BALLISTIC BODY ARMOR

PROTECTING THE PROTECTORS

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FOREWORD

The field of ballistic protection is very wide in scope, and as such, is governed by several standards that give guidance for specific sub-sets of ballistic armor, both domestically and internationally. Due to the vast range of ballistic armors available, this discussion will focus solely on the ballistic resistance of personal body armor, and more specifically, that body armor available to and worn by domestic federal and local police personnel. Appendix A lists some of the other sub-sets of armor categories and the applicable standards for each.

UNDERSTANDING THE PROBLEM

Since the day the first man threw a rock at his cave-mate, societies have been racing to develop armor that would defend against the projectiles of their enemies, or to develop projectiles that would defeat their enemy's armor. As ballistic projectiles have gotten more sophisticated with technology, armor technology has had to keep pace or be left behind. Amazing strides have been made in the last quarter century in the field of ballistic protection, but as with any use of new technology, there have been setbacks, some severe. Without stringent and effective standards of manufacture and testing, those setbacks have the potential to envelop and cripple the industry. Very recent changes to the way ballistic armor is regulated will save the industry, and the lives of the police officers who depend on it.

HISTORY OF BULLETPROOF ARMOR

Although discussions of "bulletproof" and "pistol proof" plate armor exist as early as the 1500s, the first soft ballistic armor was invented in Korea in the 1860s. During a time of increased threat from Western armies, Korea's government directed the development of bulletproof armor. Two national weapons developers discovered through trial and error that garments consisting of multiple folds of cotton could protect against the gunfire of the era, although the garments were susceptible to fire.[1]

Towards the end of the 19th century, inventors in Arizona and Illinois produced bulletproof vests made of silk, which were proven to stop the rounds from blackpowder handguns. A vest of this type of design saved the life of King Alfonso XIII of Spain in 1901.[2]

[1] Myunjebaegab – Wikipedia. http://en.wikipedia.org/wiki/Myunjebaegab.
[2] Ballistic vest – Wikipedia. http://en.wikipedia.org/wiki/Bulletproof_vest.

The two World Wars necessitated further developments in personal armor. Typically, the models of armor developed by the United States and other nations were too heavy and cumbersome for ground troops. Two specific offshoots of the search for effective armor came in the form of American flak jackets for aircraft crews, which were designed to stop shrapnel but not bullets, and the SN-42 body armor developed by the Red Army for tankers and engineers. Improvements to ballistic armor were made in time for the Korean and Vietnam wars, but the garments were still not effective in the field.[3]

A Need for Protection

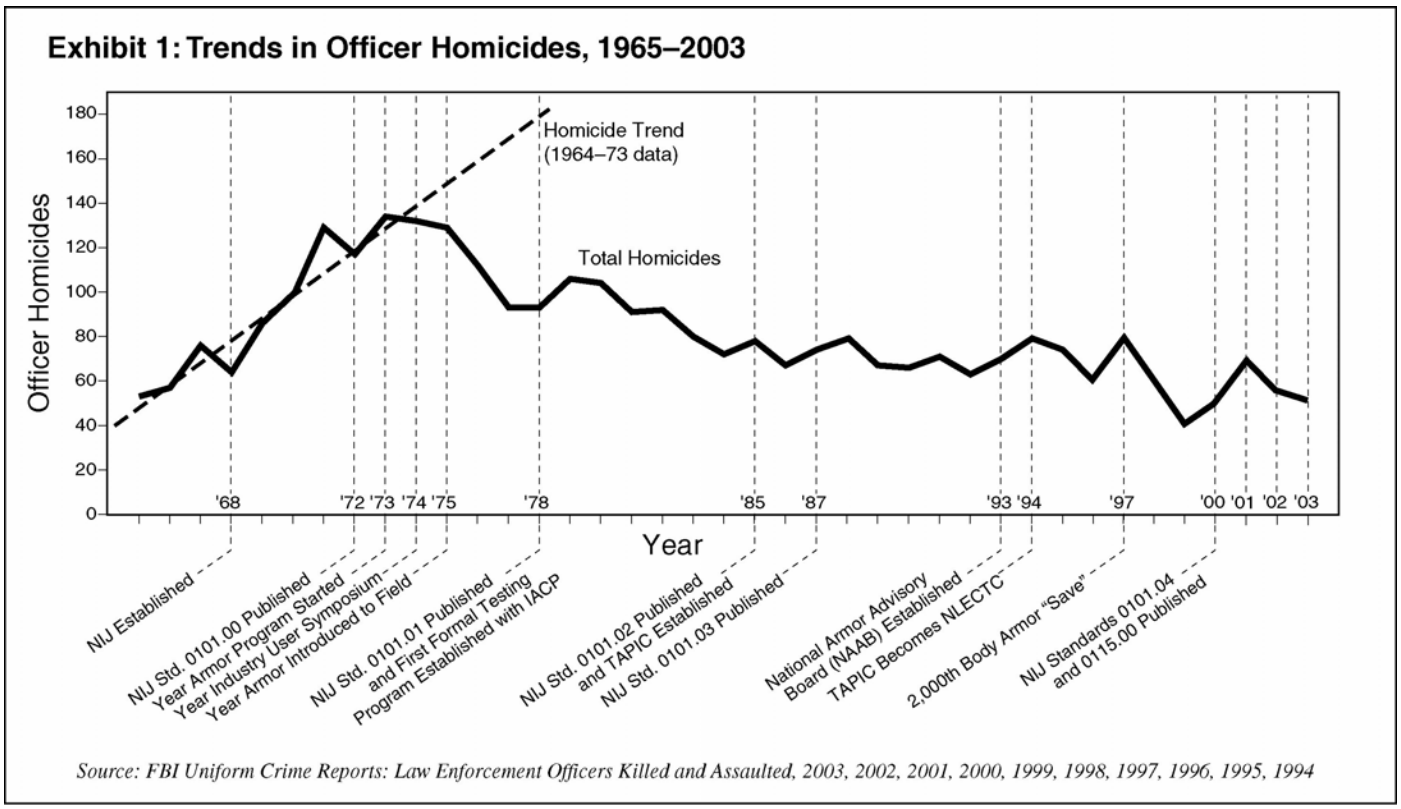

Figure 1

[3] Ballistic vest – Wikipedia. http://en.wikipedia.org/wiki/Bulletproof_vest.

The early 1970s were a dangerous time to be a law enforcement officer. From 1968 to 1973, the homicide rate of police officers increased by almost 20 each year. There was no dependable, affordable armor on the market comfortable enough or suitable to be worn on a daily basis. Through the development of new lighter and more durable materials, the bulletproof vest has gained wide acceptance and use in the law enforcement field. Forty years later, over 2900 officers' lives have been saved by their bulletproof vest.[4]

Modern Developments in Ballistic Materials

The first substantially effective ballistic armor was produced by a company called American Body Armor. Founded in 1969 and working with Smith & Wesson, American Body Armor created a "Barrier Vest" of nylon with multiple steel plates. It is considered the first widely used police vest, but was still significantly more costly than many officers or departments could afford.[5]

Kevlar®

In 1965, DuPont developed a technology for creating a spun synthetic fiber, which became the product Kevlar® in the 1970s.[6] Similar in molecular structure to Nomex© and Twaron©, Kevlar® is an aramid fiber, which is in essence a molecular combination of coal, air, and water. Kevlar® has a strength more than 5 times that of steel, with higher tensile strength and elasticity than similar spun synthetics.[7,8]

Dyneema ®

[4] Dr. Morgan, John, Assistant Director for Science and Technology, National Institute of Justice. *Body Armor Standards and Testing Technical Workshop*, November 21-22, 2005.
[5] Ballistic vest – Wikipedia. http://en.wikipedia.org/wiki/Bulletproof_vest.
[6] 1965: Kevlar®. http://heritage.dupont.com/touchpoints/tp_1965-2/depth.shtml.
[7] Aramid – Wikipedia. http://en.wikipedia.org/wiki/Aramid.
[8] Welcome to DuPont Kevlar®. http://www2.dupont.com/Kevlar/en_US/index.html.

In the 1990's, DSM patented a method of "gel-spinning" polyethylene fibers that were exceptionally light and durable. The product was named Dyneema ®, and has been adapted for use in a wide range of products, from fishing line and nets, to medical implants. In the field of ballistic protection, Dyneema ® can be used in soft armor or hard armor. The fibers are laid in sheets of parallel strands, with the sheets being laid on top of each other at 90 degree angles. The soft armor made from Dyneema® has been found to be resistant to moisture effects and temperature extremes. It is also buoyant, making it ideal for maritime uses.[9]

Spectra®

Honeywell's Spectra® line of products has been in production since the 1980s in various forms. After DSM sold the gel-spinning technology used to make Dyneema®, Honeywell expanded their Spectra® ballistic products to include a product called Spectra® Fiber. This fiber can be used for many of the same things that Dyneema® is used for, as it is very similar.[10]

Zylon®

Zylon® is the brand name of poly(p-phenylene-2,6-benzobisoxazole), which is a synthetic polyurethane fiber manufactured by Toyobo, a Japanese corporation. When it first came available in 1998, Zylon® was an instant hit. It was the lightest of any of the ballistic garments on the market, was significantly stronger than the aramids and polyethylenes, and was widely versatile for manufacturing purposes.[11] It would soon be the scapegoat of the industry.

PROBLEMS IN THE FIELD

[9] DSM – Dyneema. http://www.dsm.com/en_US/html/hpf/home_dyneema.htm.
[10] Honeywell Advanced Fibers and Composites. http://www51.honeywell.com/sm/afc/.
[11] Toyobo. http://www.toyobo.co.jp/e/index.htm.

On June 13th, 2003, a police officer in Oceanside, CA was shot in the vest at close range. The vest failed to stop the bullet as it was designed to, but the shot was closer to the edge of the vest than the specifications required. Additionally, the officer was shot multiple times, and other shots were outside the vest and would have been fatal individually.

On June 23rd, just 10 days later, an officer in Forest Hills, PA, was shot in the arm and abdomen with a gun that the vest was designed to protect against. The shot in the abdomen penetrated the vest. Luckily, the officer survived, but he was sorely wounded. In both cases, the vests were made by Second Chance, and were constructed of Zylon®.

Immediate Fallout

The most pressing question to be answered immediately was the safety of the 200,000 or so American police officers wearing Zylon®-made body armor. Within three months, Second Chance had discontinued the two models of domestic armor made from Zylon®. The company offered to upgrade the vests still in circulation with an extra set of protective panels, or to give a steep discount on new vests made from Kevlar®.[12]

In November 2003, Attorney General John Ashcroft announced the Department of Justice's (DOJ) investigation into the Forest Hills shooting. A series of tests was run on both the armor from the Forest Hills shooting as well as a batch of used armor donated by various agencies nationwide. The Forest Hills armor was found to be as much as 30% weaker than similar new armor. Even more telling, of 103 used Zylon® armors, 60 (58%) were penetrated by at least one test round. Of the vests not penetrated, 91% failed the Backface Signature (BFS) test, which is an indicator of the potential blunt trauma

[12] New York Times. "Company's Bulletproof Vests Are Questioned." nytimes.com 26 December 2003. http://query.nytimes.com/gst/fullpage.html?res=990CE4D6163EF935A15751C1A9659C8B63.

experienced by the body underneath the armor. Only 4 vests of the original 103 passed all testing.[13]

DOJ was also directed to test the upgrade kits offered by Second Chance, to determine if the kits met NIJ performance standards when used with the original vest. Second Chance provided 50 sets of upgraded armor for testing, in all three classes of soft armor. Testing conclusively showed that although the upgrade kits added protection, they did not meet existing standards for new body armor. All three classes of armor experienced excessive BFS, and 25% (2 of 8) of the Type IIIA upgrades experienced penetrations.

Following the initial and subsequent testing by NIJ, it was concluded that heat, moisture, UV & visible light, detergents, friction, and stretching may contribute to degradation of fibers in body armor. The evidence showed obvious and unexpected degradation of Zylon®-based armor.

A STUDY OF BALLISTICS AND STANDARDS

National Institute of Justice and Other Standards

The National Institute of Justice (NIJ) is tasked with researching, maintaining current, and promulgating the pertinent domestic standards in the field of ballistics. The standards "establish minimum performance requirements and methods of testing for the ballistic resistance of police body armor intended to protect the torso against gunfire."[14] NIJ has delineated five levels of ballistic protection, classified (in order of protection) as IIA, II, IIIA, III, and IV. Types IIA, II, and IIIA are designed to defeat handgun rounds of

[13] United States. U.S Department of Justice. Bulletproof Vest Partnership/Body Armor Safety Initiative: Results of Body Armor testing. By Regina B. Schofield. 1 Feb. 2007. http://www.napo.org/pr/BulletProofVestItems/BodyArmorArticle.pdf.

[14] United States Department of Justice, Office of Justice Programs, National Institute of Justice. Ballistic Resistance of Body Armor NIJ Standard-0101.06. Eds. Rice, Kirk; Riley, Michael; Forster, Amanda. Gaithersburg, MD.: Office of Law Enforcement Standards, 2008.

varying calibers and energies. Type III is an anti-rifle protection, and Type IV is for armor-piercing rifles. These last two classifications are for hard armor or plate inserts.[15]

NIJ is not the only standards body for ballistic materials. On the international scale, several countries have their own standards bodies or use other standards than the American ones. Two examples are the Australian and New Zealand AS/NZS 2343:1997 Standard for ballistic panels, and the European Standard EN 1063:1999 Security Glazing Ballistic Standard.[16] Non-NIJ standards are beyond the scope of this discussion, but it is important to note that other countries and organizations have their own standards.

Important Standards-related Terms

Two important concepts in the testing of soft ballistic armor (Types IIA, II, and III) are the ballistic limit and the backface signature (BFS). The ballistic limit is simply the velocity of a given bullet at which the armor is expected to fail 50% of the time. Failure is denoted as partial or complete perforation of the garment. This velocity value is denoted as V50 or V_{50}.[17]

BFS is a more complicated concept. In its simplest form, BFS is a measure of how much impact the bullet leaves on the substance under the armor once the armor stops the round from penetrating. BFS is measured in the lab by creating a bed of clay onto which the armor is strapped. The clay bed, called the backing, is a specific commercial grade of clay, at a specific temperature and thickness. This uniformity guarantees that test results will not be skewed based on a variance between testing materials in the lab. The armor is placed in direct contact with the backing, and the round is fired into the armor. As seen in

[15] USDOJ: Ballistic Resistance of Body Armor.
[16] CRAIG International Ballistics – NIJ EN STANAG Ballistic Standards. http://www.ballistics.com.au/technical/ballisticandstabstandards.php.
[17] USDOJ: Ballistic Resistance of Body Armor.

Figure 2, the impact of the bullet leaves an indentation in the backing material. The depth of the indent is measured and recorded as the BFS.

BFS testing is done in conjunction with the perforation testing, which is referred to as P-BFS. If the armor passed the "P" portion of the test by not allowing the bullet through the garment, it still must pass the "BFS" portion by not allowing a signature underneath the armor of greater than 44mm (1.73 inches).[18] As a point of reference, the European standard for BFS is 20-25mm.

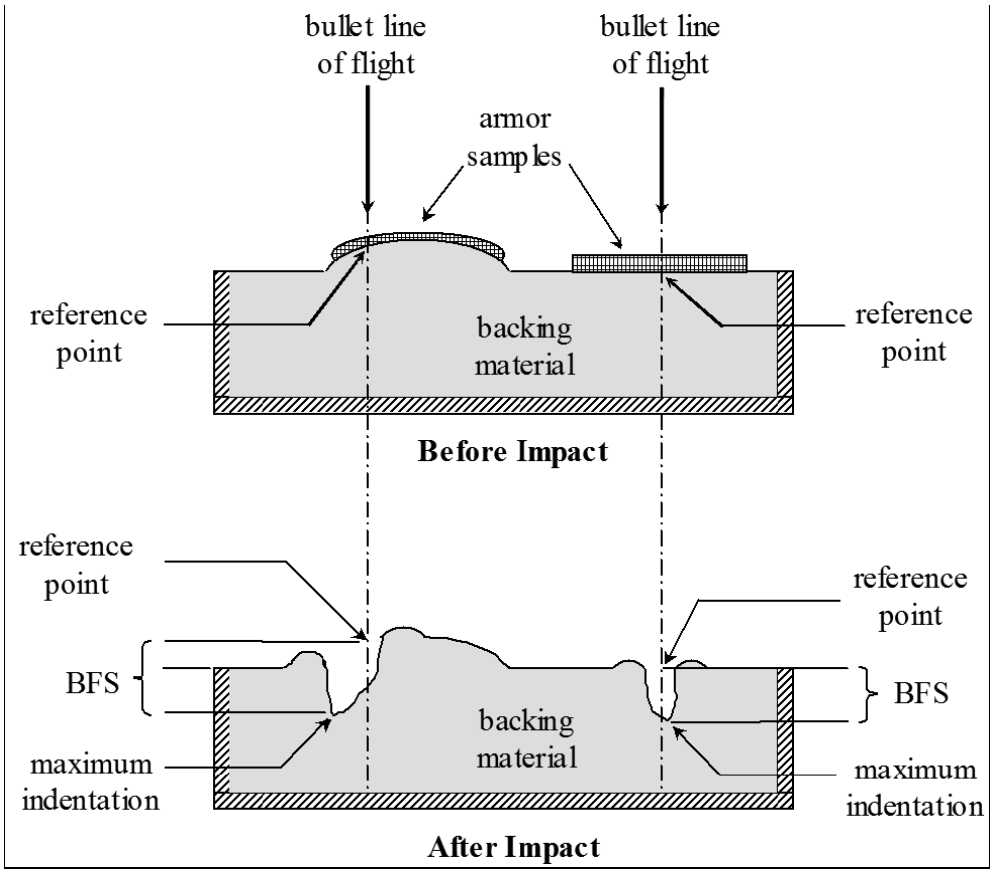

Figure 2

Detractors of this particular test claim that the injury potential from behind armor blunt trauma (BABT) is significantly greater than can be measured with BFS, and that

[18] USDOJ: Ballistic Resistance of Body Armor.

current BFS is not adequate for a host of reasons. The human body does not behave in the same manner as ballistic clay, and does not dissipate energy the same. An effect known as "penciling" can cause severe injury deeper beneath the surface than is demonstrated in the clay, all without breaking the skin.[19] Also, there is no way to measure the possibility of the energy being transferred through the body and bone to an organ that would be damaged simply by the shock. Currently, the clay method is the only approved method for measuring BFS, although there have been suggestions of using animals, cadavers, and computer modeling as other more accurate options.

NIJ 0101.06

Standards of Testing

The first NIJ standard was published in 1972, and underwent four revisions through the turn of the 21st century. The fifth revision to the NIJ ballistic standard, following the Forest Hills shooting, was released in draft form in 2007, to be finalized and published in 2008. The standard was very heavily revised, more so than all the other revisions combined. Among other things, it called for environmental testing and water submersion, in order to subject test armors to simulated conditions of heat, moisture, and mechanical damage. Earlier versions of the standard provided no testing for environmental conditions, and only a spray of water vice submersion. The revised standard also addressed the number of samples tested for certification, vest sizing, and made changes to the armor classifications and threat velocities.[20]

[19] NIST/OLES – Weapons and Protective Systems. http://www.eeel.nist.gov/oles/weapons.html
[20] *MSA White Paper on Proposed NIJ Standard 0101.06.* Raimondi, John. 18 Apr 2008. Mine Safety Appliances Company. http://media.msanet.com/www/pdfs/MSApoliceline/NIJstandards.pdf.

Armor Type	Test Projectile	Reference Velocity (Used Armor)	New Armor Test Velocity	NIJ-0101.04
IIA	9 mm FMJ RN (124 gr)	1165	1224	1120
	40 S&W FMJ (180 gr)	1066	1155	1055
II	9 mm FMJ RN (124 gr)	1247	1306	1205
	.357 Mag JSP (158 gr)	1342	1430	1430
IIIA	.357 SIG FMJ FN (125 gr)	1411	1470	1430 (9 mm)
	.44 Mag SJHP (240 gr)	1342	1430	1430
III	7.62 mm NATO M80 Ball (148 gr)	2780	2780	2780
IV	.30 cal M2AP (166 gr)	2880	2880	2880

Chart 1

As shown in Chart 1, the 5 types of armor vary by bullet caliber and velocity. One of the major changes in the NIJ standard was to eliminate one of the classes of armor that was no longer considered effective protection. Additionally, three of the five remaining classes were changed in either bullet type or velocity or both, in order to expose the armor to velocities and rounds that are increasingly likely to be encountered in the line of duty. Lastly, a category was added to the ballistic tables to allow accurate testing and grading of used armor.

Due to the immediate testing that followed Forest Hills, it was obvious that heat, moisture, light, and mechanical agitation reduced the effectiveness of Zylon®-based armor. Earlier versions of the NIJ standard assumed that armor was new, which was the mode of testing. No thought had ever been given to the degradation of armor over time. The revised standard had specifications for mechanical agitation, humidity levels, water immersion, and temperature.

In the development of the standard for environmental conditioning, a series of trials was run. Phase 1 consisted of 8 weeks of cyclical temperature and humidity exposure (35-65 °C; 75 %RH), and 3 hours of tumbling 3 times per week at room temperature for the 8 weeks. At the conclusion of Phase 1, no significant reduction was seen in Kevlar® armor performance, but there was significant reduction in Zylon® armor performance. 10 of the 18 Zylon® armor panels used in the testing were penetrated by at least one round during the 6-shot testing. Due to the relatively small sample size, it was not possible to draw strong statistic-based conclusions regarding manufacturers, materials, models, etc.[21]

Phase 2 was more rigorous. The temperature and humidity cycles were separated from the mechanical agitation, and the vests were tumbled twice a day four days a week, for an hour each time. More drastic changes in temperature and humidity were also implemented. At the end of 5 weeks, there was an even more significant reduction in Zylon® armor performance. 48 of the 75 panels in this test group were penetrated, and 10 of those were penetrated by all six shots fired. Of the remaining 27 vests that were not penetrated, 25 experienced BFS outside the allowable specifications. The official conclusion drawn from Phase 2 was that used body armor containing Zylon® may not provide the designed level of ballistic protection.[22]

Water has a significant negative effect on the strength of many ballistic fibers. Previous tests had used a water misting specification. The new specification called for samples to be submerged in a bath for 30 minutes prior to testing. This revised method provides better indication of panels' resistance to moisture.

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[21] United States Department of Justice, Office of Justice Programs, National Institute of Justice. Third Status Report to the Attorney General on Body Armor Safety Initiative testing and Activities. Hart, Sarah V. Washington, D.C.: National Institute of Justice, 24 Aug 2005.

[22] USDOJ, Third Status Report to the Attorney General.

The range of sizes of the vests tested was also expanded. 5 different sizes were now required to be tested, because preliminary evidence suggested that large armors were more easily penetrated, and smaller armor tended to have higher BFS. Also, the wider range of sizes takes into account the varying sizes of the officers wearing the armor.[23]

Standards of Manufacture

Another issue that had not been adequately addressed in earlier versions of the ballistic standard was the manufacture of the vests. For NIJ 0101.06, a regimen of manufacturing standards was established. No requirement for the base materials was addressed, as failure of the manufacturer to ensure the base materials met specifications would be discovered in the ballistic testing. However, the vests are now inspected for workmanship. Wrinkles, tears, fraying, sharp corners or edges, and uneven stitching will all remove a vest from further testing. If the vest does not closely meet the sizing template, the vest is rejected. If there is variance in a sample of vests of the same type and same size, the whole batch will be rejected.[24]

COMPLIANCE TESTING

In conjunction with revising the ballistic standard, the National Institute of Justice also strengthened their voluntary compliance testing program (CTP). The purpose of the program is to enhance confidence that the body armor being used on the street is safe, reliable, and meets all specifications for the life of the garment. In order to do that, oversight must exist at all levels of the process.

There are four basic parts to the CTP. In type testing, ballistic armor undergoes rigorous testing using standard laboratory equipment and measurements, at accredited

[23] Dr. Morgan, John, Deputy Director for Science and Technology, National Institute of Justice. *Ballistic Resistance of Personal Body Armor Revised Standards and Activities*, IACP Conference, October 15, 2007.
[24] USDOJ: Ballistic Resistance of Body Armor.

laboratories. The compliance decision is where NIJ reviews the data and determines whether the armor meets requirements. This is followed by the attestation of conformity, where NIJ formally recognizes the product and gives their official stamp of approval. Lastly, the conformity assessment provides continuous and periodic retesting to ensure manufacturers continue to meet the standards of the program.[25]

Type Testing

Type testing is the most prolonged and complicated step in the CTP. In order for a laboratory to even begin taking part in the program, they must first be accredited through the National Voluntary Laboratory Accreditation Program (NVLAP). NVLAP accredits testing and calibration labs that are found competent to perform specific tests or calibrations. NVLAP is compliant with the applicable ISO/IEC standards for laboratory conditions.[26]

Once a lab receives NVLAP accreditation, it then has to apply to be an NIJ-approved lab for the CTP. NIJ criteria (aside from being NVLAP-accredited) include that the lab be an independent third-party lab based completely in the U.S., with no conflicts of interest, as well as be agreeable to site visits by CTP officials as part of the program. The manufacturer has to meet similar requirements to be allowed into the CTP. They must be ISO 9000 compliant, agree to the CTP's program requirements, and agree to manufacture all units of compliant models identical in all respects to the original model. As with the labs, they must agree to allow NIJ full and complete access to all facilities, personnel, and records. Once the manufacturer and lab are both approved for inclusion in the program, the

[25] Morgan, *Ballistic Resistance of Personal Body Armor*.
[26] United States Department of Commerce, National Institute of Standards and Technology. National Voluntary Laboratory Accreditation Program Procedures and Requirements. Eds. Faison, C.D.; Horlick, J.; Merkel, W.R.; White, V.R. Gaithersburg, MD.: National Institute of Standards and Technology, 2008.

manufacturer can provide the lab with the model(s) it wishes to have accredited. The laboratory will perform its analysis and returns the results to the CTP.[27]

Compliance Decision and Attestation of Conformity

After reviewing the data from the lab, the CTP determines whether a manufacturer's armor model should be included on the compliance list. The compliance list (maintained at http://www.justnet.org/BatPro/) determines whether a manufacturer's vests can be purchased through the Bulletproof Vest Partnership (BVP) Grant Act. The BVP funds up to 50 percent of the cost of each vest purchased by participating agencies. Only vest models that comply with the NIJ CTP may be purchased with BVP program funds.[28]

It is advantageous for a manufacturer to be on the compliance list, in order to take advantage of the federal grant money available, but it is not technically required. However, it is very highly unlikely that the manufacturer will have much luck selling vests not on the list to police agencies, both for safety and for financial reasons. Interestingly, manufacturers place such weight in the strength of the NIJ compliance list that they will voluntarily remove their own products from the list if they see fit. In February, 2008, a major producer removed several models of vest from the list because they had been notified by DSM that the Dyneema ® used in production of those vests had exhibited some reduction in performance during certain tests administered by DSM. Those models were summarily removed from the list, and a public notice was posted to inform consumers of the problem and the recall.[29]

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[27] Morgan, *Ballistic Resistance of Personal Body Armor*.
[28] *Bulletproof Vest Partnership Program Fact Sheet.* Hammond-Decker, Linda. 24 Aug 2005. U.S. Department of Justice, Office of Justice Programs, Bureau of Justice Assistance. http://www.ojp.usdoj.gov/bvpbasi/.
[29] NLECTC Body Armor Testing Program Database. http://www.ojp.usdoj.gov/bvpbasi/.

Conformity Assessment

The conformity assessment program exists to ensure that the manufacturer continues to meet specifications with the armor being produced, as it did when it was initially found to be compliant. A manufacturer can be retested as often as every six months. The CTP chooses which lab will do the testing, and the company will submit the required armor to the lab. Just as with initial testing, no perforations of the armor are allowed, and BFS must be within the required 44 mm. It is important to note that this assessment is only of continued compliance with manufacturing standards and that none of the testing associated with this phase of the CTP is intended to test used vests or to provide any environmental aging.[30]

Conclusion

Weapon and armor technology has advanced greatly in the last quarter century, at an increasing rate. Unfortunately, the standards that govern this industry were not keeping up, and it took the death of a law enforcement officer and the serious injury of another to bring everyone's collective attention to the matter. The rigorous changes that NIJ has made to their standards of testing and manufacture have done a great deal to address these deficiencies, but more importantly, the attitude of the industry has changed. The reactive mindset has been replaced with a more proactive stance, and a system has been set in place to continually monitor the ever-changing landscape of ballistic technology. This can only be beneficial to the men and women of law enforcement, and it clearly shows government and industry commitment to their safety and the safety of the American people.

[30] Morgan, *Ballistic Resistance of Personal Body Armor*.

Appendix A

This is a partial list of other ballistic armor standards that NIJ is responsible for. Many of these standards can be found in their entirety on the Justice Technology Information network (JUSTNET), which is run by the National Law Enforcement and Corrections Technology Center (NLECTC). The NLECTC library can be found online at http://www.nlectc.org/virlib/default.asp.

NIJ Standard 0115.00, "Stab Resistance of Personal Body Armor"

NIJ Standard 0108.01, "Ballistic Resistant Protective Materials"

NIJ Standard 0104.02, "Riot Helmets and Face Shields"

NIJ Standard 0106.01, "Ballistic Helmets"