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OPERATIONAL TEST
AND EVALUATION

APR 27 2010

MEMORANDUM FOR: SEE DISTRIBUTION

SUBJECT: Standardization of Hard Body Armor Testing

All Department of Defense (DoD) hard body armor acquisition programs under DOT&E oversight will execute, at a minimum, the attached protocol for testing that results in a decision to qualify a design for full-rate production (i.e., First Article Testing). Likewise, First Article Testing conducted for sustainment contracts such as those executed for the Services by the Defense Supply Center Philadelphia will follow this protocol.

In June 2007, by Congressional direction, DOT&E began oversight of DoD testing of hard body armor. In their January 2009 report titled, "DoD Testing Requirements for Body Armor," the DoD Inspector General (IG) stated, "We recommend that the Director, Operational Test and Evaluation (DOT&E) develop a test operations procedure for body armor ballistic inserts and involve the Services and USSOCOM [United States Special Operations Command] to verify the procedure is implemented DoD-wide." The DoD IG also indicated with regard to the testing standard, "... the test operating procedure should include, at a minimum, requirements for sample size, shot pattern, types of testing, and acceptance criteria to verify the rigor of testing." As rationale, the DoD IG stated, "Standardization of body armor testing and acceptance will assure that Service members receive body armor that has been rigorously tested ..."

Between late 2007 and present, the Army conducted extensive ballistic testing against hard body armor and completed analyses of test results. Those data and analyses enabled DOT&E and the Army to develop a statistically-based testing protocol providing a high level of confidence in test results for resistance to penetration and back-face deformation. I have decided to implement that protocol as the first iteration of a DoD-wide standard for First Article Testing of hard body armor. The attachment describes this protocol and addresses related issues associated with standardizing the overall hard body armor test execution process. User input to this standard is essential, especially in identifying the ballistic threats that the armor is expected to defeat. Subsequent to the establishment of this First Article Test standard, DOT&E will work with the Services, USSOCOM, and Defense Agencies to establish a standard Lot Acceptance Test protocol.

As testing of hard body armor continues and additional data are obtained, DOT&E will publish, as necessary, updates and changes to the attached protocol. Additionally, DOT&E will work with the Services, USSOCOM and Defense Agencies to incorporate this protocol, and future changes to it, into existing test operating procedures and military standards.

J. M. Gilmore

J. Michael Gilmore
Director

Attachment:
As stated

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Hard Body Armor
Standard for Ballistic Testing

The objective of this protocol is to establish for DoD-wide use, statistically-derived test methods for hard body armor that will provide for increased confidence in the performance of personal protective equipment. This protocol also establishes standard testing references, protocols, procedures, and analytical processes for hard body armor testing.

As necessary, the Services will use the standards and information in this protocol to update Test Operating Procedures (TOPs), Military-Standards (MIL-STDs), Contract Orders-Purchase Descriptions (CO-PDs), and other documents relevant to this commodity area.

DOT&E will work in coordination with the Services, USSOCOM, and the Defense Logistics Agency to update this protocol at least annually. As this protocol is codified into the aforementioned documents, updates to this protocol may be directly addressed via updates to those documents.

Protocols established in this standard supplant those currently in practice across the DoD. However, this protocol does not address all issues associated with conducting a hard body armor test. Test agencies, contracting officials, and material developers should therefore continue to use and reference TOPs, MIL-STDs, and other guiding documents currently in use to fully explain test setup and execution procedures. This protocol is not intended to be applied against already qualified designs.

Elements of Standardization

Table 1 establishes standard reference documents and source information related to this standard. The list is not meant to be all encompassing. For elements referenced to this standard, those elements are found later in this document. Elements referenced to Service requirements documents reflect that this is a testing standard and not a requirements document. Service user representatives and the USSOCOM establish Service and USSOCOM unique requirements. This includes, for example, the threat munitions and respective velocities to be applied against this testing protocol. The one exception to this is the back-face deformation (BFD) standard. The Services and USSOCOM have adopted a BFD standard that is the BFD cannot exceed 44 mm. The Army, for hard armor, has used a BFD standard that is the BFD cannot exceed 43 mm without penalty. With the adoption of the laser scanning methodology for BFD measurement and with the analysis completed by the National Institute of Standards and Technology[1], the DoD adopts the rounding methodology described in ASTM E29-08[2] (so-called "five-even rule) for rounding the BFD measurement to 0.1 mm. Therefore, for uniformity, with this standard, and unless changed by formal requirements documents (a Service-generated, JCIDS compliant capability production document, for example), the DoD adopts as the BFD requirement the

[1] National Institute of Standards and Technology, Dimensional Metrology Issues of Army Body Armor Testing, February 17, 2010.
[2] ASTM E29-08, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications.

Services and USSOCOM adopted standard of 44mm. The DoD BFD requirement is a BFD (based on the calculated the upper tolerance limit for the data set) that does not exceed 44.0 mm.

Element	Reference
Range Setup (physical layout of test range, instrumentation, measurement devices, recording devices, etc)	TOP 10-2-210 MIL-STD-3027
Backing Material/Clay Calibration	TOP 10-2-210 MIL-STD-3027 NIJ 0101.03 * NIJ 0101.06
Fair Hit/No Test Criteria	TOP 10-2-210 MIL-STD-3027 This Standard
Definition of Complete/Partial Penetrations	This Standard
Back-face Deformation Definition and Measurement	TOP 10-2-210 MIL-STD-3027 NIST Report 17Feb2010 This Standard
Shot Patterns/Shot Order/Distribution of Test Article Size in Test Matrix	Service Requirements Documents This Standard
Sample Size/Statistical Confidence in Test Results	This Standard
Threat Munitions/BFD Requirements	Service Requirements Documents This Standard

*Upon recommendation from the DoD Clay Working Group, the DoD will standardize to a single clay calibration technique

Table 1. Elements of Standardization

Range Setup: Test range setup will be in accordance with Test Operating Procedure (TOP) 10-2-210 and Military Standard (MIL-STD) 3027. In event of conflict between those documents, the most recent version of TOP 10-2-210 will take precedence. If these documents do not meet the needs of test agencies, test agencies may adopt procedures not defined within those documents. When such an event arises, DOT&E requests those agencies provide to the approving officials for those documents a written explanation of the deficiency and the range setup procedures used that were outside the scope of the documents. Subsequently, the approving officials should consider adoption of the provided information. Likewise, if a test agency deviates from these standards, they should provide a written explanation to the approving officials describing the necessity of doing so. Any changes to TOP 10-2-210 must be fully coordinated with the Services and USSOCOM prior to implementation.

Backing Material/Clay Calibration: Backing material (clay) preparation, cold working, temperature conditioning, monitoring, life-cycle management, and calibration will be in accordance with TOP 10-2-210, MIL-STD-3027, National Institute of Justice (NIJ) 0101.03, and/or NIJ 0101.06.

Material Developers may choose between the clay calibration techniques defined by NIJ 0101.03 and NIJ 0101.06 only, until such time that a single clay calibration technique is identified by the Clay Working Group and incorporated into this standard.

Fair Hit/No Test Criteria: Fair hit/no test criteria for test anomalies other than impact velocity (yaw, shot spacing, etc) will be in accordance with TOP 10-2-210 and MIL-STD-3027. In event of a conflict between those references, TOP 10-2-210 will take precedence.

For impact velocity anomalies, Table 2 identifies the standard fair hit/no test criteria for this hard body armor standard. In the case of an under-velocity shot which results in either a complete penetration (CP) or a BFD greater than 44.0mm, the shot result will be included in the analysis to conservatively estimate soldier protection capability. If the under-velocity shot occurs on the first shot, the plate will be replaced with a contingency plate to ensure a completed test matrix.

Impact Velocity	Test Result		Evaluator Accepts or Rejects for Inclusion in Analysis		Proceed to next data point for that plate?
	Penetration	BFD	Penetration	BFD	
Acceptable	No Penetration (PP and CP)	Measured	Include as success	Include	Yes
Acceptable	Complete Penetration (CC)	Not measured	Include as failure	Not measured	Yes
Too High	No Penetration (PP and CP)	Measured	Not included	Not included	No
Too High	Complete Penetration (CC)	Not Measured	Not included	Not included	No
Too Low	No Penetration (PP and CP)	BFD ≤(44.0 mm or combat developer defined catastrophic limit)	Not included	Not included	No
Too Low	No Penetration (PP and CP)	BFD > (44.0 mm or combat developer defined catastrophic limit)	Not included	Included	No
Too Low	Complete Penetration (CP)	Not measured	Include as failure	Not measured	No

Table 2. Fair Hit/No Test Criteria for Velocity Anomalies

Definition of Complete and Partial Penetrations: Figure 1 graphically describes conditions of partial and complete penetrations associated with hard armor testing.

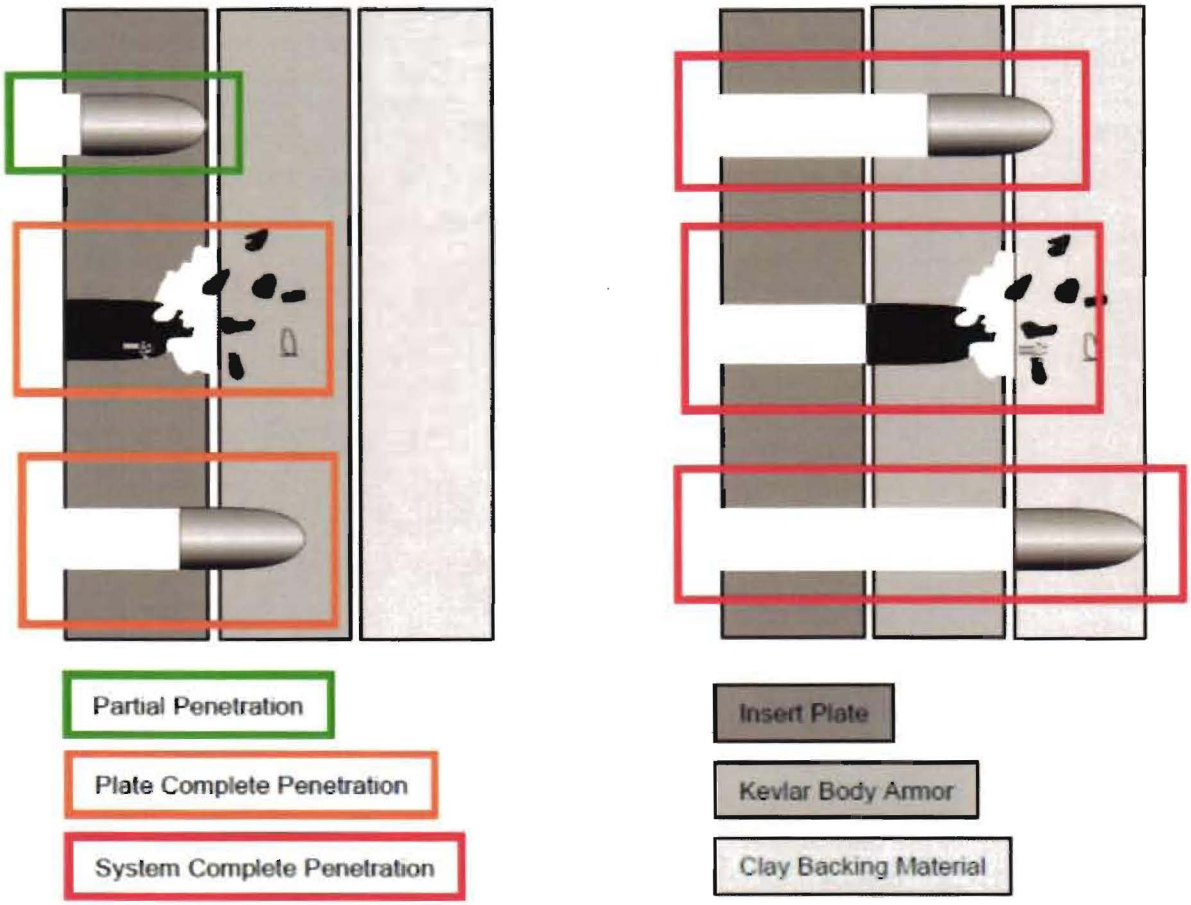


Figure 1. Partial and complete penetrations.

Partial Penetration of the Plate/Partial Penetration of the System (PP): A partial penetration of the test plate sample occurs on any fair record test shot impact that is not scored as a Complete Penetration (CP) of the test plate sample.

Complete Penetration of the Plate/Partial Penetration of the System (CP): A complete penetration of the test plate sample occurs on any fair record test shot impact in which the projectile, any fragment of the projectile, or any fragment of the armor material is ejected from the rear of the plate and passes into the first ply (minimum of one complete yarn broken) of the soft armor (ballistic package) located behind the test plate sample when it is placed into the soft armor test panel. The first ply of the soft armor (ballistic package) shall serve as a witness plate.

Figure 2 is a flow chart that depicts the decision process for determining a complete penetration of the hard armor plate.

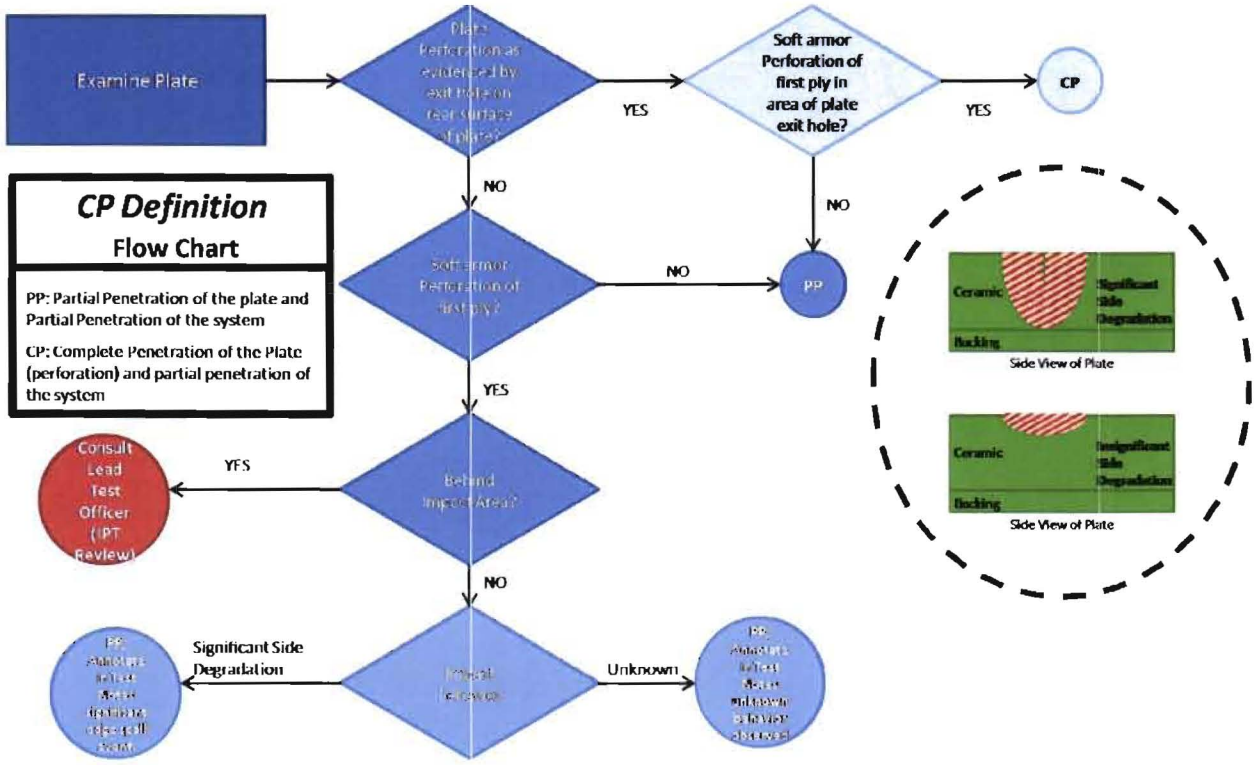


Figure 2. Flow chart for hard armor plate perforation decision.

Complete Penetration of the Plate / Complete Penetration of the System (CC): A complete penetration of the system (hard armor plate and soft armor ballistic package) occurs when the impacting projectile, any fragment thereof, or any fragment of the test plate sample penetrates the entire plate and all plies of the shoot pack and is embedded or passes into the clay backing used directly behind the armor plate and carrier/shoot pack. Complete penetrations of the plate and system are penetration failures when calculating the probability of no penetration.

If these definitions do not meet the needs of the material developer, the material developer must document deviations from these definitions and provide them to DOT&E. DOT&E will coordinate such information with the Services and USSOCOM to determine if changes are warranted to this standard.

Back-face Deformation Definition and Measurement: The DoD adopts the back-face deformation definition contained in the report of the National Institute of Standards and Technology titled, ***Dimensional Metrology Issues of Army Body Armor Testing, February 17, 2010***. That is:

The BFD measurand is defined by:

a. The basic maximum-distance-length, which is the length of the longest line segment parallel to the reference-direction between the pre-impact surface and the post-impact (BFD) surface of the clay backing material,

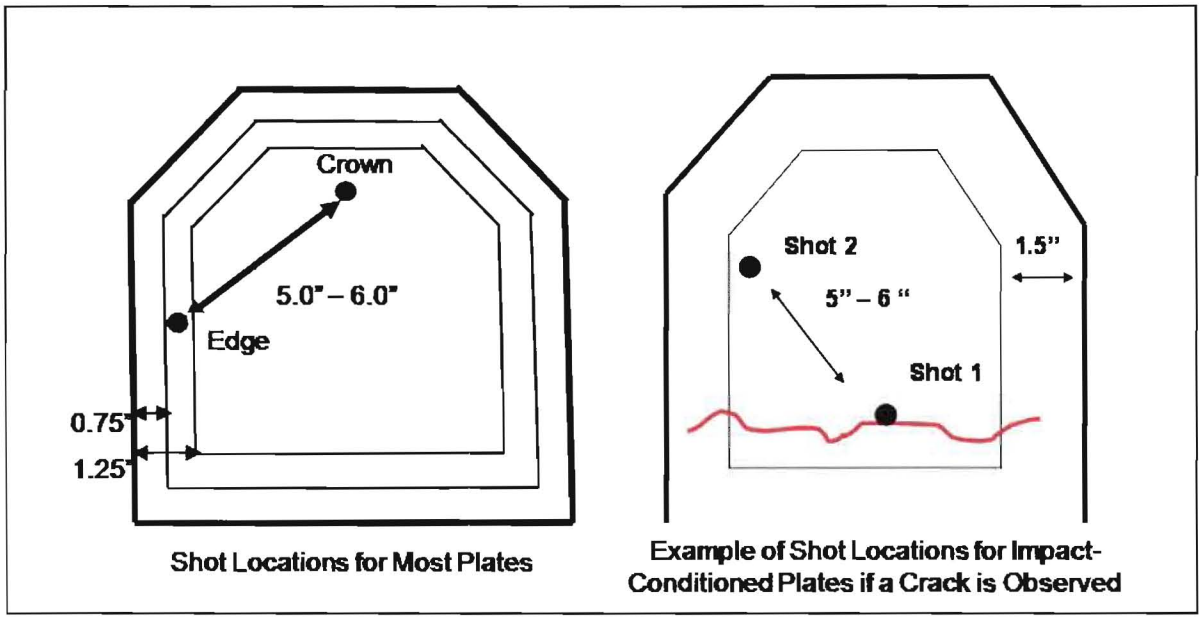
b. where the reference-direction is defined to be perpendicular to the surface of the aluminum box containing the backing material, with that surface defined as a least-squares plane fit through the front surface (i.e., facing the line-of-fire) of the box,

c. where the surface of the clay backing material, at a given location, is defined to be the arithmetic average height over a centered 0.7 mm × 0.7 mm square oriented perpendicular to the reference direction,

d. where the backface deformation surface is the surface obtained a short time after the projectile impact and the body armor has been removed, with the aluminum box in the vertical (as shot) orientation and position.

Back-face deformation will be acquired, assessed, and recorded in accordance with TOP 10-2-210 and MIL-STD-3027. That is, back-face deformation will be measured using a laser scanner attached to an articulating arm coordinate measuring machine in accordance with TOP 10-2-210 and MIL-STD-3027. In event of a conflict between those references, TOP 10-2-210 will take precedence. TOPs or other local reference documents must document any measurement uncertainty arising from this definition.

Shot Patterns/Shot Order/Distribution of Test Article Size in Test Matrix: Figure 3 depicts shot impact locations for ambient and environmentally conditioned plates (left) and for impact conditioned plates (right).



Measurements represented are for the Enhanced Small Arms Protective Insert. For the X-Small Arms Protective Insert, edge shots are between 1.0" and 1.5" from the edge.

Figure 3. Intended impact locations.

For all ambient and environmentally conditioned plates, two shots per plate will be taken as indicated in the above left graphic: one edge shot and one crown (the point at which three

curvatures of a ballistic plate converge) shot. For Impact-Conditioned Plates, two shots per plate will be taken as indicated in the above right graphic: first shot is at location of most severe crack (as determined by x-ray) and second shot is at any edge.

Table 3 defines the shot order (first shot/second shot) and locations; and, the distribution of plate size in a 60-plate protocol, which is the minimum necessary to achieve the required statistical confidence in the results (detailed later in this standard). All 60 plates must be shot against the same threat.

Environment		
	1st Shot Edge 2nd Shot Crown	**1st Shot Crown 2nd Shot Edge**
Ambient (Unconditioned)	XS, L, XL	S, M, XL
Temperature Cycling	M, L, XL	XS, S, M
JP-8 Soak	XS, S, M	M, L, XL
Oil Soak	S, M, L	XS, S, XL
Salt Water	XS, M, XL	XS, S, L
Weathered	S, M, XL	XS, L, XL
High Temperature	S, L, XL	XS, M, L
Low Temperature	XS, S, XL	S, M, L
Altitude	XS, M, L	S, L, XL
Total	**27**	**27**
Impacted*	2 XS, S, L, M, XL	
Total	**60**	

*If a crack occurs during the drop test, then the 1st shot will be taken at the most severely damaged area of the plate, as identified by x-ray. If a crack is not visible after x-ray of the plate, the 1st shot will be taken at the crown. The 2nd shot will be taken 5" to 6" away from the first shot but no closer than 1.5" to an edge.

Table 3. 60-plate protocol.

This protocol does not limit the Services or USSOCOM from conducting any additional testing as they deem appropriate. For example, USSOCOM can blend this shot protocol with their multi-plate, clock-type shot pattern. Likewise, this protocol does not prevent the Services or USSOCOM in executing additional testing methodologies, such as firing for V50 analysis.

Sample Size/Statistical Confidence in Test Results: Table 4 displays the resistance to penetration and back-face deformation statistical analysis required for this protocol. The first and second shot standards are established to provide a high level of statistical confidence in the test results. For resistance to penetration, the lower confidence level for the probability of no penetration, P(nP) is the statistic of interest and the result compared against a 90% probability of no penetration for first shot and a 70% probability of no penetration for second shot. For back-face deformation (BFD), the Upper Tolerance Limit will be computed using back-face deformation as a continuous normal random variable and the result compared against the requirement.

Resistance to Penetration		
	1st Shot	2nd Shot
Analysis Methodology	Lower 90% Confidence Level	Lower 90% Confidence Level
Back-face Deformation		
Analysis Methodology	90% Upper Tolerance Limit on BFD with 90% Confidence	80% Upper Tolerance Limit on BFD with 90% Confidence

Table 4. Statistical Analysis Methodologies

Analysis Methodologies: The Lower Confidence Level (LCL) of the P(nP) is calculated using the Clopper-Pearson method. The LCL for P(nP) is calculated for the 1st and 2nd shots by combining shot locations, plate sizes, and environmental conditions.

For BFD, the arithmetic mean of the BFD measurements for both first and second shots is calculated as well as the indicated Upper Tolerance Limit (UTL). The 90 percent UTL at 90 percent confidence provides the estimated BFD measurement below which 90 percent of BFD measurements will occur, with 90 percent confidence. The BFD UTLs are calculated for the first and second shots by combining shot locations, plate sizes, and environmental conditions.

Threat Munitions: The Services and USSOCOM will generate requirements documents that identify the threat munitions and associated velocities that will be applied against this protocol. As noted previously, the BFD requirement of not exceeding 44.0 mm will be the DoD standard until superseded by a validated capabilities document.

This protocol does not prevent the Services or USSOCOM from conducting testing with additional threats that may not be applied against this testing protocol.

Conclusion: The Services and USSOCOM will document adherence to this protocol in formal test plans and reports.