# Appendix A

# The Origin of and Rationale for the NIJ Standard

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# Appendix A
# The Origin of and Rationale for the NIJ Standard

## INTRODUCTION TO NIJ BODY ARMOR STANDARDS

### *General*

Four standards for body armor, numbered 0101.00 through 0101.03, have been successively promulgated by the U.S. Department of Justice's National Institute of Justice (ND) and its predecessor, the National Institute of Law Enforcement and Criminal Justice (NILECJ). Compliance with these standards has been voluntary--companies perceiving that benefit in the marketplace would accrue from their products' compliance with a Federal standard can submit their vests for certification according to the standard. Recognizing that different customers will feel different needs for protection, the Justice Department created standards that specify more than one level of protection: 0101.00 set standards for three types of armor, expanded to six in later standards.

The Justice Department recognized at the outset that there is no such thing as 100-percent safety. In particular, it stated that the blunt trauma (bruising of internal organs) caused by the impact from a nonpenetrating bullet on armor was to be survivable in 90 percent of cases. As will be shown below, implementors of the standard used conservative judgment at a number of stages, leading to a situation in which (as of this writing) nobody[2] wearing NIJ-certified armor has been killed by blunt trauma.

The question of technology-specific considerations-those based on current vest construction, not desired vest performance-arises repeatedly in the formulation of standards for police body armor. To date, the standards have specified performance, not construction: manufacturers are free to make a vest any way they want as long as it passes the test. However, some technology-specific considerations have crept into the standards here and there. The most obvious of these, introduced in the 0101.01 standard, is the requirement that the vest be tested wet as well as dry. This test was instituted in response to the finding that a certain vest material could be penetrated more readily when saturated with water than when dry. Granting that police officers' vests become wet and that wetness could make a difference to the ballistic performance of the vest,[3] testing under wet conditions clearly makes sense. Yet why not test the vests when they are cold, or hot, or covered with powdered sugar? The answer that vests do not, in normal use, become sufficiently cold, hot, or covered with powdered sugar to degrade their performance is at once a technology-specific consideration (somebody might someday come forward with a vest that proved highly sensitive to these conditions) and an invitation to argue about the conditions arising in normal use, including the level of wetness to which one can reasonably expect a vest to be subjected. We shall revisit the wetness issue in describing the 0101.01 standard-the purpose of raising it here is merely to show how technology-specific considerations can infiltrate a supposedly performance-oriented standard.

### *Overview of the Current Standard and the Controversy Surrounding It*

The National Institute of Justice 0101.03 Standard for concealable body armor provides for the testing of four types of soft body armor and two types of rigid armor,[4] collectively offering protection from the full spectrum of small-arms threats. Compliance with the standard is voluntary: some companies choose to comply and some do not, presumably reflecting different assessments of the benefits of NIJ certification as compared to the costs of producing compliant vests. In a gray area, some companies assert that their vests comply with the standard, but have not submitted them for official

[1] Or, perhaps, in the courtroom.

[2] In one problematic case, a very heavy bullet fired from a rifle killed an officer without penetrating his vest. Some therefore call this a death by blunt trauma, while others point to the fact that the vest and the bullet both penetrated the officer, making the death more closely resemble a regular wound and not blunt trauma.

[3] Though it need not—the material that performs poorly when wet can be waterproofed or encased in a waterproof cover and thereby retain its ballistic efficacy.

[4] As well as for a generic test of "special type" armor, whose desired level of ballistic performance is left up to the user.

**Table A-l-Summary of 0101.03 Armor Types According to the Ammunition Against Which They Are Tested**
**(velocities compared to those of Federal brand)**

| Type | Cailber | Mass (grains) | Test velocity (ft/sec) | Federal velocity (ft/seo) |
|---|---|---|---|---|
| I . . . . . . . . . . . . . . . | .22 LRHV | 40 | 1,050 to 1,100 | 1,255 |
| | .38 RNL | 158 | 850 to 900 | 755 |
| ii-A . . . . . . . . . . . . . | .357 JSP | 158 | 1,250 to 1,300 | 1,235 |
| | 9mm FMJ | 124 | 1,090 to 1,140 | 1,120 |
| ii . . . . . . . . . . . . . . . | .357 JSP | 158 | 1,395 to 1,445 | 1,235 |
| | 9mm FMJ | 124 | 1,175 to 1,225 | 1,120 |
| hi-A . . . . . . . . . . . . | 44 Magnum | 240 | 1,400 to 1,450 | 1,180 |
| | 9mm FMJ | 124 | 1,400 to 1,450 | 1,120 |
| III . . . . . . . . . . . . . . | 7.62 mm FMJ | 150 | 2,750 to 2,800 | 2,910 |
| Iv . . . . . . . . . . . . . . | .30-06 AP | 166 | 2,850 to 2,900 | 2,800 |

KEY: AP = armor piercing; FMJ = full metal jacket; JSP = jacketed soft-point; LRHV = long rifle high velocity; RNL = round-nose lead.

SOURCES: National Institute of Justice, NIJ Standard 0101.03, April 1987 [144], and William S. Jarrett, 1991 [85].

testing, while others advertise that their vests have been tested without stating the outcome of the test.

In general,[5] the armor must demonstrate an ability to stop, without the transmission of unduly concentrated blunt impact, two types of ammunition. (See table A-l.) It must do so when wet as well as when dry. The armor is shot while attached to a clay backing-the resulting dents in this backing provide a means of assessing the amount of impact that the vest would transmit to its wearer.

The velocities to be used in the test are representative of those found in commercial ammunition, with some exceptions. (See table A-l.) The most salient exceptions are the velocities specified for testing type III-A armor, which is not intended for daily wear and was created in response to the threat posed by terrorists, not common criminals. [145][6] Another exception is the velocity specified for the .357-caliber jacketed soft-point bullets used in type-II tests.

Four vests are consumed by the test[7]-one for each of the four combinations resulting from the two ammunition types and the two wet-dry conditions. Each vest has two panels, the front and the back. Each panel is shot 6 times, so that the vest model must endure 48 shots to pass. For soft body armor, the first shot on each panel is used in assessing the transmission of blunt impact.[8] For armor intended to protect the wearer against handgun bullets, two shots on each panel strike at an angle of 30 degrees away from head-on: the rest (including that used in the assessment of blunt impact) are head-on.

As of Oct. 31, 1991, 329 of the 555 models submitted for NIJ certification testing under the 0101.03 standard had passed, 221 had failed, and 5 tests were inconclusive. Penetration caused 166 failures, excessive backface signature (an index of blunt-trauma risk) caused 15, and 40 models failed because of both penetration and excessive backface signature.

Critics of the standard charge that its stringency and the variability of results force manufacturers to build unduly rugged armor, creating extra expense and discomfort for the consumer, and ultimately resulting in the perverse effect of officers dying because armor that meets the standard is so uncomfortable or expensive that it is not used. Critics point to the perfect record of armor in the field (no officer has died from a shot that his or her armor was supposed to be able to stop), much of it set by armor that has not passed-and, in many cases, could not pass-the NIJ test. In addition, they cite cases in which officers have been saved from shots that their armor was *not* rated to stop, and even cases in which subsequent "reenactment" of the shot under the laboratory conditions mandated by the NIJ standard

5 Some of what follows does not apply to the strongest of the rigid armors.

6 Numbers in brackets cite references in the bibliography in volume 1 of this report.

7 In practice, six vests are forwarded for testing, to allow for the possibility that a vest or two would be spoiled during the test process or otherwise tested inconclusively.

8 In the case of Type III armor, a verbal communication to the test facility mandates the use of the first two fair shots on each panel.

resulted in either a penetration of the vest or a backface deformation greater than that allowed by the NIJ.

Specifically, critics cite as unduly stringent the requirement that the vest retain its bullet-stopping ability even when wet. Although they have nothing against vests that perform well when wet and admit that some officers may need or desire such vests, they question a standard that makes wet-testing, and thus wet-strength, mandatory. While a variety of means to assure unimpaired performance when wet are available, all add at least a little cost, weight, and stiffness to the vest. Critics also decry the requirement that each panel endure six shots. Not only do they see six shots as an unrealistically high number in itself, but in addition they point out that the tendency of the vest to squirm about while under fire on the test fixture leads to delamination of the ballistic material and raises the probability of penetration on the later shots. They further maintain that this “bunching and balling’ of the vest does not occur when the vest is on a human torso, so that the test does not give a true assessment of vest performance in the rare case of multiple impacts. Finally, some critics claim that the maximum allowable depth of the dentin the clay (44 mm) is too little, and has no basis in physical, clinical, or experiential reality.

Upon introduction of the 0101.03 standard, many vests that had passed the 0101.02 test failed a retest under the new standard. Critics asserted that the mass failure of vests previously deemed acceptable indicated that there was something wrong with the new standard or, considering the textual similarity between the two standards, with the implementation of the new standard by the test laboratory. Others have asserted that certain practices, such as poor recordkeeping and the mixing and matching of passed panels, created undue leniency in the 0101.02 era.

Defenders of the 0101.03 standard point out that a standard for a safety-related product *should* be somewhat conservative, it being far better to fail some adequate vests than to pass even a few inadequate ones. They defend the requirement that the vest should function while wet on the grounds that, while total immersion of an officer is a rare occurrence, perspiration is not, and could readily soak a vest. They point out that officers fortunate enough to have survived shootings their vests were not rated to stop may have survived more because of the obliquity of the shot than because of superior body armor. They defend the requirement that the vest withstand six shots per panel on the grounds that the weapons available today can fire many more shots than that. They see the claim that bunching and balling does not occur on the human torso as unsubstantiated at best, and perhaps even contradicted by videos featuring the president of a body armor company shooting himself in the vest. [121] Finally, they cite animal tests performed at the beginning of the body armor program as the basis for the 44 mm backface signature criterion.[9]

## NILECJ STANDARD 0101.00

The NILECJ,[10] a part of the Law Enforcement Assistance Administration at the U.S. Department of Justice, promulgated NILECJ-STD 0101.00, *Ballistic Resistance of Police Body Armor, in* March of 1972.[11] The standard was formulated in conjunction with the Law Enforcement Standards Laboratory (LESL)[12] of the National Bureau of Standards.[13]

### *Sampling*

Each “lot” of armor submitted for certification was to be sampled at random. The standard specified the number of vests constituting an adequate sample, with larger lots requiring larger samples. Alternatively, manufacturers could assure lot-to-lot quality through application of quality control procedures. Though the standard does not explicitly state as much, the reader is left to infer that certification of an initial lot and lot-to-lot consistency as documented by ‘‘quality control charts’ would permit the manufacturer to present later lots as ‘certified.” In practice, the term “lot” is more ambiguous than one might suppose, because body armor manufacturers buy the components of body armor from different vendors at different times. A set of, vests all made at once from the same shipment of ballistic material may contain waterproof coverings made from differ-

9 Like other parts of this controversy, the relationship between the animal tests and the 44 mm criterion is explored more deeply in a later section.

10 Now the National Institute of Justice (NIJ).

11 Facts in this section come from the standard itself [141] if no Other source is cited.

12 Now the Office of Law Enforcement Standards (OLES).

13 Now the National Institute of Standards and Technology (NIST).

ent shipments of waterproof materials, and the ballistic material itself may have been made from fibers spun at different times, or scoured with chemicals produced at different times.

### Marking and Workmanship

The 0101.00 standard required that armor be "free of wrinkles, blisters, cracks, crazing, fabric tears, chipped or sharp corners, and other evidence of inferior workmanship, " and further specified that "Each armor part shall be clearly and durably marked with the manufacturer's name, brand name or logo, the model number, and the lot number. "

### Penetration

The standard specified that each armor part was to withstand 5 "fair hits" by test bullets with no penetrations, except (1) "armor fronts" were to withstand 10 "fair hits" with no penetrations, and (2) armor parts-front or back—being tested for Type .30 AP (armor-piercing) ballistic resistance were required to withstand only 1 "fair hit" by a .30-06 AP test bullet with no penetration. A "fair hit" was a hit by a bullet with velocity of at least that required for the type, striking the armor at no more than 5 degrees away from normal[14] incidence and no closer than 2 inches to the edge of the armor or to a prior hit.

Different set-ups were prescribed for the penetration test and the deformation test. The test set-up for penetration did not use the now-familiar clay backing, nor indeed any backing at all. Penetration was to be assessed with a' 'witness plate," mounted six inches behind the armor. A witness plate is a thin piece of sheet metal inspected for holes after the test by holding it up to a light. Passage of light through the witness plate signified a penetration of the vest and caused the vest to fail. In fact, "penetration by any fair hit, no matter what its velocity, shall cause rejection of the lot. "

### Deformation

The set-up specified for the deformation test included a backing made of "nonhardening modeling clay.' A method for determining the depth of the deformation in the backing (the creation of a plaster cast) was given, but the maximimum acceptable depth of the dent in the clay behind the armor was explicitly cited as "not yet established." No mention was made of the possibility of a penetration occurring during a deformation test.

### Types of Armor

The standard recognized three types of armor, known by the guns and ammunition against which they were to afford protection. (See table A-2.) These were Type .22 LR (long rifle)-.38 Special, Type .357 Magnum, and Type .30 AP. Type .22 LR-.38 Special was to be tested with the .22 caliber ammunition and, if it passed, then tested with the .38 Special ammunition. The Type .30 AP armor needed only to stop one bullet, not five.

Type .22 LR-.38 Special was to afford protection against the .22 caliber Long Rifle rounds freed from handguns and .38 Special Metal Point rounds against which it was to be tested as well as other .22, .25,.32, and .45 caliber rounds and 12-gauge#4 lead shot—protection against these latter rounds was taken for granted if the armor passed the test with .22 LR and .38 Special Metal Point.

Type .357 Magnum was to protect against the .357 Magnum rounds against which it would be tested as well as 9-mm Luger, 12-gauge #00 Buckshot, and all of the Type .22 LR-.38 Special threats-protection against these latter rounds was taken for granted if the armor passed the test with .357 Magnum ammunition.

Type .30 AP was to protect against the .30 caliber armor piercing rifle round against which it was to be tested as well as .41 and .44 Magnum handgun rounds, .30 caliber carbine rounds, 12-gauge rifled slugs, and all of the threats specified for the two other types of armor-protection against these latter rounds was taken for granted if the armor passed the test with .30 AP rifle ammunition. It was expected that Type .30 AP armor would stop the .30 caliber AP round with a ceramic material that might well be broken in the process-a nonceramic rear element was 'normally' to be made of Type .357 armor. The test of the Type .30 AP armor did not, however, include a test of the rear element.

The velocities lie towards the upper end of the range attainable by the firing of commercially available ammunition from commercially available

14 I.e, head-on,

**Table A-2-Summary of 0101.00 Armor Types According to the Ammunition Against Which They Were Tested**

| Type | Caliber | Mass (grains) | Minimum velocity (ft/sec) |
|---|---|---|---|
| .22 LR-.38 Special . . . | .22 | 40 | 1,181 |
| | .38 | 158 | 782 |
| .357 Magnum . . . . . . . | .357 | 158 | 1,261 |
| .30 AP . . . . . . . . . . . . . | .30 | 166 | 2,694 |

SOURCE: National Institute of Law Enforcement and Criminal Justice, NILECJ Standard 0101.00, March 1972.

guns.[15] The International Association of chiefs of Police (IACP) has published the research underlying these velocity selections.

### *Comments on Technology Specificity in the 0101.00 Standard*

***An*** important instance of technology specificity is the requirement that an armor part need only stop one .30-06 armor-piercing bullet in order to demonstrate Type .30 AP ballistic resistance, but it must stop 5 or 10 .357 Magnum bullets in order to demonstrate .357 Magnum Type ballistic resistance. The explicit reason for this is that Type .30 AP vests were expected to be ceramic, and thus only capable of reliably stopping a single bullet-ceramic vests absorb impact energy by shattering.

## NILECJ STANDARD 0101.01

NILECJ-STD-O1O1.O1 was promulgated in December, 1978.[16] The first full-fledged U.S. standard for police body armor, it was formulated with the active participation of the Personal Protective Armor Association (PPAA). [150] After the release of 0101.00, NIJ had established the Technology Assessment Program Advisory Council (TAPAC), to advise NIJ about the direction of its Technology Assessment Program (TAP). TAPAC recommended that NIJ establish a testing program for law enforcement equipment, including body armor. The resulting test program was administered by the IACP. [150]

### *Reasons for Replacing the 0101.00 Standard*

As indicated by its number, the 0101.00 standard was created in order to be replaced. Its writers anticipated the eventual articulation of an acceptable degree of backface deformation-they specified the test procedure, but left the allowable depth “not yet established. ” [141]

The 0101.01 standard set forth five levels of armor in place of the three specified by the 0101.00 standard. One new level was a second level for rigid armor, offering protection against a sporting, as opposed to military, rifle threat; the other was an intermediate level of protection against handguns.

The 0101.01 standard also introduced the testing of vests while wet, a reaction to the discovery that wetness could severely reduce the ballistic performance of the vest material then in most common use.[17]

### *Sampling*

The 0101.01 standard specifies that “two complete armors, selected at random, shall constitute a test sample.” Two extra armors might be needed if the tester wanted to exercise the option not to test both types of ammunition on the same panels. The 0101.00 standard’s suggested sample sizes based on lot sizes and the use of a table of random numbers to attain random selection were dropped. Moreover, no reference to the “lot” concept appears; unlike 0101.00,0101.01 does not specify that ‘penetration by any fair hit, no matter what its velocity, shall cause rejection of the lot. In fact, the standard itself does not spell out the exact consequences of failure.

### *Wet Testing*

A separate set of armor was to be tested while wet, the wetness having been attained by a gentle spray of specified rate and duration. The most obvious consequence of this wet-testing was to oblige manufacturers to make their products impervious to water.

15 “. . . the approach taken was to use actual handguns and factory ammunition to conduct the ballistic tests. . . . the measured impact velocities for each type of test round were averaged, the standard deviation calculated, and testing velocities selected to be in the upper boundary of the standard deviation. . . to provide a margin of safety should an assailant utilize ammunition providing bullet velocities at the high end of the nominal range for these bullets.” [150]

16 Facts in this section come from the standard itself [142] if no other source is cited.

17 This reduction only lasts as long as the wetness does: once dry, a vest returns to its original level of ballistic performance. It is thought that the wetness lubricates the fibers, allowing them to slip against one another more easily and eliminating the net-like action by which the vest stops the bullet.

### *Marking and Workmanship*

The 0101.01 standard again required that armor be free of specified evidence of inferior workmanship. The labeling requirements were enhanced to include size, type (according to the standard itself), month and year of manufacture, cleaning instructions, and strike face. (The strike face is the side of the armor panel intended to be hit by the bullets.)

### *Penetration*

The 0101.01 standard eliminated the witness plate and required use of clay backing for penetration testing, relying on examination of the backing material and the armor itself to determine whether a penetration has occurred. The introduction of upper limits on velocity necessitated an additional clause in the definition of a fair hit-a hit was unfair if the bullet was going too fast, except in the case of a bullet that was going too fast and even so did not penetrate. Such a hit was a fair hit.

If the vest construction included any seams, a fair hit had to be administered to a seam. Because the standard did not specify that one of the first two fair hits (those used in measuring deformation) must fall on a seam, deformation of the backing material by a hit on a seam was not required to be measured.

### *Deformation*

***An*** expected innovation in the 0101.01 standard was the specification of a maximum allowable backface deformation. No backing material was specified, although the report stated that Roma Plastilina No. 1 modeling clay was "found to be suitable.

Conditioning of the material was specified, as was a test for consistency: measuring the depths of craters formed by dropping weights onto the clay. The clay was to be maintained at a temperature between 15 and30'C (59 and 86 'F). Deformability of Roma Plastilina No. 1 and similar modeling clays depends strongly on temperature.[18] [19]

The standard specified that the dents resulting from the first two fair shots with each type of ammunition were to be no more than 44 mm deep. Hits were to be placed as far apart as possible, and the standard instructs the laboratory to "reposition the backing material (as required) to avoid any overlap of depressions. '

To be a fair hit for the purpose of measuring deformation, a bullet had to be within the allowable velocity bounds-for measuring deformation, no clause (analogous to the clause counting overspeed bullets as fair tests if they did not penetrate) allowed overspeed bullets to be considered fair if they did not create a disqualifying deformation.

### *Origin and Rationale of the 44-mm BFS Limit*

Considerable confusion and controversy surround the genesis of the 44 mm backface signature (BFS) limit, in part because the rationale for it was never documented. There *is* a rationale for the limit, at least for Type I Kevlar armor. However, the experiments recognized as necessary to assess the validity of the criterion for higher energy bullets were never completed, for fiscal reasons.

OTA has reconstructed the following account based on Army reports on research performed for the NILECJ and interviews of individuals responsible for setting the limit or conducting the research on which the limit was to be based.

It appears that there were three thrusts to the body armor research performed by the Army. The earliest research [104] and some of the later biomedical research [74, 75, 101, 127] was aimed at predicting the injurious effects of particular types of bullets striking particular types of armor at specified velocities over particular parts of the torso. For this, goats wearing various types of armor were shot, sacrificed, and autopsied.

This work originated when the NILECJ's body armor program aspired only to develop armor against "common handguns''-in practice, against .22 LR and .38 Special rounds. Although assaults by other low-energy handgun rounds-e. g., .25- and .32-caliber-were common, the .22 LR was considered the most likely of then-common handgun rounds to penetrate armor, and the .38 Special was considered most likely to cause blunt trauma if stopped. Thus the early experiments mostly used .38 Special bullets impacting 7-ply Kevlar panels at about 800 ft/s.

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18 See [8] for the dependence of Plastilina and [28] for that Of Plasticine.

19A difference in temperature ~@ explain the difference in backface deformations produced by two seemingly identical shots shown in the video *Second Chance v. Magnum Force* [121] to demonstrate to the viewer how deformation tests can bemanipulated.

Another thrust [35,[20] 114, 130] was the development of species-independent, parametric models of blunt-trauma lethality-for example, predicting lethality of shots on armor over the lung, in terms of properties of the projectile (mass, diameter, velocity), armor (mass per unit area), and victim (weight, body wall thickness). Such a model would allow data collected in previous experiments+. g., shootings of animals with tear-gas grenades-to be compared with the shootings of armored goats by bullets. This requires treating the bullet plus the portion of armor it pushes into the torso (without penetrating the skin) as a single, blunt projectile, moving slower than the bullet at impact. This blunt projectile would have the same momentum as the bullet; its effective diameter was considered to be the diameter of the depression made by the armor in the torso or, approximately, in gelatin or clay backing material. An advantage of this approach is that a parametric blunt-trauma lethality model could be used to predict the lethality of new projectile-armor combinations without shooting more animals; it would only require shooting the projectile of interest at the armor of interest on *a flesh-simulating* backing material. (See box A-l.)

A third thrust was to record the diameter and depth of the depression made by various armor struck by various bullets in gelatin [100] and clay [114] backing material. The gelatin data were to be correlated with the results of shooting the armored goats. The clay data were to be used in conjunction with the parametric blunt-trauma lethality models described above. But the Prather report [114] also compared the maximum momentary depth of indentation of gelatin by a blunt projectile with the maximum depth of indentation of clay, based on one shot per backing. This tenuous comparison allowed BFS in clay to be correlated with maximum deformation depth in gelatin, which had been correlated with ballistic parameters, which in turn had been related to nonlethality in goats and extrapolated to norilethtity in humans. This series of correlations provided the basis for the 44-mm BFS limit in NILECJ-Std. 0101.01. For this use the backing need not simulate the density or resiliency of tissue.

The Army's soft body armor medical assessment team, led by Dr. Michael Goldfarb, recommended a BFS limit of 44mm for 158-grain, .38-ca.liber bullets

**Table A-3-Backface Signature Parameters .38-Caliber, 158-Grain Projectile Versus 7-Ply Kevlar-29, 400/2 Denier**

| Film no. | Striking velocity (m/s) | Maximum depth (cm) | Maximum base radius (cm) |
|---|---|---|---|
| 30008 ........ | 243.7 | 4.82 | 4.76 |
| 30177 ........ | 253.9 | 4.99 | 4.12 |
| 30178 ........ | 255.4 | 5.17 | 5.18 |
| 30179 ........ | 249.6 | 5.00 | 4.61 |
| 30180 ........ | 247.8 | 4.72 | 4.01 |
| 30181 ........ | 249.3 | 4.88 | 4.99 |
| 30182 ........ | 251.5 | 4.60 | 3.79 |
| 30183 ........ | 249.0 | 4.64 | 4.60 |
| 30184 ........ | 259.1 | 5.08 | 4.79 |
| 30185 ........ | 254.8 | 5.20 | 4.62 |
| 30186 ........ | 255.4 | 4.80 | 4.97 |
| 30187 ........ | 254.5 | 3.98 | 4.50 |
| 30318 ........ | 249.8 | 4.65 | 4.91 |
| 30319 ........ | 246.8 | 4.71 | 3.99 |
| 30320 ........ | 247.3 | 4.84 | 3.77 |
| 30321 ........ | 245.9 | 4.14 | 3.84 |
| 30322 ........ | 248.1 | 4.42 | 4.45 |
| Mean ........ | 250.7 | 4.74 | 4.46 |
| Standard deviation ... | 4.17 | 0.33 | 0.46 |

SOURCE: LeRoy W. Metker et al., 1975 [100], table 3.

striking 7-ply, 400/2-denier Kevlar-29 armor at about 800 ii/s. Their recommendation was based in part on the gelatin deformation data reprinted in table A-3. The third column shows the maximum depth of deformation of ballistic gelatin behind 7-ply, 400/2-denier Kevlar-29 armor struck by a 158-grain, .38-caliber bullet in each of 17 shots intended to simulate the shots at the 14 armored goats examined by Goldfarb et al. [74] The maximum depths of deformation averaged 4.74 cm, with a sample standard deviation of 0.33 cm. The goats examined by Goldfarb et al. all lived until they were sacrificed 24 hours after being shot, and none sustained serious injuries. According to Goldfarb, he and his medical assessment team reasoned that goats shot under the less stressful of the experimental conditions-which correlate with gelatin deformations 1 standard deviation less than the mean, or about 4.4 cm—would be very unlikely to sustain serious or lethal trauma. Their report concludes that humans would be even less likely to sustain serious or lethal trauma under similar conditions.

To complete the correlation of trauma with deformation in clay, the researchers compared defor-

[20] See also Victor R. Clare, James H. Lewis, Alexander. Mickiewicz, and Larry M. Sturdivan, *Body Armor—Blunt Trauma Data* (Washington, DC: U.S. Department of Justice, Law Enforcement Assistance Administration, National Institute of Law Enforcement and Criminal Justice, May 1976).

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### *Box A-l—Parametric Models for Estimating Probability of Blunt-Trauma Lethality*

Under NILECJ sponsorship, the Army developed several mathematical formulas, or "parametric lethality models,' for estimating the probability of blunt-trauma lethality on the basis of numbers (''parameters' describing properties of an impacting bullet (mass and velocity), the armor (areal density, i.e., mass per unit area), and the wearer (body mass and, for some models, body-wall thickness). Most were developed just after the 44-mm BFS limit was recommended, but before issuance of NILECJ Std. -0101.01, the first standard to specify the limit. Some of the models were considered to provide a rough confirmation of the adequacy of the 44-mm limit, the medical rationale for which was limited to .38-Special bullets stopped by 7-ply Kevlar 29 armor, and especially for extending that limit to other threats and armors. In fact, the models suggest that it would be appropriate for the BFS limit to depend on the threat, the armor, and measurements of the wearer. The NILECJ opted for a simpler, conservative, uniform limit.

To use these models would require measuring the diameter of the crater made in the backing, instead of (or in addition to) its depth. It would also be necessary to measure the areal density of the armor at the point of impact, or to infer it from the other parameters.

The most highly developed predictive models developed for the NILECJ are two developed by Larry Sturdivan: one for estimating the probability of lethal blunt trauma resulting from impacts on the abdomen over the liver, the other-discussed here-for estimating the probability of lethality from impacts on the thorax over the heart or a lung. Both models predict probability of lethality based on the mass M, diameter D, and velocity V of the impacting, nonpenetrating projectile, and the body mass W and body-wall thickness T of the victim.[a] They are based on data obtained by shooting anesthetized goats and calves with blunt plastic cylinders or similar nonpenetrating projectiles used to simulate impacts of bullets stopped by armor. [130]

The model for lethality of thoracic blunt trauma is

$$P(L) = 1/(1+ \exp(34.13 -3.597 \ln(MV^2/W^{1/3}TD)))$$

or, equivalently,

$$P(L) = 1 /(1 + 6.645X10^{14}/ (MV^2MV//DW^{1/3}T)^{3.597})$$

where

- P(L) denotes the probability of lethality,
- exp() the exponential function,
- In() the natural (base-e) logarithm,
- M the projectile mass in grams,
- V the projectile velocity in meters per second,
- W the mass of the victim in kilograms,
- T the thickness of victim's body wall (skin, fascia, fat, muscle, bone) at impact point, in centimeters, and
- D the projectile diameter in centimeters.

To use the model, one must estimate the mass, diameter, and velocity (M, D, and V) of the blunt "projectile" formed by the bullet plus the portion of the armor that it pushes into the body. M, D, and V may be estimated by the method proposed by Prather et al., which requires knowing the areal density $a_d$ of the armor at the point of impact: The diameter D of the blunt projectile formed by the bullet plus a portion of the armor is considered to be the diameter of the backface signature made in clay backing by the bullet-armor combination; its mass M is accordingly the bullet mass $M_P$ plus the mass of armor over the crater:

$$M = M_P + 3.14 (D/2)^2 a_d$$

with $a_d$ in $g/cm^2$.

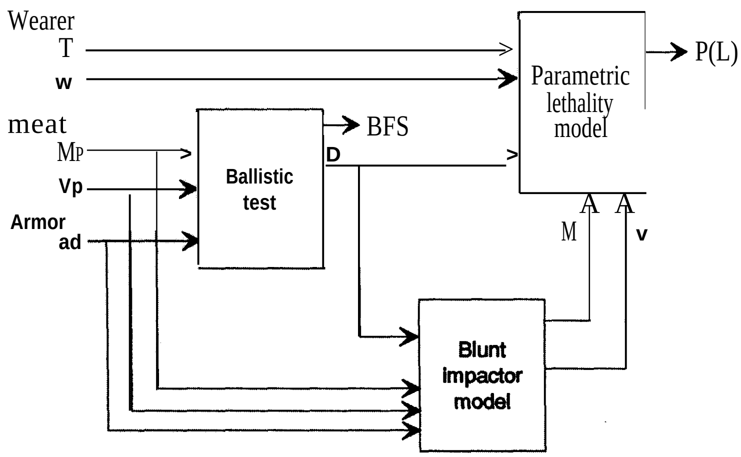
The velocity V of the blunt projectile is estimated from the velocity $V_P$ of the bullet by noting that conservation of momentum, a basic physical law, requires the momentum MV of the blunt projectile to equal the momentum $M_P V_p$ of the bullet. Hence

$$V = (M_P/M)\ V_P$$

The figure illustrates the procedure for estimating the probability of lethality from the backface signature using the parametric lethality model. It is assumed that the model applies to humans as well as to the larger animals (calves) and smaller animals (goats) shot in the experiments that generated the data to which the model was fitted. However, these animals were shot by heavy, slow, blunt projectiles aimed at especially vulnerable locations. In extrapolating predictions to assault situations, allowance should be made for less deadly targeting.

**[a] The body wall includes the skin, fat, muscle, bone (if any) and fascia covering the organs inside the abdominal or thoracic cavity. An individual's body-wall thickness varies with location.**

**Estimating the Probability of Blunt-Trauma Lethality Using a Parametric Lethality Model**




ad = areal density of armor (mass per unit area)
BFS = depth of crater
D = diameter of crater
M = mass of projectile + portion of armor pushed into crater
Mp = mass of projectile (bullet)
P(L) = probability of lethality
T = thickness of body wall (skin, muscle, bone...) of wearer
V = velocity of projectile + portion of armor pushed into crater
Vp = velocity of projectile
W = "weight" (i.e., body mass) of wearer

SOURCE: Office of Technology Assessment, 1991.

mation depth of goat thorax with that in clay, gelatin, and other backing media.[21]

The medical team also considered the fatal "massive, contralateral right lung damage" produced in the one armored goat shot with a .45-caliber bullet [101], reenactments of which produced deformations of 5.2 cm in clay and 5.3 cm in 20-percent gelatin [114].

In another, unpublished, experiment, a goat (no. 21644) wearing a 5-ply Kevlar panel was struck by a *.38* caliber bullet. Although the vest stopped the bullet and produced only a superficial skin contusion, autopsy revealed that blunt trauma had produced a massive lung hemorrhage involving roughly 150 cubic centimeters of tissue. (See figure A-l.) When the average deformation depth of .38 caliber bullets against 5-ply Kevlar was later measured in 20-percent ("ballistic") gelatin, it was only 48.2 mm, with a standard deviation of 3.9 mm. [100] From this, Dr. Goldfarb concludes that the margin of safety provided by the NIJ backface deformation standard may amount to only about half a centimeter. He questions "whether it is really worth throwing out a proven standard because of difference of a few millimeters."[22]

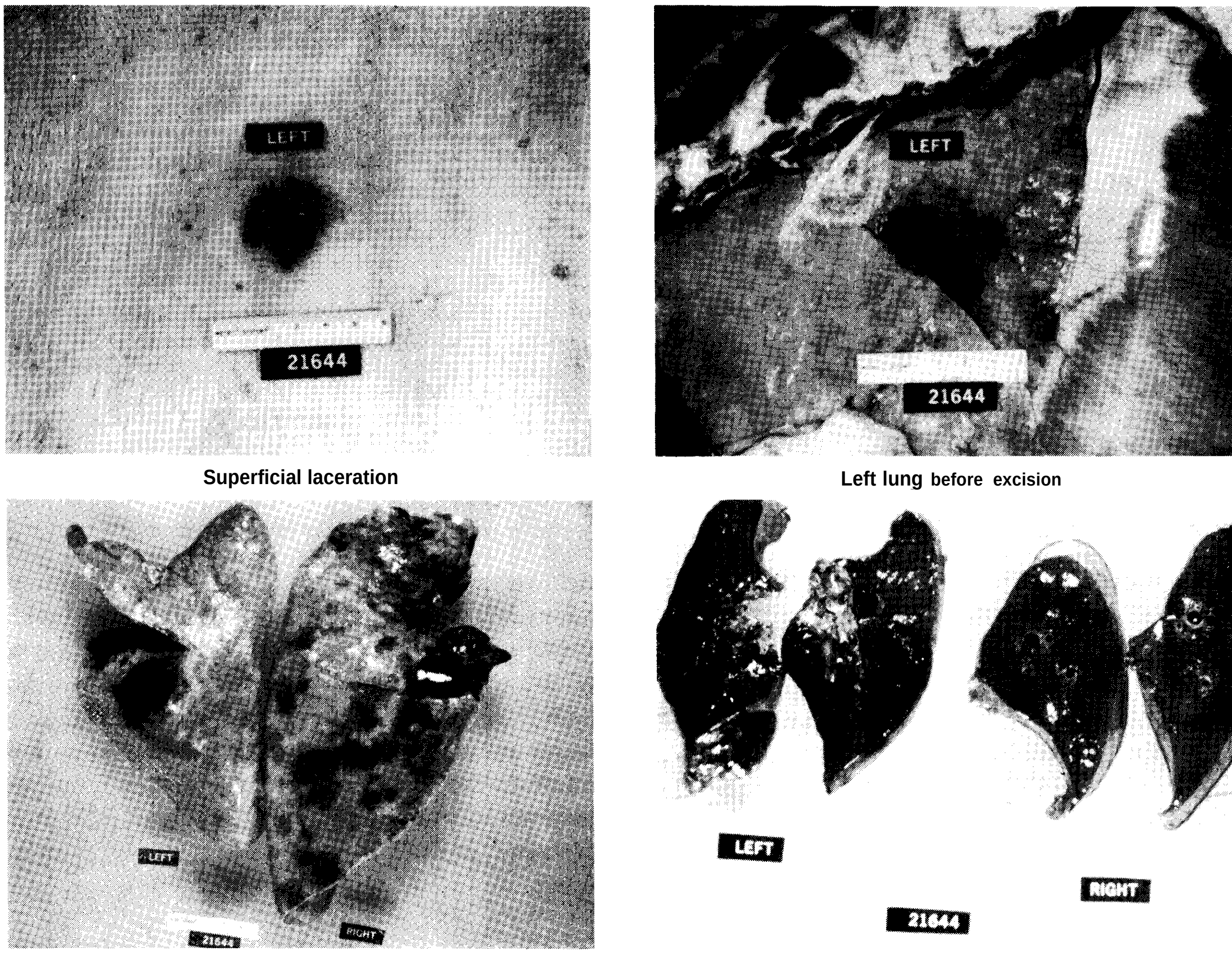
In addition, Goldfarb said that he and other medical team members were concerned that impacts that would not kill a man of large or medium build might kill a woman of medium or small build. Indeed, the parametric models suggest that a lighter person with a thinner body wall (skin, fat, muscle, bone, fascia) would not survive some impacts that a larger person would. The medical team was not asked to recommend a weight- or sex-dependent limit, so they wanted an extra margin of safety for adequate protection of small, typically female, officers.

Critics have recently noted [86, 87] what appears to be a discrepancy between the deformations listed in table 3 of [100] and the minimum, nominal, and maximum deformations shown in figure 5 of that report (reproduced in figure A-2). The discrepancy is only apparent: as we understand it, table 3 lists the maximum depth reached by any point of the indentation at any time, measured from the film. In particular, it lists four maximum depths equaling or exceeding 5.0 cm. The deformation envelopes shown in figure 5 bound the parabolic curves listed in table 1 of [100], which were obtained as fits to the (not necessarily parabolic) indentation profile read from the film frame exposed at the time of maximum indentation. The curve-fitting process generated approximating parabolas, some of which were not as

21 See table A.2 and figure B-2 of [114]; "BASELINE" refers to goat thorax.

22 Michael A. Goldfarb, M.D., personal communication, Apr. 25, 1991.

**Figure A-l—Trauma to Goat Lung Caused by 158-Grain, .38-Caliber Bullet Stopped by 5-Ply Kevlar Armor**




Superficial laceration — Left lung before excision — Left and right lungs after excision — Left and right lungs after section

SOURCE: Michael A. Goldfarb, M. D., 1991.

deep as the deepest part of the uneven surface they approximated.[23]

The NILECJ also funded similar Army experiments in which goats armored with Kevlar were shot with 9-mm and .357 Magnum bullets; however the studies were never completed (funding was stopped) and no report on them was published.[24] Mr. Lester Shubin, then the NILECJ's Director of Science and Technology, recently rationalized the specification of a 44-mm limit for all bullets and armor in NILECJ 0101.01 by noting that it was implausible that a greater BFS should be allowed for higher energy bullets, so if 44mm was appropriate for .38 Special, it was probably the maximum that should be allowed for higher energy threats. It might be that a smaller limit would be appropriate for higher energy threats, but there was no research to show what it should be.[25]

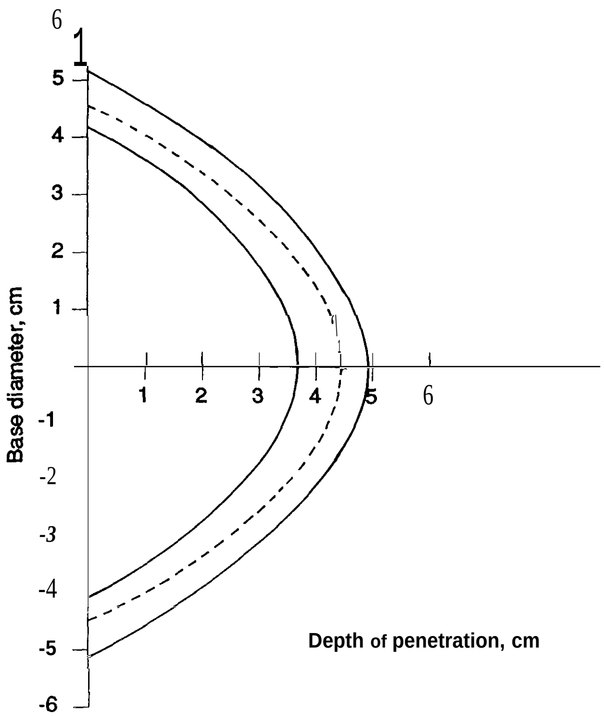
A different group of Army researchers working for the NILECJ provided additional support for a limit of about 44 mm in a 1977 report. [114] Figure B-10 of that report (reproduced herein figure A-3)

[23] For example, table 3 lists the the maximum depth of the indentation shown in film no. 30178 as 5.17 cm, but table 1 shows the equation for the parabola fitted to the indentation shown in that film $y^2 = 26.94-5.6105x$, where y is the radius of the indentation and x is its depth. The maximum depth of this fitted parabola occurs along the centerline, where $Y = 0$, and is given by $0 = 26.94-5.6105x$, or $x = 26.94/5.6105 = 4.80$ cm.

[24] Russel Prather, personal communication, Jan. 10, 1992.

[25] Mr. Lester Shubin, personal communication, Nov. 13, 1991.

**Figure A-2—The .38-Caliber Deformation Envelope in 20 Percent Ballistic Gelatin Backing 7-Ply, 400/2-Denier Kevlar 29 Armor Struck by 158-Grain, .38-Caliber Bullets**




SOURCE: LeRoy W. Metker et al., 1975 [100].

plots a curve for probability of lethality ("PROB. LETH. ' as a function of 'LN DEFORMATION. ' The accompanying text (p. 10) indicates that "LN DEFORMATION" is the natural (base-e) logarithm of deformation in centimeters, so that, for example, a deformation of 5.0 cm (50 mm) corresponds to LN DEFORMATION = 1.61, for which the curve in figure B-10 predicts a probability of lethality of about 0.15, or 15 percent. A deformation of 4.4 cm (44 mm) corresponds to LN DEFORMATION = 1.48, for which the curve predicts a probability of lethality of about 0.06, or 6 percent.

The figure also plots circles with PROB. LETH. = O or 1, indicating survivals or fatalities, respectively, in experiments. The text indicates that the data are "the original blunt impactor data," for which [100] had been cited. However, the text does not specify which of the very numerous blunt impactor data in [100] were plotted. In separate interviews, Mr. Larry M. Sturdivan and Mr. Russell N. Prather told OTA that the data in figure B-10 are for shootings of unarmored goats by blunt impactors-rigid cylinders, some with a hemispherical nose-and that the deformations recorded are the maximum depths of indentation *of the animals' skin* momentarily produced by the projectiles.[26] They are not, as is sometimes assumed, [86, 87] deformations in clay produced by reenactments. The depths were measured, according to Sturdivan, from frames of high-speed films of the impacts; the projectiles were scored at intervals along their length to calibrate the readings. The report did compare deformation of goat skin (''Baseline' and clay by blunt impactors in its table A-2 and figure B-2. However, the comparison is for only one shot per backing; it gives no indication of variation to be expected under similar conditions or of the correlation to be expected at other impact velocities and momenta.

The blunt impactors, simulating the impact of bullet plus armor, were targeted at particularly vulnerable areas. There was no adjustment (as there was in the study by Goldfarb et al.) for goat-human differences or for the imperfect targeting in actual assaults. There was no adjustment for goat-human differences because the model was intended to be species-independent; similar but more complicated parametric lethality models developed by the Army sought to explain differences in lethality on the basis of biometric indices such as weight and body-wall thickness rather than species per se. However, in order to compare figure B-10 to lethality data from actual assaults and deformation data from ballistic reenactments, the deformation data should be adjusted for clay-skin differences and the lethality data

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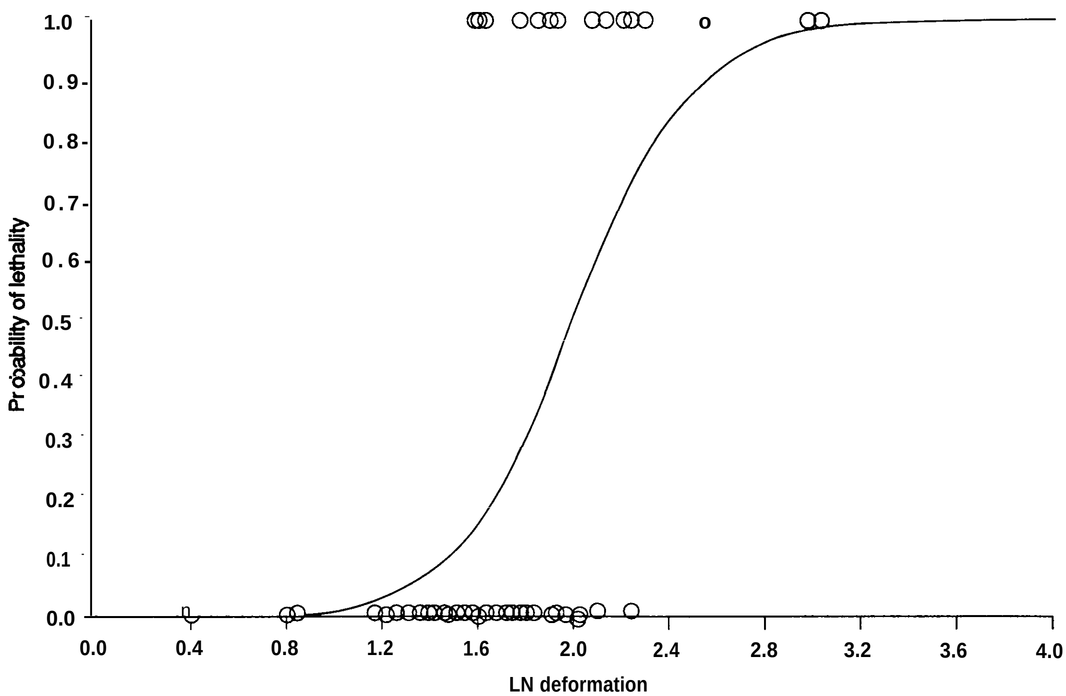
26 In response to OTA's request for the data to which figure B-10 had been fit, Russell Prather noted that he was "unsuccessful in locating the exact data set used to generate figure B-10 from report ARCSL-TR-77055,'' but "managed to locate much of the basic raw data from the blunt impactor program,'' which he provided to OTA [115]. He noted that a logistic model he fitted to the data he located was slightly more conservative (i.e., pessimistic) than figure B-10 at a deformation of 5 cm, predicting a probability of lethality of 0.20, compared to 0.15 or 0.16 for figure B-10; the former value was quoted in [114]; the latter by Prather in his letter of 18 Aprii 1991. The difference is insignificant and difficult to measure from the figure or discern by eye.

To fit the model, Prather used the Waker-Duncan method of logistic regression, which requires an initial estimate, which influences the fitted model [164]. OTA fit a model to the data using a Newton-Raphson procedure [91], which also requires an initial estimate, but it does net influence the fitted model. OTA found that it predicted a probability of lethality of 0.154 at a deformation of 5 cm, in agreement with figure B-10.

When OTA included a separate, non-overlapping set of data (provided by Larry Sturdivan) on blunt-impactor shots at goats, targeted over the liver the resulting model predicted a probability of lethality of 0.157 at a deformation of 5 cm, also in agreement with figure B-10.

**Figure A-3—Correlation of Probability of Lethality With Deformation Depth**




SOURCE: Russell N. Prather et al. 1977 [1 14]. Redrawn by the Office of Technology Assessment, 1992.

should be adjusted for imperfect targeting in actual assaults. Both adjustments would result in prediction of lower lethalities for assaults on armored humans than are indicated in figure B-10.

### *Types of Armor*

The standard specified five levels of armor: I, II-A, II, Ill, and IV. Types I, II, and IV corresponded to the three types defined in 0101.00: II-A offers protection against an intermediate handgun threat and III offers protection against a rifle threat less than that of IV, the old .30 AP type. The velocity requirements changed somewhat, and a plus-or-minus tolerance was introduced in place of the previous no-slower-than specification of velocities. (See table A-4.) presumably manufacturers were concerned that the no-slower-than specification would leave any vest vulnerable to penetration if tested by a sufficiently fast bullet.

The 0101.01 standard also provides for "special type" armor; armor whose ballistic protection is specified by the manufacturer in terms of the exact test rounds it will withstand.

### *Results of Testing Under 0101.01*

Nearly half the armor submitted on the promulgation of the 0101.01 standard failed. Manufacturers responded by improving their armor, and 87 models of armor were eventually certified according to this standard. [148, 150]

An important consequence of the wet-testing protocol is often overlooked. Not only does it require that vests withstand bullets when wet, it doubles the number of shots fired during a test. Separate vests take the damage, so there is no issue of cumulative damage on a given vest. Nevertheless, there is an issue of cumulative probability that the vest will fail on some shot or other. Vest samples that have a 95-percent chance of passing the dry shots would have only a 90-percent chance of passing both the wet shots and the dry shots, even if they performed exactly as well wet as they did dry.[27]

### *Comments on Technology Specificity in the 0101.01 Standard*

With textbook avoidance of technology specificity in their standard, the formulators reacted to the

27 Because, in effect, they have to pass two tests, which they can do with 95-percent probability each, for an overall probability of 0.95 X 0.95 =0.9025.

**Table A-4-Summary of 0101.01 Armor Types According to the Ammunition Against Which They Were Tested**

| Type | Caliber | Mass (grains) | Velocity (ft/sec) | Tolerance (ft/sec) |
|---|---|---|---|---|
| I . . . . . . . | .22 LRHV | 40 | 1,050 | +/-40 |
| | .38 RNL | 158 | 850 | +/–50 |
| II-A . . . . . . | .357 JSP | 158 | 1,250 | +/–50 |
| | 9-mm FMJ | 124 | 1,090 | +/–50 |
| II . . . . . . . | .357JSP | 158 | 1,395 | +/-50 |
| | 9-mm FMJ | 124 | 1,175 | +/-50 |
| III . . . . . . | 7.62-mm FMJ | 150 | 2,863 | +/-1 51 |
| Iv . . . . . . | .30-06 AP | 166 | 2,750 | +/–50 |

KEY: AP = armor piercing; FMJ = full metal jacket; JSP = jacketed soft-point; LRHV = long rifle high velocity; RNL = round-nose lead.

SOURCE: National Institute of Law Enforcement and Criminal Justice, NILECJ Standard 0101.01, December 1978.

**Table A-5-Summary of 0101.02 Armor Types According to the Ammunition Against Which They Were Tested**

| Type | Caliber | Mass (grains) | Velocity (ft/sec) | Tolerance (ft/sec) |
|---|---|---|---|---|
| I . . . . . . . | .22 LRHV | 40 | 1,050 | +/-40 |
| | .38 RNL | 158 | 850 | +/–50 |
| II-A . . . . . . | .357JSP | 158 | 1,250 | +/-50 |
| | 9-mm FMJ | 124 | 1,090 | +/-50 |
| II . . . . . . . | .357JSP | 158 | 1,395 | +/-50 |
| | 9-mm FMJ | 124 | 1,175 | +/-40 |
| III-A . . . . | 44 Magnum | 240 | 1,400 | +/-50 |
| | 9-mm FMJ | 124 | 1,400 | +/-50 |
| III . . . . . . | 7.62-mm FMJ | 150 | 2,750 | +/–50 |
| Iv . . . . . . | .30-06 AP | 166 | 2,850 | +/–50 |

KEY: AP - armor piercing; FMJ = full metal jacket; JSP = jacketed soft-point; LRHV = long rifle high velocity; RNL = round-nose lead.

SOURCE: National Institute of Justice, NIJ Standard 0101.02, 1985.

finding that ballistic material in common use fails when wet by requiring that the armor stop bullets when wet, not that it be waterproofed. Most manufacturers complied by using a waterproofing agent, while others placed the ballistic material in a waterproof carrier. Eventually, an alternative, non-woven, material would prove impervious to water and come into use.

The requirement that the strike face be specified stemmed from an incident in which a particular piece of armor was easily penetrated when mistakenly shot at from the wrong side.

## NIJ STANDARD 0101.02

The 0101.02 standard was promulgated in March, 1985 by NIJ's Technology Assessment Program.

### *Reasons for Replacing the 0101.01 Standard*

Researchers had become aware that, whereas a head-on shot is considered the most stressful case for rigid armor, woven armor could actually be more penetrable from an oblique angle than head-on. [150] The exact mechanics of this vulnerability evidently depend on the geometries of the weave and the bullet: a new fabric introduced in the late 1980s seemed particularly vulnerable to angle shots. [150] In particular, 9-mm bullets hitting loosely-woven Kevlar fabric penetrated best when hitting at an angle of about 30 degrees away from head-on. For soft body armor, the 0101.02 test added two shots at 30 degree angles, removing one other shot from the test so that each panel had to withstand six fair shots.

The 0101.02 standard introduced a new category of ballistic resistance, type III-A, for armor intended to withstand. the high energy handgun bullets fired by .44 Magnum handguns and 9-mm submachine guns[28,29] (See table A-5.) Some say that type III-A was introduced as a result of the increased threat to police officers on the street. Heretofore the multiplicity of the shots against a single test item armor (except for type III armor, which only receives one shot) was apparently seen only as a means of collecting an adequate amount of data. With the increased prominence of autoloading pistols and even submachine guns, however, the ability of the armor to stop more than one shot became a requirement in itself. For this reason, the placement of the shots on the vest was considered with a view to providing a basis for the evaluation of the vest's ability to stop multiple shots. [150]

The 0101.02 standard also introduced a higher level of specificity as to the placement of shots. Diagrams showed where, on a typical panel, fair shots ought to fall.

### *Sampling*

The 0101.02 standard again requires that two to four complete sets of armor be 'selected at random' from some unspecified set. In a new stipulation, these armors are to be sized for a 46"-48" chest. The

28 A submachine gun is a selective-fire weapon that fires pistol ammunition.

29 Facts in this section come from the standard itself [143] if 110 other source is cited.

rather large size lowers the likelihood of shots being deemed unfair because they are too close together. In the case of vests designed for female officers, it is difficult to believe that enough vests of such large size would be made to permit selection of four test articles "at random. "

In a new section entitled "Acceptance Criteria," 0101.02 articulates that a "model" of a vest meets the standard if it meets the workrnanship, labeling, penetration, and deformation requirements. This concept represents a departure from the ''lot' concept.

### *Marking and Workmanship*

The 0101.02 standard reiterated the marking and workmanship requirements of the 0101.01 standard. The labeling requirements were enhanced to include a requirement that the type specification explicitly state the type and the standard according to which it was categorized. Thus a label could declare a vest to be "Type II-A under NIJ Standard 0101.02." For armor of types I through III-A, 0101.02 required a warning printed in large type declaring that the vest was not intended to protect against rifle fire or attacks from edged or pointed weapons. Curiously, the labeling portion of the standard also required a label certifying compliance with the standard-presumably a manufacturer could not affix such a label prior to certification, and yet presence of the label was declared to be a requirement for certification.

### *Penetration*

***The 0101.02*** standard contained the first specific reference to vests contoured for female officers: in the case of such vests, at least one of the 30-degree angled shots had to fall on a bust cup. (The backing material under the vest was to be contoured so as to fill the bust cups.) Because the 30-degree shots are numbers 4 and 5, the resulting deformation is not measured. If the cup contains a seam, the shot must land on a seam. Though the 30-degree incidence is in principle measured between the line of fire and the tangent plane of the vest, the departure of the bust cup from the main plane of the vest makes these shots' angles of incidence questionable, and very probably less than 30 degrees.

In practice, the requirement that a seam be hit can necessitate a seventh fair shot in the case of female vests.

### *Deformation*

Backface deformation was measured only on the first fair shot under the 0101.02 standard, rather than on the frost two fair shots as under the 0101.01 standard. During the transition to the 0101.03 standard, Justice Department officials investigated rumors that the clay block used in 0101.02 testing had had a plywood backing, lessening deformation. This backing, not mandated by the 0101.02 standard, did exist but was not used for 0101.02 testing. [148]

### *Types of Armor*

The 0101.02 standard introduced the Type III-A armor, a soft armor capable of stopping .44 Magnum bullets. This armor type was created at the behest of another Federal Department, whose employees sometimes needed such protection. Some in the NIJ rue the inclusion of III-A armor in the standard, because of the implication that it is appropriate for daily use by law enforcement officers. They feel that local police departments will, acting through understandable and laudable concern for the welfare of their employees, obtain III-A vests without realizing that they are far more robust, expensive, and uncomfortable than is appropriate for police use. In that case, the probable outcome would be that the vests would go unworn. The NIJ's Body Armor Selection Guide cites Type III-A armor as ''generally considered unsuitable for routine wear. However, individuals confronted with a terrorist weapon threat may often be willing to tolerate the weight and bulk of such armor while on duty." [145][30]

### *Results of Testing Under 0101.02*

As was the case with the addition of wet testing in the transition from 0101.00 to 0101.01, the addition of an extra shot in 0101.02 made the test harder to pass. Not only did the total number of opportunities to fail increase (albeit by 20 percent instead of 100 percent), but the number of fair shots per vest actually increased, increasing cumulative damage to the vest.

Because of administrative disarray at the IACP during the 0101.02 period, it is not clear how many vests, or which ones, were tested under the 0101.02 standard. Sixty-two models were certified as having passed. [148]

30 Nevertheless, some wearers report that discomfort varies only slightly with vest thickness.

### *Comments on Technology Specificity in the 0101.02 Standard*

Angled shots against armor of types I through III-A were introduced in response to the discovery that 9 mm bullets penetrated Kevlar more readily at that angle than they did at normal incidence. This modification of the test represents the technology-specific consideration that these vests, but not the rigid vests of types 111 and IV, were likely to be made out of Kevlar and thus subject to the angle penetration.

## NIJ STANDARD 0101.03

The 0101.03 standard was promulgated in April 1987 by NIJ's Technology Assessment Program.[31] Clarifications and modifications of the test procedure have been made since.

### *Reasons for Replacing the 0101.02 Standard*

As mentioned above, it is not clear how many vests were tested under the 0101.02 standard. Worse, samples of certified models were not retained in an orderly way, so that there was no way for the NIJ to determine if the construction of a given model offered for sale was the same as the construction of the model of the same name that had passed the 0101.02 test. These circumstances were brought about by administrative disarray at the IACP. The NIJ reassigned the Technology Assessment Program Information Center (TAPIC) function of the IACP to a new grantee (Aspen Systems), but some information on body armor tested under 0101.02 could not be recovered [150] and a rationale for beginning anew with Aspen Systems was needed.

Retesting and recertification appeared to be the only recourse. The NIJ offered to pay for retesting if the manufacturers would supply the vests, but the manufacturers balked, fearing the consequences if a previously certified model should happen to fail the retest. In such a case, what would be the status of the vests of that model that had already been sold? The NIJ and the manufacturers agreed to let the results of the 0101.02 period stand, but to create for the retest anew standard, 0101.03, that would be substantially the same as 0101.02. The purpose of 0101.03 was simply that it would be a different standard, so that if a vest that had passed under 0101.02 failed the retest, it would not create an anomaly in which vest had passed and then failed the same test. [150] Even today, vests are sold on the strength of their 0101.02 compliance test.

**Table A-6-Summary of 0101.03 Armor Types According to the Ammunition Against Which They Were Tested**

| Type | Caliber | Mass (grains) | Velocity (ft/sec) | Tolerance (ft/sec) |
|---|---|---|---|---|
| I . . . . . . . | .22 LRHV | 40 | 1,050 | +50 |
| | .38 RNL | 158 | 850 | +50 |
| II-A . . . . . . | .357JSP | 158 | 1,250 | +50 |
| | 9-mm FMJ | 124 | 1,090 | +50 |
| II . . . . . . . | .357 JSP | 158 | 1,395 | +50 |
| | 9-mm FMJ | 124 | 1,175 | +50 |
| III-A . . . . | 44 Magnum | 240 | 1,400 | +50 |
| | 9-mm FMJ | 124 | 1,400 | +50 |
| 111 . . . . . . | 7.62-mm FMJ | 150 | 2,750 | +50 |
| Iv . . . . . . | .30-06 AP | 166 | 2,850 | +50 |

KEY: AP = armor piercing; FMJ = full metal jacket; JSP = jacketed soft-point; LRHV = long rifle high velocity; RNL = round-nose lead.

SOURCE: National Institute of Justice, NIJ Standard 0101.03, 1987.

Minor changes in 0101.03 as compared to 0101.02 included the elimination of the negative side of the plus-or-minus standard, so that the nominal velocity figure could be cited as a minimum. (See table A-6.) Records of tests performed under the 0101.02 standard revealed that the majority of shots fell in the plus side of the standard anyway, so that this change was not viewed as significant. [150]

In a more major change in the test protocol, the 0101.03 standard clarified the point that vests were not to be smoothed out or repositioned between shots.

Perhaps because of difficulties in determining which vests had been tested under 0101.02 and which had not, the 0101.03 standard introduced the distinction between a *model* and a style: several styles of the same model vest could all be certified by the same test, inasmuch as they were ballistically identical and only superficially different.

### *Sampling*

The 0101.03 standard takes for granted that a full set of four armors will be needed, though there is still a tester's option to test the same panel with two types of ammunition. 0101.03 says that a "style" (not a ''model,' as in 0101 .02) of a vest meets the standard if it meets the workmanship, labeling, penetration, and deformation requirements. An administrative procedure issued by TAPIC clarifies the course of

31 Facts in this section come from the standard itself [144], if no other source is cited.

action to be taken if a model fails-the manufacturer must abandon that model. [150] Not only must the manufacturer abandon the model designation, he or she may not submit a noncomplying model for retesting. [146]

Vests tested under the 0101.03 standard are archived by TAPIC for later reference. Under this system, any question about whether a given vest is the of same model as was tested can be resolved by direct comparison of the test item and the vest in question.

### *Marking and Workmanship*

The 0101.03 standard departs from the marking and workmanship requirements of the 0101.02 standard in that a distinction is drawn between ballistic panels and the carriers in which they are used. Standard 0101.03 recognizes that some armor consists of a carrier and removable panels, whereas other armor consists of a carrier containing nonremovable panels. The 'panel' labeling requirements generally follow the 'armor' labeling requirements of the 0101.02 standard, enhanced to include a serial number and model or style designation uniquely identifying the panel for purchasing purposes. Under 0101.03, care instructions have to conform to part 423 of the Federal Trade Commission Regulation Rule. Carriers with nonremovable panels must, "in addition to the label required for the ballistic element, have a label on the carrier that is in conformance with the requirements for the ballistic panels,' unless the label on the panel is not covered by the carrier. Carriers with removable panels must be labeled with an identification of the manufacturer, ''a statement telling the user to look at the ballistic panels to determine the protection provialed, ' the size, date, and model name of the carrier, care instructions, and certification of compliance with NIJ Standard 0101.03.

### *Penetration*

A clarification issued March 18, 1988 addressed the question of vests that may have been weakened by unfair hits. If a panel that has already received two or more unfair hits fails owing to penetration, the test is deemed inconclusive and another panel is tested.

A modification issued May 11, 1989 defined penetration to include "perforation of the last layer of fabric to the extent that the projectile breaks threads in that layer and protrudes from the inside surface of the layer. " [82]

### *Deformation*

The 0101.03 standard eased a special requirement formerly placed on the first shot on each panel, the one that is used in the assessment of backface signature. Under 0101.02, the velocity of this shot had to be in the upper 32.8 ft/s (10 m/s) of the allowable range of velocities.[32] In the context of its elimination of the bottom 50 ft/s of the allowable range, 0101.03 permitted the velocity of the first shot to be anywhere in the remaining 50 ft/s, not restricting it to the upper 32.8 ft/s. In this respect, 0101.03 relaxed the backface deformation standard by allowing shots of slightly lower velocity.

On October 10, 1989, H.P. White Laboratories proposed a modification under which backface deformation would be measured for all normal-incidence shots, not just the first on each panel. The measurements would be made after all of the shots were fired, so as to avoid any rearrangement of the vest between shots. (Under the current practice, the measurement of the BFS of the first shot is made right after the shot, in effect Wowing for a rearrangement of the vest.) Any deformation in excess of 44 mm would constitute a failure of the vest. The NIJ has not accepted this modification. [82]

### *Types of Armor*

The 0101.03 standard did not introduce any new armor types, nor any new shots. Subsequent modifications to the standard moved the sites of the fourth, fifth, and sixth shots slightly, to avoid placing any shot directly on threads weakened by a previous shot. [82]

### *Results of Testing Under 0101.03*

Manufacturers and government officials alike expected that some vests certified under 0101.02 would fail the 0101.03 retest purely through the operation of chance alone: as described above, this expectation was a principal reason for the creation of the 0101.03 standard in the first place. However, far more vests failed than anybody expected: 50 out of

32 NIJ STD 0101.02 [143], page 10, first paragraph. The operative sentence can be seen as ambiguous: H.P. White Laboratory personnel explained its interpretation to the OTA staff.

**Table A-7—Results of 0101.03 Compliance Retests**

| Ballistic resistance level | I | II-A | II | II I-A | III | Iv | III/Iv | Total |
|---|---|---|---|---|---|---|---|---|
| Tested | 12 | 21 | 29 | 17 | 2 | 2 | 1 | 84 |
| Certified | 11 | 9 | 11 | 1 | 1 | 0 | 1 | 34 |
| Failed | 1 | 12 | 18 | 16 | 1 | 2 | 0 | 50 |

SOURCE: National Institute of Standards and Technology, undated [1 371.

84,[33] The results of these tests are shown in table A-7.

Experts differ as to whether the slight increase in velocity caused by abandonment of the negative side of the velocity tolerance could, statistically, explain so many failures in a group of 84 vests that had previously passed.[34] However, a variety of other causes have been suggested.

As mentioned above, the 0101.02 standard provided for testing of the second ammunition type on the same vest as had been used for the first ammunition type. If a failure occurred with the second ammunition type, the successful passage with the first ammunition type was allowed to stand and the test with the second ammunition type was restarted on a fresh panel. The purpose of this protocol was to save money by consuming the minimum number of panels possible. An important consequence, however, was that the vest could have two chances to pass the second part of the test. The majority of 0101.02 testing was done in this fashion. [137]

Existing records of successful tests under 0101.02 cite some reports as "revised," without further explanation. Unsupported allegations exist that individual panels were submitted to substitute for ones that failed, until a complete set of eight passes was garnered. [137] This practice could perhaps be seen as having been fostered by the protocol allowing a restart of a second-ammunition test upon failure.

It seems possible to OTA that the large number of failures could be attributed to the 0101.03 standard's heightened strictures against smoothing down or repositioning the vests between shots. Allegations are also sometimes made to the effect that, under 0101.02, vests were intentionally strapped to the test fixture so weakly that they would fall off after a shot, producing a free rearrangement of the vest as it was reattached to the test fixture. Regardless of any change in intent, the 0101.03 standard provided (at the time of the retest) for 4 straps attaching the vest to the test future rather than the 2 used under the 0101.02 standard. Presently, the 0101.03 standard provides for 5 straps, an extra strap having been mandated by the NIJ in a procedural modification.

Because 0101.02 testing was coordinated directly between the manufacturer and the test lab, it is possible that failures existed and were not reported to the IACP. It is also possible, given the record-keeping difficulties experienced by the IACP during the 0101.02 era, that records of failures were received but not preserved in an accessible manner.

While no single difference between the 0101.02 and 0101.03 revisions, or the procedures associated with them, can satisfactorily explain the large number of failures during the 0101.03 retest, the above factors, working in concert, may have exerted a cumulative effect greater than any individual effect.

Hundreds more vests have been tested since the retest program. The results of this testing are shown in table A-8.

The deformation standard has occasioned a debate out of proportion to the number of failures attributable to deformation alone. [150] Manufacturers and

[33] Because of the recordkeeping anomalies prevalent during the 0101.02 era and because some manufacturers took the precaution Of renaming vest models before submitting them for the retest, the NIJ and NIST—though possessing evidence that some vests that failed in the retest had passed 0101 .02-cannot fully document all such cases with confidence. However, submission of the vest for a retest, as such, constituted an implicit statement that the vest had passed 0101.02 and was being retested as part of the pact that the government made with the industry when introducing 0101.03 In addition, OTA has received confirmation from members of the body armor industry that many vests that failed the retest had passed under 0101.02. No party has contested the figure of 50 out of 84, which appears in [137], page 31. This source also says, on the same page, that 62 vests passed 0101.02—it is not clear where the other 22 (i.e. 84- 62) 0101.02-compliant vests came from.

[34] Based on a review of extant records of 0101.02 testing, [137] makes a strong case (on pp. 31-33) that most shots fired in 0101.02 testing lay within the velocity window specified later for 0101.03, concluding that "the test results for at most 25 percent of the armor could be influenced to some extent by the elimination of the negative velocity tolerance."

**Table A-8-Results of 0101.03 Certification Tests** (as **of June 1991)**

| Ballistic resistance level | I | II-A | II | II I-A | III | Iv | Total |
|---|---|---|---|---|---|---|---|
| Certified | 29 | 70 | 102 | 57 | 15 | 8 | 281 |
| Failed (penetration) | 2 | 46 | 68 | 14 | 7 | 8 | 145 |
| Failed (deformation) | 1 | 1 | 1 | 10 | 2 | 0 | 15 |
| Failed (both) | | | | | | | |
| (subtotal) | (4) | (54) | (78) | (44) | (9) | (8) | (197) |
| Inconclusive | | | | | | | |
| Tested | 33 | 125 | 182 | 103 | 24 | 16 | 483 |

SOURCE: H.P. White Laboratory, Inc. June 7, 1991.

others have made statements such as "more than 50 percent of current vests fail the NIJ/NIST test procedure despite their perfect performance in the field" [87], because the rate at which vests fail the test (40 percent) greatly exceeds the rate at which they fail in the field (said to be O percent, on the grounds than no officer has ever been killed through being hit on the protected area by a bullet the vest was rated to stop). [150] Manufacturers say this discrepancy stems from over-conservatism in the standard. A more obvious reason is that vests that fail are not (presumably) presented in the marketplace for sale. Other possible reasons include the fact that vests see use against all threat levels whereas they are only tested against the most threatening level they could hope to withstand. The fact that manufacturers feel an incentive to build close to the limit so as to avoid the extra weight, bulk, heat retention, and expense incurred by having more ballistic protection than is necessary may explain why the success rate of vests has not improved despite claims of technological progress by the manufacturers.

The tendency of the test armor, if untouched, to bunch up on the clay during testing has previously been mentioned as a possible cause of failure. Tests conducted under the 0101.00,0101.01, and 0101.02 standards resulted in a large number of truncated trials because, to save money, testing stopped immediately upon a failure. The procedure of the 0101.03 test, unlike that of its predecessors, mandates continued shooting even after a failure, so that complete data are available. These data can be examined for signs pointing to bunching as a significant cause of failures.