HPW-TP-0404.01
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H.P. WHITE LABORATORY, INC.

TEST PROCEDURES

WEARABILITY OF BULLET AND STAB RESISTANT BODY ARMOR

H.P. White Laboratory, Inc.
3114 Scarboro Road
Street, Maryland 21154

REVISIONS

Date	Revision Number	Description
2/2001	HPW-TP-0404.01	Added flexure of test panel prior to Stiffness Testing (2.5.2.2). Added Addendum A on Comfort vs. Protection Added record of revisions (this page)

HPW-TP-0404.01
-Wearability of Bullet and Stab Resistant Body Armor-

Section 1.0 INTRODUCTION

1.1 BACKGROUND

1.1.1 In the early 1960's, H.P. White Laboratory, Inc. began Ballistic Resistance Testing of body armor. In the 1970's interest in body armor and body armoring materials had increased to the point of creating an entirely new industry. The focus of that industry was Ballistic Resistance but that focus eventually expanded to include Stab Resistant body armor.

1.1.2 The user's principal objection to both types of this armor has always been its discomfort. Lacking an objective means of assessing that discomfort, many Law Enforcement Agencies resort to a competitive "Wearability Test" in which members of the agency wear each of several competing models of armor during duty hours and comment on the relative Wearability of each. To use this process to evaluate all of the hundreds of models of armor available in today's market place is inefficient, unreliable and expensive.

1.2 DISCUSSION

1.2.1 To some extent, the discomfort of body armor is attributable to improper fitting, but even tailored armors will be more uncomfortable than no armor at all. It is not surprising that experience has demonstrated the greater the discomfort of the armor the more likely the user will avoid wearing the armor.

1.2.2 To reduce the reluctance to use body armor because of its discomfort, the design of the armor must minimize that discomfort without sacrificing either the level of protection of the armor or the lateral area of that protection.

1.2.3 The physical characteristics of body armor, excluding its fit, which define its level of discomfort are weight, bulk, restrictions of movement and chafing resulting from those restrictions.

1.3 SCOPE

1.3.1 The purpose of this inspection procedure is to establish those characteristics of body armor which contribute to its discomfort and provide an objective means of comparing the discomfort of any model of armor with any other model of armor.

1.3.2 These procedures combine a flexible armor's weight, thickness, lateral area of protection and stiffness to establish a numerical, **WEARABILITY RATING**.

1.3.3 The wearability rating of a RIGID armor is determined by combining its weight, thickness and lateral area of protection.

1.3.4 The wearability rating of flexible armors whose protection levels may be upgraded by the addition of optional, rigid inserts will be evaluated without the insert in accordance with 1.3.2 and with the insert in accordance with 1.3.3.

1.3.5 Specifically, exempted from this evaluation is the fit of the armor, which is individually subjective and is outside of the scope and objectivity of these procedures.

Section 2.0 PROCEDURES

2.1 TEST SAMPLING

2.1.1 The sampling required for Wearability Testing is one complete armor (front and back). Inasmuch as this wearability testing will not effect the ballistic or stab resistance of the armor, the test sample may be one of the armors submitted for NIJ-STD-0101.04 or NIJ-STD-0115.00 Testing.

2.1.2 The following data shall be transcribed from the label for the armor to the wearability test data records (Enclosures 01).

a) Manufacturer
b) Model and whether male or female configuration.
c) Level of protection (Ballistic and/or Stab Resistance).
d) Style (if appropriate)
e) Serial Number(s)
f) Lot Number(s)
g) Date(s) of manufacture
h) Size
i) After Ballistic or Stab Testing (if any) destructively disassemble and record ply count and weave (if appropriate).

2.1.3 Preparation of the wearability test sample is the same as the preparation for Ballistic Resistance Testing and may require the same destructive separation of the carrier into front and back panels as is required for Ballistic Resistance Testing (see Figure 01).

2.1.4 All wearability testing shall be conducted in the dry condition after 24 hours at 65-75° F and 30-80% relative humidity.

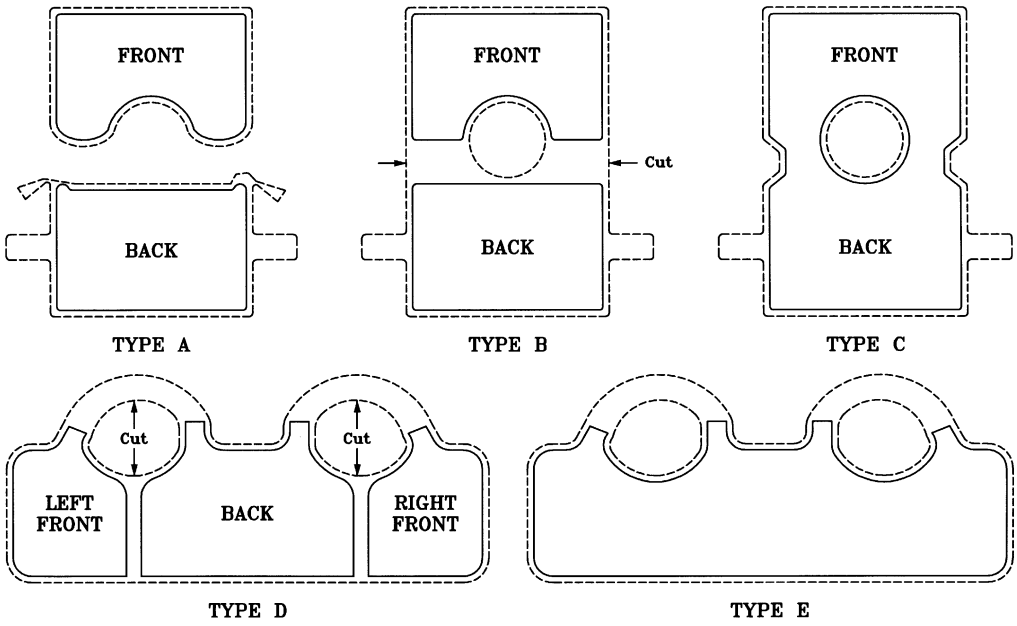

FIGURE 01. PREPARATION OF ARMOR FOR WEARABILITY TESTING

2.2 WEIGHT OF ARMOR

2.2.1 The weight of each panel shall be determined and shall include the ballistic element, rigid inserts (if any), trauma pads (if any), carrier, and all appurtenances thereto. The weight of any ballistic, upgrade insert shall be recorded separately.

2.2.2 All trauma pads are to be included in the determination of weight whether they are permanently attached or removable.

2.2.3 These weights shall be determined in pounds, avoirdupois to the nearest 0.01 of a pound.

2.3 THICKNESS OF ARMOR

2.3.1 Flexible Armor – The thickness of flexible armor shall be determined by the measurement of each panel and each measurement shall include the carrier, ballistic element and trauma pad (if any). Trauma pads are to be included in this thickness measurement whether they are permanently attached or removable.

2.3.1.1 Flexible armors designed with a pouch to accept a rigid, optional, protection-upgrade panel shall include this, empty pouch, in the thickness measurement, but will not include any portion of the bust cup of female armors.

2.3.2 PANELS WITH RIGID ELEMENTS – The thickness of rigid armors shall be determined by the same manner as 2.3.1 except that the measurements shall include the rigid element.

2.3.3 UPGRADEABLE-PROTECTION ARMORS – Flexible armors intended for a lesser protection level, but which are designed to be upgradeable to a higher level of protection, shall be thickness tested twice. The configuration of the lower-level protection shall be tested in accordance with 2.3.1 and the configuration of the higher level in accordance with 2.3.2.

2.3.4 PROCEDURE – The location of the thickness determination of the panel selected shall be dimensionally recorded and shall be as close to the centroid of the panel as possible.

2.3.4.1 The body-side of the armor shall be placed directly over a rigidly mounted, steel sphere of 1.0 ± .010" diameter.

2.3.4.2 A solid steel cylinder of 1.128 ± .010" diameter (1.0 sq. in.^{2}) shall be applied to the external surface of the armor with a force of 3 pounds and its longitudinal centerline coincidental with the vertical centerline of the sphere.

2.3.4.3 The vertical distance between the surface of the sphere and the cylinder shall be recorded as the thickness of the panel in inches.

2.4 PROTECTION AREA

2.4.1 To prepare the test sampling for protected areal determinations the ballistic elements shall be non-destructively removed from their carriers.

2.4.2 The surface area of each of the ballistic elements shall be determined by any suitable method with an accuracy of ± 2 in^2. This determination shall be of the area of the element projected onto a flat plane which includes the outer most edges of the element when at rest in a horizontal orientation without adjustments for curvature of bust cups and other pre-formed features. The area of all strapping, which extends beyond the periphery of the carrier, shall be EXCLUDED from this area determination.

2.4.3 The area of ballistic elements which are sealed in a non-ballistic cover (typically nylon or cotton) from which the ballistic element cannot be non-destructively removed, shall be determined with the excess material of the cover drawn tight against the edges of the ballistic material or folded under the ballistic material in such a way as to eliminate this unsupported cover from adding to the area of ballistic protection of the ballistic element.

2.4.4 The area of ballistic protection shall be recorded in square feet (ft^2).

2.4.5 FLEXIBLE ARMOR – The protected area of the flexible configuration shall be determined as in 2.4.1-2.4.4 above.

2.4.6 RIGID ARMOR – The protected area of the rigid insert(s) shall be computed as in 2.4.1-2.4.4 except that only the area of ballistic enhancement(s) (rigid inserts) shall be recorded.

2.5 STIFFNESS TESTING

2.5.1 The Stiffness Testing specified herein does NOT apply to armors with permanent rigid inserts (most Levels III and IV) or to configurations of flexible armor (most Levels I, IIA, II and IIIA) which have been upgraded to higher levels of protection by the addition of optional, rigid inserts.

2.5.2 The centroid of the complete front and back panels (carriers and ballistic elements) shall be determined and marked as in Figure 02.

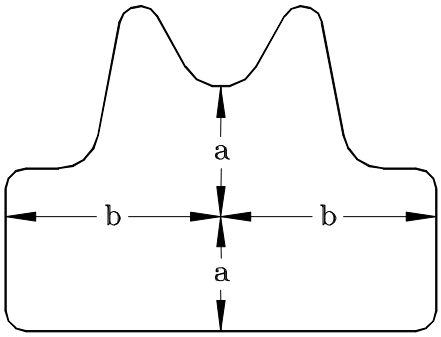

FIGURE 02. CENTROID OF ARMOR PANELS

2.5.2.2 Prior to initiation of the Stiffness Test procedures of this standard, the panel of armor to be tested will be flexed twenty times (see Figure 03) - 10 repetitions in a manner which includes the vertical centerline and centroid in the line of flexure and 10 repetitions in a similar manner which includes the horizontal centerline.

2.5.3 The Stiffness Testing specified herein shall be conducted with an apparatus configured as in Figure 03.

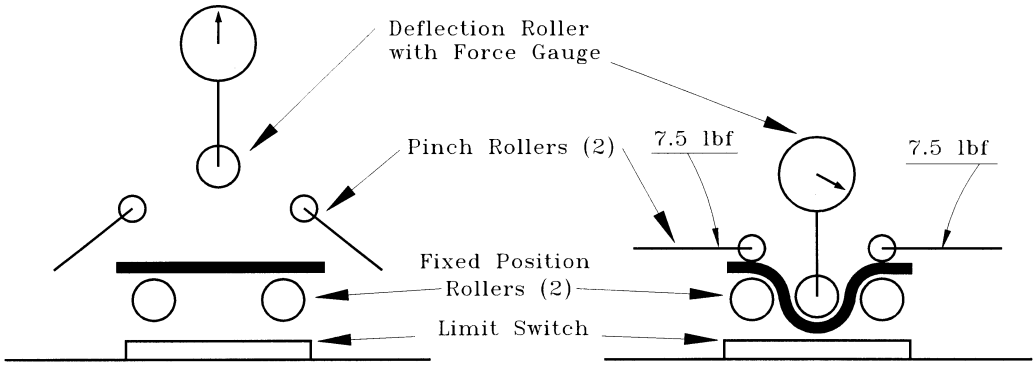

FIGURE 03. STIFFNESS TESTING

2.5.4 Two determinations of the stiffness of each panel shall be made –

1) Threat side down with the horizontal line through the centroid of the panel, parallel to, and directly under the longitudinal centerline of Roller A.
2) Threat side down with the vertical line through the centroid of the panel, parallel to, and directly under the longitudinal centerline of Roller A.

2.5.5 With no test panel in the apparatus, Roller A shall be carefully lowered and the force necessary to activate the limit switch recorded.

2.5.6 The lengths of Lines A and B of Figure 02 shall be determined and recorded as the vertical and horizontal flexure lines, A and B, respectively.

2.5.7 The first panel shall be placed, threat-side down on Rollers D and E in the apparatus with vertical centerline (a-a of Figure 02) parallel to, and directly under, the centerline of Roller A. Lower Rollers B and C, which will hold the panel in place against Rollers D, and E with an applied force of 7.5 pounds each.

2.5.8 Lower Roller A and carefully increase the force to Roller A necessary to flex the test panel and activate the limit switch.

2.5.9 Record the maximum force recorded. The force necessary to flex the panel shall be determined by subtracting the force recorded in 2.5.5 from that of 2.5.8.

2.5.10 Repeat procedures 2.5.5 through 2.5.10 with Line b-b of Figure 02 directly under, and parallel to, the centerline of Roller A.

2.6 AREAL DENSITY OF PROTECTION

2.6.1 Areal density is a term used to describe the weight of a material per unit of lateral area (lbs./ft.).

2.6.2 Areal density, for purposes of this evaluation, shall be the **WEIGHT OF THE ENTIRE ARMOR** (see 2.2) divided by the lateral area of the **BALLISTIC PROTECTION ONLY** (see 2.4).

2.6.3 The elements which constitute areal density (weight and area) are otherwise included in this procedure, however, the presentation of weight and area as areal density may be presented as supplemental information.

2.6.4 The areal density of each ballistic element shall be individually determined by dividing the weight, in pounds, of the entire panel (2.2), including the carrier, trauma pads and all appurtenances, by the surface area, in square feet, of the ballistic element of that panel (2.4).

2.6.5 The areal density of the complete vest shall be the total weight of all panels, including the carrier, trauma pads and all appurtenances, divided by the total surface area of all ballistic elements.

2.6.6 The areal density of flexible armors whose ballistic protection is upgradeable by the addition of a RIGID panel to a higher level of protection shall be computed twice (2.6.7 and 2.6.8).

2.6.7 FLEXIBLE ARMOR – The areal density of the flexible configurations of armor shall be computed by dividing the weight of the COMPLETE FLEXIBLE PANEL (2.2) by the area of protection only (2.4).

2.6.8 RIGID ARMOR – The areal density of rigid armors shall be computed by dividing the weight of the complete panel – flexible and rigid (2.2) by the area of protection of the rigid insert only (2.4).

2.6.9 UPGRADEABLE ARMORS – the areal density of flexible armors, which can be upgraded in protection level with an optional rigid inset, shall be computed once for the flexible configuration in accordance with 2.6.7 and for the rigid configuration in accordance with 2.6.8.

SECTION 3.0 WEARABILITY

3.1 GENERAL

3.1.1 Wearability of body armor, as used herein, is defined as a numerical rating to be used only to establish the RELATIVE comfort of two or more models of flexible bullet resistant and/or stab resistant armors.

3.1.2 The wearability rating is established by mathematically combining measured values of weight, thickness, lateral area of protection and stiffness of the armor to form a single, numerical rating of the comfort of the armor for which conventional units of measure are valueless.

$$WR = \frac{A}{W \times T \times S}$$

-WHERE-

W = Complete WEIGHT of armor including carriers, covers, straps, closures, trauma pads, pouches, etc. Expressed in pounds avoirdupois (lbs.)

A = Lateral AREA of protection of all ballistic elements including front panels, back panels, groin protectors, etc. expressed in square feet (ft^2).

T = THICKNESS of carrier with ballistic insert expressed in inches (in).

S = STIFFNESS of the panel expressed as the force necessary to flex the carrier with ballistic insert divided by the length of the flexure line expressed in pounds force ÷ inches (lbf/in).

3.1.3 Vests with a larger numerical WEARABILITY RATING (WR) will be more comfortable than vests with a lesser numerical rating.

ADDENDUM A
HPW-TP-0404.01

COMFORT VS. PROTECTION

A.1 GENERAL

A.1.1 The WEARABILITY RATING is intended to reflect the relative comfort of armors without respect to the type of protection (ballistic or stab resistant) nor the level of that protection.

A.1.2 A relatively comfortable vest that offers only the minimum, acceptable level of protection may not be as suitable as a less comfortable vest, which offers a greater level of protection. Generally, the comfort of a body armor is achieved at the expense of protection which renders the compromise between comfort and protection extremely important when selecting the armor.

A.1.3 Should it be necessary, or desirable, to combine the wearability AND protection of armor in a manner, which will facilitate an objective comparison with other armors, we suggest the procedures of A.2 or A.3.

A.1.4 The procedures of A.2 and A.3 assume the protective armor has been tested and certified by the National Institute of Justice for Bullet Resistance (A.2) in accordance with the requirements of NIJ-STD-0101.04 or Stab Resistance (A.3) in accordance with the requirements of NIJ-STD-0115.00.

A.2 BULLET RESISTANT ARMOR

A.2.1 This procedure for combining the Wearability and Bullet Resistance of an armor combines the Wearability Rating of the armor (HPW-TP-0404.01) and the V50 developed during Bullet Resistance Testing (NIJ-STD-0101.04).

A.2.2 Combining the Wearability and Ballistic Resistance of an armor by multiplying its Wearability Rating by the V50 of the armor, divided by 1000, will provide a single, combined rating. This combined rating will reflect the Wearability **AND** the Ballistic-Resistance properties of the armor and may be compared with the combined rating of any other armor providing the V50's of the armors being compared were developed with the same ballistic threat (caliber, bullet weight and bullet type). The **LARGER** the product of these multiplications the better the compromise between wearability and protection.

EXAMPLE

Armor:	A	B	C
Wearability Rating(WR)	30.7	33.2	31.9
V50 w/9mm, 124 gr. FMJ	1750 fps	1600 fps	1700 fps
$\frac{(WR)(V50)}{1000}$	$\frac{(30.7)(1750)}{1000}$	$\frac{(33.2)(1600)}{1000}$	$\frac{(31.9)(1700)}{1000}$
COMBINED RATING(CR)	**53.7**	**53.1**	**54.2**

In this example, Vest A is the least comfortable but offers a higher level of protection than either Vests B or C, Vest B is the most comfortable but offers the least level of protection, and Vest C may be the best compromise between comfort and ballistic protection.

A.3 STAB RESISTANT ARMOR

A.3.1 This procedure for combining the Wearability and Stab Resistance of an armor combines the Wearability Rating of the armor (HPW-TP-0404.01) and the results of Stab Resistance Testing (NIJ-STD-0115.00).

A.3.2 Combining the Wearability and Stab Resistance of an armor by multiplying its Wearability Rating by the square of its Stab Resistance Threat (Level 1, 2 or 3) divided by the average, plus 10, depth of penetration of its Stab Resistance Testing will provide a single combined rating. This combined rating will reflect the Wearability **AND** Stab Resistant properties of the armor and may be compared with the combined rating of any other armor providing the Stab Testing has been performed with the same classification of threat of NIJ-STD-0115.00 (spike or edge). The **LARGER** the resultant numerical values obtained by this mathematical combination the better the compromise between wearability and protection.

EXAMPLE

VEST:	A	B	C	D
Type	Spike	Spike	Spike	Spike
Wearability Rating(WR)	30.7	33.2	31.9	32.2
Stab Protection Level (L)	3	2	1	1
Average Penetration(P)*	8.2	0	0	1
$\frac{(WR)(L^2)}{P + 10}$	$\frac{(30.7)(3)^2}{18.2}$	$\frac{(33.2)(2)^2}{10}$	$\frac{(31.9)(1)^2}{10}$	$\frac{(31.9)(1)^2}{11}$
COMBINED RATING(CR)	**15.28**	**13.28**	**3.19**	**2.9**

*** Maximum allowable by NIJ-STD-0115.00: 11.33**

In this example, Vest A is the least comfortable, but offers the greatest level of stab protection and may be the better compromise between wearability and protection with a Combined Rating of 15.28. Vest B, while more comfortable than Vest A (33.2 vs. 30.7), offers a lesser level of protection (2 vs. 3) and may not be as good a compromise of protection and wearability (13.28 vs. 15.28). For the same level of protection, Vest C, though less comfortable, may offer a better compromise of wearability and protection than Vest D (3.19 vs. 2.90).

H.P. White Laboratory, Inc.

- WEARABILITY -

(HPW-TP-0404.01)

Date: Job Number:

Manufacturer: Model: Protection Level:

Date Rec'd: Type: Standard:

Ballistic Material: Male/Female:

Size:

Aramid	*PBO*	*Ceramic*	*Metal*
Polyethylene	*Hybrid*	*Composite*	*Other*

	Front	Back	Other	Sum	Average
Serial Number:					
Lot Number:					
Area of Protection, **A** ($ft.^2$):					
Gross Weight, **W** (lb.):					
* Ballistic Material Weight (lb.):					
Overall Thickness, **T** (in.):					
* Ballistic Material Thickness (in.):					
Vertical Flexure Line, **L** (in.):					
Horizontal Flexure Line, **L** (in.):					
Measured Vertical Flexure Force (lbf.) 1:					
2:					
3:					
Measured Horizontal Flexure Force (lbf.) 1:					
2:					
3:					
Average Vertical Flexure Force (lbf.):					
Average Horizontal Flexure Force (lbf.):					
Corrected Vertical Flexure Force, **F** (lbf.):					
Corrected Horizontal Flexure Force, **F** (lbf.):					
Vertical Stiffness, **S** (lbf./in.):					
Horizontal Stiffness, **S** (lbf./in.):					
Average Stiffness, **S** (lbf./in.):					
Effective Areal Density (lb./$ft.^2$):					
* Areal Density of Ballistic Material (lb./$ft.^2$):					
Wearability Rating, **WR**:					

Flexure Force Zero Offset (lbf.):

1:
2:
3:
Avg:

Wearability Rating:

Measurements preceded by an asterisk (*) require destruction of the vest.

(Calculated using **bold** values)

Number of Layers: Front Closure (Y/N): Removable Carrier (Y/N):

* Description of Stitching:

* Individual Layer Description:

Remarks:

Equations:

$$\text{Areal Density} = \frac{W}{A} \qquad \text{Stiffness, } S = \frac{F}{L} \qquad \text{Wearability Rating, } WR = \frac{A}{W * T * S}$$

W = Weight, A = Protected Area, F = Flexure Force, L = Flexure Line, T = Thickness

Note: A higher Wearability Rating is indicative of a more comfortable vest.