shield, waiting for the blast event. Other shield holding configurations were possible but were beyond the scope of this initial effort. Load cells in the forearms of Ironman were used to estimate the risk of upper extremity fracture from the overpressure loads applied to the shield surface. Blunt impact forces measured by the forearm load cells varied from 670 lbs at 20 feet to 18 lbs at 60 feet. The approximate force to fracture the forearm axially (down the length of the forearm) the way Ironman was holding the shield is approximately 750 lbs.[4] Shear force (across the forearm) the way this shield is held by responding SWAT members is 270 lbs. Therefore, there is a significant potential of forearm fracture if the responder is within 35' of the IED (see Table 6).

It should be noted that head injuries are possible. During one test, enough shrapnel hit the face shield/helmet on one Ironman head form that the force sheared the steel (1/4" pipe nipple) neck of the Ironman holding the shield. It is likely that these impacts could have caused a blunt trauma to the head. The Ironman with the shield suffered non penetrating hits to the face shield during test #3 and #6. There was also a penetrating hit during test #6 while the broken neck was discovered after test #7 the shrapnel from test #6 may have contributed to the damage (refer to Table 3). In future studies, it is recommended that the silicone head/neck form also be instrumented to better evaluate the potential blunt force injury from these penetrating injuries.

### 4.4 Shrapnel

Shrapnel added to the device caused a significant injury risk at all standoff distances tested. The velocity of the shrapnel varied from 3376 to 1507 feet/s. The number of impacts to the torso behind the armor was as high as five impacts per test. The data suggests the number of impacts and the velocity of the shrapnel were not affected by standoff distance. The data also suggests the mass and velocity of the shrapnel were sufficient to penetrate bare skin behind the shield at all standoff distances including the largest standoff distance of 60 feet. This study did not evaluate if a combination of the shield and body armor could defeat and stop the shrapnel from penetrating the body. Depending on the type of responder involved, first response patrol officers or SWAT, the body armor worn will be of different strengths. SWAT in most instances uses heavier body armor.

The risk to life from penetrations to the bare skin was estimated using the ComputerMan software residing within ORCA.[5] This system uses the straight line vector of the projectile through the body to estimate the velocity degradation and damage caused by the projectile passing through each organ. Risk to life from the damage caused is quantified by ComputerMan using the Abbreviated Injury Scale (AIS). AIS is a 0 to 6

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[4] Pintar F, Yoganandan, N Eppinger R (1998) Response and Tolerance of the Human Forearm to Impact Loading. SAE 983149, Proc 42nd Stapp Car Crash Conference

[5] Saucier, R. and Kash, H.M. III, ComputerMan Model Description, U.S. Army Research Laboratory ARL-TR-500, August 1994.

anatomical scoring system developed by the automotive community.[6] An AIS-0 indicates no risk to life and an AIS-6 is a fatal injury. The AIS is not an injury scale, in that the difference between AIS-1 and AIS-2 is not the same as that between AIS-4 and AIS-5.

In this study, it was observed that the risk of life was dependant on the location of the penetration in the body. If the fragment penetration was to the region surrounding the heart, there was an 80% probability that the heart would be penetrated and up to 40% of the lung volume could be lost. These injuries would be classified as AIS-6 injuries or fatal injuries. If the projectile penetrated slightly lower on the torso at these velocities, 50% of the liver could be damaged and more than 50% of the stomach could be affected. These injuries are classified as AIS-5 injuries or serious injuries. Penetrations to the abdominal region could cause AIS-4 injuries. AIS-3 injuries are penetration to the extremities that may sever an artery or vein. If the artery or vein is compromised, the time to shock from the penetration would be within 10 minutes.

### 4.5 Bio-hazard

The rough footprint for the bio-hazard appeared to be about 120'. Torso gel was located out to a 120 foot radius from where the suicide bomber IED was situated. This information stems from roughly mapping the gelatin impact zone around the bomber. In future testing, this hazard should be further investigated in order to help define safe standoff distances for potential victims.

## 5.0 Summary and Recommendations

Twelve tests were conducted during this very successful initial test program that captured significant lethality/injury data for first responders to a suicide bomber incident. Safe standoff distances for SWAT to set up in order to protect the approaching bomb technician were not established during this test series. The shrapnel from any of the test series explosions was a danger at all distances for the shrapnel tests. Greater distances should be used during future testing. Additional shielding that could fully protect the first responder also needs to be evaluated. Further testing is required before we can give a reasonable safe distance to SWAT or first responders.

### 5.1 Lessons Learned

The threat from a Person Borne Improvised Explosive Device (PBIED) is very real at distances outside the radius of the vests and shields utilized in this test series. The shields and vests are not designed to stop steel shrapnel traveling at the rate of rifle munitions.

SWAT personnel and the first responders need to be made aware that the bomber has to be kept at a distance greater than 60 feet. The responders also need to have shielding in addition to distance between the bomber and any potential victims.

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[6] Baker, SP O'Neill B, Haddon W (1974) The Injury Severity Score: A Method for Describing Patients with Multiple Injuries and Evaluating Emergency Care. J Trauma, 14:187-196.

The recommendations made in the "Initial Law Enforcement Response to Suicide Bombing Attacks" (a previous NBSCAB project) that advises the first responder to place the compliant bomber on the ground with the device under his/her torso needs to be re-iterated.  This idea is a valuable tool when confronted with a PBIED.

This report needs to remain classified as "Law Enforcement Sensitive" to protect this information from dissemination to those who would misuse it.

### 5.2 Data Results

Fifteen channels were recorded per test, which included pressure, acceleration, and arm force data.  Because of the simplicity of the Ironman mannequin and the miniDAS, only one person was required to field all of the data systems.

The pressure data appears to be somewhat modified from ideal spherical "point" charges. The pressure time histories seem to have additional characteristics (peaks) not normally associated with free field explosive detonations. Further, the pressure field around Ironman also seemed somewhat distorted from the expected pressures.  It is likely that the flight of the shrapnel and the gelatin from the bomber contributed to unexpected and additional pressure peaks in the recorded pressure time histories.

The whole body acceleration levels were low for the entire test series.  In fact, the Ironman mannequins were never tipped over (although they were rocking at times).

The new Ironman forearm load measuring system worked well and gathered relevant data.  Interestingly, however, after each test the Ironman's elbows had rotated until the shield was resting on his legs.  Although, as yet there are no definite reasons for this effect, it is believed that the negative phase of the pressure history probably pulled the shield down.

The shrapnel loading on both Ironman units was severe during this test program.  Also, the high speed video showed that there was a significant spread in shrapnel velocities, which provided for a longer duration lethal environment.

### 5.3 Lethality Results

Table 7 summarizes the lethality results. The major potential for injury to first responders at standoff distances of 60 feet comes from shrapnel accelerated by the detonation. These injuries can be fatal if the shrapnel intersects a major organ or artery. If a projectile does not strike the body, tympanic membrane ruptures to unprotected ears are likely at standoffs less than 30 feet.  Furthermore, fractures to the forearms from the overpressure wave pushing on the shield are likely at standoffs less than 35 feet.  The risk of injuries to the lungs or whole body displace related injuries are low at all standoffs that were tested.

**Table 7 Probability of Injury Summary**

| Standoff | Lung Injury | Ear Drum Rupture | Whole Body Motion | Fore Arm Fracture | Penetration Injury |
|---|---|---|---|---|---|
| 20 | Low | High | Low | High | ? |
| 25 | Low | High | Low | High | High |
| 30 | Low | Moderate | Low | High | High |
| 35 | Low | Moderate | Low | High | High |
| 60 | Low | Low | Low | Low | High |

?=data missing

**Preliminary Ballistic Shield Blast Standard**

Data from this initial test series suggests that for the type and amount of explosives tested, the type and weight of shrapnel utilized, and pre-set Ironman placement a "safe" distance was not established. At 60 feet, all of the measured injuries were low except for shrapnel penetration. During our limited test effort, the Type III ballistic gear tested seemed to stop most of the PBIED shrapnel at this distance. It should be pointed out however that the shrapnel velocities are still high at 60 feet and the probability of injury if an unprotected area is struck is high. Shrapnel hits to the shield at the higher speeds will also have an effect on the officer holding that shield. At 60 feet, first responders without a shield stand a significant risk of a penetration injury. Even with the protection of the shield, unprotected areas are subject to injury if hit by shrapnel. Further testing needs to be completed to find the standoff distance where the level III armor is 100% effective. The SWAT team and first responding officers need to utilize all available shielding and cover in this environment.

Additional testing should be conducted in order to further verify these preliminary results. The future testing should also be initiated at a greater distance. A lethality/injury distance should to be established. Once a face-to-face safe distance has been determined, it would be beneficial to change the range configuration by putting Ironman at different angles to the PBIED. This could be accomplished by moving Ironman out of the direct line of shrapnel dispersion. Approaching the bomber from the side reduces the threat from shrapnel because there is less area on which to put shrapnel. This was evident from this test series as only the front of the body had shrapnel in place. If the front or back are the only areas containing shrapnel, then approaching from the side would be the safest route. Consideration should be given to testing a higher level ballistic protection system. Other systems may be capable of stopping the shrapnel from penetrating the shield. The higher level may also be capable of protecting the SWAT team member from overpressure injury closer to the PBIED. One purpose of the testing was to determine how close the SWAT team can get to the bomber. This test series shows that even with a shield, 60 feet is too close. Although a heavier ballistic protection system may assist the SWAT response, the first responder patrol officer on scene will most likely have only a Type II vest.

Attention should be paid to the shrapnel events of this test series. The shrapnel seemed to fly as if it was fired from a large caliber, high powered shot gun located on the chest of the bomber. It flew out at roughly a 25 deg angle to the left and right of the PBIED. This would be a very devastating attack in an urban environment. As mentioned earlier in the lessons learned segment, if the bomber can be forced to lie down on top of the explosives and shrapnel charge pointing it into the ground the IED hazards would be greatly reduced for nearby first responders and any potential victims.

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