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Assessing the Methodology for Testing Body Armor

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Assessing the Methodology for Testing Body Armor

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Background

- Armor manufactured from various materials has been used throughout recorded history
  - Animal skins → fabrics → wood → metal → advanced materials
- US forces wear body armor for ballistic protection from
  - Penetration of projectiles
  - Blunt force trauma of impact

Modern Body Armor

- Kevlar and ceramic materials used in modern armor systems
  - Lighter than traditional metallic alloy-based armor
  - Ceramics have superior hardness, low density, and high compressive strength
- Typical insert (“plate”)
  - Consists of a layer of dense boron carbide or silicon carbide backed by a layer of metal or polymer composite
  - Entire plate wrapped in tightly woven ballistic fabric
  - Plate breaks up an incoming projectile and dissipates its kinetic energy

Interceptor Body Armor

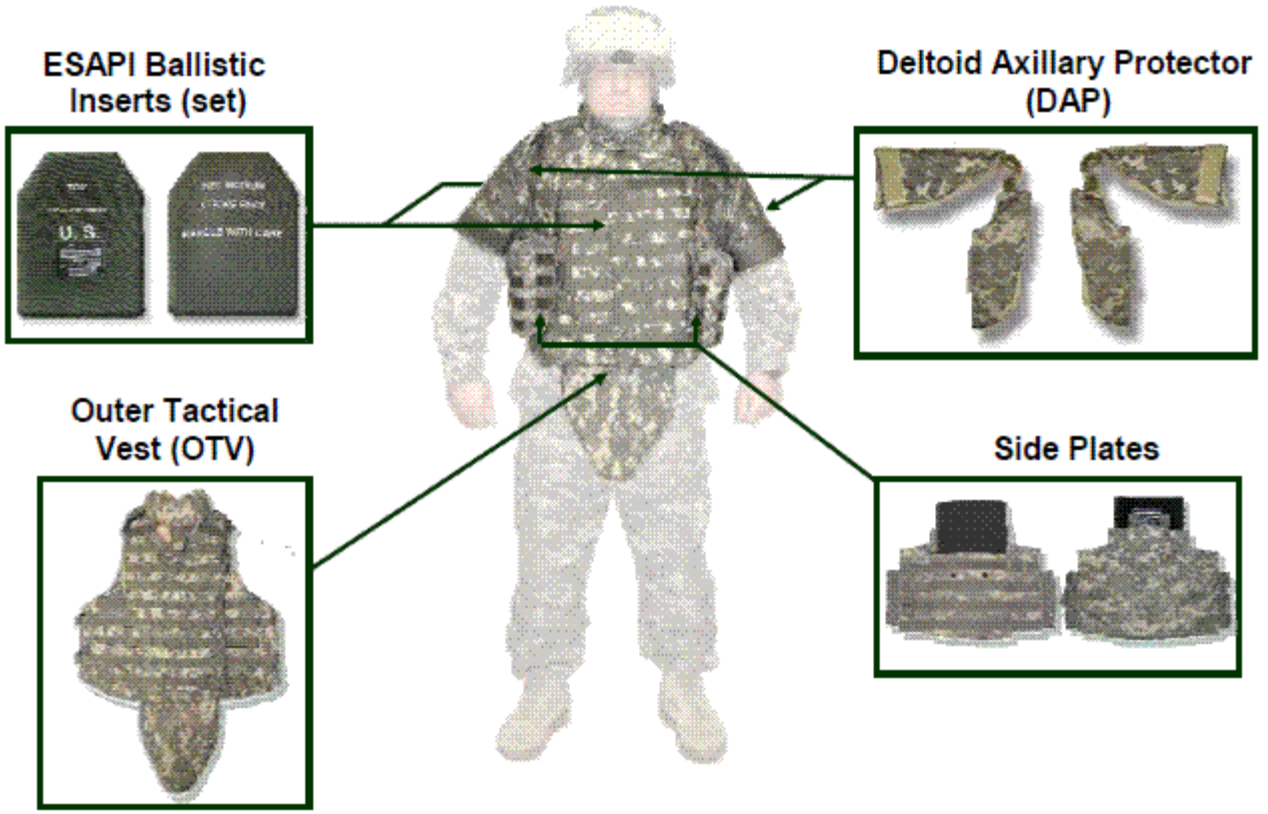


Figure 1. Interceptor Body Armor

Source: "DoD Testing Requirements for Body Armor", Inspector General, United States Department of Defense, Report No. D-2009-047, January 29, 2009.

USSOCOM Body Armor

Figure 2. Releasable Body Armor Vest

Source: "DoD Testing Requirements for Body Armor", Inspector General, United States Department of Defense, Report No. D-2009-047, January 29, 2009.

Current Body Armor is Effective

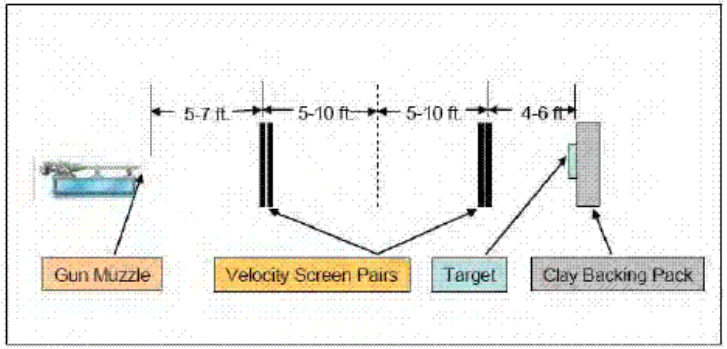
- Program Executive Officer – Soldier: "…*there have been no known soldier deaths due to small arms that were attributable to a failure of the issued ceramic body armor*"
- Ceramic materials preferred because they are relatively light compared to traditional armor made of metallic alloys
  - However, all effective body armor systems currently add a significant burden of weight on the soldier
  - Interceptor body armor (size medium) w/ all protective plates ~ 33 lbs.

150 lbs. of lightweight gear

Sources: Phase I Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, Dec. 30, 2009 & https://peosoldier.army.mil/factsheets/SEQ_SSV_IBA.pdf (accessed 7/26/10).

Body Armor Testing, In Brief

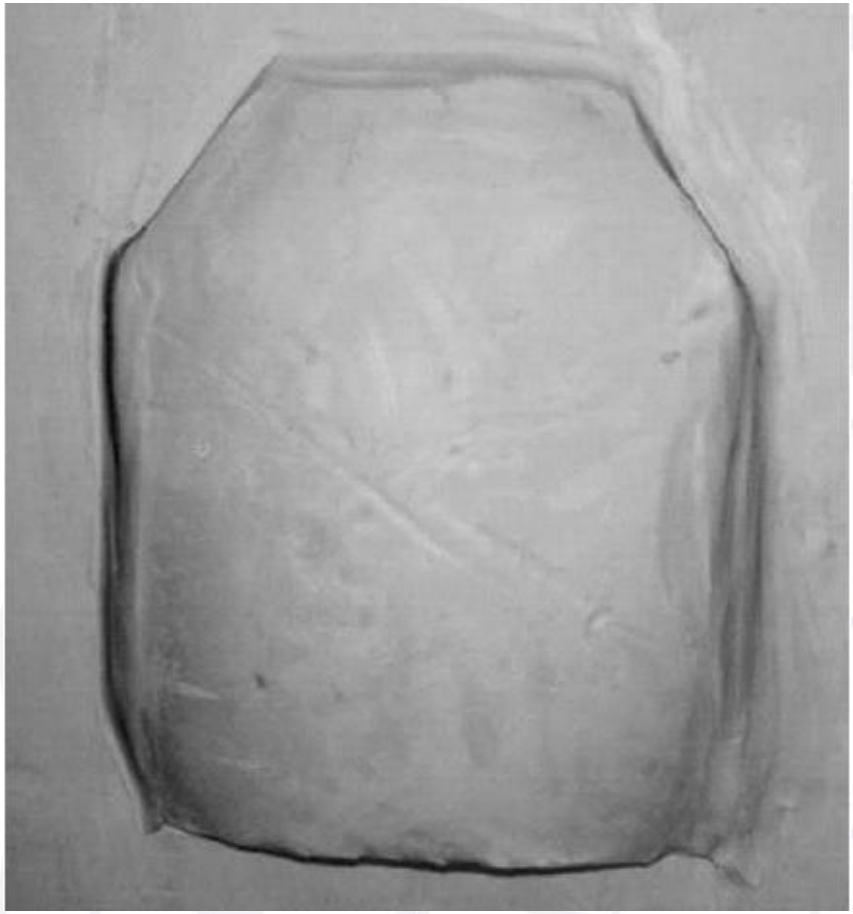
- Before awarding contracts to buy body armor, DoD conducts “first article testing” or FAT
- Goal is to determine whether product meets purchase specifications
- For body armor, it is a destructive ballistic test
  - I.e., representative armor is shot at under various conditions



Source: Phase II Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, April 22, 2010.

Clay as Recording Medium

- Test consists of mounting “shoot pack” on clay backing
- Use of clay based on Prather et al. (1977) study which found clay measurements could be “*correlated to tissue response for use in characterizing both the penetration and deformation effects of ballistic impacts on soft body armor materials*.”
- Changes in clay formulation over time have resulted in extensive effort to try to maintain test clay consistency



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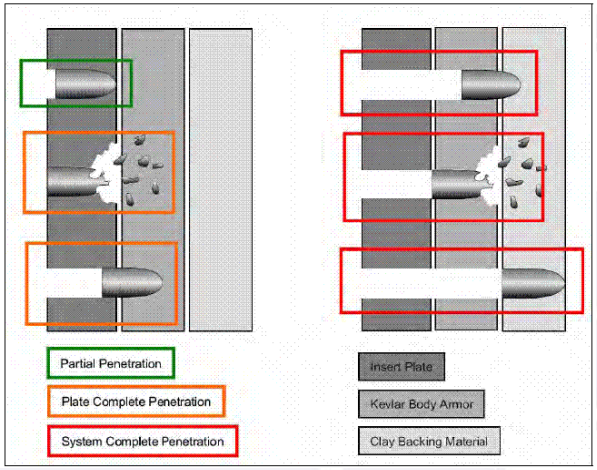
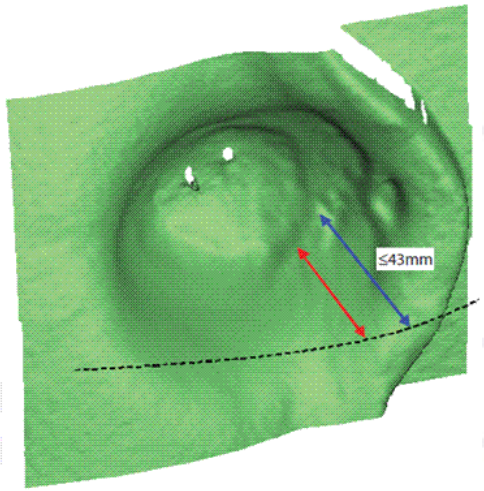
Test Metrics

- Penetration
  - Resistance to projectiles fired at a constant velocity
  - May be partial (plate, Kevlar) or complete (bullet or bullet fragments into clay backing)
- Back face deformation (BFD)
  - BFD is the depth of the crater left in the clay after impact
  - Surrogate measure for blunt force trauma





Source: Phase II Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, April 22, 2010.

Original Army FAT Protocol

- Total of 27 plates tested:
  - 1 plate against threats “A,” “B,” and “C” and 3 plates against threat “D” in ambient conditions
  - 1 plate for each of nine environmental conditions
  - Also, 12 plates for “V_{50}” tests
- Passing standards
  - For threats “A,” “B,” and “C,” no penetration allowed and BFD less than 48 mm
  - For threat “D,” a point system was used to score shots based on penetration and BFD
    - An accumulation of six or few points was passing

Source: Phase II Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, April 22, 2010.

(Some) Body Armor Testing Issues

- Testing protocols differ across DoD
- Army protocol not statistically based
  - DoD IG: "*standardization of body armor testing and acceptance will ensure that Service members receive body armor that has been rigorously tested and will provide uniform protection in the battlefield*"[1]
- Clay-based testing:
  - Clay formulation has changed over time, resulting in a formulation that is temperature sensitive
    - How much variation in test results attributable to variation in test conditions and how much due to plate variation unknown
  - Scientific connection between clay test results and protection of human beings tenuous at best

[1] "DoD Testing Requirements for Body Armor", Inspector General, United States Department of Defense, Report No. D-2009-047, January 29, 2009.

NAS Committee

- Three-phase study
  - Phase 1: Completed 30 December 2009
  - Phase 2: Competed 22 April 2010
  - Phase 3: Starts 9 August with meetings scheduled over ~ three months
- First two phases conducted as intense four-day meetings
  - Days 1 and 2, briefings and site visits
  - Days 3 and 4, draft committee letter report
- Chaired by retired Army Major General with 7-8 members (engineers and statisticians)

Phase I

- DOT&E tasked the committee to:
  - "…*comment on the validity of using laser profilometry/laser interferometry techniques to determine the contours of an indent made by a ballistic test in a non-transparent clay material at the level of precision established in the Army's procedures for testing personal body armor*."
  - "…*provide interim observations regarding the column-drop performance test described by the Army for assessing the part-to-part consistency of a clay body used in testing body armor*."

Source: Phase I Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, December 30, 2009.

Digital Caliper

- Digital caliper used to measure BFD has several shortcomings, including
  - If deepest location in the clay indent is displaced from the aim point, must estimate original clay surface at the impact point
  - Caliper subject to operator judgment because one must measure a soft, deformable surface by barely touching and yet not disturbing the clay
- Standard error for measuring etched metal gage block on order of 0.1 mm; for BFD in soft clay medium on the order of 1 mm

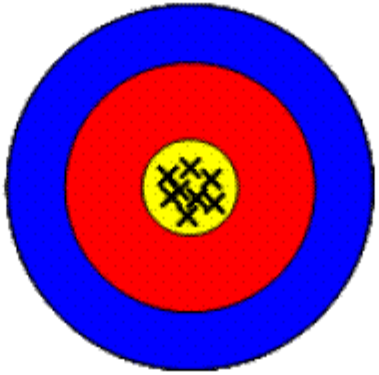
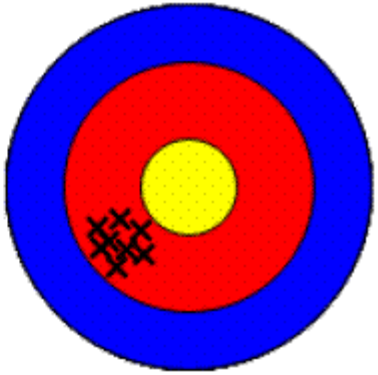
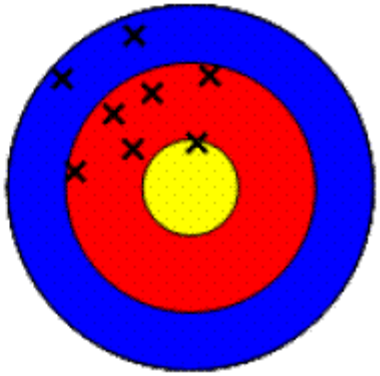
Source: Phase I Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, December 30, 2009.

Laser Profilometry/Interferometry

- Laser used to take three dimensional measure of clay surface before and after test
  - Differences of two surfaces used to measure BFD
- Benefits:
  - Does not require contact with clay
  - Measurements collected over whole surface
- However, system more complicated and costly

Source: Phase I Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, December 30, 2009.

Accuracy vs. Precision

	Accurate	Inaccurate (systematic error)
Precise		
Imprecise (reproducibility error)		

Source: Phase I Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, December 30, 2009.

Phase I Recommendations

- "*The digital caliper is adequate for measurements of displacements created in clay by the column-drop performance test…*"
- "*Surface profilometry by a laser… is a valid approach for determining the contours of an indent in a nontransparent clay material at a level of precision adequate for the Army's current ballistic testing of body armor*."

Source: Phase I Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, December 30, 2009.

Phase II

- DOT&E tasking
  - "*In Phase II, the committee will consider in greater detail [than in Phase I] the validity of using the column drop performance test described by the Army for assessing the part-to-part consistency of a clay body within the level of precision that is identified by the Army test procedures*."
  - "*The final report will document the committee's findings pertaining to…the appropriate use of statistical techniques (e.g., rounding numbers, choosing sample sizes, or test designs) in gathering the data*."

Source: Phase II Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, April 22, 2010.

Proposed New FAT Specifications

- Total of 60 plates tested spread over a combination of plate sizes, environmental conditions, and shot order
- Passing standards:
  - Penetration:
    - One-sided 90 percent lower confidence bound for the probability of complete system penetration is greater than 0.9 (first shot) and greater than 0.8 (second shot)
  - BFD:
    - First shot: one-sided 90% upper tolerance limit for BFD must be less than 44.0 mm with 90 percent confidence
    - Second shot: one-sided 80% upper tolerance limit for BFD must be less than 44.0 mm with 90 percent confidence

Source: Phase II Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, April 22, 2010.

Statistical Protocol Allows Explicit Risk Trade-Offs To Be Made

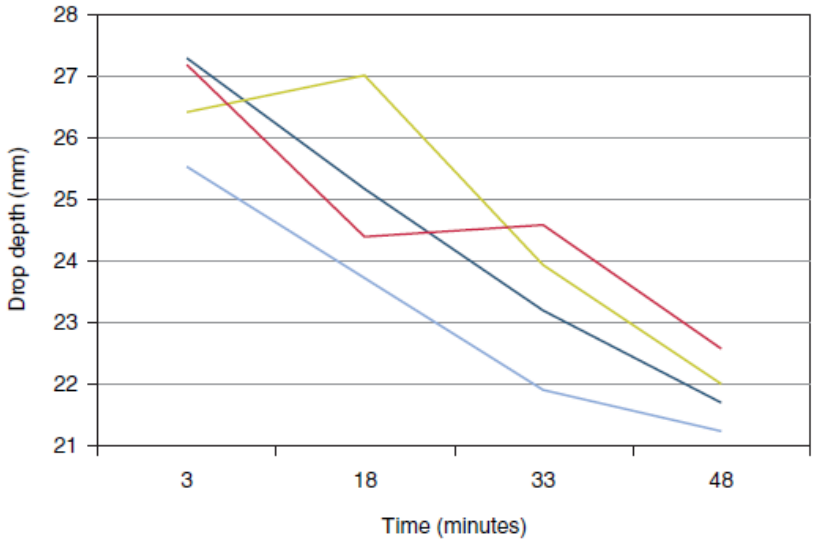
TABLE 4 Risk Comparisons for Probability of Complete Penetration

Sample Size	Allowable Failures	True P (No Penetration)	Requirement	Government Risk	Manufacturer Risk
15	0	0.98	0.86	0.206	0.261
22	0	0.98	0.90	0.098	0.359
40	1	0.98	0.90	0.080	0.190
60	2	0.98	0.90	0.053	0.119
60	2	0.99	0.90	0.053	0.022
60	2	0.92	0.90	0.053	0.868
300	9	0.98	0.95	0.000	0.082
6,000	134	0.98	0.975	0.000	0.092

Source: Phase II Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, April 22, 2010.

Variation Introduced by Test Protocol Unknown

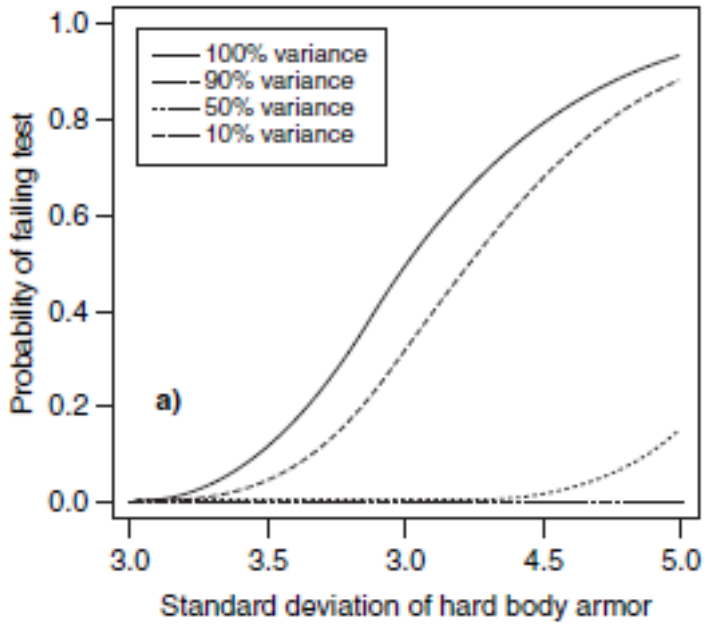
- "Column drop" test used to test clay for consistency prior to ballistic testing
  - Clay heated until indentation depth of weight dropped into clay meets standard
  - Indentations from 3 drops must all be within 25 mm ± 3 mm
- Yet clay performance may still vary substantially due to temperature and other factors
- How much variation this introduces into ballistic test results unknown



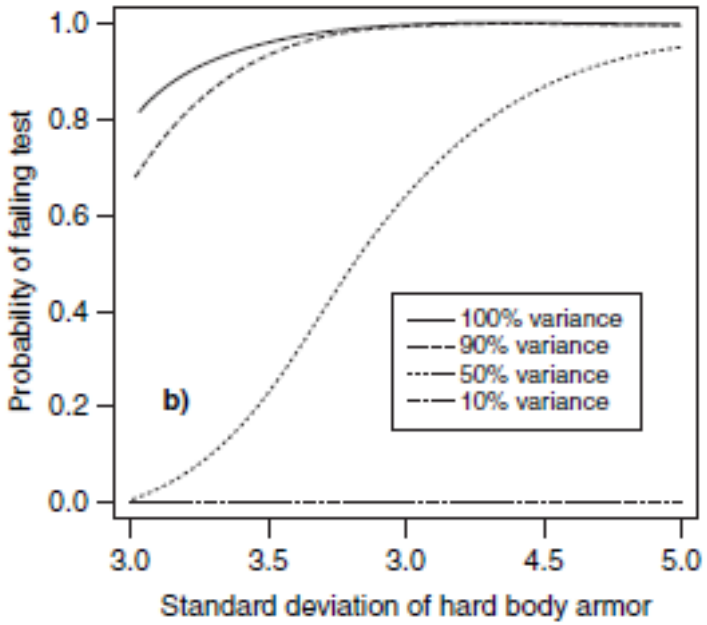
Source: Phase II Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, April 22, 2010.

Effect(s) of New Protocol Standards on Manufacturers Unknown

If manufacturer's average BFD = 38 mm, probability of failing testing for various process and testing standard deviations



If manufacturer's average BFD = 40 mm, probability of failing testing for various process and testing standard deviations



Source: Phase II Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, April 22, 2010.

Some Phase II Clay-Related Recommendations

- "…*expedite the research necessary both to quantify the medical results of blunt force trauma on tissue and to use those results as the updated mathematical underpinnings of the back face deformation (BFD) body armor testing methodology*."

- "*The Army should develop ballistic testing performance specifications and properties that will lead to a short-term, standard replacement for the current Roma Plastilina #1 oil-based modeling clay*."

- "*Since oil-based modeling clay is time and temperature sensitive, a post-drop calibration test is needed to validate that the clay remains within specification at the end of a body armor test*."

Source: Phase II Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, April 22, 2010.

Phase II Recommendations Related to Statistical Methodology

- "*The committee unequivocally supports the concept of a statistically based test protocol…*"

- "*…the Army should quickly develop and experiment with a gas gun calibrator, or equivalent device…to estimate as accurately as possible the variation of back face deformation measurements both within a given box and between boxes, under realistic testing conditions using existing test protocols*."

- "*…the results of the experiments and analyses proposed in this report, should be used as due diligence to carefully and completely assess the effects, large and small, of the proposed statistically based protocol before it is formally adopted across the body armor testing community*."

Source: Phase II Report on Review of the Testing of Body Armor Materials for Use by the U.S. Army, The National Academies, April 22, 2010.

Phase III

- DOT&E has tasked the committee to:
  - Develop ideas for revising/replacing the Prather study methodology
  - Provide a roadmap to reduce variability of clay processes and how to migrate from clay to future solutions
  - Within the time and funding available, review and comment on methodologies and technical approaches to military helmet testing