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Ballistic Resistance of Armored Passenger Vehicles: A Practical Guide to Testing

*Idaho National Laboratory
Defense Systems and Technology
Directorate*

*National and Homeland Security Division
(WFO Project: 03707)*

July 2005

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Idaho Falls, Idaho 83415

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ABSTRACT

This guide establishes a test methodology for determining the overall ballistic resistance of the passenger compartment of assembled nontactical armored passenger vehicles (APVs).

Because ballistic testing of every piece of every component of an armored vehicle is impractical, if not impossible, this guide describes a testing scheme based on statistical sampling of exposed component surface areas. Results from the test of the sampled points are combined to form a test score that reflects the probability of ballistic penetration into the passenger compartment of the vehicle.

FOREWORD

This document was prepared to provide the Physical Protection subcommittee of the Technical Support Working Group with a test protocol and quality method for testing the ballistic resistance of armored passenger vehicles (APVs). The method presented herein was developed in response to a proposal submitted by the Idaho National Engineering and Environmental Laboratory in June 2002, which responded to Broad Area Announcement 02-Q-4665, Requirement R-829B. Requirement R-829B, which addresses the ballistic resistance of an APV, is part of a group of protection and performance requirements dealing with blast, transparent armor (glazing), and vehicle performance. Requirement R-829B focuses on the armor system for personnel protection; it excludes testing and qualification of the tires, batteries, gas tanks, and other vehicle components.

The testing methodology and procedure presented should be reviewed in context with other development elements outlined in the R-829 requirement series. The format of this methodology generally follows that of NIJ 0108.01, *Ballistic Resistant Protective Materials*, but a commentary has been added in Appendix A to clarify and establish the basis for the methodology. The selection and categorization of threats were validated through field-testing; however, at the committee's direction, field validation of this test methodology and procedure was not required. The test protocol and method presented in this can be validated after field-test issues have been identified and resolved. This guide supports the body of requirements outlined in R-829.

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COMMONLY USED SYMBOLS AND ABBREVIATIONS

A	ampere
ac	alternating current
AM	amplitude modulation
AP	armor piercing
APV	armored passenger cle
cd	candela
cm	centimeter
CP	chemically pure
c/s	cycle per second
d	day
dB	decibel
dc	direct current
C	degree Celsius
°F	degree Fahrenheit
diam	diameter
emf	electromotive force
eq	equation
F	farad
fc	footcandle
fig.	figure
FM	frequency modulation
ft	foot
ft/s	foot per second
FMJ	full metal jacket
g	acceleration
g	gram
gr	grain
H	henry
h	hour
hf	high frequency
Hz	hertz (c/s)
i.d.	inside diameter
in.	inch
ir	infrared
JSP	jacketed soft point
J	joule
L	lambert
l	liter
lb	pound
lbf	pound-force
lbf·in.	pound-force inch
lm	lumen
ln	logarithm (natural)
log	logarithm (common)
M	molar
m	meter
min	minute
mm	millimeter
mph	mile per hour
m/s	meter per second
N	newton
N·m	newton meter
nm	nanometer
No.	number
o.d.	outside diameter
Ω	ohm
p.	page
Pa	pascal
pe	probable error
pp.	pages
ppm	part per million
qt	quart
rad	radian
rf	radio frequency
rh	relative humidity
RN	round nose
s	second
SD	standard deviation
sec.	Section
SWC	semi-wadcutter
SWR	standing wave radio
uhf	ultrahigh frequency
uv	ultraviolet
V	volt
vhf	very high frequency
W	watt
λ	wavelength
wt	weight

area = unit^2 (e.g., ft^2, in^2, etc.); volume = unit^3 (e.g., ft^3, m^3, etc.)

Prefixes

d	deci (10^{-1})
c	centi (10^{-2})
m	milli (10^{-3})
μ	micro (10^{-6})
n	nano (10^{-9})
p	pico (10^{-12})
da	deka (10)
h	hecto (10^{2})
k	kilo (10^{3})
M	mega (10^{6})
G	giga (10^{9})
T	tera (10^{12})

Common Conversions (See ASTM E380)

ft/s × 0.03048000 = m/s0
lb × 0.4535924 = kg
ft × 0.3048 = m
lbf × 4.448222 = N
ft·lbf × 1.355818 =J
lbf/ft × 14.59390 = N/m
gr × 0.06479891 = g
lbf·in. × 0.1129848 = N·m
in. × 2.54 = cm
lbf/in. × 6894.757 = Pa
kWh × 3,6000,000 = J
mph × 1.609344 = km/h
qt × 0.9463529 = L

Temperature: (T °F-32) × 5/9 = T °C
Temperature: (T °C × 9/5)+32 = T °F

Ballistic Resistance of Armored Passenger Vehicles: A Practical Guide to Testing

1. PURPOSE

This guide establishes a test methodology for determining the overall ballistic resistance of the passenger compartment of assembled nontactical armored passenger vehicles (APVs).

Because ballistic testing of every piece of every component of an armored vehicle is impractical, if not impossible, this guide describes a testing scheme based on statistical sampling of exposed component surface areas. Results from the test of the sampled points are combined to form a test score that reflects the probability of ballistic penetration into the passenger compartment of the vehicle.

2. SCOPE

This guide is limited to assessing the ballistic resistance of an APV to small arms fire. It does not address threats from explosive blasts, explosive-formed-weapons, collision impacts, or hand-held weapons. The explosive (blast) resistance of the vehicle, the ballistic resistance of the transparent armor (glazing), and the vehicle performance shall be addressed by other guides being developed in response the Broad Area Announcement 02-Q-4665, Requirement R-829B. This guide does not address other APV functions, such as protection of critical systems (engine cpu, fuel, brake, and coolant systems) and tactical features (run-flat tires, ram bumpers).

Ballistic resistance of an APV may be achieved through a variety of design approaches and material combinations. In order to encourage innovation within the vendor community, this guide contains no provision regarding design or materials; rather, it emphasizes verification of the performance of the final product via a rigorous ballistic performance evaluation.

This guide presents both the requirements for the test procedure, and recommendations for methods or practices to meet those requirements. While this document presents recommended practices as a guide, it utilizes common terminology for a standard and its format generally follows that of NIJ 0108.01, *Ballistic Resistant Protective Materials* and MIL- STD-662F, Department of Defense *Test Methods Standard*. Requirements are denoted by the use of “shall” or “must.” Suggestions and recommendations are denoted by the use of “may,” “should,” or “recommended.”

3. BALLISTIC RESISTANCE TEST PROCEDURE

The test procedure describes the general sequence of protocols to be carried out and the requirements that must be met for each step of the protocols. It is not necessary that the operations be carried out in strict sequential order, as the individual testing organizations may find it more efficient to carry out preparatory steps in parallel or out of sequence.

Each of the following subsections briefly describes a step in the test procedure and refers to those sections containing specific requirements relevant to that step.

3.1 Determine the Ballistic Resistance Level Desired

Armor may be designed and installed to provide varying levels of protection, depending on the desire of the client and the level of the perceived threat. Therefore, this guide provides for four different levels of ballistic testing for weapons ranging in penetration performance from handguns to armor-piercing rifles.

Section 4 describes the four levels of protection recognized by this guide and sets requirements for the test weapon and projectiles to be employed in the test procedure.

3.2 Select and Prepare a Vehicle for Testing

A vehicle selected for testing must be representative of vehicles provided for sale or distribution. The test vehicle should be prepared for the test by removing any interior furnishings or other vehicle unarmored elements that impede the performance of the test or the evaluation of the results. Vehicle preparation shall meet the requirements of Section 5.2.

3.3 Prepare the Firing Range and Test Equipment

Section 6 sets the requirements to be employed for the firing range and test equipment during the test. It also sets the requirements for the instrumentation and its calibration. However, this guide makes no provisions regarding range safety. It is the responsibility of the testing organization to develop and observe safe range practices during each test.

3.4 Determine Vehicle Vulnerability Zones

This guide defines eight distinct vehicle surface zones by vehicle and armor constructions and by perceived vulnerability. All zones are to be identified and boundaries demarcated following the requirements of Section 7.

3.5 Select Targets Within Zones

The number of shots required to develop high confidence test results can be reduced by using a random sampling scheme to select the targets to be fired upon. This scheme is created by generating a uniform array of potential targets and then selecting, via random number generation, the final target list. This guide requires 28 shots in each zone. For vehicles that meet the performance requirements, this provides for an average estimated 90% lower confidence bound on the zone-specific probability of stopping threats of at least 90% (see Appendix A for additional commentary). Section 8 describes the procedure by which potential targets are identified, and final targets are selected.

3.6 Install Witness Panels

Witness panels fabricated from 0.020-in.-thick aluminum sheeting are used to determine penetration or nonpenetration into the passenger compartment. This guide does not address the lethality of the penetration of the armor solution—any penetration is regarded as lethal and a failure. Witness panels are placed behind armored zones prior to being tested, and are examined subsequent to each shot fired. It is not necessary to place all witness panels prior to the test; rather, witness panels may be placed behind each zone or partial zone prior to that area being tested. This approach facilitates the placement and post-mortem examination of the witness panels. Requirements for the material type, construction, and placement of the witness panels are presented in Section 9. Examination of witness panel to determine pass/fail is discussed in Section 11.3.

3.7 Test Weapon and Ammunition

Standard test weapons, projectiles, and muzzle velocities are prescribed to ensure consistency of results. Weapon parameters and recording requirements are presented in Section 10.

3.8 Fire and Record Test Rounds

A test round will be fired upon each selected target in each zone following the requirements of Section 11. Test rounds shall meet the requirements of Sections 4 and 10. The velocity of each round shall be measured and recorded. Certain tasks are required to be performed before and after each shot as follows:

Prior to each shot:

- Orient the vehicle and/or marksman to achieve the required angle of incidence or obliquity
- Measure and record the angle of incidence
- Set up the chronograph.

After each shot:

- Record the bullet’s velocity
- Record the impact location and make a fair hit determination
- Inspect the witness material for penetration and record the findings
- In the event of a fair hit failure without penetration, add another target from the randomly generated list of potential targets for the zone in which the failure occurred.

3.9 Evaluation of Results and Determination of Acceptance

The results of the firing sequence are determined by evaluating the shots (fair hit evaluation) and determining the penetration or nonpenetration of each shot.

The subject vehicle shall be deemed to have passed test requirements for the threat level at which it was tested when it meets the acceptance criteria of Section 12 and suffers no more than three penetrations into the passenger compartment, with not more than one penetration in any one zone over the course of the test when 28 shots are fired upon each zone.

4. CLASSIFICATION OF THREAT AND RESISTANCE LEVELS

Armored passenger vehicles shall be classified into one of four resistance levels based on the level of threat successfully defeated following the methodology of this guide. Threat levels are based on the experimentally determined penetration performance of common firearms and projectiles against metallic and ceramic targets (see Appendix B). To be assigned a given resistance level, the test vehicle must successfully defeat the highest performance projectile of that class. Table 1 summarizes the classes, representative firearms, and projectile requirements for each class.

Table 1. Summary of threat and resistance levels.

Level	Description	Required Test Firearm	Nominal Test Bullet Mass (gr/g)	Test Bullet Velocity (fps and m/s)
1	All common handguns	.44 Magnum, Lead SWC or .357 Magnum	240/15.6 158/10.2	1400 ± 15 fps 427 ± 5 m/s 1425 ± 15 fps 434 ± 5 m/s
2	Medium-power rifles firing non-armor-piercing rounds	22-250 pointed lead	55/3.6	3705 ± 10 fps 1129 ± 3 m/s
3	High-powered sporting rifles	300 Winchester Magnum jacketed lead core	200/13	2795 ± 15 fps 852 ± 5 m/s
4	All rifles firing armor-piercing rounds	30-06 AP M2	165/10.7	2785 ± 10 fps 849 ± 3 m/s

Hand-loaded ammunition may be required to achieve some of the bullet velocities required in the following sections.

4.1 Level 1 (Common Handguns)

Level 1 includes all commonly available handguns with muzzle energies ranging from approximately 130 J (22 LR) to approximately 1420 J (.44 Magnum). Weapons included in this category are 22-, 38-, 40-, 45-, and 9 mm-caliber handguns, as well as the high-power .357 Magnum and .44 Magnum. Specialty, very high-power handguns such as the .357 Maximum, .454 Casull, .475 Linebaugh, .500 Linebaugh, .445 SuperMag, .475 Maximum, and .500 Maximum are not included or considered in this category.

The test weapon for Level 1 shall be either a .357 Magnum or a .44 Magnum handgun or test barrel. Test bullets for the .357 Magnum shall be 158 gr (10.2 g) jacketed soft point, with a measured velocity of 1425 ± 15 fps (434 ± 5 m/s). Test bullets for the .44 Magnum shall be 240 gr (15.6 g) lead semi-wadcutter, with measured velocity of 1400 ± 15 fps (427 ± 5 m/s).

4.2 Level 2 (Medium-power Rifles)

Level 2 includes all medium-power rifles firing non-armor-piercing rounds with muzzle energies ranging from approximately 2000 J (22-250) to approximately 3000 J (7.62 × 51 mm). Examples of weapons included in this category are 22-250, 7.62 × 51 mm NATO, .308 Winchester, and 7.62 × 39-mm (lead core).

The test weapon for Level 2 shall be a 22-250 rifle or test barrel. Test bullets shall be lead pointed soft point, with a mass of 55 gr (3.6 g) and a measured velocity of 3705 ± 10 fps (1129 ± 3 m/s).

4.3 Level 3 (High-power Sporting Rifles)

Level 3 includes high-power sporting rifles firing non-armor-piercing rounds with muzzle energies ranging from approximately 4000 J (30-06) to approximately 5000 J (300 Winchester Magnum). Examples of weapons included in this category are the 30-06, 7.62 × 54R, and 300 Winchester Magnum.

The test weapon for Level 3 shall be a 300 Winchester Magnum rifle or test barrel. Test bullets shall be of jacketed lead core construction, with a mass of 200 gr. (13 g) and a measured velocity of 2795 ± 15 fps (852 ± 5 m/s).

4.4 Level 4 (Rifles Firing Armor-piercing Rounds)

Level 4 includes all rifles firing hard-cored armor-piercing rounds. Examples of Level 4 rounds are the 7.62 × 51 mm AP FFV (Bofors AB), 7.62 × 51-mm AP (Hirtenberger Patronfabrik), 7.62 × 51-mm AP P80 (Fabrique Nationale), and 30-06 AP M2 (U.S. Armory). Also included in this category are the 7.62 × 39-mm 1943 mild steel core, 7.62 × 39-mm API BZ, and 5.56 × 45-mm M855.

The test weapon for Level 4 shall be a 30-06 (7.62 × 63 mm) rifle or test barrel. Bullets shall be of type AP M2 with mass of 165 gr. (10.69 g) and measured velocity of 2785 ± 10 fps (849 ± 3 m/s).

5. VEHICLE SELECTION AND PREPARATION

5.1 Vehicle Selection

The test vehicle shall be a current production sample of an armored passenger vehicle. Materials, design, dimensions, and manufacture of the ballistic resistant elements of the test vehicle shall be identical to that of vehicles produced for distribution or final sale, as verified by design, material, and process documentation.

It is permissible to subject only the right or left half of a vehicle to this ballistic test for evaluation at a given protection level. This leaves the other half of the test vehicle available for testing at a different level, or for other purposes of the owner's choosing. To exercise this option, the vehicle vendor shall provide evidence to the testing agency that the armor solution on the untested side is symmetrical to that on the side tested. Such evidence may be visual inspection of accessible armor, supplemented with design drawings of armor in difficult-to-see locations. The testing agency shall document this inspection and include any submitted drawings in the test report.

5.2 Vehicle Preparation

5.2.1 Environmental Conditioning

The test vehicle with the armor installed shall be stabilized in an environment between 50 and 90°F for 12 hours prior to ballistic testing. If the test is performed outdoors in inclement weather conditions, the test vehicle may be brought back indoors between shots to regain the initial temperature condition. Composite armor solutions, such as textile/organic adhesive and ceramic/organic laminate, can be affected by temperature and humidity and therefore must be evaluated per MIL-PERF-46103 guidelines. The environmental test results or the rationale for the omission of the test should be documented in a test report.

5.2.2 Interior Furnishings

All vehicle interior furnishings (dashboard, instrument panel, glove box, seats, armrests, headliner, and airbags) shall be removed from the vehicle prior to testing. This allows correct placement of the witness material, and facilitates evaluation of results.

5.2.3 Exterior Components

Unarmored vehicle exterior components that obscure targeting or impede the conduct of the test may be removed. For example, exterior mirrors and associated trim should be removed to aid in gridding and targeting. Because most modern door handles are flush with the door surface, it is not usually necessary to remove them.

6. RANGE AND TEST EQUIPMENT

6.1 Range

6.1.1 Orientation

The test range shall allow for correct orientation of the test vehicle with respect to the test weapon for all armor surface zones. A combination of ramps for the vehicle and an elevated platform for the marksman may be necessary to achieve the required angle of incidence for hood, roof, and bulkhead areas.

6.1.2 Firing Distance

Weapons in class I shall be fired from a distance of no greater than 10 m from the targeted surface. Weapons in classes II, III, and IV shall be fired from a distance of no greater than 50 m from the targeted surface.

Longer firing distances may be employed if documentation is provided that projectile energy at the target is equal to or greater than that delivered by the standard projectile fired from the standard distance. Ballistic calculations employing the measured muzzle velocity, firing distance, and published projectile ballistic coefficient are an acceptable form of documentation.

A standard measuring tape is acceptable for determining the proper standoff distance. Sonic and optical-based electronic measuring devices are not recommended where surfaces are not flat.

6.2 Test Equipment

6.2.1 Chronograph

The chronograph shall have a current, NIST-traceable calibration with a precision of 1 µs and an accuracy of 2 µs. Its triggering devices shall be of either the photoelectric or conductive screen type. Either two or three chronograph stations can be used. Ballistic radar is not recommended for this type of test. The measurement of test round velocities using the chronograph shall follow the requirements of Section 11.

7. IDENTIFICATION AND DEMARCATION OF VULNERABILITY ZONES

Prior to being tested, the exterior surfaces of the test vehicle shall be categorized into zones and targets demarcated so as to be easily visible to the marksman conducting the ballistic test. Zones shall be determined hierarchically so that locations meeting the definition of more than one zone are determined in the following order of preference:

1. Special features
2. Door seams
3. Glazing seams
4. Pillars and window frames
5. Firewall
6. Rear bulkhead
7. Door panels
8. Roof panel.

Most zones will be comprised of multiple noncontiguous parts, hereafter referred to as subzones. Zone boundaries shall be demarcated such that they are easily visible to the marksman at firing distance. Boundary markings shall not exceed a 19 mm (3/4 in.) width. Acceptable marking methods include, but are not limited to, indelible marker, adhesive tape, or paint. To facilitate the hierarchical order, it will generally be beneficial to mark the zone boundaries in the order given above.

7.1 Special Features (Zone 1)

This category includes door handles, keyholes, mirror, and other external equipment mounts. Any features that penetrate the passenger compartment envelope, such as spotlights and antenna wire passageways, are also included.

7.1.1 Mirror Mounts

Mirror mount subzones are defined as the area extending from the forward side window glazing seam to the base of the A-pillar. The lower border of the subzone aligns with the bottom of the side window as viewed from the vehicle exterior.

7.1.2 Door Handles

Door handle subzones include all surfaces within 2 cm of the visible exterior door handle perimeter.

7.1.3 Other Penetrations

Special feature subzones other than mirror mounts or door handles shall include all surfaces within 2 cm of the external features of the penetration or mounted component.

7.2 Door Seams (Zone 2)

These zones include all unglazed surfaces within 2 cm of the centerline of a door seam.

7.3 Glazing Seams (Zone 3)

This zone includes all unglazed surfaces within 2 cm of glazing. Seam location shall be based upon the edge of transparent armor rather than the seam apparent from the vehicle exterior.

7.4 Pillars and Window Frames (Zone 4)

This zone is composed of all pillar surfaces greater than 2 cm from the centerline of door seams and glazing seams. This includes surfaces between the glazing seam and door seam at the top and sides of doors windows.

7.5 Firewall (Zone 5)

The firewall zone includes hood, grill, headlights, and front quarter-panel surfaces through which a shot could be fired into the passenger compartment. The extent of the firewall zone is defined as those areas through which any line between 0 and the maximum permissible angle of incidence to the vehicle exterior surface of 60 degrees passes through the passenger compartment. Shots on this zone shall be directed along the shortest path from the external target to the passenger compartment, with the constraint that the angle of incidence to the external surface not exceed 60 degrees.

Using a visual aid such as an angle gauge, determine the bounds of the zone where a line toward the passenger compartment at the maximum angle of incidence just touches the passenger compartment. Note that, due to the discontinuity of slope between the hood and quarter-panels, the boundary transition may not be continuous here.

7.6 Rear bulkhead (Zone 6)

The rear bulkhead zone includes trunk and rear quarter-panel surfaces though which a shot could be fired into the passenger compartment. The bounds of the rear bulkhead zone are defined as those areas through which any line between 0 and the maximum permissible angle of incidence to the vehicle exterior surface of 60 degrees passes through the passenger compartment. This concept is explained in greater detail in Section 8.4. On sport utility vehicles, the rear bulkhead zone is composed of rear quarter panel and tailgate or rear door surfaces.

Determine the zone boundaries following the method presented in Section 7.5. Note that, because the trunk compartment is typically empty, all rear-facing surfaces are included in the zone if they meet the aforementioned criteria.

7.7 Door Panels (Zone 7)

The door zone includes all door surfaces greater than 2 cm distant from edges, seams, or special features. On sport utility vehicles, station wagons, and others that have no rear bulkhead, this zone includes the rear quarter-panels and tailgate, or rear doors. The zone does not extend below the floor of the passenger compartment.

7.8 Roof Panel (Zone 8)

The roof zone includes all surfaces composing the top of the passenger compartment greater than 2 cm from the centerline of door seams and glazing seams.

8. SELECTION AND DEMARCATION OF TARGETS

This section presents the methodology for marking a grid to indicate potential targets in each zone, and randomly selecting a subset of the grid points to be fired upon. A nomenclature of line and area zones is employed to distinguish between features that are essentially one-dimensional, such as door and glazing seams, and features that are two-dimensional, such as hood, roof, and door panels. The former are referred to as line zones, and the latter as area zones.

8.1 Special Features (Zone 1)

Special features shall be gridded as an area (two-dimensional) zone following the procedure of Section 8.6. Given the limited area available in this zone, a grid size of 3 to 5 cm is recommended in order to generate an appropriate number of potential targets.

8.2 Door Seams (Zone 2) and Glazing Seams (Zone 3)

Door and glazing seams are line zones (one-dimensional) and potential targets shall be determined by the procedure described in Section 8.7.

8.3 Pillars and Window Frames (Zone 4)

Pillars and window frame subzones shall be gridded as either area or line zones depending upon the local width of the subzone. Pillar and window frame subzones spanning greater than 10 cm between seams shall be treated as area zones, and targets identified following the procedure of Section 8.6. Locations less than 10 cm wide but greater than 2 cm wide shall be treated as line zones, with the line equally spaced between the seams defining the pillar zone. Line pillar zones will be targeted following the procedure of Section 8.7. Pillar window frame subzones of width less than 2 cm need not be targeted.

8.4 Firewall and Rear Bulkhead (Zones 5 and 6)

Firewall and rear bulkhead surfaces are area zones and shall be targeted following the procedure described in Section 8.6.

8.5 Doors and Roof (Zones 7 and 8)

Doors and roof panels are area zones and shall be targeted following the procedure described in Section 8.6

8.6 Grid Procedure for Area Zones

The following procedure applies to zones identified as area zones such as doors, roof, rear bulkhead, firewall, special features, and pillars greater than 10 cm in width.

Within the boundary lines established for each panel or subzone, a uniform rectangular grid shall be established and marked. The grid spacing may be selected by the test agency, but shall not exceed 12 cm. Grid spacing shall be uniform within each subzone and among all subzones in a zone. Grid spacing may vary from zone to zone. It is recognized that subzone shapes do not lend themselves to perfectly rectangular, evenly spaced grids. Reasonable approximations of this ideal are therefore acceptable.

All grid intersections, including those at the zone or panel boundary, are considered potential targets, and shall be uniquely numbered within each zone (with the number sequence continuing across subzones). When all potential targets have been identified and labeled, targets to be fired upon shall be determined following the procedure of Section 8.8.

8.7 Grid Procedure for Line Zones

The following procedure applies to line zones such as door seams, glazing seams, and pillars less than 10 cm wide.

For each line segment, mark and uniquely number potential targets on the zone centerline at a uniform spacing. Point spacing may be determined by the testing agency but shall not exceed 12 cm. Point spacing shall be uniform within each subzone and across all subzones in a zone. Point spacing may vary from zone to zone. Numbering of potential targets should be sequential from segment to segment, so as to avoid the possibility of nonunique target numbers.

When all zone potential targets have been identified and numbered, the targets to fire on shall be determined by the procedure described in Section 8.8.

8.8 Random Selection of Final Targets from Potential Target Group

Within each zone, 28 targets shall be selected from the population of potential targets by random selection. In performing the random selection, all potential targets should be randomly ordered and the order recorded. The first 28 targets on the randomly ordered list become the initial targets. If any of the initial targets are eliminated for failing fair hit tests as described in Section 11.2, new targets are selected in order from the randomized list.

Any documentable method of randomly ordering the list based on the generation of random numbers by computer means is acceptable. Haphazard selection by human means is not acceptable. Selected targets shall be recorded in the test documentation and marked on the vehicle in such a fashion as to be distinguishable from unselected potential targets. The complete randomly ordered list of potential targets shall be recorded in the test documentation prior to shooting.

9. WITNESS PANELS

9.1 Material

Witness panels shall be fabricated from 0.020 in. thick sheets of aluminum alloy 2024-T3 or –T4.

9.2 Construction

The aluminum sheeting shall be rigidly mounted to support frames. All edges of the sheeting shall be firmly stapled, taped, or fastened to the supporting frames. The supporting frame may be constructed of metal or wood. The design of the frame must be sufficiently strong to maintain an upright position even under multiple impacts. The unsupported portions of the aluminum sheeting must be sufficiently large to cover the entire section of the intended test area.

9.3 Placement

Frame-mounted witness panels shall be placed between the back face of the target area and the passenger compartment such that a penetrating projectile or generated fragments must pass through the witness panel to enter any part of the occupied space. The nominal distance between the back face of the target area and the front face of the witness panel must be no greater than 15 cm.

The frontal firewall armor can be fabricated using multiple pieces of aluminum sheeting to approximate the contour of the dashboard and the foot-well.

10. TEST WEAPON AND AMMUNITION

10.1 Weapon

Test weapon parameters, including make, model, and barrel length, shall be documented in the test report.

10.2 Ammunition

10.2.1 Commercially Obtained or Factory-Standard Ammunition

Ammunition parameters, including bullet caliber and weight, powder type and manufacturer, model, lot number, and date of manufacture, shall be documented in the test report

10.2.2 Hand-Loaded or Nonstandard Ammunition

If commercially available ammunition does not achieve specified velocity, it may be necessary to hand-load ammunition. (Loading parameters and procedures are usually found in the loading handbook provided by the ammunition manufacturers and loading personnel should adhere to the manufacturer recommendations).

For each batch of ammunition to be employed in the test, record the projectile (core and jacket) material, type and weight, powder charge make, type and weight, primer make and type, shell loading date, and name of the person reloading.

10.2.3 Environmental Conditioning

Ammunition to be used for firing of test rounds must be stabilized in a constant temperature environment between 60 and 80ºF for a period of at least 12 hours prior to the ballistic test.

11. FIRING OF TEST ROUNDS

11.1 Weapon and Target Positioning

The weapon and target shall be positioned so that the projectile will impact the exterior vehicle surface at an angle of incidence (or angle of obliquity) of 5 degrees or less with the following exceptions.

- Mirror Mounts
- Firewall (hood and front quarter panels)
- Rear bulkhead (trunk and rear quarter panels)
- Front door seam.

Shots on these locations shall be directed along the shortest line into the passenger compartment to the extent that the angle of incidence with the vehicle exterior surface does not exceed 60 degrees or cause a ricochet, whichever occurs first.

Weapons can be stored at room temperature between shots when testing is performed outdoors in extreme weather conditions.

11.2 Determination of Fair Hit

Fair hit criteria are promulgated to ensure that a minimum threat severity is maintained for all shots on the vehicle. Each test round shall be evaluated with respect to accuracy, projectile velocity, angle of incidence, and proximity to other hits to determine whether it constitutes a fair hit. Shot evaluation shall meet the requirements of Sections 11.2.1 to 11.2.4.

11.2.1 Accuracy

The accuracy, or distance between the target center and the center of the point of impact, shall be measured and recorded for each test round. Accuracy shall not be less than 2 cm to constitute a fair hit.

11.2.2 Projectile Velocity

The velocity of each round fired at the test vehicle shall be measured with a chronograph. Nonpenetrating rounds with velocities below the acceptable range are to be struck from the results. Penetrating rounds shall be included in the results per the definition of a fair hit in Section 13. Rounds with velocities above the acceptable range may be accepted at the discretion of the testing agency. Over-velocity rounds need not be considered in determination of penetrations.

11.2.3 Angle of Incidence

The angle of incidence, as defined in Section 13, of all shots fired on the test vehicle shall not exceed 5 degrees, except as noted in Section 11.1.

11.2.4 Multiple Hits

Shots closer to a previous hit than 2.5 projectile diameters center-to-center shall be considered multiple hits. This is approximately 1.5 cm for 5.56-mm ammunition and 2 cm for 7.62-mm ammunition. Multiple hits that otherwise meet fair hit criteria may be considered a fair hit at the discretion of the testing agency, but need not be considered for determination of a penetration. Evaluation of the initial shot of a multiple hit group is not affected by the treatment of subsequent shots. The occurrence of multiple hits shall be documented in the test report.

There is currently a lack of consensus among the TSWG committee on the proper treatment of multiple hits. In the interim, this guide currently addresses only individual hits, and makes allowances to permit exclusion of poor multiple-hit performance from the results.

11.3 Determination of Penetration

To determine if any shots have defeated the armor solution, the witness panel shall be carefully removed from the vehicle and held with its back to a 60 watt light bulb —a standoff distance of less than 15 cm between the back of the witness panel and the light source is recommended. If visible light can be observed through any indentation or minute perforation on the 0.020-in. thick aluminum sheet, penetration or failure of the armor solution has occurred, and the penetration location shall be clearly marked on the witness panel. The final tally of the number of penetrations and zones where failure occurs shall be logged in the test report.

11.4 Shots Failing Fair Hit Criteria

For each nonpenetrating shot failing to meet the criteria for a fair hit, the next available target in the randomly ordered target list for the affected zone shall be selected and fired upon.

Shots that fail to meet fair hit criteria, but nevertheless penetrate the witness plate shall be considered valid penetrations. No alternate target is selected or fired upon in this case.

12. EVALUATION OF RESULTS

The test vehicle will be deemed to have met the requirements for the tested level of protection if, upon completion of this ballistic test with 28 shots fired into randomly selected targets in each of the 8 zones, no more than three penetrations occur, with no more than one penetration in any one zone.

13. DEFINITIONS

angle of incidence. The angle between the line of flight of the bullet and the perpendicular to the plane tangent to the point of impact (see Fig. 1) on the vehicle exterior surface. Also known as the angle of obliquity. Also known as angle of obliquity.

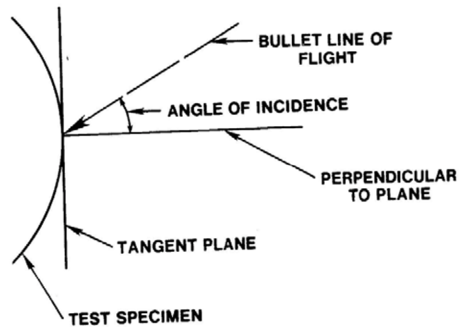

Figure 1. Angle of incidence (obliquity).

fair hit. A hit that impacts the vehicle armor (a) at an angle of incidence no greater than that specified in Section 11 for the armor surface involved, (b) within 2 cm of the designated target location, and (c) at an acceptable velocity as defined in this guide. A bullet that impacts at too high a velocity, but does not penetrate, shall be considered a fair hit for the determination of nonpenetration, but need not be considered for the determination of penetration.

full metal jacketed (FMJ) bullet. A bullet made of lead completely covered, except for the base, with copper alloy (approximately 90 copper-10 zinc).

jacketed soft point (JSP) bullet. A bullet made of lead completely covered, except for the point, with copper alloy (approximately 90 copper-10 zinc).

lead bullet. A bullet made of lead that is alloyed with hardening agents

panel or subzone. A contiguous portion of a zone separated from other portions of that zone by interceding portions of one or more other zones (a door is a panel or subzone separated from other door subzones by door seams and glazing seams).

penetration. Perforation of a witness plate by any part of the test specimen or test bullet, as determined by passage of light when held up to a 60-W light bulb.

strike face. A ballistic resistant (armor) surface of an armored passenger vehicle intended by the manufacturer to be exposed to the weapon threat.

semi-wadcutter. A bullet shape characterized by a flat nose and a tapered section leading to a cylindrical bullet body with a sharp break where the taper meets the body.

testing agency. Person or persons conducting the ballistic resistance test, having no stake in the outcome of the test.

zone. A vehicle region or group of regions characterized by similar armor construction and perceived ballistic resistance. A zone need not be contiguous.

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APPENDIX A

Commentary to Ballistic Resistance of Armored Passenger Vehicles: Testing Guide

CONTENTS

Commentary to Ballistic Resistance of Armored Passenger Vehicles: Testing Guide

Organization of this Commentary

Topics presented in this commentary are titled and numbered according to the sections and paragraphs of the Guide to which they refer. As commentary is not required for all sections of the Guide, numbering of the commentary is not necessarily sequential.

1. Introduction

The ballistic resistance test methodology reflects an attempt to balance competing interests of simplicity, affordability, confidence, accuracy, and repeatability. To maintain its coherence and readability, long discussions of the issues and rationale for the methodology chosen are not included in the guide, but relegated to this commentary. The intent of this commentary is to inform the reader of the reasoning behind the requirements, to illustrate and expand on fine technical points, and provide examples of the method being applied to a test vehicle.

This commentary does not lay out any requirements beyond those explicitly stated in the Guide. Should there be an apparent conflict between statements herein and those in the Guide, the Guide shall govern.

The Guide was developed with the expectation that it would be conducted by a competent, unbiased testing agency. The staff struggled for some time to create a method that would discourage cheating, but arrived at the conclusion that cheating is not possible to control with a guide. Similarly, the method requires a high level of competence in the testing staff to assure its safe conduct with repeatable results.

3. Ballistic Resistance Test Procedure

The intent of this section is to provide the first-time reader with a roadmap of the guide, presenting a quick overview of the steps composing the test, and directions to where specific requirements are set for each step. The procedure comprises the following steps:

- Determine the level of protection desired.
- Select and prepare a vehicle for test
- Prepare the firing range and test equipment
- Determine vehicle vulnerability zones
- Select targets within vulnerability zones
- Install witness panels
- Select and characterize the test weapon and ammunition
- Fire upon the test vehicle and record results
- Evaluate results and determine acceptance

4. Classification of Threat and Resistance Levels

It is not possible to construct an armored passenger vehicle impervious to any conceivable threat. It is therefore critically important to clearly describe to the consumer what level of protection he or she may expect from a vehicle passing this test.

For the sake of simplicity and clarity, only four classes of small arms are recognized by the Guide. These are

- Level 1, Common handguns
- Level 2, Medium-power rifles
- Level 3, High-power sporting rifles
- Level 4, Rifles firing hard-core armor-piercing rounds

These levels are based broadly on the weapon muzzle energy, and more specifically on the penetration performance against homogeneous metallic targets determined via live-fire depth-of-penetration tests conducted at the Idaho National Laboratory in 2004. All weapons in a given group outperform all weapons in lower-numbered groups. Within each level the best performer, i.e. the weapon/round combination that produced the deepest cavity (not necessarily the greatest cavity volume) in the INL test series, is identified as the test weapon/round for that level.

4.1 Level 1 (Common Handguns)

In some instances the performance of two weapons is nearly identical. The INL depth-of-penetration tests found the .357 Magnum and .44 Magnum to produce similar penetration performance against metallic targets. In this case it makes no sense to restrict the choice available to the testing agency, and so both are deemed acceptable as the test weapon.

4.2 Level 2 (Medium-power Rifles)

The test weapon specified for Level 2 may at first seem nonintuitive. The 22-250 fires a small projectile at a lower muzzle energy than other weapons in its class. However, its velocity is approximately 1000 fps higher than its classmates, and this shows in its high tested depth-of-penetration performance, exceeding that of all other weapons in Level 2.

5. Vehicle Selection and Preparation

5.1 Vehicle Selection

The requirements of this section are intended to assure the final user that the APV on the street provides the same level of protection as the test specimen. As design changes sometimes bring unintended consequences, the acceptance of one armor solution may not be carried forward to solutions employing different armor geometries or materials.

In order to reduce the financial burden of this test on the APV producer, it is permissible to test only one side of the vehicle. However, it is possible that the left and right sides of the vehicle may not be symmetrical. This would be especially true for the firewall and rear bulkhead areas. To the extent that the "natural" features of the vehicle (e.g., steering column, engine block etc.) are meant to be part of the protection system this is important. Therefore it is required that the armor solution be substantially symmetrical for this option to be employed.

5.2 Vehicle Preparation

5.2.1 Environmental Conditioning

Environmental conditioning requirements are set to minimize the variability of armor material properties to temperature and humidity. Because they are more strongly affected by environmental conditions, textile-ceramic composite armor solution if used must be qualified separately by environmental testing per the requirements of MIL-PERF-46103 prior to carrying out the test procedure for the vehicle.

Note that temperature conditioning of test ammunition is also required (Paragraph 10.2.3) to assure consistent penetration performance.

5.2.2 Interior Furnishings

In order to allow the proper placement of the witness panel and direct observation of any perforation point on the armor panels it may be necessary to remove most of the interior furnishing such as dashboard, instrument panel, glove box, seats, steering wheel, some trim panels, consoles and rear heater/blower. An ideal test platform would be a stripped down OEM vehicle with only the armor solution present.

6. Range and Test Equipment

No comments at this time.

7. Identification and Demarcation of Vulnerability Zones

The vehicle surface is divided into 8 zones to ensure that locations of significant vulnerability such as transitions, seams, and penetrations are tested as well as large panels in the doors and roof. Because the surface topology of a vehicle can be complex, a hierarchical system is established so that the zone determination may be made unambiguously for the whole vehicle.

Regardless of surface area, the same number of shots is required to be fired into every zone. This is necessary to support the statistical confidence required of the results. It also implies a testing bias to smaller zones, as the shot density is greater there. This is not accidental. Smaller zones such as Special Features tend to be geometrically more complex and more difficult to armor. Thus the ballistic resistance will tend to be less uniform than in the roof zone, for example, making higher shot density appropriate.

It is important to distinguish between zones and subzones. There are only eight zones on the vehicle, each being composed of one or more subzones. Subzones may be noncontiguous. Thus while Zone 8 (Roof Panel) may be a single large zone, Zone 7 (door panels) may be composed of four distinct door panel subzones, and Zone 1 (Special Features) may comprise four door handles, two mirror mounts, and a spotlight mount.

7.6 Rear Bulkhead (Zone 6)

Although the rear door or tailgate of sport utility vehicles more closely resembles a passenger door than the rear bulkhead of a sedan, it is classified as part of the rear bulkhead zone. This allows the proper number of shots to be fired on the overall vehicle, by maintaining 8 zones, and keeps the correct shot density in the door and rear bulkhead zones.

8. Selection and Demarcation of Targets

8.1 Special Features (Zone 1)

Zone 1 is composed of areas of a vehicle that are typically difficult to protect properly and completely. This includes, for example, external side view mirror mountings and door latch locations. A grid spacing of 3 to 5 cm is recommended to generate a sufficient number of potential targets to choose from. At this grid spacing, good shot accuracy will be required to ensure shot spacing greater than the minimum noninterference distance of 2.5 times the largest caliber (7.62 mm).

8.2 Door Seams (Zone 2) and Glazing Seams (Zone 3)

Door and glazing seams are considered transitions that typically require overlapping protection. While door seam lines are allowed to follow the external manifestation of the seam, glazing seams are required to follow the actual edge of the transparent armor, which may differ significantly from the external window frame.

8.8 Random selection of final targets from potential target group

A simple method of random selection can be achieved using an Excel spreadsheet as follows. First enter the numbers 1 through n (where n is the number of potential target locations in the zone) in a column of a worksheet. In an adjacent column assign a random number using Excel's "RAND()" function. Then sort the two columns using the random number column as the key for sorting. The first 28 numbers in the first column after this reordering are the randomly selected target numbers. If additional target locations are needed, they are selected in the order specified by the random list.

As a specific example of target selection, suppose there are six pillars in the pillar vulnerability zone, with 42 potential targets in all six pillars. Each pillar has 7 numbered potential targets. Then the potential targets in the first pillar should be numbered 1-7, those in the second pillar should be numbered 8-14, etc. The numbers 1-42 are entered into a column in an Excel spreadsheet labeled "Target Number." In an adjacent column labeled "Random Number," the formula "=RAND()" is entered in each cell. Then the two columns are sorted using the random number column as the key. After the sorting procedure, the first column of target numbers will then be in a random order so the first 28 numbers in the first column denote the selected targets. These numbers are entered into the test matrix record for the evaluation and a suitable mark is placed in the center of each of these grid squares in the pillar zone of the vehicle.

9. Witness Panels

9.2 Construction

It should be obvious that different style and design of mounting frame will be required to match the special features commonly found inside a vehicle. For example, the construction of a pillar witness panel and frame would probably be tall and narrow and slightly curved up to match the general contour of the vehicle.

9.3 Placement

In order to meet the 15 cm maximum standoff requirement, locations with complex geometry may necessitate curved or multiple staggered witness panels. The interior of the firewall, for example, could be covered by a short, curved witness panel beneath the dashboard, backed by a taller flat panel directly behind the dash (see Figure A-1). Care must be taken to ensure no gaps between witness panels staggered as such.

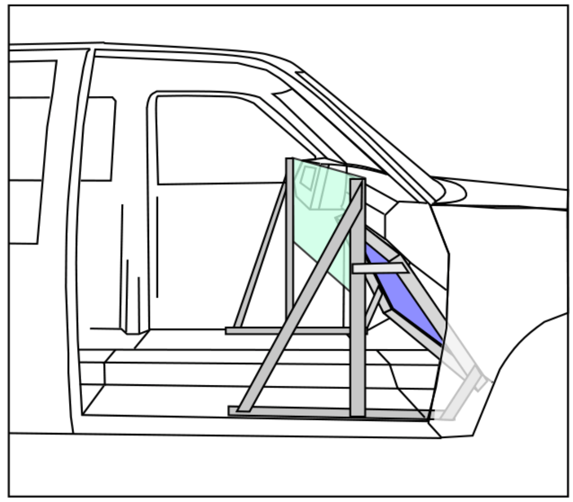

Figure A-1. Illustration of an acceptable configuration of the firewall witness panels. Two overlapping panels are employed to meet coverage and standoff requirements.

10. Test Weapon and Ammunition

Most of the test weapon and ammunition requirements pertain to documentation in the test report. This facilitates third-party review of the test, and enhances repeatability. The requirement for environmental conditioning of the ammunition is set to enhance predictability and repeatability of the terminal ballistics of the projectiles.

11. Firing of Test Rounds

11.2 Determination of Fair Hit

11.2.2 Projectile Velocity

Projectile velocity requirements are set to ensure that impact energy does not fall below a minimum value. Shots with low energy obviously don't challenge the armor as much as shots in the correct range. Therefore it is reasonable to expect that a penetrating under-velocity shot would have penetrated at higher velocity as well. Therefore penetrating under-velocity shots are considered fair hits. Similarly, nonpenetrating over-velocity shots may also be considered fair hits, since it may reasonably be expected that the armor would refuse the same shot at lower velocity.

11.2.3 Angle of Incidence

Angle of incidence requirements are set to present the greatest challenge to the armor. The only places that the 5 degree requirement is not applied are those locations where the projectile impacting at that angle would not enter the passenger compartment, and is therefore not a threat to the occupants. In these locations, it is desired that the projectile travel through as little material as possible before entering the cabin, and that it not ricochet off the exterior surface. Therefore the requirement is set that the line of flight be along the shortest path to the passenger compartment, but that it not be so shallow as to risk a ricochet.

11.2.4 Multiple Hits

There is currently a lack of consensus in the user community regarding the role of multiple hits in armored passenger vehicle testing. In the interim, this guide tests only single hit ballistic resistance. In instances where two hits may interact on the armor, the testing agency is allowed to strike the results of the second shot, and select an alternate target.

It is recommended that multiple hit performance for ceramic or novel materials that are intrinsically brittle be conducted separately at the coupon level.

11.3 Determination of Penetration

In order to expedite the test procedure, the testing agency may choose to inspect the witness panels after all shots on that location have been fired. There is some concern among the staff that this approach may increase the difficulty of identifying the source of witness panel perforations, especially in cases where a penetrating projectile generates shrapnel that also perforates the witness panel. In those instances where a group of closely spaced shots produces multiple perforations in the witness panel, a carefully documented analysis of the source of the perforations will be necessary.

12. Evaluation of Results: Details and Rationale for the Statistical Sampling Approach

The impracticality or impossibility of testing the armor protection of every square inch of an armored vehicle makes an approach based on testing a small subset of points a necessity. Because only a small fraction of the vehicle surface is actually tested, uncertainty as to the true level of protection provided by the armor is unavoidably induced in the evaluation. The analysis of results from such tests and the decision to accept or reject a vehicle must measure and account for this inherent uncertainty in order to be valid. A test method based on statistical sampling is the standard approach to minimizing and quantifying uncertainty in such cases.

The use of a statistical test design allows one to obtain the optimal balance between cost and uncertainty and to base vehicle acceptance on quantitatively estimated performance at specific confidence levels. The primary characteristic of a statistically designed test is that target points on a vehicle are chosen at random. It is this randomness that assures representativeness of the results and affords the ability to accurately estimate the uncertainty in the overall vehicle protection capability based on the observed results from a small set of target locations.

12.2 Zones

To ensure adequate testing of all vehicle features, the guide is based on separate evaluations of specific zones on a vehicle, with the final score being the average of the zone-specific results. Zones were defined so as to include areas of the vehicle of similar original design and material as well as similar armor structure. By delineating these relatively homogeneous areas and concentrating on estimating the protection level achieved in each zone, a more complete assessment of a vehicle's capabilities is obtained.

12.3 Zone Weighting

Based on the zone concept, the overall performance score is determined by averaging the zone-specific results to obtain an average protection level for the entire armored vehicle. Each zone is assigned equal weighting to ensure that all types of components are equally protected. An alternate weighting scheme might be to assign weights according to the relative surface area of the zones (e.g. special features would get a much lower weight that door panels). This type of weighting scheme would make more sense if it could be assumed that there is equal probability of a shooter targeting any specific point on the vehicle. However, if one supposes that a shooter would tend to concentrate shots on types of features (zones) known or expected to contain weak points in protection, the necessity to weight all zones equally becomes a more logical scheme.

Under the assumption that all zones are of equal importance (lethality to passenger is not considered) the optimal distribution of test shots over the vehicle is to place the same number of shots in each zone, regardless of relative zone size.

12.4 Outcome Measure

In statistical terms the basic measure of interest in assessing the protective capabilities of a particular zone type of an armored vehicle is the probability of protection. A zone that prevents all possible shots fired at it from entering the passenger compartment of a vehicle would be said to have a protection probability of 1.0 or 100%.

To estimate the protection probability for a zone, a certain number of shots are fired at randomly selected target locations in the zone and the number of penetrations counted. If n is the number of shots fired and x the number of penetrations that occur, then the estimated protection level p is calculated as

$$p = \frac{x}{n}$$

(It is common to express the probability on a percentage basis, e.g. 1.0 = 100% probability and .50 = 50% probability. However in the remainder of this discussion, values between 0 and 1 will be used to avoid confusion with the concept of confidence level which is always stated in percentage terms.)

Because not every target location in a zone is tested, p is actually only an estimate of the true probability of protection. If 10 shots are fired at a zone with 0 penetrations, the estimated protection probability is the maximum possible value of 1.0, but there is the possibility that the true value is actually lower than that. For example, if 10 additional locations are tested, one or more penetrations might occur. To explicitly account for this uncertainty regarding the true value, it is of interest to calculate a credible lower bound for the true probability of protection given the observed results. It is such a lower bound that is used as the scoring mechanism for the guide.

With statistical sampling we can calculate a probable lower bound on the true protection probability that takes uncertainty into account. However, for the same reasons there is uncertainty in estimating p as described above, there is also uncertainty in estimating a lower bound on p. That is, we cannot be 100% confident that we have correctly identified a lower bound. The more conservative the estimate of the lower bound, the more likely it is in fact a true lower bound. For example, with 10 shots and 0 penetrations, we would have more confidence in a value of 0.80 than we would in 0.9 as a lower bound on the true value of p. A value of 0.0 is the only lower bound on the true value of p in which there is 100% confidence. Because lower bound calculations with different levels of confidence can be stated, the confidence level needs to be stated in order to properly interpret the bound and in order to ensure bounds calculated for different tests are comparable measures.

In this guide all lower bound values are calculated such that the chances that true protection probability is in fact less than the estimated lower bound is fixed at 10%. This gives a statistical confidence level of 100-10% = 90%. This lower bound value is referred to formally as the 90% lower one-sided confidence bound (90% LCB) on the true probability of protection.

12.5 The Relationship of Number of Shots to Uncertainty in Results

Obviously, the smaller the uncertainty in estimating p the better, i.e., the 90% LCB for the true protection probability is as close to the estimated p as possible. For the fixed confidence level of 90%, reducing the uncertainty can only be achieved by increasing the number of shots. Thus, reduced uncertainty comes at increased cost.

Returning to the formula for estimating the probability of protection, if n = 5 shots are fired at random at a zone and x = 0 penetrations occur, then the point estimate of the protection probability is x/n = 5/5 = 1.0. If 45 shots are fired at random at a zone and no penetrations occur, the point estimate is also 1.0. Intuitively there is more evidence of complete protection when there are more shots than when there are fewer. This intuition can be proved correct by calculating the 90% LCB for specific values of n. (The appropriate statistical calculation to obtain the 90% LCB involves the binomial probability distribution because of the pass/fail criteria.) For x = 0 and values of n from 5 to 45, 90% LCBs are plotted in Figure A-2. In the plot, the point estimates are shown as open circles and 90% LCBs by the bars below the point estimates.

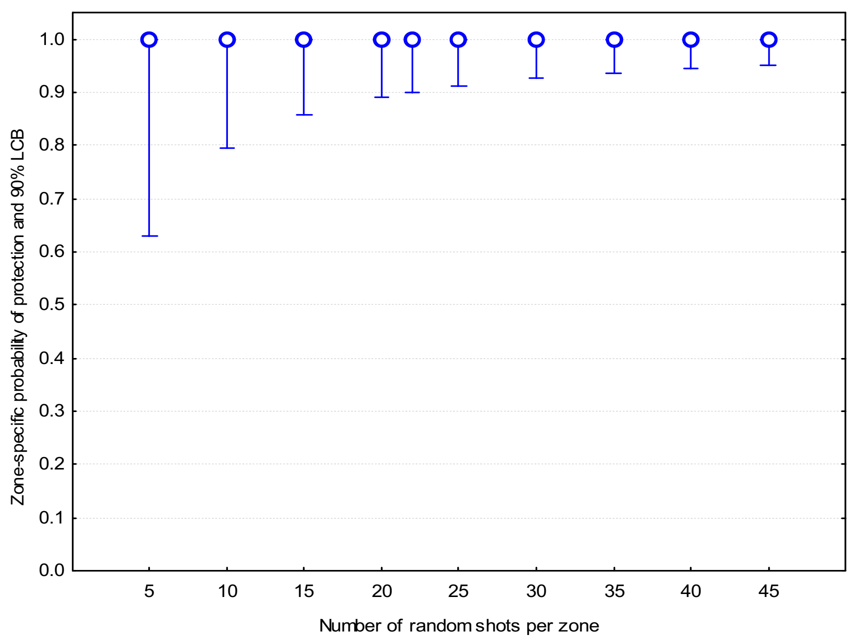

Figure A-2. The relationship of number of shots to calculated 90% LCBs on the probability of protection for a single zone when no penetrations occur.

The plot shows that, while the point estimate for the probability of protection is 1.0 in all cases, the 90% LCB varies from 0.63 when n = 5 to 0.95 when n = 45. The plot also shows that as n increases there is a diminishing return in the increase in the 90% LCB values (e.g., going from 10 shots to 20 shots raises the LCB by about twice what going from 20 to 40 shots does).

This guide uses as an acceptance criteria that a vehicle must demonstrate an overall average 90% UCL greater than 0.90. Figure 1 shows that with zero penetrations, this level of protection for a single zone can be demonstrated with 22 test shots per zone. This then was taken as the minimum number of shots to consider per zone for the guide.[a]

With 22 shots per zone, every zone must show no penetrations in order for the vehicle to be accepted. (With 22 shots and no penetration in each zone, the average 90% LCB over all zones will also be 0.90, resulting in a passing score and acceptance.)

12.5.1 Allowing for Penetrations

Designing armor that offered complete protection from penetration may not be realistic. In that case, the test guide should allow for a small number of penetrations. With a small number of allowable penetrations, it is still possible to determine that a vehicle has a protection probability lower bound of 0.90 with 90% confidence if the number of test shots per zone is increased sufficiently from the minimum of 22 per zone needed if no penetrations occur.

It seemed reasonable to require obtaining an average 90% UCL of 0.90 while limiting penetrations to:

- No more than one penetration per zone
- No more than three zones total with penetrations.

Any vehicle with more than one penetration in a single zone or more than three zones with a penetration would automatically fail the test and the 90% LCB need not be calculated.

Given these requirements for allowable penetrations, the results needed for passing for various values of n can be calculated. Relevant results are plotted in Figure 2.

Points above the horizontal line in the graph constitute a passing score (i.e., average LCB greater than 0.90). Anything below the line indicates failure. The figure starts with n = 22 as that is the minimum number of shots in each zone that will result in a passing score if no penetrations occur. The figure stops at n = 28 because that is the minimum number of shots in each zone required to produce a passing score if the worst allowable case of one penetration in each of three zones occurs.

Based on the assessment of the pattern of results in Figure 2, it was determined that the guide could be simplified by fixing the number of shots to be fired in each zone at 28. (As opposed to the alternative of requiring 22 shot per zone with additional shots allowed if penetrations occur). With n = 28 shots per zone, while the vehicle average 90% LCB will be above 90%, the minimum possible zone-specific 90% LCB (i.e., for a zone with one penetration) for a successful vehicle will be 0.83. If it were desirous to have each specific zone to pass at the LCB level of 0.90, even with a penetration, then a total of 38 shots per zone would be required (see Figure 3).

[a] See reference article: Proctor, C. H. and Luko, S. N., "On Bounding a Near-Zero Probability when Zero Occurrences Appear in a Sample," JTEVA, Vol. 30, *3*, May 2002, pp. 245-250.

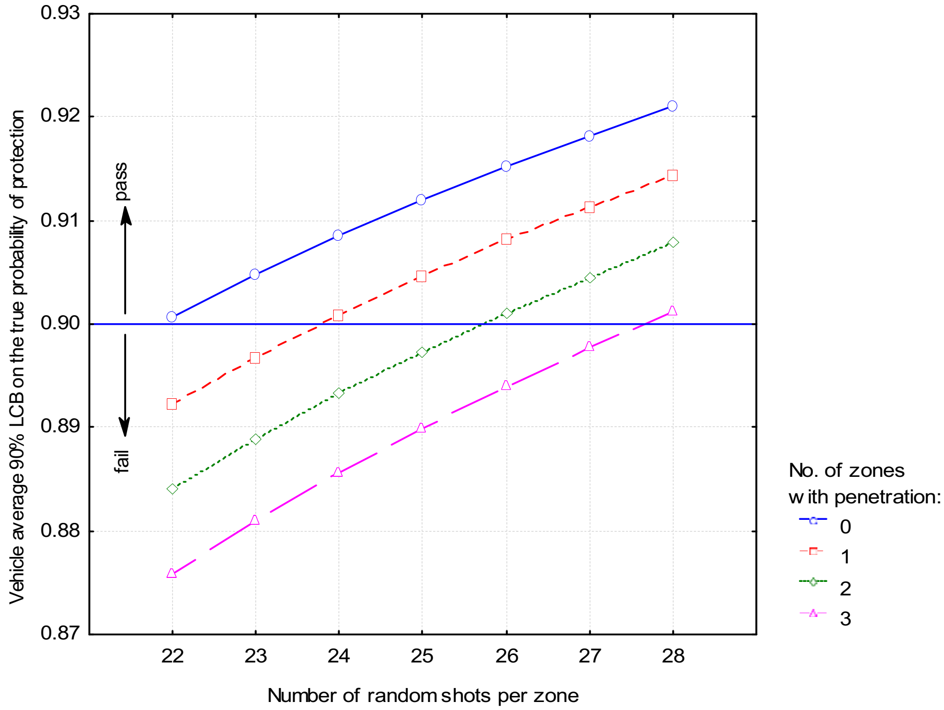

Figure 2. Vehicle average 90% LCB values for up to three zones with single penetrations by number of shots per zone.

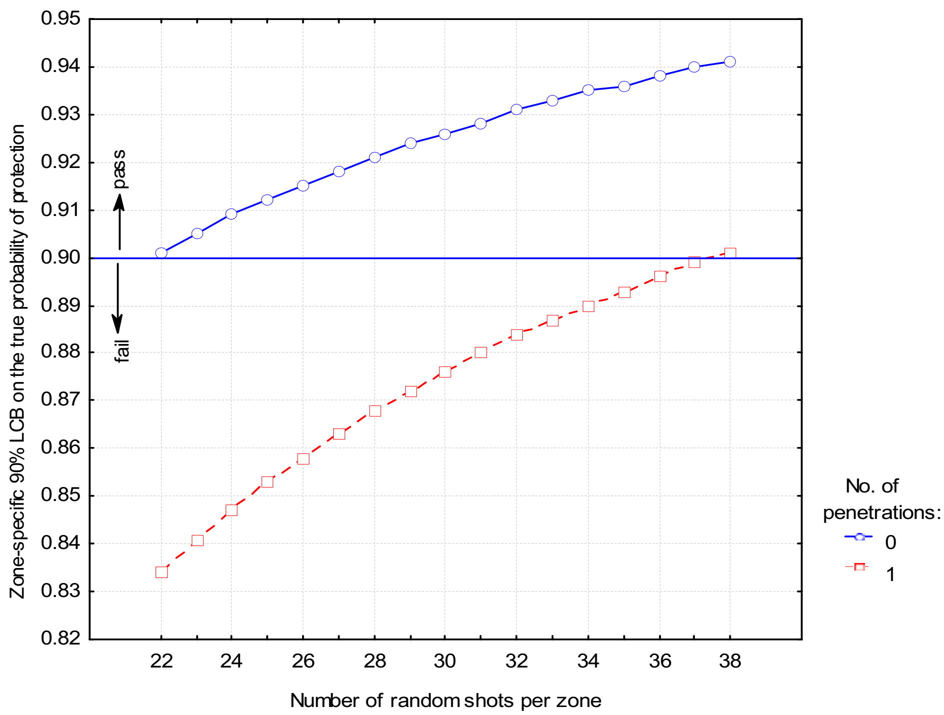

Figure 3. Zone-specific LCB with a single penetration as a function of number of shots per zone

APPENDIX B

Depth of Penetration Summary

APPENDIX B

Depth of Penetration Summary

Based on the depth of penetration data in Table B -1, two categorization scenarios can be considered.

Categorization Scenario I

Level 1. All handguns ranging from 40-cal to 9 mm with average penetration depth of less than 0.100 in. into 6061T6 aluminum alloy blocks. Recommended round for armor component tests would be 124 gr (8 g) 9 mm parabellum using 10 to 12 cm or SMG barrel at 330 ± 12 m/sec at 5 m standoff.

Level 2. All magnum handguns with average penetration depth at above 0.100 in. Preferred test round would be 158 grs (10.2 g) 357-cal magnum firing from 6 in. barrel at 5 m standoff. Recommended muzzle velocity at 425 ± 15 m/s.

Level 3. All rifles firing non-armor-piercing rounds. Recommended test round is 7.62 x 39 mm M1943 ball mild-steel core at 731 m/s at 6 m feet standoff.

There appears to be a difference of opinion regarding the highest threat in this category. NIJ 0108, AS/NZS 2343 and BS 5051 standards suggested NATO standard M80 9.7 g 150 grs round. However, the current DOP data showed the 7.62 x 39 mm mild steel core round exhibited a 44% increase in penetration depth. The discrepancy is probably due to the fact that only 7.62 x 39 mm lead core rounds were tested in the past experiments. It has been found that the standard 7.62 x 39 mm lead core rounds definitely possess less penetration power than the NATO M80 round. Another factor that might affect the consideration was the lack of long range accuracy of 7.62 x 39 mm round.

Special category. All armor-piercing rounds including 5.56 M855.

Categorization Scenario II

Level 1. All handguns, including magnum handguns with average penetrations less than 0.200 in. into 6061 aluminum alloy. Preferred test round would be a 158 gr .357-cal magnum, firing from 6 in. barrel at 5 m standoff. Recommended muzzle velocity at 425 ± 15 m/s.

Level 2. All rifles firing non-armor-piercing rounds. Recommended test round is 7.62 x 39 mm M1943 mild-steel core at 731 m/s at 6 m standoff

Special category. All armor piercing rounds including 5.56 M855.

It appears that the latter scenario is desirable because the simplification of the threat levels would reduce the confusion in identification of product quality and provide more equitable comparison.

Table A-1. Depth of penetration summary chart – test results.

Weapon	Average Velocity (ft/sec)	Average DoP (in)	Protective AD (lb/sq ft)[b]	Cavity volume (in^3)	Volume/DoP (in3/in)[c]
40 cal, 165 gr	1110 ± 12	0.055	0.79	0.102	1.848
22 cal, standard lrhv	1000 ± 27	0.056	0.81	0.026	0.456
45 cal, 230 gr ball	820 ± 11	0.056	0.81	0.063	1.126
38 cal, RN, 6” barrel, 154 gr, reload @4.5 gr	875 ± 40	0.059	0.86	0.047	0.789
38 cal +p, 6” barrel	894 ± 40	0.066	0.95	0.060	0.908
9 mm parabellum, SMG barrel, 124 gr, reload @4.2 gr	1083 ± 3.5	0.077	1.10	0.071	0.923
44 cal magnum, 240 gr	1402 ± 12	0.117	1.69	0.229	1.946
357 cal magnum, 158 gr	1428 ± 11	0.126	1.81	0.189	1.502
308 (7.62 × 51), 168 gr BTHP 10.9 g	2509 ± 30	0.643	9.26	N/A	N/A
308 M80 ball, 147 gr FMJ	2635 ± 10	0.677	9.74	N/A	N/A
22-250, 55 gr, pointed soft point	3704 ± 9	0.751	10.81	N/A	N/A
30-06 168 gr	2778 ± 8	0.799	11.51	N/A	N/A
30-06 180 gr	2805 ± 12	0.806	11.61	N/A	N/A
300 Win Mag 220 gr, Barns solids #30842	2791 ± 11	0.864	12.44	N/A	N/A
300 Win Mag 200 gr, Bear Claw P300WT1	2795 ± 13	0.905	13.03	N/A	N/A
7.62 × 39 1943 mild steel core	2350	0.980	14.11	N/A	N/A
5.56 × 45 M855	3115 ± 20	1.035	14.91	N/A	N/A
7.62 × 39 API BZ	2458	1.320	19.01	N/A	N/A
30-06 APM2	2788	1.800	25.92	N/A	N/A

b Protective Areal density (AD) = Depth of penetration x areal density of aluminum (14.4 lb/sq ft)

c Cavity volume determination was based on the measurement data obtained by a computerized measurement machine (CMM) and numerical integration. Cavity volume is only an indicator on lethality of the round on human bodies.