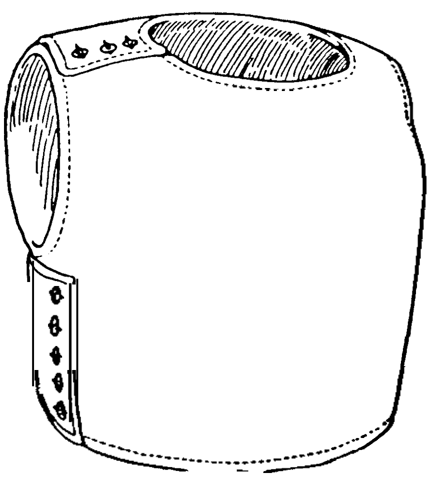
# Police Body Armor Standards and Testing

**Examples of Soft Armored Undergarments**



**Silken body armor of the type Austrian Archduke Francis Ferdinand was reported to have worn on the day he was assassinated by a shot in the neck in 1914.**

SOURCE: Bashford Dean, 1920. [53]

**Modern soft body armor containing layers of material made from synthetic fiber. This armor uses woven fabric; other soft armor uses sheets of nonwoven material made by bonding synthetic fibers with adhesive.**

SOURCE: Second Chance Body Armor, Inc., 1991.

## INTRODUCTION

Every year, about 60 sworn police officers are shot to death in the line of duty.[1,2] At the same time, about 20 are saved by wearing armor. Had all the officers shot in recent years been wearing armor when shot, another 15 per year would likely have been saved from fatal gunshot wounds, roughly doubling the present number saved, and more than 15 others would likely have been saved from death by other causes.[3]

Most police officers serving large jurisdictions report they have armor and wear it at all times when on duty and clearly identifiable as police officers [102]. The kind of armor usually worn is soft armor, which is designed to be concealable-most styles are undergarments-and comfortable enough to be worn routinely. Such armor is designed for protection from handgun bullets but not from rifle bullets or edged or pointed weapons such as knives or icepicks. The distinctive, nonconcealable 'tactical'

[1] Most lethal shootings are felonious; a few are accidental.

[2] Many unsworn police officers, such as private security guards, are also shot to death.

[3] See Findings, below.

### *Box A—How Soft Armor Works*

***Soft body*** armor works by catching the bulletin a net-like web of very strong fibers. The bullet stretches not only the few fibers it hits, but also others in contact with them, and many more that those pull. As in any net, the key to success is that many fibers, even those not actually touching the bullet, elongate in response to the collision and so absorb the energy of the bullet. Even so, materials available today do not permit the construction of a vest from a single ply of fabric-a number of layers, often about one or two dozen, are needed to stop a bullet.

Soft armor has been made from a variety of natural and, more recently, synthetic fibers. For example, silk, which had been used for armor in medieval Japan, was used in American ballistic (bullet-resistant) armor late in the nineteenth century. It attracted Congressional attention after President William McKinley was assassinated in 1901, and was said to have been worn by Archduke Francis Ferdinand of Austria when he was killed by a shot in the head, which precipitated World War I. Although it provided some protection against handgun bullets at low velocity (e.g., .40-caliber lead or .45-caliber jacketed at 400 feet per second), it could not stop higher velocity handgun bullets (e.g., .45-caliber jacketed at 600 feet per second), much less rifle bullets. This shortcoming, together with the expense of silk (then about $80 per garment), made silk armor unattractive to the U.S. Ordnance Department in World War I. [53]

The tensile-strength-to-weight ratio ("tenacity") of silk-no more than about 5 grams per denier [89]—was surpassed by synthetic fibers such as nylon (8 g/d) and, later, Kevlar® (26 g/d) and Spectra™ (35 g/d). Some spider silk has even greater tenacity, [162] but it cannot be cultivated and collected economically as silkworm silk can. Genetic engineers are striving to develop a way to copy it.

During the Second World War and the conflict in Korea, the United States Army developed soft armor made of nylon. These vests provided considerable protection, but were very bulky.

Concealable soft body armor as we know it today was made possible in the mid-1960s, when a solvent for polyaramid plastic was discovered; this permitted the production ("spinning") of polyaramid fiber (see box B). Polyaramid fibers have higher tenacity than nylon does, and less elongation before breaking than silk or nylon. The first soft body armor for police use, however, was of nylon. Richard C. Davis holds several patents relating to police body armor, [47, 48,49, 50] including one [47] for a small, light nylon vest designed to protect the wearer's vital organs from the short-barreled, medium-caliber handguns known as "Saturday night specials. " The application for this patent was filed on May 8, 1972.

Today, several types of polyaramid fiber are marketed under the names Kevlar® (by the duPont de Nemours Co., Inc.) and Twaron® (by Akzo, Inc.). The fiber is woven into fabric by weavers (two or three produce most of the U.S. ballistic fabric), and the fabric is used in the construction of vests by several U.S. and foreign manufacturers, The first "save" credited to Kevlar® armor occurred in 1973.

More recently, soft armor has been made from fibers of extended-chain polyethylene (ECPE). Produced by Allied-Signal, Inc., the fiber, marketed as Spectra™, has greater tenacity and slightly less elongation than Kevlar™. Although some Spectra™ fiber is woven into Spectra™ fabric for armor, Spectra™ is also used by Allied-Signal in the manufacture of Spectra Shield®, a nonwoven composite material used in soft as well as rigid armor (see box C). A single thin, flexible sheet of Spectra Shield® is made by (1) bonding a single layer of closely spaced parallel fibers together with Kraton™ resin (produced by Shell Chemical) to form a single ply, (2) bonding two such plies together, one rotated 90 degrees from the other, and (3) coating each surface of the two-ply sheet with a film to reduce friction and abrasion. Several such sheets are required to provide protection from handgun bullets: Spectra Shield® was first sold to body armor manufacturers in 1988.

Some manufacturers make "hybrid" armor by sandwiching sheets of Spectra Shield® between layers of Spectra™ or Kevlar® fabric.

Untreated fabric woven from either polyaramid or ECPE fiber loses some ballistic performance when it is wet. Possibly the water lubricates the intersections of the weave, so that stretching fibers slip on their neighbors rather than pulling them into sharing the work of stopping the bullet. There are three options for preventing or reducing this effect:

- The fiber or fabric may be treated by any of several processes to promote water-repellency.
- Armor panels of untreated fabric may be encased in waterproof covers.
- Armor panels may use enough untreated fabric to provide the ballistic resistance desired even when wet.

Upon drying, untreated fabric of either type regains its original ballistic performance. The ballistic resistance of panels of Spectra Shield® non-woven composite material is unaffected by wetness.

**SOURCE: (Office of Technology Assessment, 1992.**

### *Box B--Kevlar[R] and Twaron[R]*

Kevlar[R] is strong fiber made from polymeric aromatic amide (polyaramid) plastic by dissolving it in a special solvent and spraying the solution through a small nozzle called a spinnerette. The solvent evaporates, leaving the plastic fiber, which has a strength-to-weight ratio about five times that of steel. The possibility of making polyaramid plastic was hypothesized in 1939. It was synthesized and identified at DuPont in 1960, but polyaramid fiber could not be produced until 1965, when Stephanie Kwolek, a chemist at DuPont, discovered a practical solvent.

At about the same time, a team at Akzo, Inc., a multinational firm headquartered in Holland, independently discovered a practical solvent and applied for a patent for the manufacture of polyaramid fiber, which DuPont named Kevlar[R] and Akzo later (1984) named Twaron[R]. DuPont contested the patent. A consent decree of the International Trade Commission settled the dispute; terms of the settlement included cross-licensing but barred Akzo from marketing Twaron[R] in the United States until late 1990.

Before Kevlar[R] was used for body armor, it was used as a substitute for steel in the manufacture of radial tires, including those designed for police cars. It does not melt but does pyrolyze (decompose) at very high temperature. It loses some strength as its temperature is increased but remains strong enough to be used for applications requiring high strength-to-weight ratio at high temperature--e.g., in the telescoping nozzles of solid-fuel rocket motors of the Peacekeeper (formerly MX) missile.

"Kevlar" is a registered trademark of DuPont de Nemours and Co., Inc. "Twaron" is a registered trademark of Akzo, Inc.

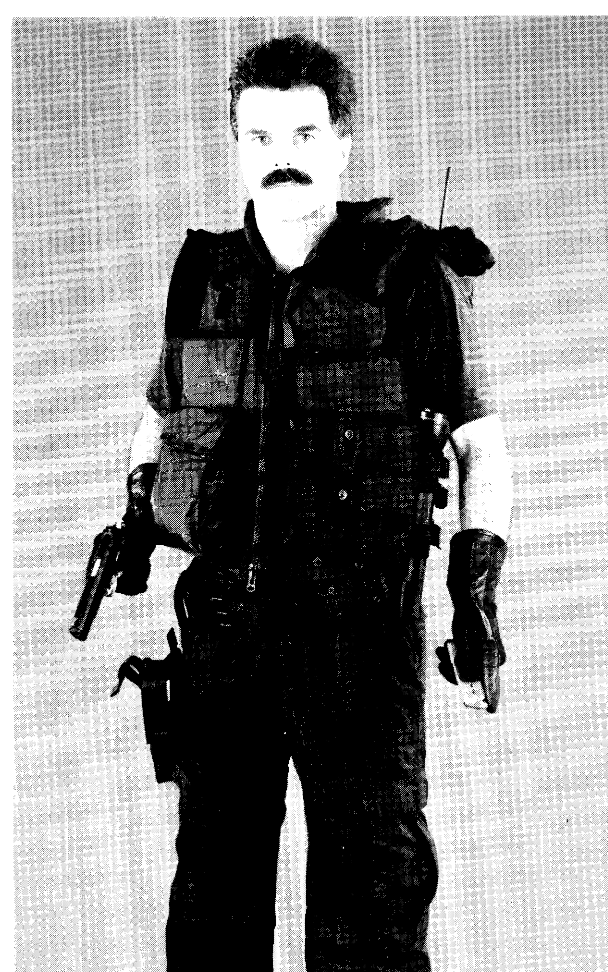
SOURCE: Office of Technology Assessment, 1992.

armor worn by police SWAT (Special Weapons and Tactics) teams for protection from rifle bullets as well as pistol bullets is more familiar to many laymen.

Garments of both types are sometimes called "bulletproof vests,' but no garment will *certainly* stop any bullet. Indeed, there is no guarantee that a bullet of a type a garment is designed to stop will not kill a wearer. Much of the body is not covered by the protective panels of a particular armor: an astute purchaser may choose a model from the many on the market, fully aware of that coverage limitation. However, *the ability of armor to stop bullets--its "ballistic resistance ''-cannot be discerned by inspection; it must be inferred from the results of tests in which sample armor is shot.* Because such testing is destructive, vests slated for marketing are not tested. Moreover, the conditions under which an officer is shot are unlikely to be identical to test conditions.

In 1972, in an effort to provide police departments guidance in such testing, the National Institute of Law Enforcement and Criminal Justice (NILECJ), a part of the Department of Justice, issued a standard for ballistic resistance of police body armor, NILECJ Standard 0101.00. It specified general procedures and specific types of bullets and velocities to be used in tests to determine whether samples

**Example of Tactical Armor Designed for Protection from Rifle Fire**



SOURCE: Point Blank Body Armor, Inc., 1991.

## Box C—Spectra® and Spectra Shield™

Woven Fabric

***Spectra®*** is a registered trademark of Allied-Signal, inc., for the high-strength synthetic fibers the company produces from extended-chain polyethylene (ECPE). Key properties of these fibers (marketed under the brand name Spectra 1000) include low weight and high strength, as well as resistance to impact, moisture, abrasion, chemicals, and puncture.

The first successful commercial application for Spectra fibers, introduced in 1985, was as a substitute for steel in ropes and cordage. Other applications that followed include puncture- and cut-resistant safety gloves.

For soft body armor applications, Spectra fibers are woven into bullet-resistant fabrics or, more commonly, used as a reinforcing fiber in a flexible, nonwoven composite material called Spectra Shield™, introduced in 1988. Thicker, rigid Spectra Shield™ is also made for use as hard armor in helmets, radomes (protective coverings for radar antennas), sonar, and other applications.

Spectra fibers are made by a process called gel-spinning. Extended-chain polyethylene molecules containing 70,000 to 350,000 carbon atoms are dissolved in a solvent which is heated and forced through tiny nozzles called spinnerets. The resulting jets of solution cool and harden into plastic fibers, which are drawn, dried, and wound onto spools for further steps in manufacturing. This fiber-producing process aligns the extended-chain polyethylene molecules so that the hydrogen atoms of each molecule bond with those of its neighbors. This gives Spectra® a tensile strength greater than aramid fibers. Spectra® is also less dense than other fibers; its specific gravity is only 0.97, so it floats. Pound for pound, it is 10 times as strong as steel.

Spectra Shield™ is made by aligning Spectra® fibers side by side and bonding them with a flexible Kraton resin (produced by Shell Chemical) to make a single-ply sheet. Two plies of such sheets are crossed, so that the fibers in one are perpendicular to the fibers in the other, and bonded together. The resulting 2-ply, cross-plied sheet is coated on each side with an abrasion-resistant film to make one thin, flexible sheet of two-ply Spectra Shield™ composite material for use in body armor (see figure). [4][1] Thicker, multi-ply panels for use as structural armor are made by cross-plying additional layers before coating.

A ballistic panel for an armor garment could be made by cutting multiple layers of two-ply Spectra Shield™ into the desired shape, stacking them up like pancakes without stitching them together, and enclosing them in a cloth cover. The cover need not be waterproof, because Spectra Shield™ is highly water-resistant. Exposure to water has no effect on its ballistic resistance. Spectra Shield™ is also highly resistant to degradation by chemicals such as household bleach.

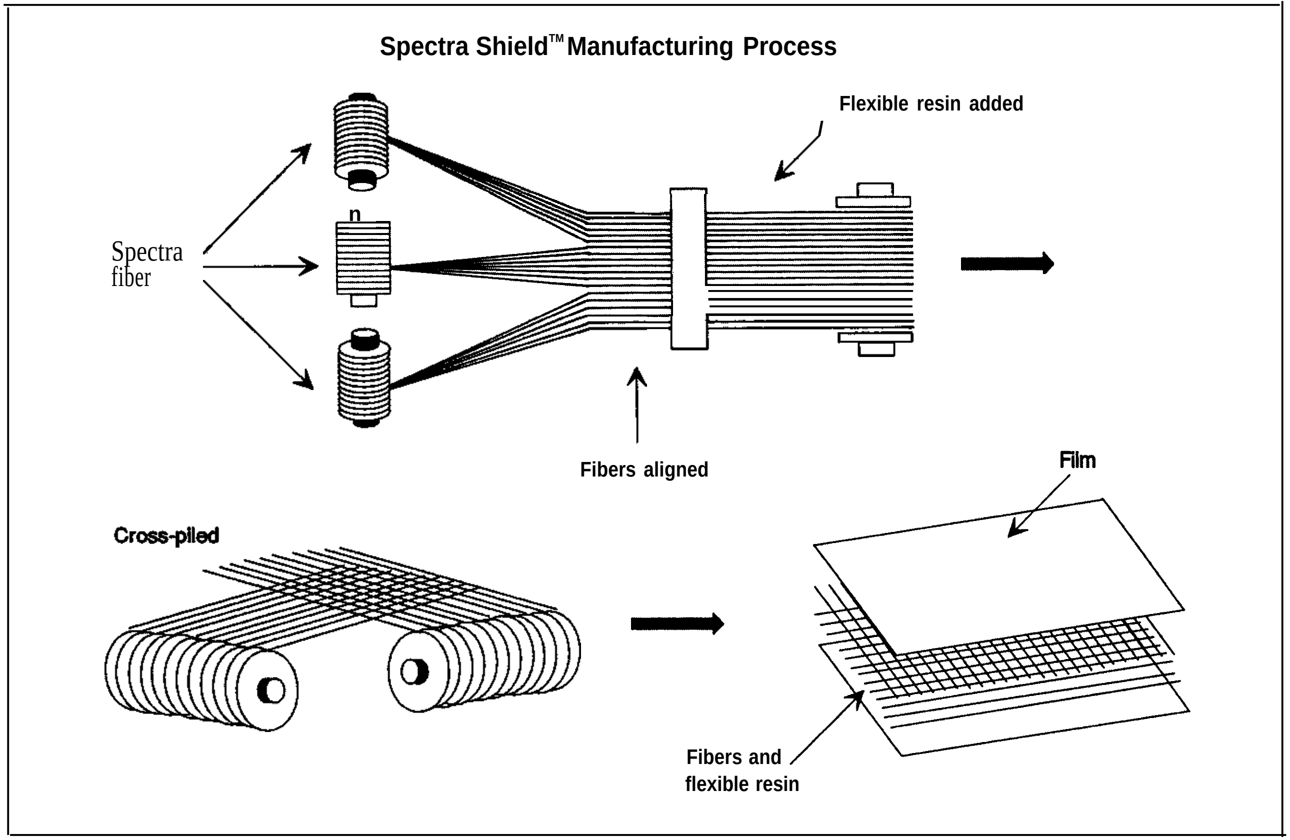
Another notable characteristic of Spectra Shield™ is the high velocity-12,300 m/s-at which the stress imparted by a bullet propagates within the armor outward from the point of impact, which allows the bullet's energy to be absorbed by a large area of the armor. In the 1 to 2 milliseconds during which a low-energy bullet is decelerated by armor and backing material, [100] part of its energy would be distributed over and absorbed by the entire ballistic panel. Spectra® fabric and Spectra Shield™ can be ignited but only when their temperature reaches 675 ‘F; they are less flammable than cotton or polyester fabrics typically used for police uniforms. Flame-retardant tactical armor has been made by enclosing Spectra Shield™ in a carrier garment made of flame-retardant fabric. Spectra® melts at about 150 *C (about 300 ‘F), but Spectra® fabric retains 94 percent of its room-temperature ballistic resistance at a temperature of 160 *F. Armor so hot would be excruciatingly painful and would bum skin in less than a second, [128] so ballistic resistance at so high a temperature is almost irrelevant.

Spectra Shield® stored for 90 days at 160 ‘F and then allowed to cool to room temperature regained its room-temperature ballistic resistance.[2]

1 See also Gary A. Harpell et al., “Ballistic Resistant Composite Article,” U.S. Patent 4,623,574, Nov. 18, 1986.

2 Viz., $V_{50}$ measured per MIL-STD-662D using a .22-cal., 17-gr fragment-simulating projectile.

SOURCE: Office of Technology Assessment 1992.




of armor had certain types of ballistic resistance defined in the standard. It was a voluntary performance standard-i. e., armor could be sold without meeting the standard, but if it were tested and passed, the manufacturer could certify this on the label. Armor made from any type of material could, if thick enough, meet the standard.

The .00 standard specified a reproducible but arbitrary ballistic test, uncorrelated with physiological protection: There was no attempt to correlate penetration in the test with risk of penetration in service, and it did not attempt to gauge protection from injury by stopped bullets.

NILECJ Standard 0101.00 has been superseded thrice: by NILECJ Standard 0101.01 in 1978, by NIJ (National Institute of Justice) Standard 0101.02 in 1985, and by NIJ Standard 0101.03, the current standard, in 1987. The .01 standard was the first to be based on a quantitative safety criterion and biomedical experiment (shootings of animals) intended to demonstrate that samples of armor *like those passing the test* would perform as required in service.

The current standard, like its predecessors, is necessarily the result of an implicit trade-off among simplicity, economy, realism, reproducibility, risk to consumer, and risk to producer.[4] For example, a wide variety of bullets impact at unknown velocities in assaults, but, in the interest of reproducibility, the test requires particular types of bullets to be fired at velocities varying by no more than 50 feet per second.

Each revision had its proponents and its critics, but the latest version evoked unusual controversy when "NIJ funded the retesting of all models tested under the .02 program. However, less than half-34 out of 84-of models tested passed under the new standard."[5] [151] This surprised NIJ as well as those

**[4] The rationale for each revision is discussed in detailin appendix A of this report.**

**[5] Those involved have later pointed out that the poor record-keeping of the .02 era precludes definite knowledge of which vests passed, or indeed of which were tested. The issue is further clouded by the fact that NIJ permitted the manufacturers of vests passed under .02 to resubmit them under different designations, and even to submit totally different vests. The Government felt the change from .02 to .03 obliged them to offer a free test, but the manufacturers could choose what vest to test.**

in industry who had been consulted about the revision. A DuPont spokesman later claimed, ''Both sides [NIJ and the Personal Protective Armor Association (PPAA), an industry group] agreed '03' was to be no more stringent than '02.' " [13] The PPAA devised its own standard, PPAA Standard 1989-05, which is demonstrably less stringent but also, the PPAA argues, more realistic and reproducible (i.e., results of similar tests are more likely to be similar). Many purchasers, prospective purchasers, and wearers of body armor have been confused by the controversy, and some manufacturers attribute a decline in sales to the confusion.

Critics of the NIJ standard, including some manufacturers of armor material and garments, point to the large fraction of .02-certified models failing the .03 test as evidence of excessive stringency of the .03 test. They point to the mixed results of .03 tests of samples of the same model (sometimes labeled as different models) as evidence that the .03 test yields ''inconsistent' results; some critics have called the test "a crap shoot. ' They question the rationale for crucial aspects of the standard, such as a test intended to gauge protection against serious or lethal blunt trauma (bruising or tearing of internal organs) that could be caused by the impact of a bullet stopped by the armor. They charge that the conservatism of the standard and the variability of test results induce manufacturers to make armor that is heavier, stiffer, less comfortable, and more costly than is necessary to provide the nominal protection certified. Most importantly, they charge that excessive cost reduces sales, and excessive discomfort reduces wearing, of certified armor, with the result that officers who could have been saved by good uncertified armor (or armor certified to comply with a less stringent standard) have been killed not wearing it: "Police officers are not dying in defective body armor. Police officers are dying because they are not wearing body armor!!" [15] They also believe that the standards controversy itself reduces the sales and wearing of good armor.

Defenders of the NIJ standard, also including some manufacturers of armor material and garments, believe that the standard's testing requirements and procedures are warranted by the ballistic threats facing police officers and rebut arguments for changing it. They claim the PPAA standard is not stringent enough. They ascribe variation in test results to variation in vest construction. Gross variation in the construction of supposedly identical vests—such as differing numbers of fabric layers—can be seen in the archives of NIJ's Technology Assessment Program Information Center (TAPIC).

A legislative remedy to the controversy has been attempted twice: Two identical bills introduced in the 10lst Congress, H.R.4830 and S.2639, would, if enacted, have made it a criminal offense to manufacture, distribute, or sell armor not complying with NIJ Standard 0101.03 or any superseding standard issued by NIJ. H.R. 322, a bill introduced in the current (102d) Congress, contains the same language.

This report of OTA'S assessment of police body armor standards and testing was requested by Senator Joseph R. Biden, Jr. (Chairman), Senator Strom Thurmond (Ranking Minority Member), Senator Dennis DeConcini, and Senator Edward M. Kennedy of the Senate Committee on the Judiciary, Congressman John Joseph Moakley, Chairman of the House Rules Committee, and Congressman Edward F. Feighan of the House Committee on the Judiciary and of its Subcommittees on Crime and on Economic and Commercial Law.

The purpose of the study was to clarify the issue of whether NIJ Standard 0101.03 should be revised, and if so, what actions Congress might take. Congress would like to know whether the standard is informative and fair to purchasers and wearers of armor, as well as to manufacturers of armor and its component materials. Purchasers and wearers need to know how confident they can be that certified armor will protect them or to what degree uncertified armor will be less protective. Manufacturers are justified in demanding that the standard not discriminate unfairly against their products. Principal points of uncertainty are: how confident wearers can be that samples of a model, other samples of which have passed the test, will protect them in the line of duty (and under what circumstances); how confident manufacturers can be that testing more samples of the same model would yield similar results; how confident prospective purchasers can be that they won't be defrauded; and whether performance characteristics of dubious value are being tested.

Specific points of contention include the following:

- Whether armor must be tested wet (as well as dry), as the standard specifies.