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DESIGN AND TESTING OF CHEMICAL/BIOLOGICAL PROTECTIVE GARMENT SYSTEM—GENERATION 6

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14. ABSTRACT This report describes the efforts of the Garment Team (GT) at the Philadelphia University Laboratory for Engineered Human Protection (LEHP) to design and fabricate prototypes of garments that are chemically protective (CP), yet provide superior comfort for Warfighters. The GT used a spiral development process to develop modular designs for such garments, while considering facility of use and cost considerations, as well as comfort and protection. Among the tasks described are selecting cooperating and collaborating vendors for materials (shell fabrics, laminates, carbons, membranes, fasteners, etc.); evaluating and down selecting materials to identify those best suited for the planned garment types; identifying and employing design and performance enablers that contribute to the optimization of protection, comfort, and facility of use while controlling cost; producing succeeding generations of CP garments that are continually improved through spiral development cycles; and assessing performance and merit of CP garments produced by the GT. This report describes work on Generation 6 garments. Assessments were conducted at LEHP, DEVCOM Soldier Center (NSRDEC), and contractors' sites where specialized equipment and expertise were available. Results of the assessments are included in other reports that are appended to this report. LEHP work supports the Warrior Systems Technology Program.					
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Acknowledgements

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DESIGN AND TESTING OF CHEMICAL/BIOLOGICAL PROTECTIVE GARMENT SYSTEM—GENERATION 6

1. Introduction

The Garment Team (GT) of the Philadelphia University Laboratory for Engineered Human Protection (LEHP) developed prototype chemical protective ensembles designed to protect Warfighters against chemical warfare agents while providing comfort and facility of use to the wearer. This report describes the iterative design process and materials used by the GT, summarizes the construction, test methods and test results for the ensembles, and presents conclusions drawn from the results. The work described was performed between January 2010 and June 2011 under Department of Defense University Research Initiative Grants (W911QY-09-1-0001 and W911QY-10-0002) administered by the U.S. Army DEVCOM Solder Center (Natick Soldier Research, Development and Engineering Center (NSRDEC)), in support of the Warrior Systems Technologies Program.

The original objectives of LEHP's research included:

- Develop a modular two-piece ensemble with both fixed hood and removable hood coat designs, trouser, and separate two-piece carbon undergarments.
- Optimize garment design for fit, functionality, ease-of-movement, performance, overall comfort and cost.
- Improve ease of donning and doffing of both uncontaminated and contaminated garments.
- Use human factors and motion routine test results as an integral part of the design and development process to include biophysical and ergonomic comfort, ease of movement, range of motion, and garment durability, especially at seams and junctures.

This report contains information on the design and testing of the LEHP Generation 6 ensemble. The Generation 6 ensemble is the sixth iteration of the LEHP prototypes and is the second two-piece garment to be designed.

This report, along with the garment patterns supplied to NSRDEC provides information for a knowledgeable practitioner to duplicate the methods and garments created by under this effort.

2. Garment Design and Materials

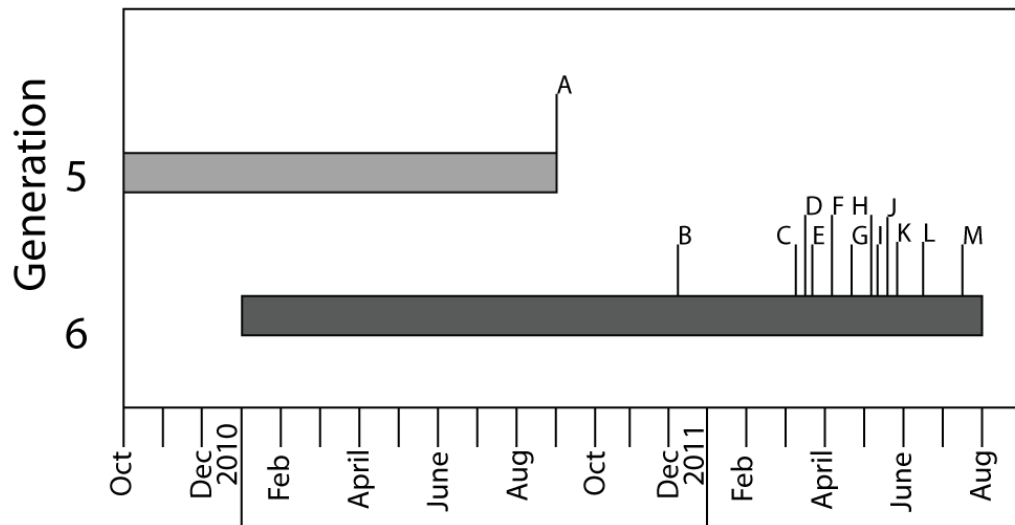
2.1 Generation 6 Prototype

Initially, the GT reviewed the existing two-piece Joint Service Lightweight Integrated Suit Technology (JSLIST) garment, as well as other military-issued chemical protective ensembles, and participated in discussions with scientists at the Navy Clothing and Textile Research Facility (NCTRF) and NSRDEC. The GT also visited a variety of fabricators of protective materials and reviewed available closure systems making use of zippers, stretch cords, gripper tape, hook-and-loop fastener tape, and other novel closures.

Earlier generations developed by the GT were coverall and two-piece designs. Those five prior prototypes designed and evaluated by the GT were described in Technical Reports PHILA-LEHP-GT-TR-08-02, *Design and Testing of Chemical/Biological Protective Coverall System, Generations 1–3*, PHILA-LEHP-GT-TR-09-01, *Design and Testing of Chemical/Biological Protective Coverall System, Generation 4*, and PHILA-LEHP-GT-TR-11-01, *Design and Testing of Chemical/Biological Protective Coverall System, Generation 5*. Results from earlier prototypes influenced the design of subsequent generations. Figure 1 shows the timeline for Generation 6 and for events that influenced its development, as well as overlapping events from Generation 5.

Generation 6 (see Figure 2) is an updated version of the original two-piece Generation 5 garment. Two versions of the coat were produced; a fixed hood version (see Figures 3 and 4) and a removable hood version (see Figures 5 and 6).

The two-piece outer garment features a zip-together trouser and coat, articulated sleeves and legs, hood/mask interface specific to the Joint Service General Purpose Mask (JSGPM), and knee-pad pockets, among many other features. A two-piece carbon undergarment (see Figures 7, 8 and 9) was designed to be worn under the two-piece outershell.



- A- Human Factors at NSRDEC- August 30, 2010
- B- NSRDEC Annual Review at PhilaU - December 2-3, 2010
- C- Human Factors at PhilaU- March 10, 2011
- D- Human Factors at PhilaU- March 14, 2011
- E- Human Factors at PhilaU- March 31, 2011
- F- FAST at Research Triangle Institute- April 5-8, 2011
- G- Contaminated Doffing at Hazmat Science Applications - April 19-21, 2011
- H- Human Factors at PhilaU- May 5, 2011
- I- Human Factors at PhilaU- May 10, 2011
- J- Human Factors at PhilaU- May 11, 2011
- K- Human Factors at PhilaU- May 12, 2011
- L- ASTM Ninth Symposium on Protective Clothing- June 16-17, 2011
- M- Human Factors at NSRDEC- June-July 2011

Figure 1. Timeline for Generation 6 of GT-Designed Protective Garments.



Source: RTI.¹

Figure 2. Generation 6 Garment—Fixed Hood Version

The Generation 6 ensemble was sent for evaluation at three sites: (1) Research Triangle Institute (RTI) for Fluorescent Aerosol Screening Test (FAST); (2) Hazmat Science Applications (HSA) for contaminated doffing; and (3) NSRDEC for human factors studies.

The initial phase of the garment design process involved experimentation with a variety of available fabrics, consideration of human ergonomic concerns, and a spiral development process of design building on what was learned from the previous five prototype garment systems.

¹ With the exception of photographs from testing reports compiled by outside agencies, all illustrations in this report were created by Kristen Hultzapple and John Venafro of LEHP.

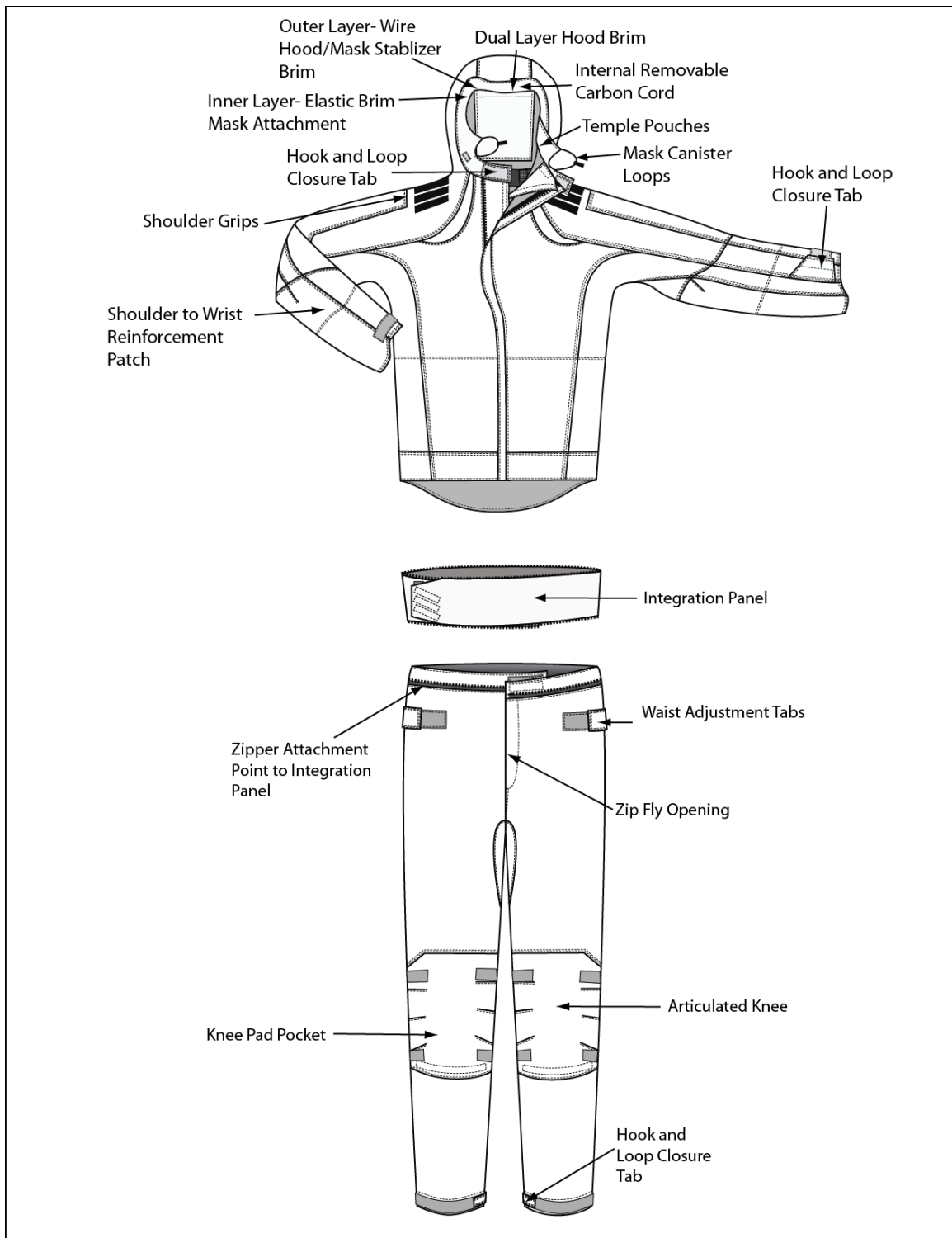


Figure 3. Generation 6 Shell Flat Sketch—Front—Fixed-Hood Version.

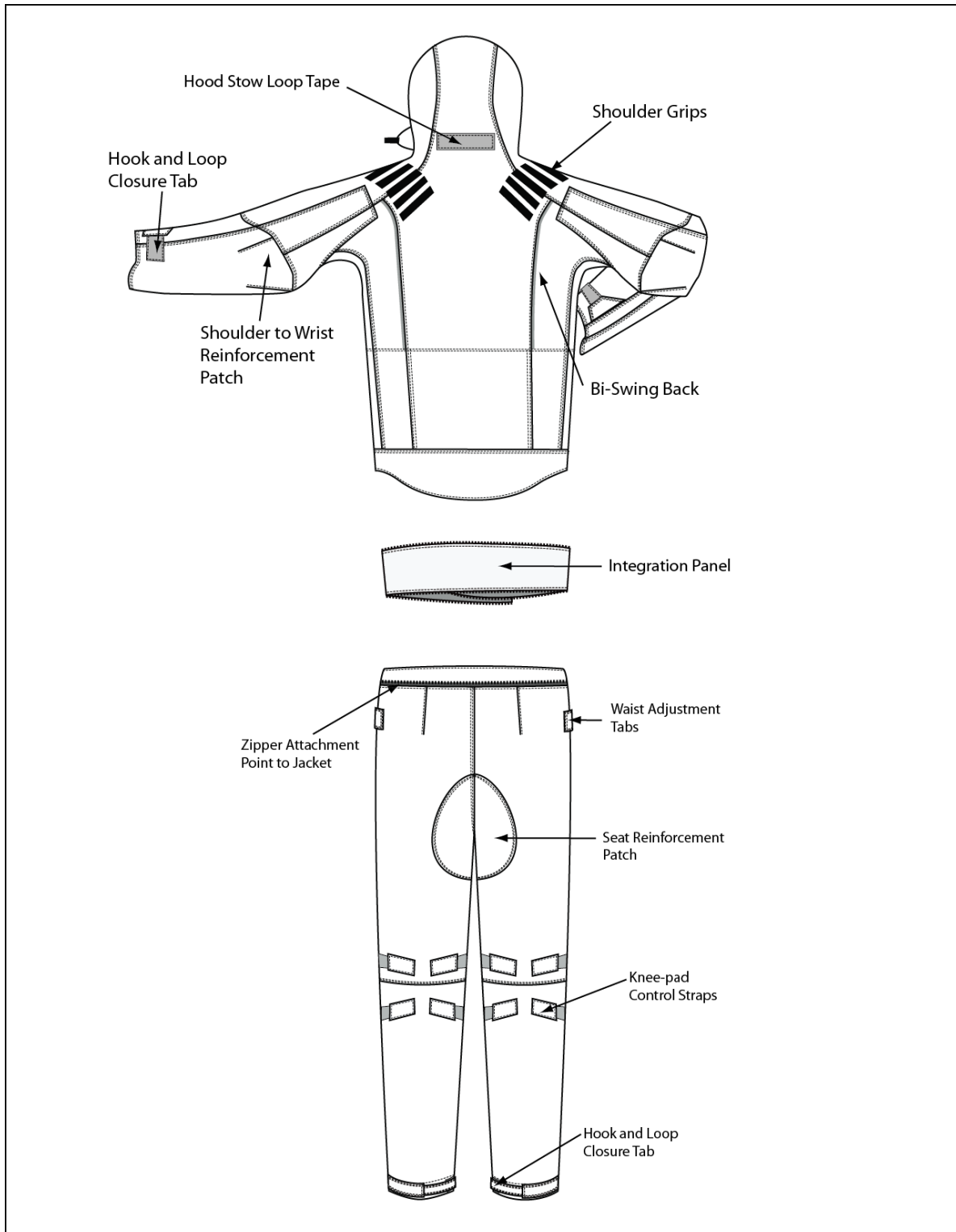


Figure 4. Generation 6 Shell Flat Sketch—Back—Fixed-Hood Version.

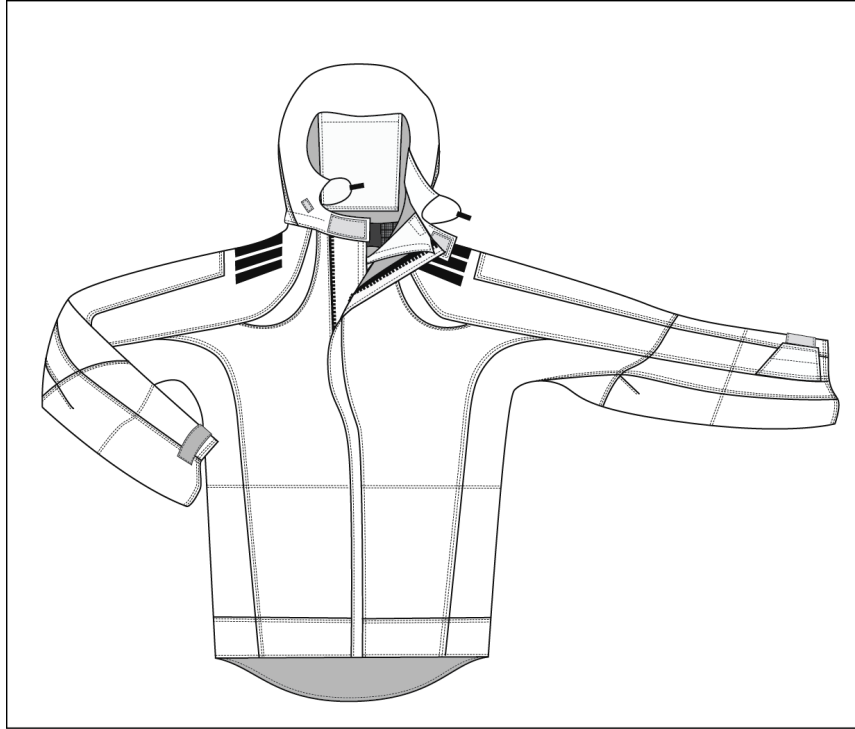


Figure 5. Generation 6 Shell Flat Sketch—Front—Removable-Hood Version.

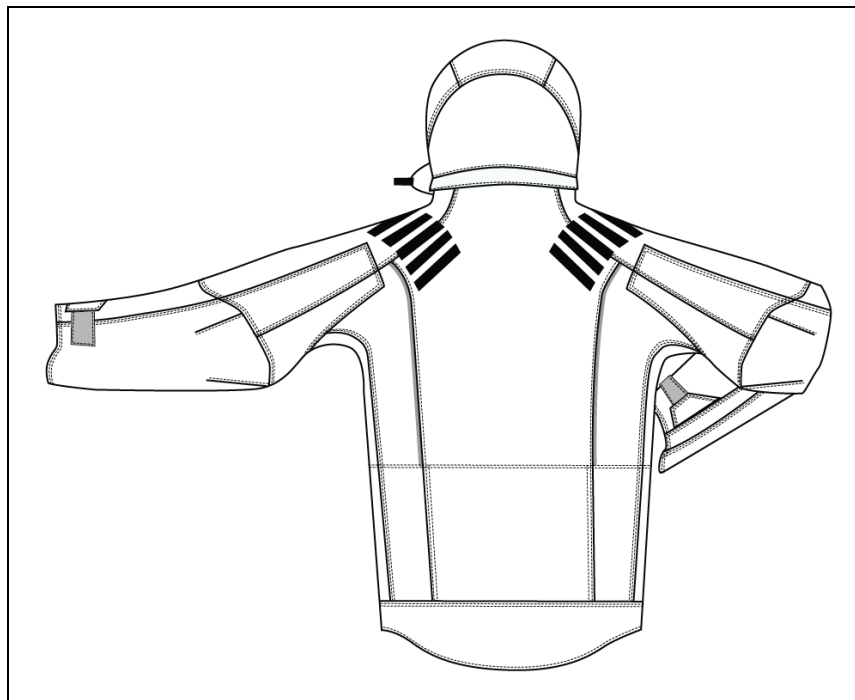


Figure 6. Generation 6 Shell—Back—Removable-Hood Version.

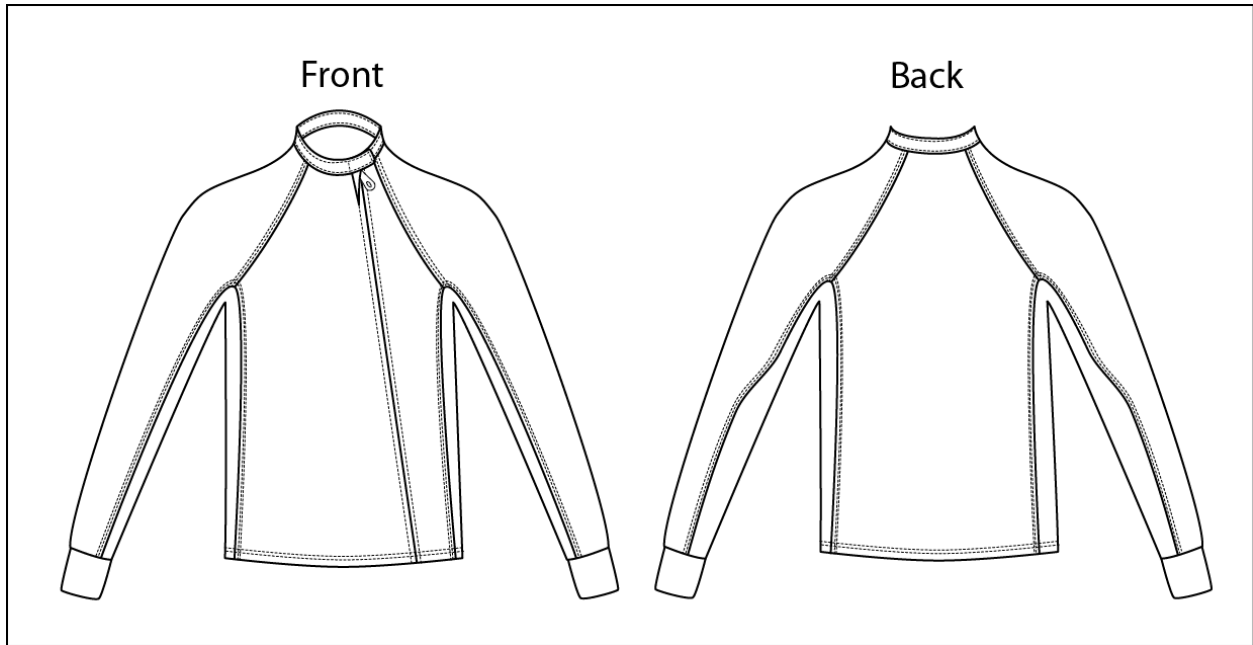


Figure 7. Generation 6 Carbon Shirt—Collar Neck.

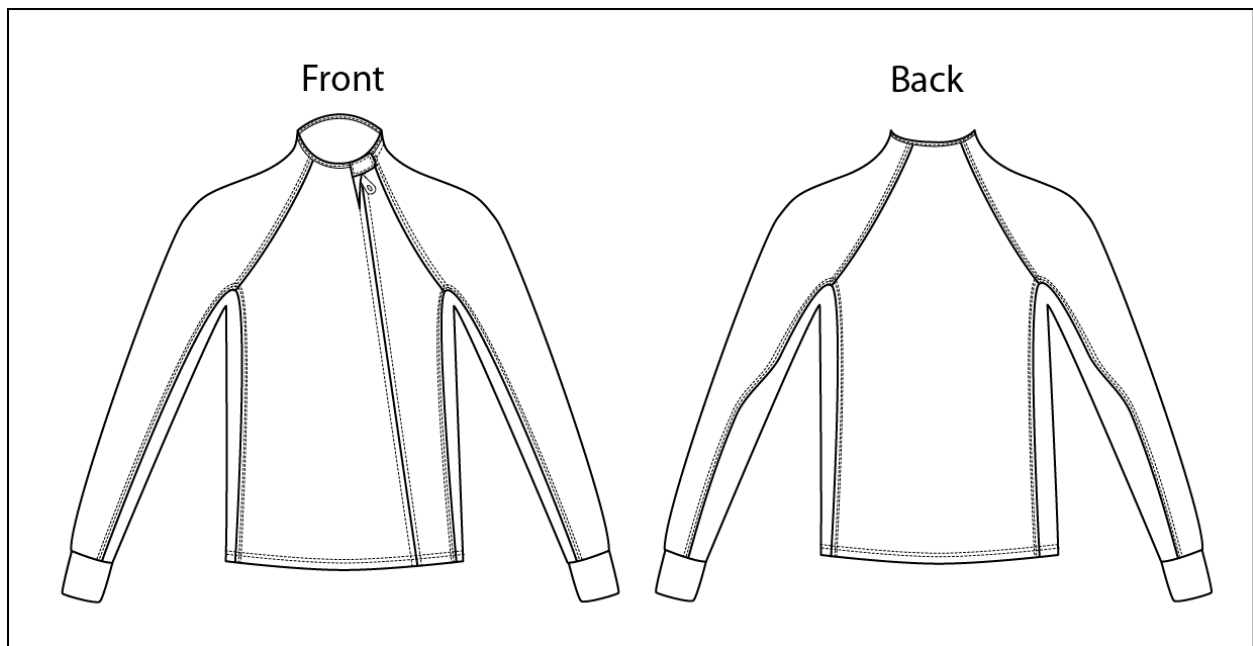


Figure 8. Generation 6 Carbon Shirt – Funnel Neck.

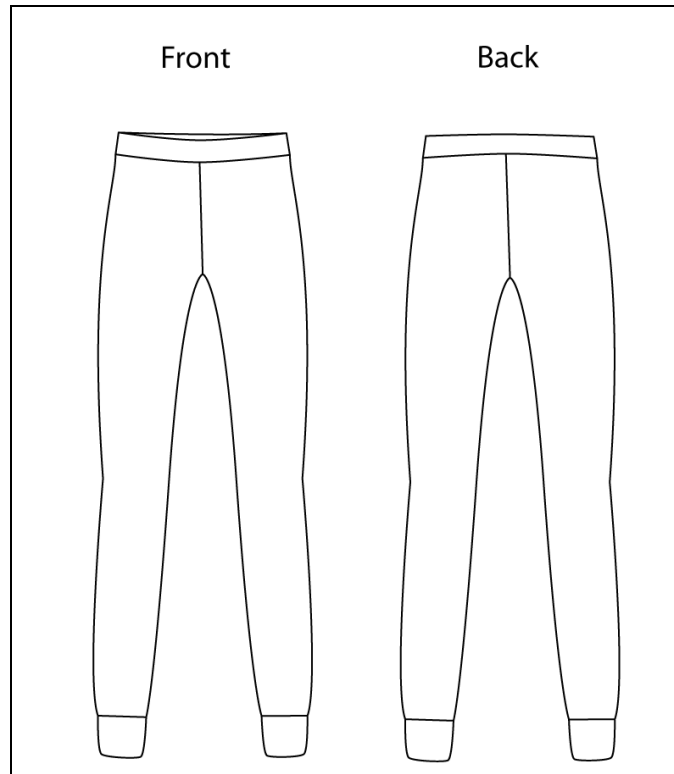


Figure 9. Generation 6 Carbon Drawer.

2.2 Design Process

The GT evaluated materials in conjunction with the Materials Evaluation Team (MET), and then selected and vetted various shell, carbon and membrane materials; closures, including zippers, ties, cording, and hook-and-loop fastener tape; and other components that were considered for use in construction of the ensemble. This process, accordingly, included the use of novel manufacturing techniques and innovative garment design.²

At LEHP's inception the military was issuing the JSLIST coat and trouser ensemble. The JSLIST is an air-permeable, two-piece garment system comprised of two fabrics, a permanent carbon layer and a durable water and oil repellent outershell fabric. The GT, with guidance from NSRDEC and NCTRF, created a two-piece outershell with separate carbon undergarments to eliminate the need for a sewn-in carbon-containing layer.

The Generation 6 ensemble is intended to be worn directly over undergarments together with the alternate of the outershell being worn as a duty uniform. The garment was designed taking into consideration interfaces with the JSGPM, and with gloves and boots at the wrists and ankles. It maintained the need for field relief with a fly zipper and the ability of the garment to be donned

² The LEHP GT works with Ricochet Manufacturing, Inc. in Philadelphia, combining both groups' experience in garment design and taking advantage of Ricochet's expertise in manufacturing civilian emergency rescue barrier protective first-responder garments.

individually or with a partner, and also considered the doffing process after the garment had been contaminated.

Principal considerations included life expectancy of the garment, the possibility of lowering garment cost, and reducing the need for multiple garment sizes to be inventoried, as well as lessening the burden of disposing of spent garments. For example, the JSLIST has a life expectancy of 45 days once it has been removed from the protective vacuum-sealed packaging and exposed to the air. The design of the LEHP two-piece ensemble employs removable carbon components so they could be discarded at the end of their exposure life and replaced, while the existing two-piece ensemble shell could be reused with new carbon undergarments. The concept was to reduce the number of garments being discarded only because they had been exposed to the air, and their carbon was no longer useful. Additional garment design challenges will be addressed later in the report.

3. Methods and Test Results

3.1 Overview

Obtaining test data is critical to the spiral development process. Various in-house and off-location facilities provide feedback on comfort and protection of the garments. The Generation 6 ensemble was evaluated as summarized below.

Human Factors (external)—This test was completed at NSRDEC by Rose Guerra. It included donning the garment in various Mission Oriented Protective Posture (MOPP) levels, while performing a preselected motion routine. Two soldier participants were used, all of whom were familiar with the JSLIST garment. Participants wore ancillary equipment such as helmets, backpacks, and body armor. This evaluation is important to the GT because it provided an outside evaluation of the garment using soldiers who have been trained to use the JSLIST, and provided feedback and comparisons. Selected results are presented in the body of this report. The complete test report is in Appendix A.

Human Factors (internal)—This series of tests was performed at Philadelphia University in conjunction with the Biophysics Team. The motion routine used was based on that done at NSRDEC. Once the selected number of trials had been completed the Biophysics Team analyzed the data for scientific validity. Results from one generation may then be compared to preceding generation prototypes. Selected results are presented in the body of this report. This test is also invaluable to the GT for quick design changes before sending the garments to more costly testing. Additional information about the human factors (HF) evaluations conducted at LEHP is in Appendix B.

Fluorescent Aerosol Screening Test (FAST)—This test was performed at Research Triangle Institute (RTI) in Research Triangle Park, NC. The test participant entered a large chamber in MOPP 4 where he then performed a series of motions requiring about one-half hour. A large fan blew fluorescent fingerprint powder onto the test participant during the duration of the test. The garment was doffed and then the test participant's body was assessed using a black light. This test provided data about where contaminant may penetrate the garments and reach the body through breaches at the interfaces. Selected results are presented in the body of this report. See Appendix C for LEHP planning notes for FAST and Appendix D for FAST results.

Contaminated Doffing (CD)—This test took place at Hazmat Science Applications (HSA) in Santa Fe, NM. Hazmat Science Applications is a unit of Northern New Mexico College. This test assessed the facility of doffing a contaminated garment without transferring agent to the wearer. During this evaluation the test participant was covered in a fluorescent fingerprint powder and then taken through a decontamination line. Once the garment and ancillary equipment had been completely doffed a black light was used to show any "contaminant" that had been transferred onto the body. The process could be stopped at any point, and a black light used to examine specific steps. Selected results are presented in the body of this report. See Appendix E for LEHP notes and Appendix F for the complete test report.

This chapter discusses the construction and evaluation methods, and the results of the evaluations for the 10 components of the Generation 6 protective garments:

- (1) Fabric
- (2) Dual-Layer System
- (3) Hood/Mask Interface
- (4) Articulated Knee and the Knee-Pad Pocket
- (5) Articulated Sleeve and Elbow Reinforcement
- (6) Torso and Zippered Integration Panel
- (7) Bi-swing Back and Shoulder Grips
- (8) Closures
- (9) Shoulder Stabilizer Strap
- (10) Hood Retention Flap

Significantly more detail regarding design of each feature is provided below. Each design section includes methods and results pertaining to that design feature. Important results from FAST, CD, and HF testing are included in each section.

3.2 *Fabric*

Because fabrics that provide chemical protection generally have had low breathability (and sometimes additional shortcomings such as bulk and stiffness), protective clothing is often hot and uncomfortable. Throughout the design process effort was made to optimize comfort and protection. Two fabric pairings were chosen for this prototype; both are permeable systems backed with carbon, which does not require seam sealing, and would allow production to take place at many sewing facilities.

Because many resources were dedicated to selecting the fabrics for Generations 4 and 5 LEHP was asked to not explore new fabrics and to continue with the ones already sourced. One exception to this was the replacement of 96X. Because this fabric was no longer available from the supplier, an updated version (43Y) was substituted for use as a carbon undergarment.

During fabric evaluation, samples were sourced from leading textile suppliers. Table 1 lists fabrics that were used by the Garment Team for Generation 6. The table includes air permeability values for the fabrics considered

Table 1. Fabrics Used by the GT for Generation 6.

LEHP Code	Cloth Characteristics						
	Fabric Structure	Structure Type	Fiber Blend	Coloration Method	Functional Treatment	Weight (oz/sq. yard)	Air Permeability ft ³ /ft ² /min See Note 2
31B Shell	woven	plain weave	multiple fibers	universal camouflage print	durable water- and oil-repellent (non-flame-retardant)	5.20	9.02
78C Shell	Laminate	330d Cordura® shell with microporous ePTFE membrane and tricot backing	100% nylon 6,6 330 denier (Cordura) polyester tricot knit backing	jet dyed green	microporous ePTFE membrane, durable water repellent finish	6.12	9.41
43Y Under-garment	Laminate - stretch	Spherical carbon with multiple fabrics	Fibers combination with carbon	Dyed grey, dyed black	N/A	10.39	36.12
63A Under-garment	Knit - stretch	active carbon filter material, polyester/ Elastane 2-way stretch jersey knit material	polyester/ Elastane carbon	Dyed black knit	N/A	8.60	87.46
96X Under-garment See Note 1.	Laminate - stretch	Spherical carbon with multiple fabrics	Fibers combination with carbon	Dyed grey	N/A	11.42	21.74

Note 1. The manufacturer of 96X (used in earlier generations) discontinued the product and replaced it with 43Y, which was used in Generation 6. Information about 96X is in this table to allow comparison with 43Y.

Note 2. Air permeability is measured by sending air at a constant flow rate to a swatch of material and discharging the air to the atmosphere through the sample. LEHP's data were collected on the Kato Tech Co., Ltd. Air Permeability Tester Model KES-F8. The air resistance results obtained were converted to air permeability units as specified in ASTM D 737.

3.2.1 Methods

For information about the methods used to select fabrics used in Generations 5 and 6, see Technical Report PHILA-LEHP-GT-TR-11-01, *Design and Testing of Chemical/Biological Protective Coverall System, Generation 5*.

3.2.2 Results

Because the GT was not authorized to carry out penetration testing on the individual fabric pairs, the level of protection that each fabric system provided was not known. All fabrics used were deemed by the suppliers to be suitable for chemical defense. Because a principal objective of the LEHP undertaking was to improve comfort, the GT focused on fabrics (otherwise meeting requirements) that provided the greatest comfort as determined by the data collected on fabrics made available to LEHP for this phase of the effort.

3.3 Dual-Layer System

During evaluations of the previous LEHP garments it was noted that a separate carbon and shell system proved very successful in both FAST and especially CD testing. For Generation 6 it was decided that GT would continue to design an ensemble comprised of two layers: an outer shell that could alternately be worn as a substitute duty uniform, though probably not directly against the skin, and a separate disposable inner carbon liner. An important issue with integrated carbon suits used by the military today is the carbon's shelf life. Once the carbon's life expires, disposal of the entire suit is necessary, resulting in much undesirable waste and expense. In an effort to be more cost-effective and conserve resources, LEHP created a garment that separates the disposable component from the reusable portion, thus extending lifetime of the entire ensemble. This is especially useful for garments that have not seen actual contamination and are being discarded only because the carbon life has expired. LEHP did not have resources to investigate the cost of an integrated carbon suit vs. safely decontaminating a shell garment for reuse once actually contaminated with chemical warfare agents.³

In addition to cost and waste factors, it was observed during CD at Hazmat Science Applications during testing of the Generation 3 garment that in the cases where the test participant wore the garment shell with a separate carbon bodysuit, the doffing was more successful; less contaminant was found on the body after completion of the doffing procedure compared with the identical shell garment worn with carbon cuffs instead of the separate carbon bodysuit. In fact, in one test, use of the separate carbon bodysuit rendered the subject's body 100% free of contaminants as determined by black-light inspection.

3.3.1 Methods

The GT complied with NSRDEC's request to streamline the design, making it closer to a duty uniform fit.

The fitted undergarments (Figures 10, 11, and 12) were made from knitted stretch carbon fabrics. Because this carbon and shell combination is intended to be worn without a duty uniform, it is a very comfortable option. In situations where a Warfighter will be required to wear this garment for extended periods of time, the Generation 6 ensemble may prove more comfortable than options that require the duty uniform to be worn underneath.

Two different carbon shirts were produced in each 43Y and 63A fabrics. In both designs the fitted carbon shirt features a raglan articulated sleeve design with an underarm gusset for increased flexibility and range of motion. The shirt contains an asymmetric center-front zipper and a zipper stop shield to minimize abrasion and discomfort at the neck caused by the zipper tab. The zipper is positioned to terminate at the left side of the neck, which is opposite of the outer shell to avoid "stacking" of the zipper tabs. One shirt has a mock turtleneck collar and hook-and-loop closure complete the shirt and the additional shirt has a funnel neck with a hook-and-loop closure. The carbon drawers are long-underwear style and feature non-elasticized carbon cuffs and a cotton elastic-ribbed waistband that can be readily pulled down for waste

³ As noted earlier, LEHP questions whether such a practice warrants consideration.

relief. The ensemble also includes a carbon hood (balaclava, see Figure 13) to be worn over the head; this hood interfaces with the JSGPM.

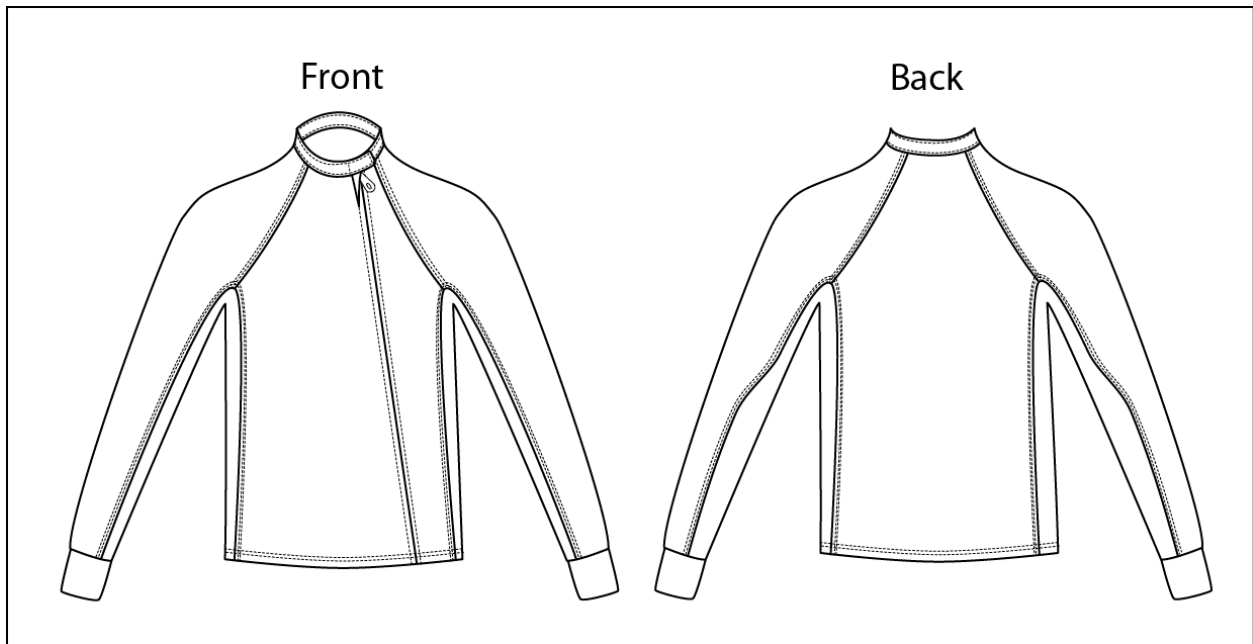


Figure 10. Generation 6 Carbon Shirt—Collar Neck.

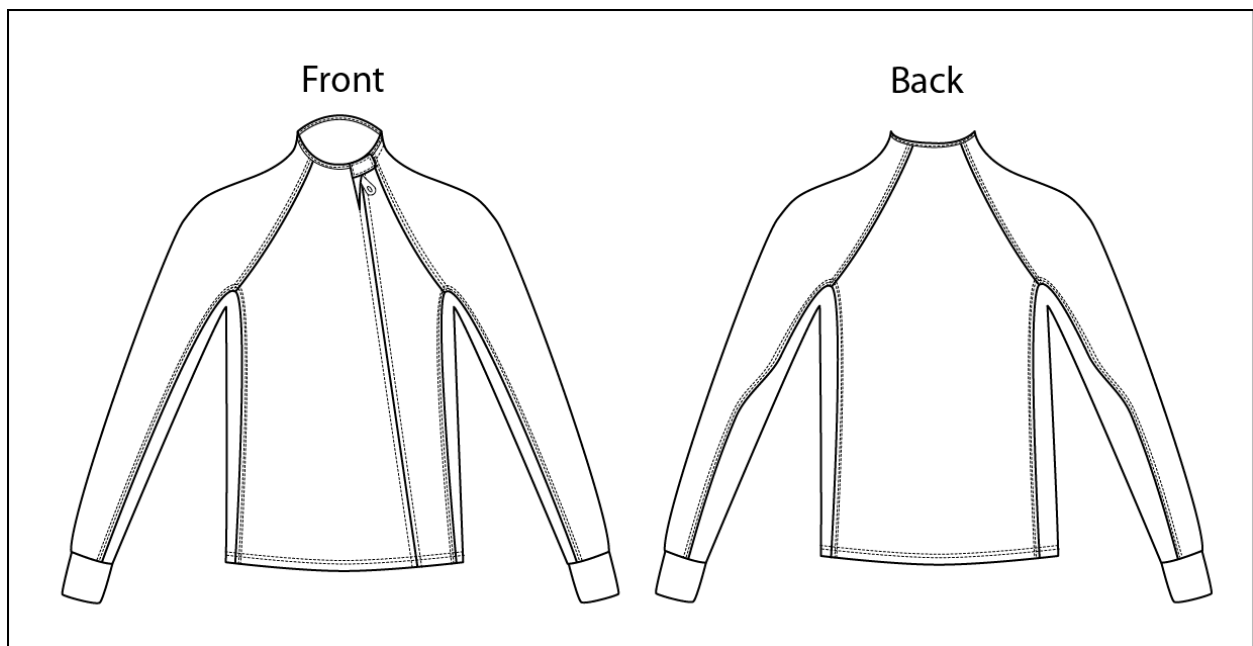


Figure 11. Generation 6 Carbon Shirt—Funnel Neck.

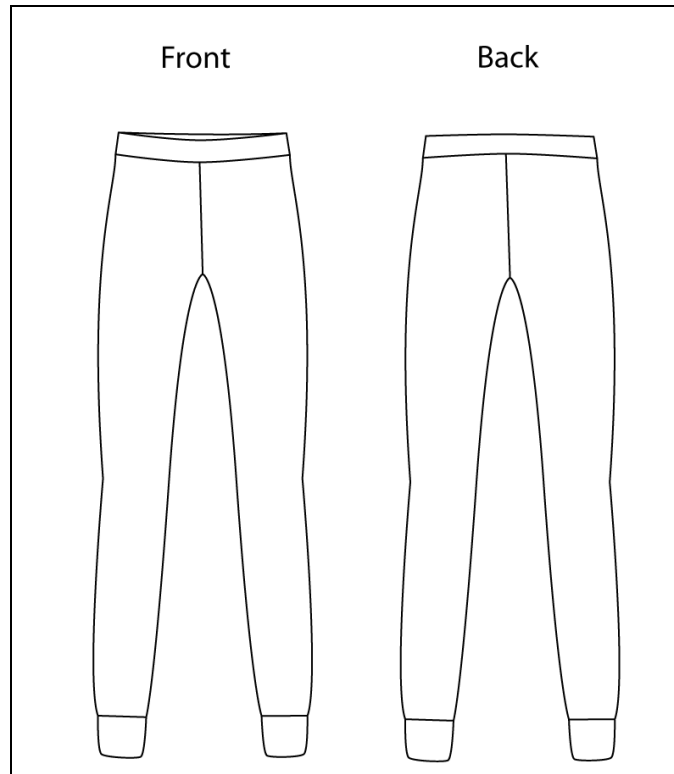


Figure 12. Generation 6 Carbon Drawer.

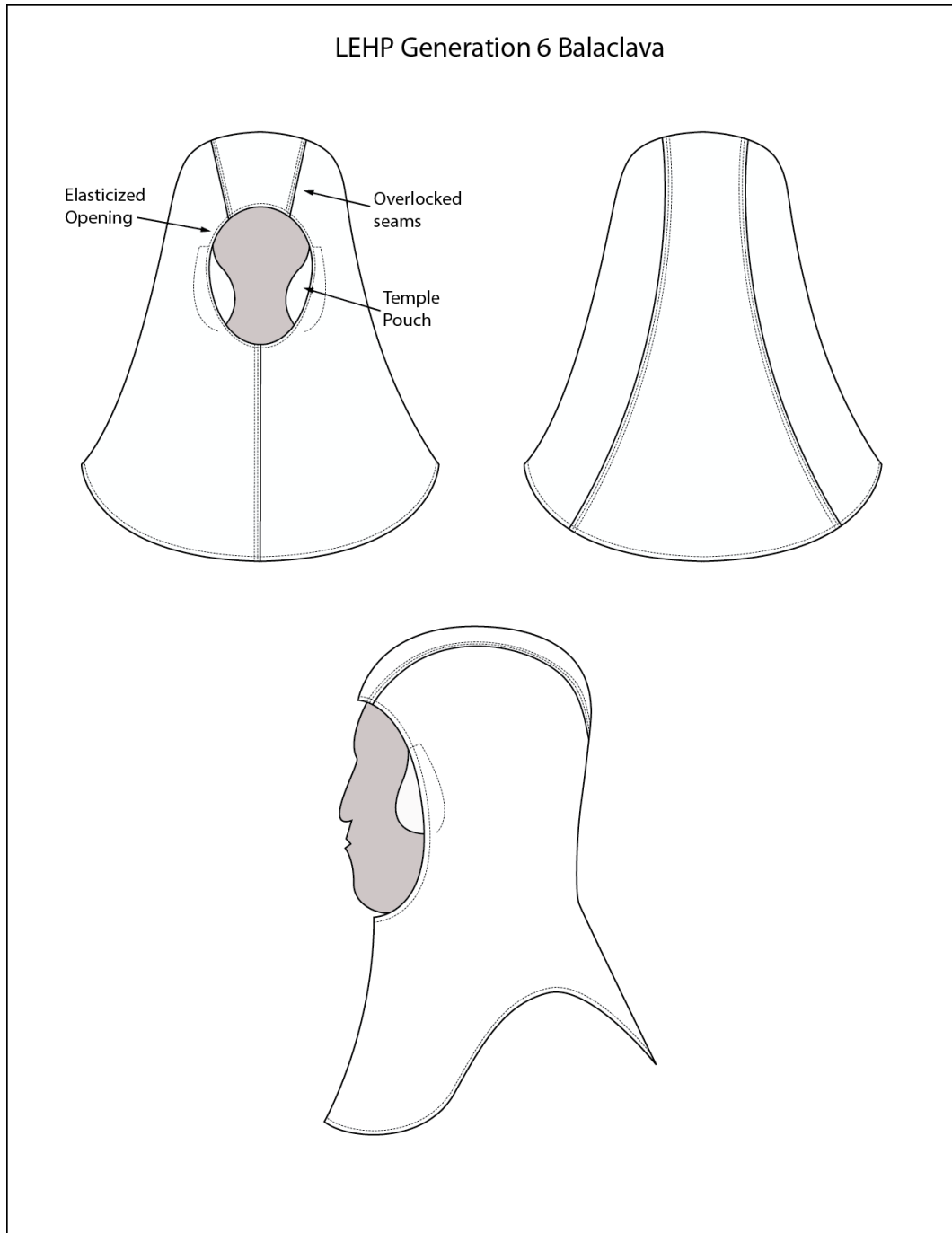


Figure 13. Generation 6 Carbon Hood Flat Sketch.

3.3.2 Human Factors Results

During human factors evaluation at NSRDEC the test participants disagreed which was the more comfortable fabric used for the carbon undergarments, although overall they both agreed that the undergarments were comfortable. One participant preferred 63A because he felt it was lighter and had more stretch. The other test participant felt that 63A felt slightly itchy and preferred 43Y because it felt smooth against his skin. Once the participants donned the outer shell garments they said they could not distinguish between the undergarments' comfort level.

Both participants preferred the collar-neck to the funnel-neck shirt style because they felt it was slightly more comfortable

Generous overlap was supplied to the trouser and shirt on the undergarments. The sleeves and legs also were judged to be long enough.

The two test participants appeared to have some difficulty donning the balaclava correctly by themselves. When the balaclava and the mask had been donned, the participants did not seem to notice whether the balaclava was in place correctly around the mask. This difficulty could be easily remedied by making a check of the balaclava's position a part of the training process.

While wearing the entire ensemble, test participants rated all configurations as thermally comfortable.

During human factors evaluation at Philadelphia University, test participants judged the Generation 6 garment to be significantly more comfortable than the JSLIST for the critical fabric characteristics (thermal comfort, stiffness, and scratchiness) that were assessed.

3.3.3 FAST Results

Undergarment fabric 63A and 43Y each were used for four FAST evaluations performed at RTI for a total of 8 tests. The outergarment fabrics were 78C and 31B. No significant difference in protection was found between the two fabrics. See Appendix C for LEHP planning notes for FAST and Appendix D for FAST results.

3.3.4 Contaminated Doffing Results

Undergarment fabrics 63A and 43Y were used for all eight contaminated doffing trials. 43Y was used four times: two in the collar-neck style and two in the funnel-neck style. Fabric 63A was used four times, as well: two in the collar-neck style and two in the funnel-neck style. All configurations performed as intended with no observable differences.

For details of the contaminated doffing trials, see Appendices E and F.

3.4 Hood/Mask Interface

The interface between the hood and the mask is a critical area for maintaining the protective seal; this interface is also one of the most difficult areas in which to prevent penetration of contaminants. Because of the concave shape of the JSGPM at the temple areas, the GT attempted to seal the area with filled pouches of corded wrapped cotton batting, a two-piece wire hood brim, and elastic canister loops. In the efforts to optimize this interface, the GT

implemented numerous design changes during the past five years. The team had to provide optimal comfort while the wearers bent their necks, and also provide full protection at this vital interface.

For the Generation 6 garment LEHP designed two hood styles. One jacket featured an attached hood, much like the Generation 5. The other jacket had a detachable hood, which allowed it to be removed while the shell garment was being worn as a duty uniform.

Both hoods cover the wearer's head and fasten around the mask. Therefore, the challenge areas are at the forehead and eye/temple where a tightly closed seal is needed. Bellowing is also a concern in this area; this vacuum effect can bring air and contaminants inside the garment. Additionally, at this interface the hood/neck area of the protective garment wraps around and closes under the chin covering the front zipper, providing additional sealing at this crucial interface.

3.4.1 Methods

The GT continually revised the under-chin area of the garment to provide the most comfort while bending the neck. The neckline was scooped out and the neck flaps were slightly redesigned to fit better with the mask. The hood was scaled down as well, to fit better underneath the helmet.

Generation 6 incorporated a one-piece inner hood shield and elastic edge grip to establish a contour interface with the mask at the neck (see Figure 14).

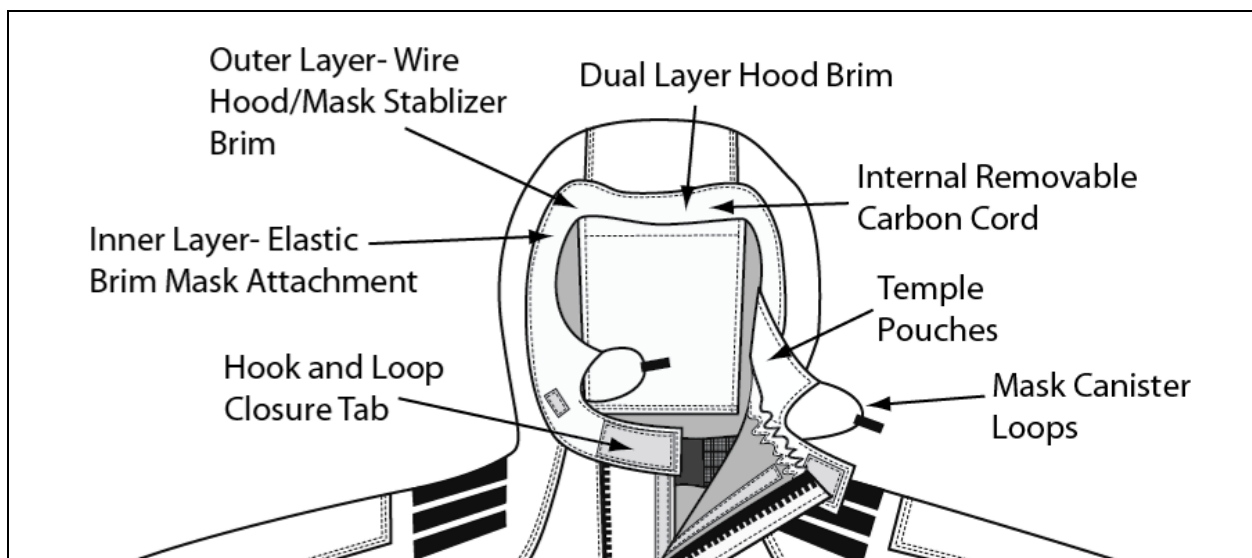


Figure 14. Generation 6 Hood/Mask Interface—Fixed-Hood Version.

During Generation 6 development, much of the design effort was focused under the neck area to improve flexibility and fit. Stretch panels were inserted into the seam between the underarm gusset and the center front jacket pieces. These panels were entirely backed up by the same shell fabric used in the rest of the garment to maintain protection.

A removable carbon brim rope cord was employed at the center front brim on the forehead area above the mask lens to create an additional layer of carbon barrier protection and prevent liquid contamination of the wearer during the decontamination process. Such liquid contamination was experienced with Generation 3 during contaminated doffing tests.

The fixed hood version was designed with a construction seam over the crown (see Figure 15). This seam ran from the neck area up over the crown of the head to the neck area on the adjacent side. This modular feature allowed greater options for mission-specific hood/mask interface manufacturing thus providing unlimited opportunity for modularity in design development and application of mask frames to address mission-specific requirements. The overall garment style could remain consistent, and a variety of mask styles could be accommodated with minimal disruption in uniform availability. A full uniform could be manufactured without the mask frame front panel, and orders could then be placed for suits with specific mask compatibility. The manufacturer might benefit economically by producing large numbers of the uniforms without the mask panel; by sewing only one seam the basic uniform can be fitted to different masks. Once the mask frame panel is attached is it not easily removed and will not be compatible with masks other than the one for which it was designed. This option has the potential for translation into cost savings because limited retooling for manufacturing would be required, and management of equipment storage and procurement efficiency would be enhanced.

In the removable hood version, one would only have to unzip the hood and zip on another hood designed to integrate with masks other than the JSGPM.

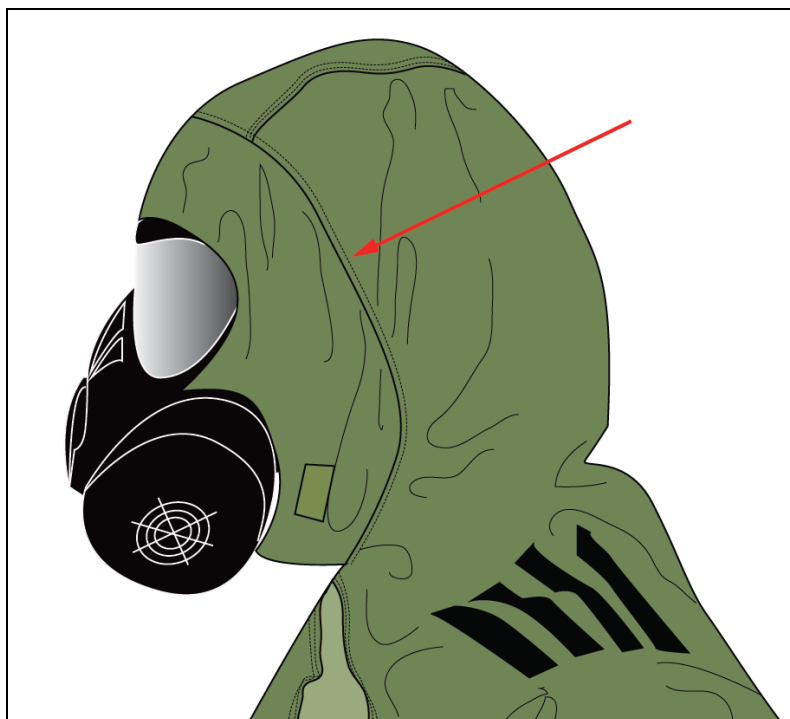


Figure 15. Generation 6 Hood Seam.

The shell garment is intended to be worn with a separate carbon balaclava (pullover hood) to protect the wearer's face and head from contamination in areas not protected by the mask; see Figure 16.

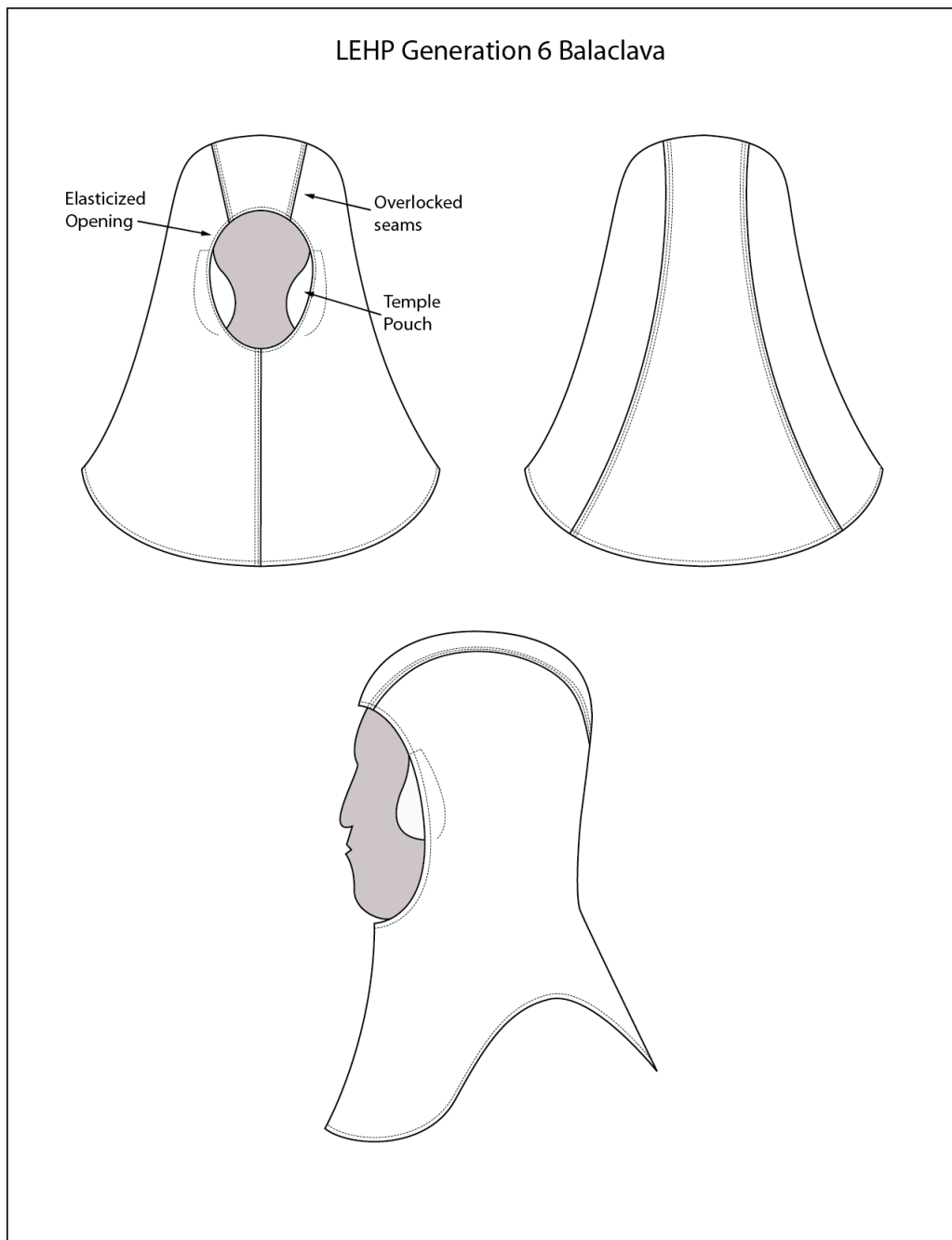


Figure 16. Generation 6 Carbon Balaclava (Pullover Hood) Flat Sketch.

3.4.2 Human Factors Results

During human factors evaluation at NSRDEC no restriction was reported while moving the neck and participants did not notice a difference between fabrics used or hood styles.

Participants also did not have difficulty securing the wire brim around the mask or attaching the canister loops around the mask. Wearing the gloves while doing this, however, appeared to make the undertaking more difficult, and the researcher suggested changing the donning procedure so the gloves are donned last.

It was noted that some of the wire brims seemed to be slightly bent out of shape and did not fit the mask exactly. But because this is a prototype, and the GT focused more on the design than the actual material of construction, it is possible an alternate could be found that would retain its shape.

During human factors evaluation at Philadelphia University comfort and range of motion in the head/neck area was judged to be comparable to the JSLIST.

3.4.3 FAST Results

Excerpts from the April 2011 RTI FAST report are below. For an overview of the garment configurations tested, see Table 2. Additional information about the report results is in Appendix D. With the exception of Figure 17, the photographs in this subsection are from that report.

The JSGPM was used in all the April 2011 FAST tests.



Figure 17. Generation 6 Fixed Hood and Removable Hood.

Note: In the FAST report tests 1 and 9 were considered a separate task contracted by NSRDEC to evaluate a garment made from a different fabric. The results were communicated to NSRDEC in a separate report that is not included here.⁴

⁴ The findings are not summarized here either.

Table 2. Garment Configurations for FAST.

Garment Configuration Tested	Tues	Tues	Tues	Wed	Wed	Wed	Thurs	Thurs	Thurs	Fri
	Test 1: 0920 hours	Test 2: 1100 hours	Test 3: 1330 hours	Test 4: 0900 hours	Test 5: 1100 hours	Test 6: 1330 hours	Test 7: 0830 hours	Test 8: 1100 hours	Test 9: 1330 hours	Test 10: 0800 hours
Gen 6 Fixed Hood-SPM	8 See Note 1								9	
Gen 6 Fixed Hood-31B			9	8						
Gen 6 Fixed Hood-78C		7			7					
Gen 6 Detachable Hood-31B								7		7
Gen 6 Detachable Hood-78C						13	8			
Gen 6 Carbon Undergarment-Collar 43Y			9					7		
Gen 6 Carbon Undergarment-Collar 63A		7				13			9	
Gen 6 Carbon Undergarment-Funnel 43Y				8						7
Gen 6 Carbon Undergarment-Funnel 63A					7		8			
Gen 6 Carbon Cuffs	8									
JSGPM mask and balaclava	X	X	X	X	X	X	X	X	X	X
7 mil butyl with cotton liner	X	X	X	X	X	X	X	X	X	X

Test 2⁵: “Various areas of aerosol deposition evident on neck and head. Note the outline of the mask strap is evident below the ears” [Figure 18].

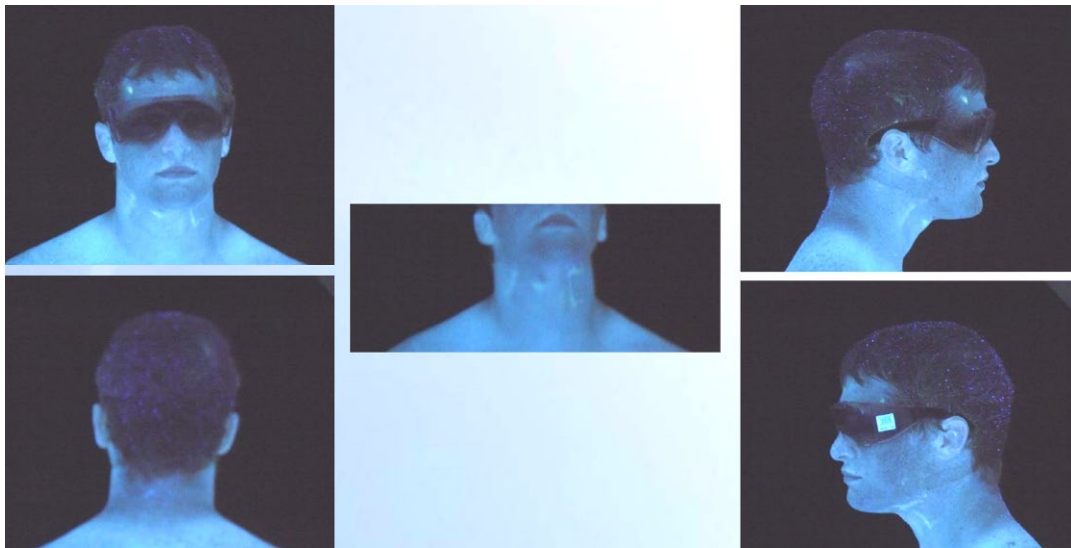


Figure 18. Generation 6 Hood/Mask Interface FAST Test 2 Results—Deposits of Simulant on Face, Neck, and Hair.

Test 3⁶: “Some aerosol deposition is evident along the mask line” [Figure 19].

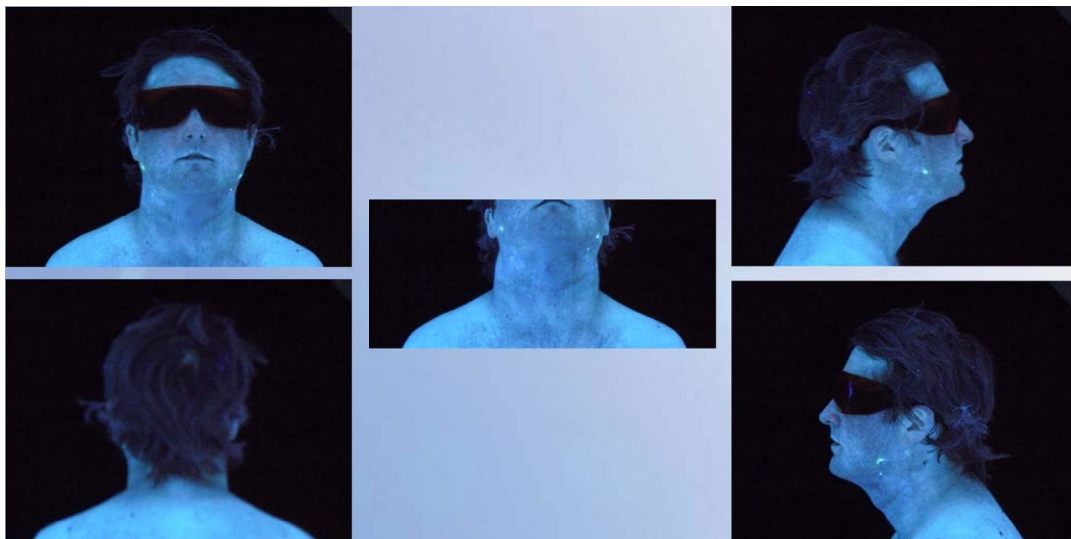


Figure 19. Generation 6 Hood/Mask Interface FAST Test 3 Results—Deposits of Simulant along Mask Line.

⁵ In the RTI report, this test is identified as Test 1959.

⁶ In the RTI report, this test is identified as Test 1960.

Test 4⁷: “Aerosol deposition was evident on sides and back of neck” [Figure 20].



Figure 20. Generation 6 Hood/Mask Interface FAST Test 4 Results—Deposits of Simulant on Neck.

Test 5⁸: “Some small areas of light deposition evident along mask line” [Figure 21].

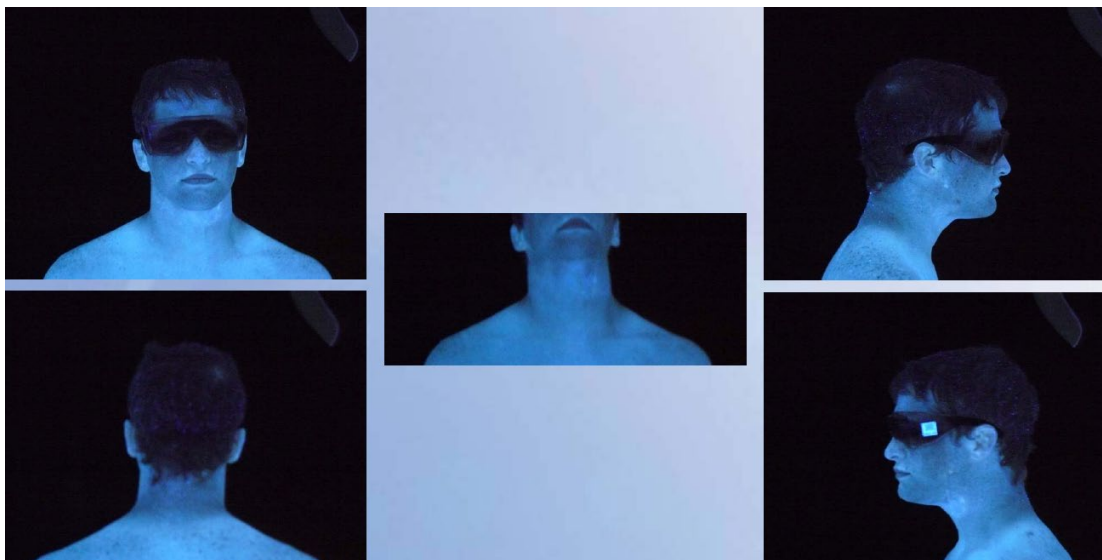


Figure 21. Generation 6 Hood/Mask Interface FAST Test 5 Results—Deposits of Simulant along Mask Line.

⁷ In the RTI report, this test is identified as Test 1961.

⁸ In the RTI report, this test is identified as Test 1962.

Test 6⁹: “Aerosol deposition was evident on the neck with a small spot on the left side of neck” [Figure 22].

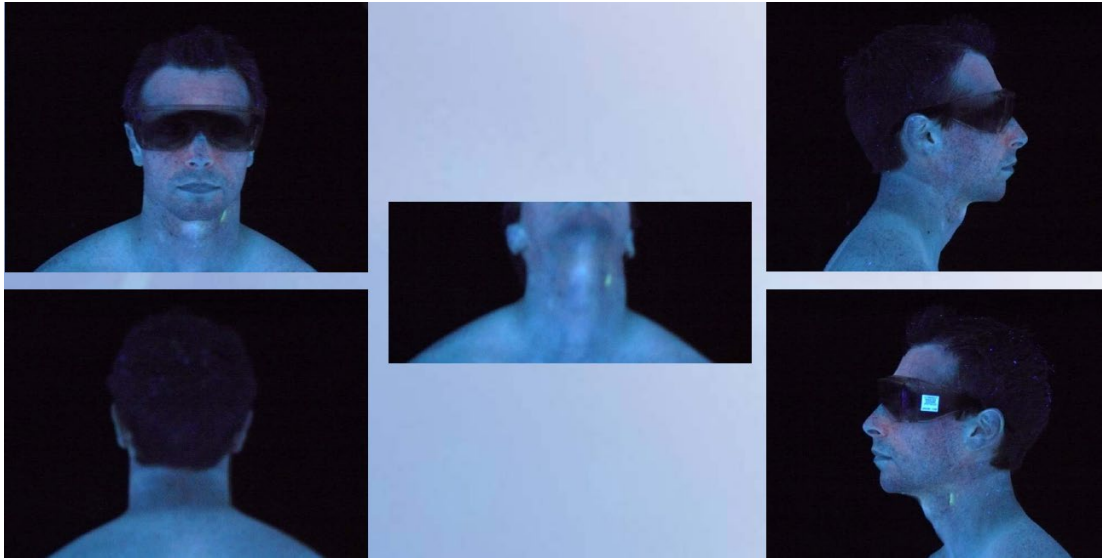


Figure 22. Generation 6 Hood/Mask Interface FAST Test 6 Results—Deposits of Simulant on Neck.

Test 7¹⁰: “Some aerosol deposition evident on front of neck” [Figure 23].



Figure 23. Generation 6 Hood/Mask Interface FAST Test 7 Results—Deposits of Simulant on Front of Neck Only.

⁹ In the RTI report, this test is identified as Test 1963.

¹⁰ In the RTI report, this test is identified as Test 1964.

Test 8.¹¹: “Head and neck appeared clean with perhaps a small amount of aerosol deposition at front of neck [Figure 24].

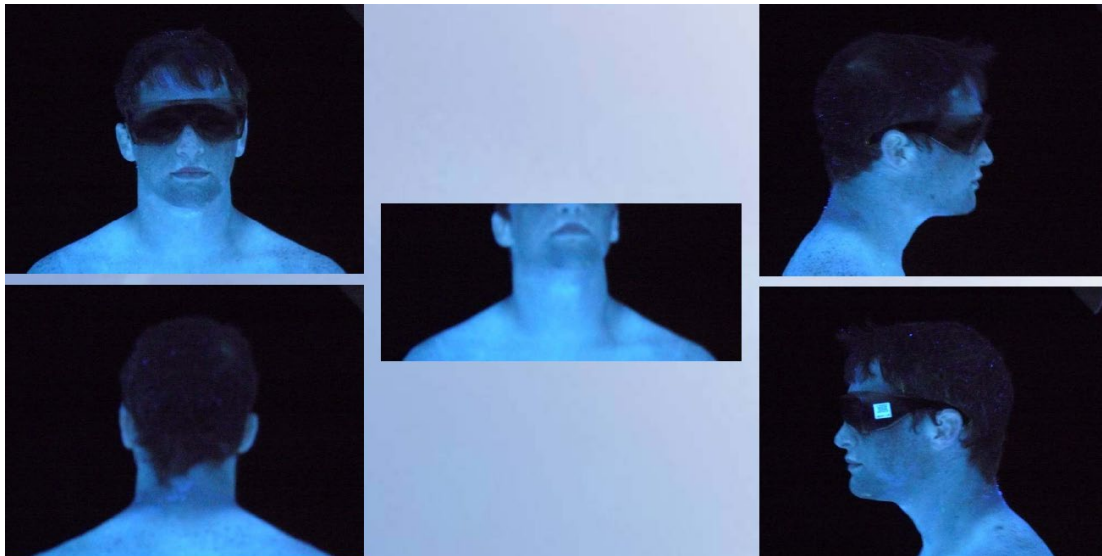


Figure 24. Generation 6 Hood/Mask Interface FAST Test 8 Results—Light Deposits of Simulant on Neck.

Test 10.¹²: “Aerosol deposition at front of neck was evident” [Figure 25].

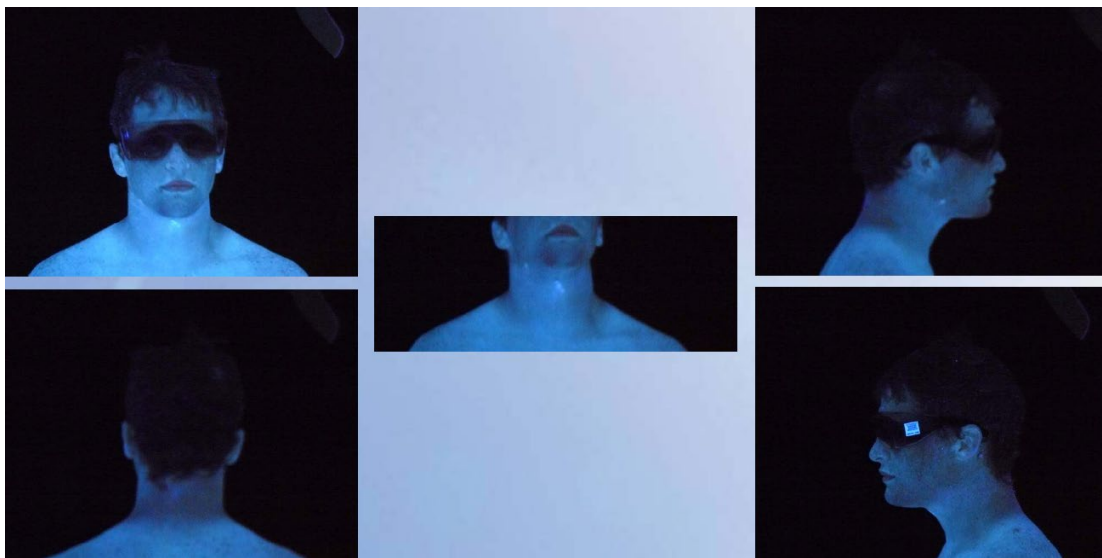


Figure 25. Generation 6 Hood/Mask Interface FAST Test 4 Results—Deposits of Simulant on Neck.

¹¹ In the RTI report, this test is identified as Test 1965.

¹² In the RTI report, this test is identified as Test 1967.

Overall, FAST results have continued to improve with each generation. In the Generation 6 FAST, very little simulant was deposited on the face and neck. The GT seems to have solved the issue of simulant leaching in at the temple areas, but now it appears to be breaching the seal near the jaw line, a problem that would have to be addressed in future designs based on Generation 6.

3.4.4 Contaminated Doffing Results

Because of the nature of the dusting procedure during CD, different results are expected than from FAST. During FAST the participant is subjected to aerosol being blown in a chamber for approximately 30 minutes; while inside, the participant performs a series of motion routines. The contaminated doffing procedure is to dust the participant for five minutes to coat the subject and minimize any penetration onto the body due to the bellows effect. Eight tests were performed on the Generation 6 garment. Table 3 shows which fabrics and configurations were used in each run.

Table 3. Garment Configurations for Contaminated Doffing Evaluation.

Garment Configuration Tested	Tues	Tues	Tues	Wed	Wed	Wed	Thurs	Thurs	Thurs
	Dry Run	1400	1700	1100	1400	1530	0830	1100	1100
Gen 6 Fixed Hood-31B	1 See Note 1	1		1					
Gen 6 Fixed Hood-78C			1					2	
Gen 6 Detachable Hood-31B							2		2
Gen 6 Detachable Hood-78C					1	1			
Gen 6 Carbon Undergarment-Collar 43Y	1	1					2		
Gen 6 Carbon Undergarment-Collar 63A			1		1				
Gen 6 Carbon Undergarment-Funnel 43Y				1					2
Gen 6 Carbon Undergarment-Funnel 63A						1		2	
JSGPM mask and balaclava	X	X	X	X	X	X	X	X	X
JB1GU Glove	X	X	X	X	X	X	X	X	X
AFS Overboot	X	X	X	X	X	X	X	X	X

Note 1: Numbers in the table rows correspond to the test participant number.

Overall, contaminated doffing results were very positive. Only in Test 2 was any simulant seen on the head. A bright spot was seen on the top of the head; the spot seemed to be decon water that soaked through the garment. It did not appear to be transferred during the doffing process but due to excessive water being sprayed during gross decon. After this test the GT paid special attention to the amount of decon solution being sprayed on the test participant. No other instances of solution soaking through the garment to the skin occurred after this.

In fact, the garments performed so well overall that it was decided to “push” the garments. In Test 7 no gross decon was performed, and in Test 8 no gross decon was done and the test participant self-doffed, meaning he removed the garment unassisted. In both cases the test participants came out clean. This is quite a victory for the Garment Team because it shows that in an emergency situation, the Generation 6 garment can be removed by a soldier by himself and without gross decon, if necessary.

The report issued by Hazmat Science Applications said: “Subjectively, it is noted that the PhilaU protective ensembles performed exceptionally well. CDT methodology has been employed in various forms dating back to the 1980s, and HSA staff have been directly engaged in those

activities since 2002. During this time, a variety of military PE configurations have been the subject of CDT activities, including bomb suits, coveralls, and multi-piece ensembles. Several of these configurations have performed reasonably well with respect to CDT goals (to test the ability of the PE to prevent or minimize contamination transfer to unprotected skin/uniform beneath the protective barrier); nonetheless, HSA concluded that the PhilaU prototypes performed as well or better than other PE configurations subjected to the CDT process.”

3.5 Articulated Knee and the Knee-Pad Pocket

To provide more movement and offer a better ergonomic design, articulated knees were included in the design of the pant. The knee-pad pocket is attached to the outside of the garment so that an extra layer of protection is provided by a removable neoprene knee pad (see Figure 26).

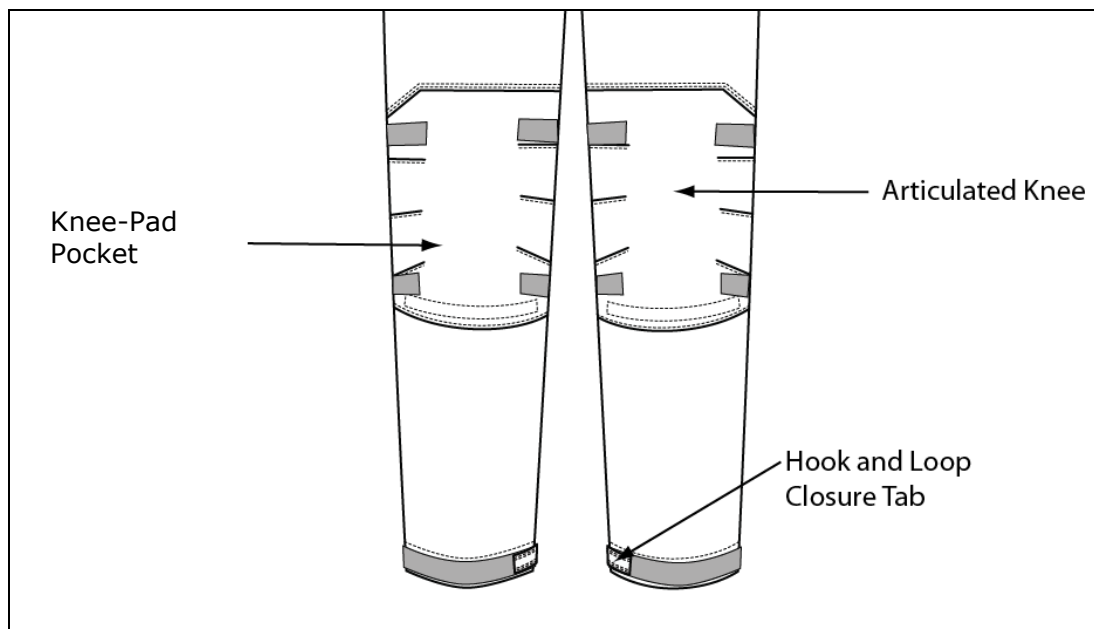


Figure 26. Generation 6 Articulated Knees with Knee-Pad Pocket.

3.5.1 Methods

The knee-pad pocket mimics the shape of the knee on the pant and the design feature of the removable knee pad was carried into the Generation 6 garment. The pocket continues to open at the bottom to eliminate the chance of liquid pooling in it. Hook-and-loop tape keeps the pocket closed, preventing loss of the knee pad.

Knee-pad control straps were slightly angled in the Generation 6 pant to give a more ergonomic fit. In this prototype they were comprised entirely of elastic, instead of elastic sewn to fabric tabs. This allowed the control straps to retract more easily into the casing behind the knees and allowed the subject to wear this feature in a more relaxed position (see Figure 27).

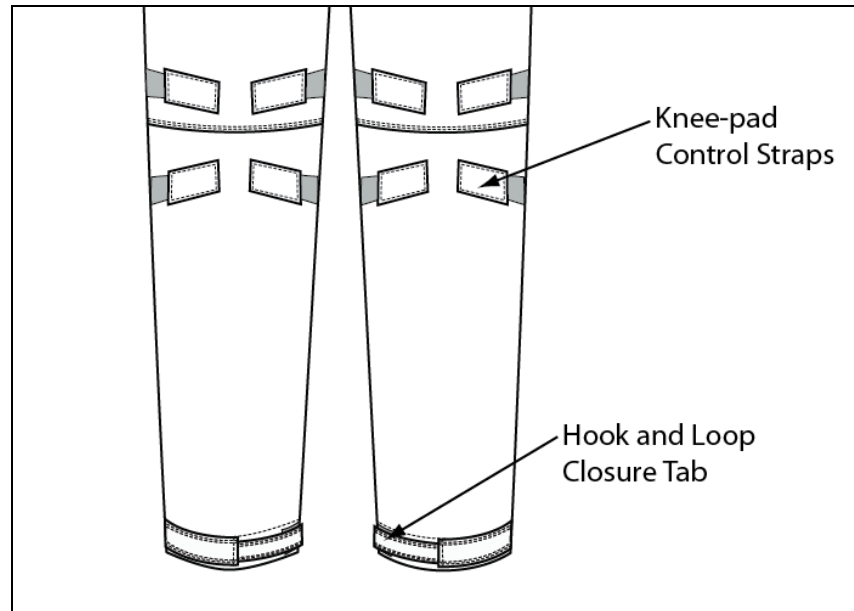


Figure 27. Knee-Pad Control Straps.

3.5.2 Human Factors Results

At NSRDEC nothing was noted about the knee-pad pocket or the knee-pad control straps; therefore, the GT assumes that no problems were found with either.

Likewise, at Philadelphia University HF evaluations no problems were identified.

3.6 Articulated Sleeve and Elbow Reinforcement

3.6.1 Methods

Generation 6 kept the design of the articulated sleeve (Figure 28) and elbow reinforcement (Figure 29) of Generation 5. This design helps to provide the wearer with better comfort while bending at the elbow, and creates a more ergonomic design. A seam and two darts increase the elbow area and to allow excellent articulation while bending the elbow. The elbow area is reinforced with an additional layer of fabric to prevent wear at this joint. The elbow reinforcement continues to mimic the shape of the articulated sleeve and provides an extra layer of protection to high-abrasion areas.

3.6.2 Human Factors Results

No comments relating to the articulated sleeve and elbow reinforcement were noted at NSRDEC or at Philadelphia University HFs evaluations.



Figure 28. Articulated Sleeve—Front View.



Figure 29. Articulated Sleeve with Elbow Reinforcement Shown—Back View.

3.7 Torso and Zippered Integration Panel

It has been shown that there is potential for contaminant to penetrate at the waist area of two-pieced garments (upper and lower pieces) and several concepts have been evaluated to improve this interface and reduce and/or eliminate such penetration. The GT designed an integration panel much like a powder skirt intended to prevent snow from coming up underneath a ski jacket. The integration panel used to join the coat and trousers on the Generation 6 ensemble has the potential to improve this interface.

3.7.1 Methods

The integration panel is designed so that it can zip to both the jacket and the pant, forming a quasi-coverall. This idea has been addressed by other organizations, but the key difference is that the LEHP integration panel takes into account the sizing issue. Other designs can match only jackets and pants of the same size (for example, a medium jacket to a medium pant) because the zippers are the same length. Unlike other designs, the Generation 6 garment allows the integration panel to be completely zipped off of the jacket. This way a user can wear a large jacket and a medium pant, or any other combination, just by zipping on the corresponding integration panel. For example, if a user needs a large jacket and medium pant, he wears an integration panel with a large zipper at the top and a medium zipper at the bottom.

Some simulant was seen on the torso in FAST for Generation 5 likely due to this interface. To resolve this challenge the GT redesigned the closure method at this juncture to provide better protection. The inner flap behind the zipper was extended, and hook-and-loop tape was added to provide better protection. On the integration panel, the hook-and-loop tape was repositioned to achieve a better closure and prevent simulant from penetrating this area.

The donning sequence for the integration panel is shown in Figures 30 through 33.

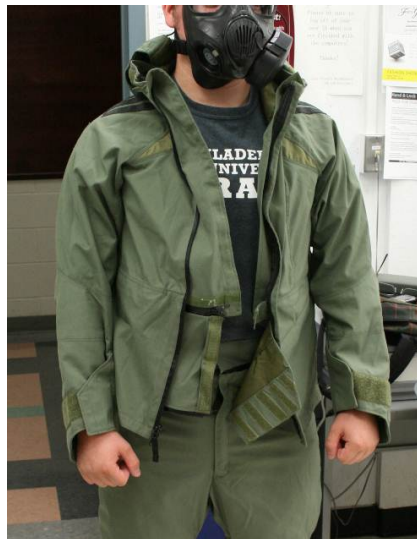


Figure 30. Ensemble after Donning Integration Panel.



Figure 31. Integration Panel Zipped First to Jacket.

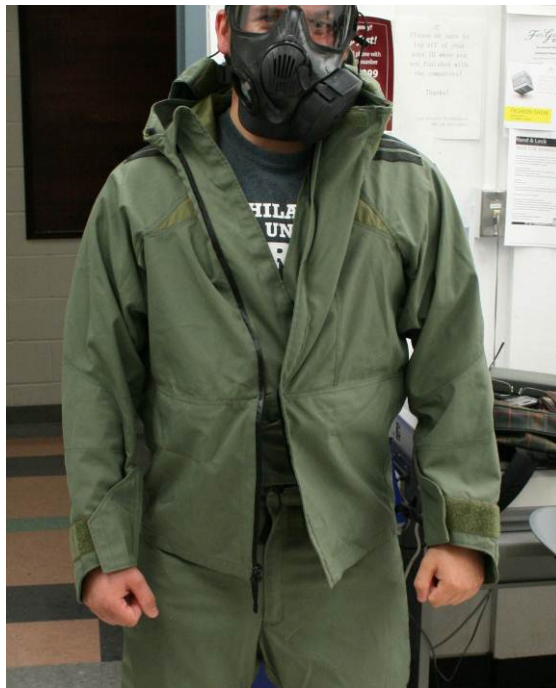


Figure 32. Integration Panel Zipped to Both Jacket and Pant.



Figure 33. Integration Panel Tucked Up Under Jacket.

3.7.2 Human Factors Results

At Human Factors Evaluation at NSRDEC test participants noted that there was bulk at the waist resulting from the integration panel. Some discomfort was reported because of this bulk when the participant performed the low crawl. This discomfort was mainly a result of the body armor being worn. Test participants said the discomfort was only moderate, but it is a cause for concern for long-term wear.

No restriction was reported in the torso or integration panel area.

Participants had difficulty closing up the garment due to its complex nature, but after donning and doffing the garment several times the participants found the process much easier. With proper training how to close the garment this should not be an issue; however, further revisions can be considered in future generations. No difficulty was reported relating to the task of attaching the integration panel onto the pants while wearing both pieces.

Participants felt that the zippered waist closure was safer and provided more protection than the JSLIST and also felt that the zippered waist closure was more comfortable than the JSLIST crotch cord.

At Philadelphia University the JSLIST was found to be significantly easier to don than the Generation 6 garment. This is likely due to the complexity of the integration panel. Although it was more complex, participants preferred the integration panel's style of attaching the pant to the jacket over the crotch cord on the JSLIST.

3.7.3 FAST Results

The following results are from Philadelphia University Fluorescent Aerosol Screening Tests (FAST) Test Report, April 2011 (Appendix D).

In eight tests at FAST no simulant was seen on the torso (see Figure 34), a great improvement over the Generation 5 garment. The Generation 5 garment saw some hazing on the torso, likely due to a breach at the interface between the integration panel and the jacket. The design changes implemented by the GT proved successful and eliminated any hazing seen in this area. No difference was noted between the fixed-hood and replaceable-hood versions.

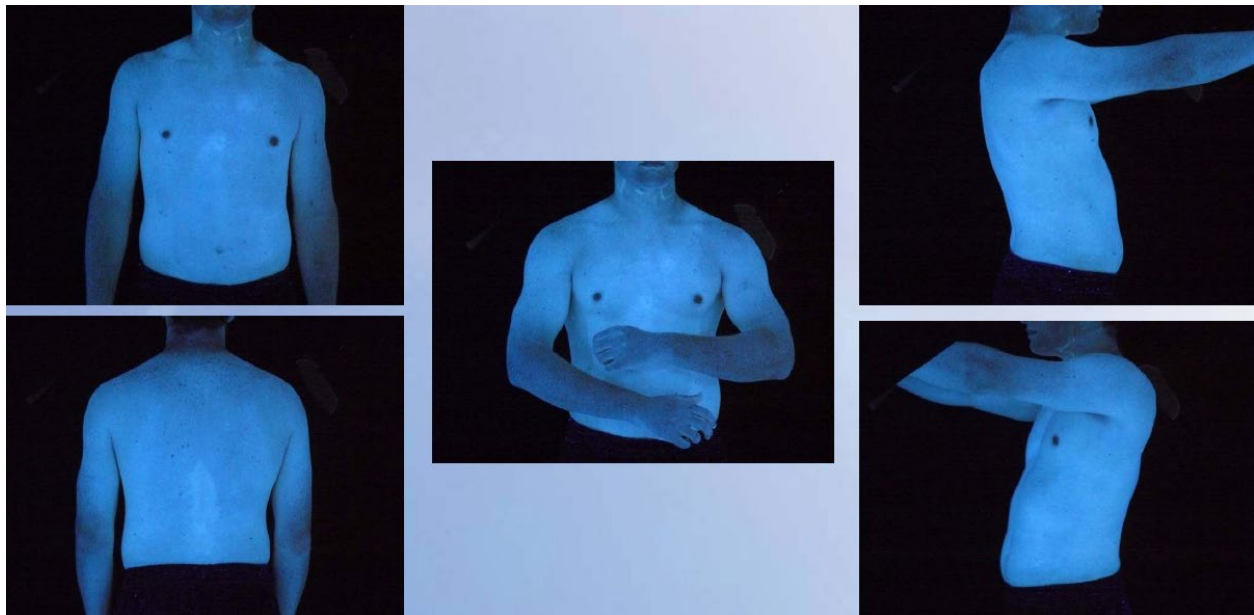


Figure 34. Test 2.¹³ FAST—Shows No Simulant on the Body.

3.7.4 Contaminated Doffing Results

The garments performed very well during contaminated doffing evaluation, and a simulant haze was not seen on the body as was seen in the Generation 5 garment. Small smudges, drips or specks of simulant or decon solution were seen in only three tests; in the rest of the tests the body was clean.

Test 3: Small smudges on left back shoulder; test participant said he felt the helper brush his shoulder during the removal process of the carbon shirt.

Test 4: Four small blue drip spots on the right shoulder area. Two on front shoulder and two on back. One small drip spot on left back shoulder. Procedures were subsequently refined to provide more even application of the spray.

¹³ In the RTI report, this test is identified as Test 1959.

Test 8: Two specks of orange near center front above pectoral muscle on right side. One speck further right below the pectoral muscle. One speck at front of shoulder. One speck on left elbow. These were not blue and were believed to result from lint.

3.8 Bi-Swing Back and Shoulder Grips

3.8.1 Methods

A bi-swing (“action”) back allows the user a better range of motion than is seen in its absence. The large pleats on the shoulder blade provide increased flexibility, especially while wearers cross their arms (Figure 35).

Shoulder grips were redesigned on the jacket in this prototype to increase flexibility but still help prevent gear slippage. The grips provide extra protection to a high-abrasion area and also help to keep backpacks and body armor at the desired position on the body.

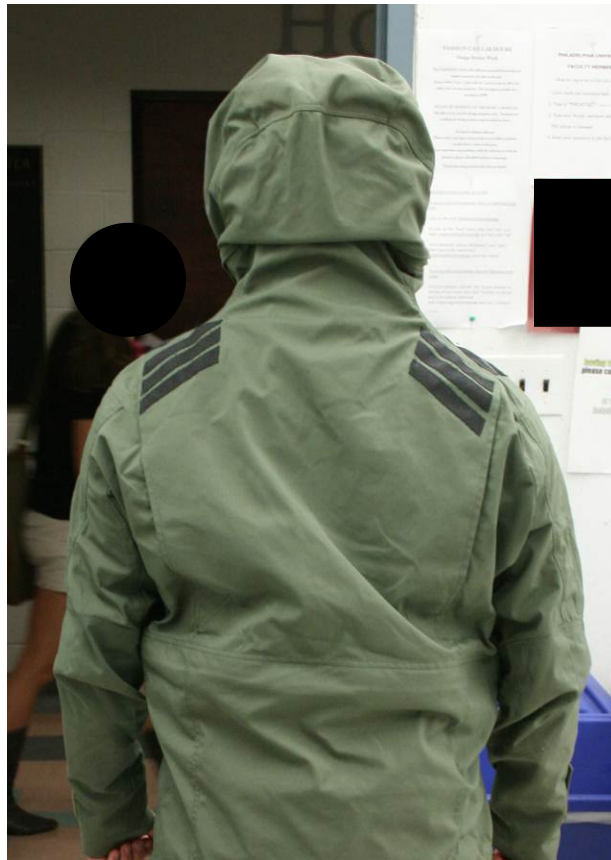


Figure 35. View of Back—Shoulder Grips and Bi-Swing Back.

3.8.2 Human Factors Results

During human factors evaluation at NSRDEC, no restriction was noted in the shoulder or arm areas. No restriction was found during Philadelphia University human factors evaluations, either.

3.9 Closures

3.9.1 Methods

Closures, in particular zippers, must address a number of challenges. Where closures marry at least two fabrics and where these openings must be backed by carbon interfaces, the GT had to consider a number of issues: performance against chemical agents, flexibility, price point, ease of use (opening and closing), availability (in-stock or special-order), garment placement (center front vs. off-to-the-side, pit-zip venting, etc.), and integrity of seal. During the Generation 3 garment evaluations the GT found that a water-resistant YKK coil zipper (YKK URETEK Part# CT40L-86-DABL E 5/8) suited the needs of the garment very well and has been used since.

Water resistant zippers were used at the front asymmetrical zipper, the fly on the pant, and for the zippers on the integration panel. The field-relief zipper in the carbon bodysuit is YKK continuous coil zipper size #5. This zipper was not water resistant.

The YKK water resistant zipper has continued to perform well under all testing. All zippers were viewed as easy to use, and no problems were recorded with their operation.

3.10 Shoulder Stabilizer Strap

At a September 2007 visit to Cherry Point Marine base the Generation 3 garment was shown to a group of pilots and aircrew. During a gear-donning demonstration and discussion, uniform shoulder displacement of the current Marine-issued flight suit (CWU-27/P) was seen to result from gear straps. The GT designed an internal shoulder mesh/elastic stabilizer strap for Generation 4. This feature was intended to control the garment's position on the shoulder, resisting shoulder slide-off caused by gear straps, and preventing the resulting restriction of head movement. Incorporating elastic into this gear strap helped to prevent any movement restriction.

Because of favorable response to this design, the shoulder stabilizer strap has been carried over to the Generation 6 garment.

3.11 Hood Retention Flap

3.11.1 Methods

In the fixed-hood version of Generation 6, a hood retention flap was provided for hood stowage when not in MOPP 4. The hood can be rolled up and fixed in place by the hook-and-loop tape on the hood retention flap over the rolled-up hood to the loop secure tape at the center back shoulder area.

3.11.2 Results

No discomfort was reported due to this feature in either PhilaU or NSRDEC evaluations.

3.12 Costing

3.12.1 Methods

To produce an estimated cost, the GT tracked the time required for sewing a Generation 6 two-piece shell.

3.12.2 Results

Having added the total minutes for the sewing operations, the GT estimates that two hours and fifty-nine minutes are required to complete the Generation 6 coverall shell. At \$15 per hour the price for labor costs would be \$44.85. However, fabric is often the most expensive part of this type of garment.

The following fabric utilizations were found by making a marker.

- The Generation 6 fixed-hood shell requires 5.79 yards of 60-inch-wide fabric.
- The Generation 6 collar-neck two-piece carbon undergarment and balaclava require 2.97 yards of 58-inch-wide fabric.
- The Generation 6 funnel-neck two-piece carbon undergarment and balaclava require 3.13 yards of 58-inch-wide fabric.

Fabric prices vary greatly according to the types of fabric and the size of the lot ordered. Shell fabric 78C was estimated at \$33 per yard. Carbon-undergarment fabric 63A was estimated at \$10.39 per yard from advice by the fabric supplier.

Producing the Generation 6 shell would cost a total of: \$235.92 (excluding fastener and thread costs).

$$\$44.85 + (5.79 \times \$33) = \$235.92$$

Due to time restrictions a labor-cost time study was not done for the carbon undergarment. Because both carbon suits are simple designs compared to the shell, the GT estimates that each would require no more than one-half hour to complete.

$$\$7.50 + (2.97 \times \$10.39) = \$38.35 \text{ collar-neck version}$$

$$\$7.50 + (3.13 \times \$10.39) = \$40.02 \text{ funnel-neck version}$$

An estimated total labor and fabric cost for the Generation 6 garment shell and carbon ensemble would be about \$275 (excluding fastener and thread costs, manufacturer's overhead and markup, etc.).

This is a sample-scale production cost estimate. Actual costs in a larger-scale production run could be less.

4. Conclusions

4.1 Fabric

The GT is satisfied with the choice of 78C/63A and 31B/43Y fabric pairings and feels the test participant's feedback on these fabrics was very positive.

Participants preferred either 63A or 43Y for different reasons, but felt that ultimately either would be acceptable for use. They also liked both 78C and 31B shells, but one participant noted that he perceived 78C to be more protective.

4.2 Dual-Layer System

While evaluating the two carbon backup systems integrated into the LEHP garments in earlier generations, garments that featured a fully separate carbon layer were found to provide better protection than those with the carbon cuff version. During doffing, it was observed that the participant exits the decon chamber cleaner when wearing a separate carbon bodysuit. When the shell is doffed with a carbon bodysuit underneath, the risk of accidentally brushing bare skin with the contaminated shell is greatly lowered. When removing the carbon bodysuit, the participant is in a relatively clean environment, which also lowers the risk of contaminating his body, making use of a carbon bodysuit more desirable to the user.

This belief in the efficacy of a separate carbon suit was again supported during CD assessment of the Generation 6 ensemble.

4.3 Hood/ Mask Interface

The hood/mask interface has continued to significantly improve over time; the continuing spiral development of this interface has led to many novel design concepts and improvements in protection. This vital interface now has increased protection as documented through FAST testing, and is comfortable to wear as shown by human factors evaluation. Novel addition of the wire brim and the elastic cord canister loops has no doubt contributed to the improved protection seen at this juncture. Though this interface has incorporated many changes through the generations, including Generation 6, this interface continues to be an area where the GT seeks improvement. The temple area, due to the nature of the shape of the JSGPM, is a difficult one for maintaining a snug interface. No difference was seen in comfort or protection between the Generation 6 detachable-hood or fixed-hood style jackets.

4.4 Articulated Knee and Knee-Pad Pocket

The articulated shape was favored by the subjects and served to increase the range of motion while bending the knee. The Generation 6 changes were well-received by HF evaluation participants.

4.5 Articulated Sleeve and Elbow Reinforcement

The shaped elbow reinforcement is successful in providing abrasion resistance in areas that the subject may wear through in a regular duty uniform. The reinforcement from the upper wrist to the lower shoulder area provides an extra layer of fabric to protect against any wear to the main

body of the suit. The improved shape of the articulated sleeve in Generation 6 has improved flexibility in the elbow area.

4.6 Torso and Zippered Integration Panel

The Generation 6 garment is the second two-piece pant and jacket system designed by the GT. The integration panel was successful in keeping out all of the contaminant, an improvement over the Generation 5 garment. Design changes made to the Generation 6 resulted in no simulant penetration onto the body during FAST.

4.7 Closures

For purposes of the LEHP garment a YKK water-resistant coil zipper was found to be satisfactory for all the zippers: jacket front, fly, and integration panel.

4.8 Shoulder Stabilizer Strap

This design feature has obtained favorable results and would be suitable for use if another generation is designed.

4.9 Hood Retention Flap

The hood-retention flap has proven useful while the hood is not being used.

5. Recommendations

Following are the Garment Team's recommendations based on complete testing of Generation 6:

1. Refine the two-piece ensemble evaluating both fixed and removable hood systems with a variety of helmets, including those that incorporate electronic devices.
2. Continue to revise the hood/mask area to improve protection and convenience, and to allow use with masks other than JSGPM. These improvements might include collapsible hood-mask integration elements for more comfortable stowage when in a non-threat environment and surrounding the wearer's face with a carbon-covered foam element designed to fill in the contours of a gas mask.
3. Consider methods of providing more convenient storage of exposure-sensitive removable elements; a method to be considered would be shrink-wrapping.
4. Revise integration panel on two-piece garment to lessen bulk at waist to eliminate voids and increase closure protection.
5. Identify ways to improve integration between garment and other gear, such as gloves and boots.
6. Evaluate additional areas of stretch fabric in the shell to increase comfort and mobility.
7. Explore rail-style zippers to reduce possibility of penetration by toxins and contribute to quiet donning and doffing by reducing zipper noise.
8. Experiment with elbow pads containing impact padding to reduce gear stress.
9. Consider use of a cooling/exhaust system.
10. Identify ways that Generation 7 garments could be made easier to don than Generation 6.
11. Conduct the following tests on garments:
 - a. Preliminary fog testing to identify system gaps and voids requiring design revisions prior to further testing.
 - b. FAST at RTI to provide information on aerosol blowthrough penetration at interfaces such as wrists, ankles, hood/mask, and zippers while motion routines are performed in a controlled environment.
 - c. Contaminated doffing at Hazmat Science Applications to provide information on contaminant transferred onto the body during doffing of the contaminated garment. This is an important test as it validates design of the garment system and ensures its clean removal after exposure to contaminants.
 - d. Human factors evaluations at both NSRDEC and Philadelphia University so that motion routine studies will continue to provide significant data about wearers' perceived

comfort, and their ability to perform discrete and mission-relevant movements. This evaluation also provides observation of ease of donning and doffing procedures.

e. Expand evaluations to include tests such as MIST, protection factor, penetration of live agent or simulant through the fabric systems and fasteners (zippers, hook-and-loop tape), exit smoke testing to identify closure voids not revealed by FAST, and field testing.

12. Design garments for explicitly defined challenges and missions.

13. Incorporate protection against threats in addition to chemical (as specified by NSRDEC).

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Appendix A

Test Report Human Factors Evaluation of LEHP CB Protective Garment—Generation 6 Prototype

(Reprint of original)

TEST REPORT

HUMAN FACTORS EVALUATION OF LEHP CB PROTECTIVE GARMENT -- GENERATION 6 PROTOTYPE

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August 2011

Distribution authorized to U.S. Government agencies and their contractors only—Test and Evaluation, August 2011. Other requests for this document shall be referred to Commander, US Army Natick Soldier Research, Development and Engineering Center, ATTN: RDNS-WSH-H (E. Hennessy), Natick, MA 01760-5020.

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TEST REPORT:

HUMAN FACTORS EVALUATION OF LEHP CB PROTECTIVE GARMENT -- GENERATION 6 PROTOTYPE

1.0 INTRODUCTION

The Laboratory for Engineered Human Protection (LEHP) at Philadelphia University, Philadelphia, PA, is working to develop a chemical biological (CB) protective garment, applicable for military personnel, that enhances wearers' physical and thermal comfort relative to the currently issued family of CB garments. This is a Congressionally-funded effort, with technical oversight assigned to Ms. Carole Winterhalter of NSRDEC. LEHP has worked iteratively, creating, assessing, and refining prototypes based upon human factors assessment, thermal properties assessment, FAST testing and contaminated doffing evaluation. After several years of designing 1-piece overgarments, LEHP was asked to explore ideas for a 2-piece garment. The Generation 6 prototype is the second 2-piece garment developed by LEHP to receive a human factors assessment at NSRDEC, Generation 5 having been tested during the summer of 2010. The ensemble features a jacket and trouser set that zip together and a separated carbon shirt and carbon drawer that serve as the CB protective undergarment. A CB protective balaclava head covering is also part of this prototype.

The objective of the current evaluation is to conduct an initial human factors (HF) laboratory assessment of the Generation 6 (Gen 6) CB protective ensemble developed by LEHP.

Many of the details of the garments and the evaluation are similar between Gen 5 and Gen 6 versions; the reader is referred to the Gen 5 test report for further details not present in this report.

2.0 METHODOLOGY

2.1. Scope of Assessment

The following HF dimensions were investigated for each Gen 6 protective ensemble:

1. Adequacy of fit.
2. Comfort: Subjective reports of non-thermal and thermal comfort.
3. Range of motion and maneuverability.
4. Ease of donning, adjusting, and doffing.
5. Protective interface with the CB accessories with which it would be worn, to include: CB protective over boots, gloves, and mask.
6. Compatibility of ensemble with common military equipment, to include ballistic vest, backpack, and canteen.
7. Perceived safety, including snag hazard.
8. Overall acceptability to the Soldier for performing his mission while wearing the ensemble

These dimensions were assessed for MOPP 2 and MOPP 4 levels of wear.

2.2. Test Items: LEHP Prototype Generation 6 (Gen 6)

As indicated above, the Generation 5 garment concept involves a CB protective carbon shirt and carbon drawer (undergarment) worn beneath a jacket-trouser set overgarment (shell). A balaclava is worn with the JSGPM mask when MOPP 4 protection is needed along with the attached hood of the overgarment jacket. Undergarments in two types of fabric were assessed, with each type having two different neck styles. Two different overgarments were assessed, and each of the two types was designated for use with one specific type of undergarment. Each overgarment also had two different hood styles. A third protective garment was also assessed, designed to be worn alone (without an undergarment). Fabric and design characteristics of the prototypes are provided below. More detailed descriptions are found in the Gen 5 report.

2.2.1 Undergarment

2.2.1.1 Features

The undergarment is made from a carbon-based material that is intended to provide protection against chemical agents in vapor form. It consists of a carbon shirt and carbon drawer with the shirt worn over the drawer. The undergarment is meant to fit snugly, like long underwear. The shirt of the undergarment is a jacket-style (as opposed to a pull-over) that features a front closure zipper that runs diagonally (from lower left side to the center of the neckline). There is a tab-over (hook and loop) closure at the neckline. The ankle cuffs are an extension of the drawer material (just separated by a seam) and they are not perceptibly narrower than the drawer leg width. They are neither ribbed nor elastic. Wrist cuffs on the shirt, however, are narrower than the shirt sleeve, and the fabric is knit and ribbed. Two different necklines were featured in the undergarments – one is referred to as a “funnel neck” and the other as a “collar neck”

The “collar neck” had a small (approximately 1 inch tall) collar attached at the top of the shirt. The collar neck contained the tab-over closure for the garment neck. The second neckline was called the “funnel neck” which had a finished seam (rolled and sewn) at the top of the garment but also included a tab-over neck closure.

2.2.1.2. Types

Two different types of undergarment were assessed. Each type was made of a different material. One type was designated as type 63A; the other type was designated as 43Y. The 63A type was part of the Gen 5 ensemble. The two types were distinguished by feel of the material and a slight visual difference in the material. In addition, the 63A undergarment is colored gray on the inside surface while the 43Y is black throughout. Each of these types was designated for use with only one of the overgarment types. Each type was also constructed with each of the two neckline types.

Therefore, the types and styles of undergarment evaluated were as listed in the table below:

Table 2-1. Evaluated Undergarment Types.

Type	63A	43Y
Neck Style	Funnel Neck	Funnel Neck
	Collar Neck	Collar Neck

2.2.2 Shell

2.2.2.1 Features

The shell jacket and trousers are made from a water-resistant laminated fabric; they are intended to provide protection against chemical agents in liquid and aerosol form. The jacket and trousers can be zipped together at the waist using what is called an "integration panel." The shell features resemble those found on the Gen 5 garment.

Shell Jacket

The main design features of the shell jacket are:

- The jacket closes at the front using a zipper up the midline of the torso.
- The jacket does not have a waist adjustment cord
- A shoulder stability elastic band, conforming to the width of the wearer's back and holding the garment shoulders and back in position.
- A series of narrow strips of black gripper fabric on the outside of the shell on each shoulder. These strips are designed to keep gear, such as a backpack, from slipping off and to enhance durability in this high wear area.
- A portion of the wrist length is longer across the back of the hand, featuring a curved shape.
- Vertical pleats are present on each side of the back of the jacket to provide leniency. The jacket length features a longer, curved portion at the center of the back.
- The jacket includes a hood, similar in style to earlier LEHP prototypes.
 - The top, front contours of the hood are formed by firm, encapsulated wire that conforms to the contours of the eye protection area of the JSGPM mask.
 - Elastic cords extend from the hood on either side to affix around the canisters of the JSGPM, further holding the hood in place.
 - An inner hood flap several inches wide is used to hold the hood in a rolled-back hood position when not needed.
 - The hood features a dark roll of fabric called a carbon cord across the front, top edge (not shown in drawing). Its purpose is to prevent water from seeping into the carbon hood during the decontamination process (e-mail communication with lead designer).
- At the lower end of the jacket, there is an inner skirt with zipper feet that encircle the torso and connects to matching zipper feet on the trousers. This inner skirt resembles a cummerbund when donned, and is called the integration panel.

There were two types of hood on each jacket. One jacket featured a fixed hood, permanently attached as part of the jacket. The other hood was removable by means of a zipper which circled the garment at the base of the hood. Otherwise, the hood features were identical for both types.

Shell Trouser

Adjustable waist tabs are featured on the trousers to allow a comfortable fit. These tabs also permit the wearer to adjust trouser height for an appropriate crotch and leg length. The fly zipper is typical for trousers. The back of the trousers feature a seat reinforcement patch in the crotch/upper thigh area.

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There are horizontal zipper tabs slightly above the waistline encircling the torso. These align with the zipper pulls on the jacket, permitting the trousers and jacket to be connected.

As in prior garment versions, there is a knee pad pocket and knee pad that slips into the pocket. On the lower thigh and upper shin, just above and below the knee pad pocket, there are adjustment tabs that cinch the trouser to a comfortable width and permit flexible positioning of the knee pads, vertically, on the leg. Hook and loop tabs are also used at the ankles for cinching the trousers over CB protective boots.

Balaclava

Gen 6 features a balaclava made from the same CB protective material as the undergarment. There were therefore two different types of balaclava evaluated (63A and 43Y). The balaclava fits snugly on the scalp and protects the neck and the portions of the face that are not covered by the mask when MOPP 4 protection is needed. The balaclava face opening features small attached pads that protrude into the face opening at each side of face to fill in the temple area to protect against chemical penetration.

The balaclava is meant to be stored within the mask case, attached to the mask, for instant donning when the mask is needed. It provides backstop protection beneath the shell hood and at the neckline of the shell jacket.

2.2.2.2. Types

Three different shell types were tested. All had the features listed in section 2.2.2.1; they varied only in the shell's fabric. One type used the same material as the Gen 5 prototype, and was labeled 78C. This garment was provided in an OD green color similar to JPACE. The second type was provided in Army Combat Uniform camouflage and was labeled 31B. The third type was constructed of a fabric with a semi-permeable membrane; this was called the SPM garment.

The 78C and 31B garment fabric had slightly different feel and appearance (besides the color), but otherwise the garments resembled one another, and appeared to be the same weight or similar. The SPM garment felt different from the other two and was noticeably heavier.

The 78C and 31B garments (as stated previously) were constructed in two versions, one with a removable hood and one with a fixed hood. The SPM garment had only a fixed hood version. The semi-permeable membrane garment is not worn with any undergarment or balaclava; the other two garments were intended for use with only one of the two undergarment types: 78C with 63A undergarment and 31B with 43Y undergarment.

Therefore, a total of nine garment configurations were evaluation – the combinations of undergarments and shells evaluated are listed in the following table, which includes the undergarment neck variants as well.

Table 2-2. Matrix of Test Garments Evaluated.

Undergarments	Neck Type	Overgarments				SPM
		78C		31B		
		Fixed Hood	Detachable Hood	Fixed Hood	Detachable Hood	
63A	Collar Neck	X	X			Not Applicable – the SPM garment did not include undergarments or balaclavas
	Funnel Neck	X	X			
43Y	Collar Neck			X	X	
	Funnel Neck			X	X	

2.2.3 Protective Interface Points on Prototypes

There are several protective interface points along the undergarment and shell 2-piece system.

- **Waist:** A horizontal circumferential zipper is present at the waist so that it can connect the shell trousers to the jacket for CB penetration protection.
- **Waist:** Above the connecting zipper, there are multiple hook and loop patches intended to strengthen CB protection in the midriff area. These connections are found on and around the integration panel, which resembles a cummerbund on a tuxedo. The bottom of the panel zippers to the trousers, and the top of the panel zippers to the jacket. The jacket and trousers cannot be attached without this panel (in most cases) because the jacket zipper is too high (between the chest and stomach) to meet the trouser zipper (at the top of the waist).
- **Ankles:** Standard doctrine was followed regarding ankle closures. The donning instructions provided by the designers also met this doctrinal guidance. The test participants were instructed to don their combat boots over the cuffs of the undergarment. The CB overboot was then donned over the combat boot, and the shell trouser was cinched around the overboot with hook and loop at the ankle.
- **Wrist:** For the non-FR glove system, the cotton liner and the CB protective butyl layer are both inserted beneath the wrist of the CB protective Gen 6 undergarment for optimal protection and to facilitate and orderly decontaminated doffing process. Note that this does not agree with the donning procedure provided by the designers (which placed only the liner under the undergarment cuff, with the CB protective glove worn over the undergarment sleeves).
- **Neck and Face:** A CB protective balaclava is attached in advance to the face mask, like a hood would be attached on other face mask systems. After protective breathability is established with the respirator, the balaclava is flipped over the head and shoulders and tucked into the neck and collar area of the shell jacket. The balaclava is meant to cover the neck and the portions of the face that are not covered by the mask.
- **Neck, face, and head:** A hood attached to the shell of the jacket raises over the CB protective mask. An inner wire on the front of the hood (referred to in the provided donning instructions as a “metal brim”) provides conformance the shape of the eye

protection portion of the JSGPM mask. To completely surround the mask, the hood is cinched below the neck with hook and loop.

2.2.4 CB Protective Items

The chemical protection items required with a garment to provide head-to-toe CB protection were used to assess the interfaces. These include:

- CB overboots: Alternative Footwear Solution (AFS), which is the current standard-issue CB protective overboot for the Army and other Services.
- CB gloves - non FR: JB2GU non-FR. This glove system consists of a butyl style CB protective glove worn over a knit, cotton sweat absorption liner.
- JSGPM mask: includes integrated respirator and eye protection. It comes with an optional hood which was not required due to the balaclava and shell hood on the Gen 6 prototype.

2.2.5 Other Equipment

To assess compatibility between the CB garment prototype and commonly worn Soldier equipment, the following items were used in the evaluation:

- Improved Outer Tactical Vest (IOTV) with front and rear plates installed
- Mock M4 rifle
- Rucksack. A large, square rucksack weighted to 40 lbs. Requires waist strap and chest strap to stabilize.
- Canteen. This was employed to assess operational arm range of motion needed for lifting the canteen above head to drink (simulated – canteen was empty).

Note: Helmets were not worn in this evaluation. A helmet will not stay seated on the head without being strapped at the chin. The current-issue Advanced Combat Helmet (ACH) does not have sufficiently long straps to be fastened closed when current and legacy CB masks and hoods are worn. Nonetheless, there is a potential incompatibility here if the shell hood and balaclava add enough bulk that the helmet no longer fits.

2.3 Garment Fit and Sizing

The Gen 6 shell size tested was patterned to be the same size as prior LEHP garments; past garments were coverall/jumpsuit style and designed to match a JPACE 40 Regular in size. The prediction range for JPACE 40 Regular is 185-200 lbs weight and 68-72 inches tall. It is expected that the Gen 6 prototypes follow this same patterning and sizing. Only Subjects with an adequate fit in the Gen 6 were selected for participation in this evaluation.

2.4. Test Participants, Location, and Schedule

Two Active Duty Soldiers were recruited as test participants (TPs). Both were members of NSRDEC's Human Research Volunteer company. For reference, TP height, weight, and other body dimensions are listed in Table 2-3, below.

Table 2-3. *Body Dimensions of Test Participants.*

Dimension	TP 1		TP 2	
	mm	inches	mm	inches
Stature	1729	68.1	1760	69.3
Crotch Height	848	33.4	854	33.6
Chest Circumference	954	37.6	1025	40.4
Waist Circumference	852	33.5	877	34.5
Weight	175 lbs.		177 lbs.	
Combat Boot Size	9.5 W		10 R	

Despite being slightly lighter than the minimum weight for the matched size (40R), both of the test participants who took part in the evaluation fit into the Gen 6 prototypes well. Both wore size medium regular ACUs and had a very good to excellent fit in their own ACU, as well.

Neither of the two test participants had combat experience. Both had worn chemical protective ensembles only during Army basic training (which for both was within the last 8 months to a year). Neither Soldier had had other training with any chemical protective ensembles or equipment. This is typical among the members of the Human Research Volunteer company. However, they were quite familiar with the methods and procedures needed to attain a MOPP 4 level of protection, and were able to work with the garments and provide appropriate, relevant feedback throughout the evaluation.

The evaluation took place during July 2010 in NSRDEC's Human Systems Integration Laboratory. The temperature was controlled and was maintained at 71 degrees throughout testing.

2.5 Assessment Approach

TPs first donned JSLIST up to MOPP level 4 to re-familiarize themselves with JSLIST garments, the donning process and the comfort and heat levels attained in the JSLIST ensemble, mask, overboots, and gloves.

As the basic approach for the test garments, the same process was used. Both TPs dressed in and wore all of the Gen 6 ensembles at MOPP 2 and MOPP 4 levels. To be more specific, the sequence of activities for each garment system (undergarment, shell, balaclava, etc.) was as follows:

- Familiarization with the garment and components—the TP was introduced to the garments and all of their features, apparent differences between them, how they interface with each other and the other CB equipment, and the donning and doffing processes to achieve MOPP 2 and MOPP 4 protection levels.
- TPs donned each garment ensemble by following the provided donning procedures, stopping as necessary to cover the steps that follow.
- Don undergarment only and perform three movements (touch toes, raise arms, climb and reach) to assess range of motion.

- Don shell over undergarment but do not connect shell trousers to shell jacket and perform the same three movements to assess range of motion
- Connect the shell jacket and trousers via zipper and hook and loop flaps, and perform the same three movements to assess range of motion
- Don remaining CB and other equipment. TP was now fully dressed in MOPP 2 plus IOTV and performed 14 movements to assess range of motion. Later, he performed the same 14 movements while fully encapsulated in MOPP 4. The movements – which have military relevance -- were selected to challenge interface points such as the neck or the ankles and to collectively engage all parts of the body. The climb and reach motion, for example, puts stress on the ankle, waist, and wrist interfaces; tossing a mock grenade requires twisting the torso; and low crawl engages nearly all parts of the body from the shoulders down. The list of specific movements is presented when the findings for range of motion are presented in the Results section of this document.

During most of the evaluation session, the TP was either donning, adjusting, and forming protective interfaces or he was performing movements. The evaluation was conducted on a one-on-one basis, with the evaluator working closely and directly with one test participant at a time. During the donning process, the TP was asked to rate the ease of conducting the donning subtasks as well as the entire process. For every movement activity, the TP was asked to rate the level of restriction. TPs provided ratings of comfort in MOPP 2, MOPP 4, and in the undergarment alone, to include thermal comfort. The TPs also were asked to report at any time during the session if they felt discomfort, a breach in CB protection, or movement in CB interface connections that could lead to a breach. TPs and the evaluator discussed what had taken place during activities in MOPP 2, MOPP 4, and after doffing the prototype, in a verbal questionnaire format. Throughout the session, the evaluator recorded observations of anything problematic or unusual/unexpected in ease/difficulty of donning, restriction in movement, or breaches in CB protection. A complete evaluation session required about 12 hours per TP. The information gathered has been integrated and is presented below in the Results Section.

3.0 RESULTS

The results that follow apply to all of the test garments in most cases, because the garments are more similar than dissimilar. Specific results, comments, or other items applying to a garment type (e.g., undergarment, shell) or style (e.g., 63A, 78C) are called out in those sections by type or style.

3.1 Findings according to Human Factors Characteristics

The following sections present the evaluation findings on primary human factors characteristics (fit, comfort, compatibility, protective interface, and others).

3.1.1 Adequacy of Fit

Both of the TPs in this evaluation fit well into the test garments. The garment sizes of both the undergarment and shell were appropriate for proper fit. Sleeve length and trouser leg length were adequate and appropriate for these two TPs as well.

Undergarments.

Both of the test participants had an acceptable fit in both of the undergarment types. Additionally, the undergarments did not appear to fit differently due to the material difference between types. The undergarments fit like long underwear, and were close-fitting but not snug or tight. Both TPs had an overlap between undergarment top and pants of at least 4 inches. Neither subject experienced a breach (i.e., no separation between the undergarment parts occurred) while raising the arms or touching the toes while wearing either type of undergarment.

Shells—31B and 78C

The two TPs had acceptable fits in the outer shells as well. Neither of the TPs had an overly loose fit in the shells, nor were any of the garment shell types too small or too tight to provide adequate body mobility. Both reported that the garments fit well, in their judgment. For both TPs, the waist area of the outer garment was “baggy” for all of the garment types when the shell coat and trousers were zippered together as a one-piece garment. However, the excess material at the waist was a result of the design and size of the integration panel rather than a fit issue. This will be discussed in detail later.

SPM

The SPM garment fit similarly to the other two shells. Fit was unaffected by the lack of an undergarment. The SPM shell also demonstrated the same type of bulk at the waist as the other shells, resulting from the design of the integration panel and its closure method.

3.1.2 Comfort (Non-Thermal)

Entire ensemble

In general, the TPs felt that the garments were comfortable during the short time that they were worn. They felt that the garments were no less comfortable than the JSLIST. The TPs main concern about comfort revolved around the bulk present at the waist area. This bulk was pressed into the stomach when wearing the IOTV. Although TPs indicated that this slight pressure most often only caused an awareness of the bulk, they wondered whether the bulk would cause discomfort over time. TP1 said that the bulk caused “moderate discomfort” only when crawling. At other times, TP1 did not note any discomfort from the bulge at the waist. TP2 never noted any discomfort at any point, even when prone and crawling with body armor.

Neither TP experienced any chafing, rubbing, or hot spots from any of the tested ensembles.

Undergarments

Both TPs noted textural differences between the two undergarment types, which led them to comment on their impressions of each type.

TP1 noted that 63A was “itchier than 43Y.” He reported itchiness immediately upon donning the 63A undergarment. However, once the shell was donned, he reported that the undergarment

did not actually cause him to itch. He also noticed that the balaclava felt was scratchier. TP1 noted that once he donned an outer shell, the undergarments felt the same to him inside the shell. When asked for an undergarment preference, TP1 said he preferred 43Y to 63A. He explained that his choice came down to comfort—he noted that 43Y felt smoother, and softer, and he said that 63A irritated his arms slightly once he was sweating. TP1's reports point out that impressions of comfort and texture are important to acceptability, even if they ultimately are unfounded.

TP2 noted that 63A was rougher than 43Y. He did not find that 63A was less comfortable than 43Y, nor did it feel any different on his limbs than 43Y, especially once he donned a shell. TP2 felt that 63A seemed cooler. He thought that 63A would have been itchier than 43Y, but 63A was not itchy against his skin. TP2 indicated that of the two styles, he would choose 63A, because it was lighter, thinner, and "stretchier" to him than 43Y was. Again, impressions were important, driving TP2's preference, and also his initial concern about itching.

Once the TPs donned the shell garments, both reported that the two undergarments felt the same inside the shells. Any concerns they had prior to donning the shells were resolved.

Neither TP felt that the undergarments were uncomfortable.

3.1.3 Thermal Comfort

Both TPs were asked to rate their feeling of thermal comfort while they were at MOPP 4 and wearing body armor. For all of the garments except the SPM, both TPs said they were "very warm" on a thermal sensation scale ranging from "neutral" to "unbearably hot." Additionally, both TPs reported that they felt 'comfortable/OK' on a 5 point thermal comfort scale that ran from 'comfortable/OK' to 'intolerable.' Neither TP was able to distinguish between undergarments in terms of thermal comfort once they donned a shell. TP2 said that the thermal comfort level in any of the garments (except SPM) was the same as what he felt in JSLIST.

Both rated the SPM garment as "hot," and said it was noticeably warmer within than the other undergarment/shell combinations. Both indicated that this heat level was 'slightly uncomfortable.' The TPs' impressions of increased temperature within the SPM garment were likely due to the garment itself rather than from any heat buildup--the lab temperature was maintained at a maximum of 71 degrees, and the TPs were given a break between garments to cool off prior to donning the next item.

Neither TP reported that they were sweating more than slightly. This is to be expected, as the exertion level was low, time in each ensemble was relatively limited, and the room was air conditioned. However, TP1 felt he was sweating more in the SPM garment than in the other garments.

3.1.4 Range of Motion

Range of motion was examined several times. TPs performed three of the motion tasks (touch toes, raise arms over head, climb and reach) as a check for mobility issues after donning the undergarment alone, after donning the shell without connecting the coat to the trousers, and after connecting the coat and trousers. Test participants completed all 14 mobility tasks in MOPP 2 and in MOPP 4 while wearing the IOTV.

Table 3-1 lists the mobility tasks performed and the areas of the body that each task covers.

Table 3-1. Body Mobility Movements Performed During Evaluation

Head, Neck, Torso	Knees, Legs, Ankles	Upright Actions
• Look to each side • Look up/look down • Raise both arms • Bend to touch toes • Simulate tossing grenade • Simulate drinking from canteen	• Kneel to fire • Perform low crawl with weapon • Fire from prone position • Simulate tossing grenade	• Climb & reach motion • Jog across the room and back • Move forward to fire weapon • Don, adjust-to-fit, and remove backpack

After each of the movements, test participants were asked to indicate whether they felt some or no restriction in conducting the movements, or, if it occurred, that they were unable to perform the task.

Restriction was noted only during MOPP 2 and MOPP 4 for the head movements, when TPs looked side to side and up and down. Both TPs said that this restriction was slight, and both they and the evaluator felt that most of the restriction was due to the body armor holding the neck material in place on the shoulders. A check of mobility without the IOTV in both MOPP 2 and MOPP 4 confirmed that there was little to no restriction of mobility from the suit alone. There was ample material at the neck and within the hood to allow the head to move freely without body armor. In addition, the fixed and detachable hood versions of the shell coats did not differ enough in mobility to be distinguishable to the TPs.

The type of undergarment or shell had no effect on restriction, since TPs reported restriction or a lack of restriction on the same movements regardless of which garment combination they wore, including the SPM. The TPs did not perceive any difference in mobility between the 78C/63A and 31B/43Y combinations and the SPM.

Of the tasks performed, the low crawl involves the most parts of the body, and would be the task most likely to exhibit restriction if any were present. The TPs did not report any restriction of mobility during the low crawl from the garments. Observation of the TPs during crawling confirmed that all of the garment systems appeared to allow full extension of the legs and arms and offer full torso mobility, at least for these two TPs (who fit well into the garments).

3.1.5 Donning/Doffing

Unless otherwise noted, the comments apply equally to all of the shells and/or all of the undergarments, since the design and donning process are the same across garments.

Note that the procedure sent with the garments was used at least once for each of the garments. The procedure differs somewhat from doctrine in a few ways. First, the process states that the undergarment wrist cuffs are worn over the glove sweat liner and under the butyl glove gauntlet, with the shell sleeve secured over the outer glove gauntlet. This is contrary to doctrine, which instructs soldiers to tuck the CB glove gauntlet under the undergarment sleeve cuff, and then secure the shell sleeve over the glove as well. Operationally, soldiers do often layer the gloves as written in the instructions. Therefore, the TPs used the process as written the first time, and for all subsequent trials they followed doctrinal practice. They did not consider either method to be difficult. The elastic cuffs on the undergarment sleeves allowed them to easily tuck the CB glove under it.

The second difference from doctrine is that the gloves are donned earlier in the process in the prototype method. This differs from the standard MOPP process where the gloves are donned last, as the last step to achieve the MOPP 4 protection level. In going from MOPP 2 to MOPP 4 (as in this evaluation), the mask is donned first (with bare hands), all interfaces are secured (except the wrist area), and then the gloves are donned. By donning the gloves earlier, the remaining tasks are made more difficult. This is especially true of donning and securing the protective mask and shell hood, but it also affected the use of zippers and proper closure of hook-and-pile fasteners. Therefore, the provided donning process was used once to assess the ease with which TPs could don the garments and other CB items using it. After the first time, TPs used a modified version of the donning instructions, moving the mask and glove donning steps to their proper places.

TPs were able to easily don the undergarment and shell parts, and they were able to adjust the leg and waist straps properly to make the shell comfortable. Connecting the shell jacket to the shell trousers was easy as well. The only part that was somewhat complicated and therefore slightly less easy was closing the fasteners at the midriff.

The closure system used on the integration panel appeared complex to the test participants. In fact, TP1's first comment was that the garment was "way too complicated." The method will become more familiar with practice, and the TPs actually did not feel that it was difficult once they had donned and doffed the garments a few times. Once they knew the closure process, they were able to close and seal the shell efficiently, with an emphasis on trying to reduce the bulk they created at the midsection. Both reported that it was not difficult to close the shell jacket, but the flaps sometimes stuck to other pieces of hook and pile tape, adding to the donning time needed. In addition, the inner flap had to be laid correctly or it would occasionally catch in the vertical zipper or not allow the other connectors to mate properly. An additional issue of complexity is that the integration panel can be connected to the trousers upside-down, because the zippers on the panel will mate with both horizontal zippers (on the coat and on the trousers)

in either orientation. This complicates reattachment of the panel should it ever be removed completely—users must understand the correct orientation of the panel.

Both TPs felt that they would always store and don their shell jacket and trousers connected as a one-piece item, because donning then became quicker, since the connecting zipper did not need to be zipped. They did not consider using the connecting zipper to be difficult, but it added another step that would not be necessary when the shell was donned as a one-piece garment.

When donning the shell as a one-piece garment, the TPs donned both parts of the undergarment before donning the bottom half of the shell. They then donned the boots, the top half of the shell, and, if donning to MOPP 4, the gloves and mask. This process was easy for them to complete.

Doffing the shells and the undergarments was easy for both of the test participants.

The balaclava and mask were easy to don as a unit. However, the balaclava often slipped off the mask when it was pre-installed. This was a potential breach, and is discussed in-depth in the following section.

Further details on donning and attaching the closures at the midsection are discussed in the following section.

3.1.6 Protective Interfaces

As with previous generations of this system, the evaluation looked at two aspects of protective interfaces: achieving the interface and maintaining it during movements. The sections below summarize what occurred during the evaluation for each garment interface location.

Note that most of the human factors concerns arose in reference to the protective interfaces, or with the garment features that deal with the interfaces. The discussions that follow note these concerns in the appropriate category along with the interface information. Unless specifically noted, the concerns apply to all types of the test garments.

At the waist

The undergarment interface was not breached for either test participant. Both test participants had at least a four inch overlap between jacket and trousers. The two parts never separated when the TPs raised both arms, touched their toes, or performed a climb and reach. Additionally, when the TPs doffed the outer garment at the end of a trial, there was no breach present, and there was no indication that the garments had separated during any of the movement tasks while the outer garments were worn. Note, however, that the two test participants were at the low end of the stature range for the test garment size. Additional testing is needed to determine whether taller wearers (those closer to 72 inches in height) also have adequate overlap and no breaching of the overgarment.

The outer garments' waist interface was the most complex of the interfaces to close properly. Both test participants noted that it was difficult to understand at first. However, once they had secured all of the parts of the waist interface a few times, they understood the system and the method, and found it straightforward and relatively easy to use.

Despite TP comments that they understood how to fasten the closure, the closure is complex enough that during an emergency situation involving rapid movement to MOPP 4, wearers may close it incorrectly or inadequately without sufficient familiarity and practice.

The horizontal (connecting) zipper was easy to understand and fasten. TP1 noted however, that on the SPM garment, the connecting zipper seemed a bit more difficult to fasten than those on the other garments. It took him a second or two longer to fully close that zipper because the material got hung up once or twice on the way around his body.

The hook and loop fasteners (especially tabs A, B, and C as labeled on one garment) in the waist interface were the parts that caused initial confusion. When unfastened, the various flaps fall against one another and stick to the hook and pile areas, and they must be removed (unstuck) and moved to the proper location prior to securing the closure. Once the TPs understood the proper sequence for closure, they were able to unfasten the stuck tabs, prepare them for fastening, and secure them properly.

Each of the flaps had a potential problem or issue. Flap A tended to self-stick to hook and pile tape within the garment. In some cases it appeared that flap A was properly closed when this occurred, although it was not secured in the proper location. Flap A could also be misaligned so that the inner placket flap ends up outside flap A, rather than inside. This caused TPs to open the inner flap and flap A to correct the closure. If flap A is misaligned, flaps B and C do not align properly. Of all of the steps involved in closing the integration panel, flap A and the inner panel are the most likely to be mis-configured. The inner flap must go over the flap on the left side, whereas the TPs assumed until taught that it belonged under the left side placket flap. Misalignment can be mitigated somewhat by training, but may not be eliminated, especially when under the pressure of an emergency requiring rapid progression to MOPP 4.

The mating point (the pile) for flap B never lay flat by itself once the connecting zipper was fastened. It had to be straightened out by hand in order to seal flap B properly. This usually meant pulling upward on the jacket to make the pile for flap B lie flat. Figure 3-1 shows TP1 with shell 31B ready to be fastened, with flap B's mating point highlighted. Even when properly fastened, flap B and the material it connected would fall forward and hang off the body, generating a source of bulk. Once the material fell forward, securing the rest of the closure flaps became more difficult, since the alignment of the flap parts changed and required moving the flap sections to realign them prior to connection.



Figure 3-1. TP1 wearing 31B shell, showing Flap B's mating point not laying flat prior to securing waist closure (Flap B mating point circled). All shells exhibited this issue.

Flap C was difficult to close properly (due to misalignment) if the preceding flaps were misaligned, which occurred several times in donning.

Flap D hung loose when unfastened. It partially obstructed access to flaps A, B, and C, and sometimes stuck to them, as TPs went about securing the waist closure. Extra care was required to keep flap D out of the way as A, B, and C were secured in order. Again, training and experience will make this process easier, and both would be critical to the success of the garment and the safety of the wearer.

Once secured, the waist closure area (specifically the integration panel) was very baggy for both test participants. The material comprising the closure (the integration panel and the closure flaps) settled into place by moving downward and away from the body. Also, depending on how the other flaps were aligned underneath, flap D would not always lay fully flat. Figures 3-2 and 3-3 show views of the bulk at the closure before securing the jacket, and 3-4 shows the visible bulk with the jacket zipped closed.



Figures 3-2 and 3-3. TP1 in shell 31B (left) and shell 78C right, with waist closure secured prior to zipping jacket closed. Notice that waist interface flaps do not lay flat when secured.



Figure 3-4. TP1 in shell 78C after zipping jacket closed. Note the bulge of material visible at waist with jacket closed. All shells exhibited this bulge when zipped closed.

TPs were unable to take up any of this slack, other than by pulling the garment upward off the shoulders until the integration panel flattened out (see Figure 3-5). A much taller test participant (approximately 6 inches taller) might have been able to achieve a flatter panel at the waist because his additional height would raise the garment and therefore potentially remove the slack. Note, though, that a much taller wearer would likely predict into a long length garment, not the tested regular length. The two TPs in this evaluation were somewhat lighter (by 8-10 pounds) than the cutoff for JPACE size 40 (185 pounds). However, it is doubtful that if they were heavier that the integration panel would have lay much flatter, since greater height appears to be needed rather than slightly greater weight or girth. In fact, prior to testing, evaluators initially thought that the integration panel was a height adjuster used to make multiple lengths of a garment by varying the height of the panel. Based on these findings, varying the size of the integration panel may assist in reducing the bulk at the waist area.



Figure 3-5. TP1 pulling the shell upward until waist closure bulk flattens out. Note how high shell has been raised. All shells tested were similar, 78C shown.

This bulk was obvious to both test participants even without wearing body armor. Body armor made the bulk more noticeable to the TPs, by pressing the layers of the integration panel and its closures into the stomach. TP1 reported “moderate discomfort” when he crawled with body armor. Under field conditions, the bulk is likely to cause discomfort for many wearers. TP1 also commented that the bulge seemed more noticeable to him in garment 78C than in 31B; he thought that might be because 78C’s material appeared stiffer to him than 31B’s.

The bulk of the waist closure did not seem to affect the integrity of the chemical protective seal. It appeared that the closure remained sealed once fastened at the waist and never opened during activities, because, upon doffing the garment, all of the closure flaps were still attached as they had been prior to the mobility tasks. Assuming the garment had been closed properly and a proper seal was achieved, the TPs would have been protected.

During the trials where TPs wore CB gloves (rather than following MOPP 2 doctrine), securing the waist interface was more difficult for both TPs. The TPs did not feel that the connecting zipper was more difficult to close with gloves. However, the gloves made it harder to select flaps (that may have been caught on hook and pile), straighten the flap interfaces, and secure the closure. Both TPs noted that the closures other than the zipper were at least slightly difficult to use with gloves. The added difficulty is another reason why the gloves should not be donned earlier than doctrinally prescribed.

At the wrists

Regardless of the donning method used (undergarment cuff over or inside of outer CB glove), the interface at the wrist was easily secured. TPs had no difficulty with either method.

There was one instance where the outer garment's sleeve cuff moved during an activity. TP1 reported that both of his sleeves moved up during the low crawl in garment 78C and undergarment 63A. This exposed the elastic cuffs of the undergarment on both hands, minimally on the left wrist and about 2 inches on the right (in the area where the outer garment sleeve is cut back). Figures 3-6 and 3-7 show the wrist cuffs in the position where they remained after raising and lowering the arms. TP1 guessed that he may have secured the sleeve fasteners less tightly than in the other conditions, although he said the fastener tightness felt the same to him. Because a large portion of the butyl glove gauntlets were still tucked inside the undergarment sleeves, this is not considered a breach. Since this occurred only once across both TPs and all of the garments, it is unlikely that the sleeve length is too short. More likely, a more tightly fastened sleeve would have kept the sleeve from moving off of the undergarment cuff. It does indicate that there is a need for proper adjustment of the cuff interfaces to maintain protection.



Figure 3-6 (left) and 3-7 (right). Final position of left and right wrist cuffs for TP1 in shell 78C after raising and lowering arms. This is the only time the undergarment gauntlets were exposed—see text.

At the ankles

The undergarment cuff was tucked inside the combat boot (for all but the SPM garment). The AFS CB protective boot was donned over the combat boot and the shell trousers were cinched over it with a hook and loop closure. For both of the TPs, trouser length was adequate for securing the boot at the optimal location (beneath the top fastener). Both TPs found it easy to

secure the trouser cuff in place over the boot. The shell trouser legs did not move from the position where the TPs had cinched them closed at the outset, regardless of the activities the TPs performed in the garments. As would be expected, all of the garment types performed similarly, including SPM.

At the neck, face, and head

Securing the head, neck and face involved the garment hood, the JSGPM mask, and the provided balaclava. In general, the test participants did not have difficulty in securing the neck and head interface. The items/areas involved in securing the head, neck, and face are listed below, and human factors concerns noted for each are listed. Features or issues discussed are common to all test garments unless specific mention of a type is made.

Mask donning

Both test participants were able to don the mask without difficulty, and without interference from the balaclava, which had been pre-installed on the mask prior to donning. They were able to attain a proper seal and adjust the headband straps for comfort and sealing. The only difficulty they encountered was during the trials where they wore CB gloves prior to donning the mask. The gloves made it difficult for the TPs to find and grasp the adjustment straps to tighten the headband. The difficulty is further reason to follow the doctrinal donning order in going from MOPP 2 to MOPP 4.

Balaclava

The JSGPM mask compresses when the balaclava is pre-installed on the mask. The rubber face piece of the mask (primarily at the top/forehead area) compresses inward from the pressure of the elastic of the balaclava when the mask is left inside out in preparation for donning. The balaclava then moves away from the edge of the mask, sliding off the rubber of the mask either immediately or when the mask and balaclava are donned.

When both TPs donned the balaclava, it moved upward off of the upper rim of the mask, and left their heads exposed. Both were unaware that this had occurred—they could not feel any difference. Unless a buddy were to notice and correct the gap, this is a breach of protection, assuming the balaclava is another line of defense for agents that move inside the garment hood. Neither TP pulled the balaclava over the head quickly or forcefully to cause it to pull off of the mask. Even when they worked carefully, the balaclava pulled off of the top of the mask slightly, exposing the forehead. The JSGPM has neither a lip nor a “second skin” at the top, both of which would retain the balaclava better.

Figure 3-8 shows the balaclava on TP1 immediately after donning, with the TP’s hair and forehead visible between the mask and balaclava. This was the most extreme case seen during the evaluation, although the balaclava did not stay on the mask in every trial.



Figure 3-8. Balaclava immediately after donning. Note extent of exposed head. Photo shows 43Y balaclava, but both balaclavas had this problem.

Tucking the balaclava into the shell jacket was easy when the IOTV was not worn.

With the IOTV on, both TPs were able to successfully tuck the entire balaclava into the shell, but they considered it somewhat difficult to complete with bare hands, and worse with CB gloves. The main problem was that the IOTV held the jacket against the torso and removed much of the “working space” available to use for access. In addition, TPs sometimes tucked the balaclava in between the garment’s back panel and the shoulder elastic strap within the garment, rather than outside of the strap (between the strap and the back). When the balaclava is tucked in between the elastic strap and the outer shell, it creates a large mass of material at the back of the neck, which not only causes bulk but also risks a breach if it is not fully flat. TPs were instructed regarding the strap and they were able to tuck the balaclava in the correct location outside of the strap on subsequent attempts. Without the IOTV, TPs were able to avoid the strap on every donning trial, without attempting to avoid it.

Garment hood

The garment hood was easily raised over the head and located in place around the mask. TPs found that locating the hood brim around the mask was easy. The brim did not always fall into the proper location fully; there was often a gap at the top of the head (see Figures 3-9 and 3-10), or worse, a large open area at the TPs’ cheeks on each side (see Figure 3-11). The brim aligned properly some of the time, while most other times it did not. In addition, the same mask that could be aligned properly on one trial did not align the second time that garment was donned. Note that the hood was donned and aligned to the mask as best as possible without further adjustment from bending the wire brim to better align the mask. No guidance was provided as to whether bending the wire brim is appropriate to fit the brim to mask to achieve a seal. However, based on the brim’s performance, bending the wire brim appears to be necessary. In the case of the side (cheek) breaches, a large amount of bending may be required, and may not achieve a full seal in that area.



Figure 3-9. Small gap at hood brim/mask interface, TP1 in 78C shell.



Figure 3-10. Small gap at hood brim/mask interface, TP2 in 31B shell.



Figure 3-11. Large gaps (circled) at temple areas of hood brim/mask interface. TP1 in 31B shell.

It is unclear whether a wearer could fully achieve a seal without help if bending the wire brim is needed. A buddy would likely be needed at least to verify that the brim has the best possible seal. Adjustment by bending will add time to the hood donning process, and the soldier's readiness will be affected until the brim is sealed properly. With experience, users may be able to bend the brim prior to donning the shell jacket to assist later in achieving a seal.

TP1 was unable to secure the hood brim at the sides while he wore gloves—he could not feel whether he had placed the hood brim's wire behind the protrusions at the sides of the mask.

Note that the hood brim wire is likely to be bent during storage of the garment in a rucksack, etc. (regardless of whether the detachable or the fixed hood is used), and therefore, wearers are likely to need to make some adjustments whenever they don the hood.

The TPs had little difficulty in securing the elastic canister cords around the filter canisters. The provided tabs were helpful in moving the cords to the proper locations. However, the TPs could not easily find and hold the tabs with the CB gloves on, when they wore the gloves in their initial donning trial. Again, this is a reason to don the gloves after rather than before the mask. Additionally, as with the Gen 5 prototype,

fastening the cords sometimes pulled the sides of the hood too far forward at the temples and then the sides of the hood had to be re-tucked behind the small mask lips at the temples. TPs were instructed to fasten the canister cords first, then to move the hood brim into position behind the lips.

Securing garment

Both TPs found that securing the garment was easy. This included both zipping the shell jacket to the neck and fastening the hook and pile neck tabs.

Securing the zipper placket was easy. The lower end of the inner flap (at flap A) needs to be secured properly for the upper part of the inner flap to lay properly for the length of the chest. This was accomplished prior to donning IOTV in MOPP 2, so that TPs did not have to doff IOTV to transition to MOPP 4. Before donning the IOTV, they also zipped the chest zipper high enough that they were able to reach the zipper pull with the IOTV on. Reaching the zipper pull and zipping the shell jacket closed with IOTV was a bit challenging for the TPs, but they did not find it difficult.

Securing the neck closure (once the zipper was up) involved bringing the neck tab on the right side across to fasten against a pile patch on the garment, and then moving the left side tab over to the pile patch on the right side tab. Occasionally, one or both of the tabs would fall inside the shell collar, and the TP could not locate it. Once they knew that it was folded inside the collar and potentially stuck by hook and pile, they were able to find it, pull it out, and fasten it properly. Enough hook and pile tape was present at this closure that even when the TPs misaligned the closure, it remained secure. The design of the closure prevents users from connecting the flaps at an extreme angle (such as in an X), as well as providing enough hook and pile tape that misalignment does not allow risk of opening the seal due to insufficient hook and pile contact.

All of the garments but the SPM performed as discussed above. For the SPM, the difference was that no balaclava was used, since the SPM does not use an undergarment. The closure is not high enough on the neck to seal fully against the mask. When the head is raised, a large breach is exposed on the neck. Recommend using the JSGPM's optional hood with the SPM garment; although it will be difficult to secure the hood inside the SPM shell while wearing body armor, a breach at the neck is far worse. Figure 3-12 shows the extent of the breach at the neck as the test participant looked upwards.



Figure 3-12. TP2 looking up while wearing the SPM garment and JSGPM mask without a balaclava. Note breach at neck.

3.1.7 Compatibility with Gear

The Gen 6 garments were compatible with all of the other equipment items tested with them. The TPs had no problems in throwing grenades; donning, doffing and wearing a loaded rucksack; aiming an M4 rifle, and simulating drinking from a canteen. The IOTV was also compatible with the test garments.

IOTV compatibility warrants some additional comments:

As previously noted, it was somewhat difficult for TPs to tuck the balaclava into the jacket collar and a bit of a challenge to zip up the jacket fully while wearing the IOTV, but TPs could accomplish these tasks.

The type of hood did not affect IOTV compatibility with the garments, although it did affect the interface between the IOTV and the hood. The fixed hood versions had no items of note. The IOTV collar sometimes lay at the hood zipper on the detachable hood version. However, the TPs could not feel the zipper or the IOTV collar against their necks, and their head mobility was not affected. When raising the arms, the IOTV collar moved inward, but the hood zipper was not pushed into the neck. Because the IOTV collar lay in the correct location and did not interfere with either TP's neck or mobility, it appears that the detachable hoods have enough play in the material to avoid problems. It is possible, though, that wearers with different body types (e.g., shorter necks, etc.) may find that the zipper and the collar contribute to neck mobility limitations or neck irritation.

Figures 3-13 through 3-16 show TPs wearing the IOTV with the removable collar on shell 31B and 78C.

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Figures 3-13 and 3-14. Left and right side views of TP1 wearing IOTV with Shell 78C with detachable collar.



Figures 3-15 and 3-16. Right side and rear views of TP2 wearing IOTV with Shell 31B with detachable collar.

3.1.8 Safety

There were no safety issues observed. The only potential safety/health hazard observed during this evaluation was that TP1 mentioned that the 63A undergarment felt itchier to him, and was

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'scratchier' once he began sweating. TP2 noted no similar issues. This may point to an irritation issue for some wearers over time as they sweat.

3.1.9 User Acceptance

Both TPs found all of the test ensembles acceptable, including shells and undergarments. They felt that any of the ensemble combinations would be acceptable for MOPP 2 and MOPP 4. They further said that they would be able to accomplish their missions in any of the garment ensembles, and found all of the garments suitable for accomplishing their mission tasks.

The two TPs did have preferences for particular styles of undergarment and overgarment, based on their brief wear periods in each one. They also had preferences for some of the features of the garments. These preferences are discussed below.

Undergarments

Both undergarments were acceptable to the TPs. They each preferred a different undergarment, and for different reasons. TP 1 stated that he preferred 43Y over the 63A. He said that 43Y was softer and more comfortable. TP1 found 63A was slightly irritating when he sweat in it. TP2 preferred 63A, finding it lighter, thinner, and more stretchable than 43Y. TP2 also felt that the 63A was cooler than the 43Y, since he assumed that the two outer shells were the same thickness and would feel the same with the same undergarment underneath. TP2 did not experience any irritation in either undergarment.

Both TPs preferred the collar neck over the funnel neck. TP1 said that he didn't really have a reason for preferring the collar neck other than he felt he liked it better. TP 2 said that the funnel neck seemed more uncomfortable to him than the collar neck, so he preferred the collar neck. When they were specifically asked, neither could tell the two collar types apart during or after the test activities.

Given that undergarment preference was equivocal, both material versions should be considered in future iterations, since otherwise (from a human factors perspective) they performed similarly in this evaluation. The collar neck should be considered over the funnel neck.

Overgarments

All three types of overgarment were acceptable to the TPs. They did, however, show a preference for one type over the others. Both preferred 78C over the 31B and SPM. They based their preference on impressions of the fabric from which the shells were constructed, rather than any operational or human factors concerns. Both said that they preferred 78C because they felt it would be more protective in a CB environment. TP1 also felt it would be more durable. Note that neither TP was able to distinguish one shell type from another once they were fully suited in MOPP 2 or MOPP 4 and the IOTV.

TP1 stated that he also liked the 31B fabric, and felt that it was similar to that of his ACUs.

Both TPs preferred both the 31B and the 78C over the SPM. Both stated that the SPM felt hotter inside than either of the other two shells; TP1 said the SPM was "a lot hotter." Both noticed that it felt physically heavier when held in the hands than either of the other two shell types. Nonetheless, they both felt that the SPM was acceptable for mission use as a CB protective garment.

Despite the TP preferences, the three shells performed similarly from a human factors perspective except for the SPM's increased weight and heat load.

Overgarment Features

The test participants also expressed preferences for certain attributes or features of the garments that they tested.

- Hood Type. TP1 initially expressed a preference for the detachable hood. He felt that having a detachable hood would keep the hood out of the way. Later, however, he conceded that the hood could be easily misplaced and would also require time to attach in order to ready the garment for MOPP level 4. TP2 did not express any preference for hood type.

Neither TP was able to distinguish the fixed hood style from the detachable hood style of garment once they had donned the shell. They did not feel the zipper or zipper seam of the detachable hood at any point in the evaluation, whether or not they wore the IOTV.

[As previously noted, the TPs were unable to detect any difference between undergarment neck styles once the shell was donned, either.]

- Integration Panel. Neither TP saw the need for a removable integration panel. They would not choose to remove the panel entirely due to fears of losing it, so they did not understand why it was removable. They both stated that a single zipper would be adequate for connecting the pants and jacket. They did not mind a connecting zipper; indeed, they both stated that they felt more protected in a garment that connected the two parts with a zipper.

Related to this issue is donning the garments as a one piece item (as if it were a coverall). Both TPs preferred donning the garment as a one piece item (i.e., with the jacket and pants already zippered together). They cited the ease of donning one item as well as the reduced time to don (versus zippering the pieces together). They did not see any disadvantages to storage and use as a one piece garment, nor did they see any advantages to use as a two piece system. They both added that, in the field, the typical soldier also would likely use the garments as a one piece system.

- Both TPs preferred a simpler closure system at the waist. Although they were able to fasten the closure properly, both felt it would be 'nice to have' a less complex closure design. They agreed that lettering the flaps (by some permanent means) would be

helpful. They also stated that by reducing the complexity of the closure, the bulk they experienced at the waist might be reduced. Since bulk at the waist was their main concern, the TPs also agreed with any changes that would reduce it.

3.2 Comparisons to JSLIST

The test participants in this evaluation had no CB protective garment experience, other than their initial training in Basic Training. However, each of them wore JSLIST over a T shirt and PT shorts (as they wore under each of the undergarments, as well) at the start of the evaluation, so that they would have a frame of reference to use later in assessing the prototype garments. The following comparison points summarize items that have been pointed out throughout this report.

- Prototype garments were preferred over JSLIST. Both TPs preferred the test garments over the JSLIST. As described previously, the TPs felt that the prototype garments were better than the JSLIST for a number of reasons.
- Prototype garments were perceived as safer than JSLIST. The TPs felt that the Gen 6 garments were safer. Based on their perceptions, they contended that the zipper connection and the shell materials used meant that the Gen 6 garments would protect them better than JSLIST would.
- TPs preferred the waist interface of the Gen 6 garments. They cited not only safety (a completely closed attachment point instead of JSLIST's overlap) but also noted that the zipper method was more comfortable to wear than a crotch retaining cord. However, they saw no need for the removable integration panel and the significant amount of bulk it caused at the waist.
- Temperatures in all of the suits (except SPM) were about the same. The TPs said that regardless of the undergarment/shell combination, all of the prototypes felt the same as each other and the JSLIST in terms of thermal comfort. The SPM was hotter than JSLIST, even in a cool laboratory and cool-down breaks between garments.
- Donning times were longer than necessary in Gen 6 garments when used as a two piece shell system. Despite JSLIST being a two-piece garment, the TPs felt that the complex closure of the prototypes would take them longer to secure than JSLIST, even after they became familiar with it. Both TPs said they would prefer to don the systems as one piece coveralls (for both ease and speed). If they were required to don the jacket and pants separately, TP 1 felt that the extra donning time would be acceptable because he felt that the Gen 6 garments would protect him better (and he accepted that tradeoff). TP2 said the only downside to the Gen 6 garments would be the donning time as a two piece garment.

4.0 CONCLUSIONS

4.1 Areas of Concern

- The complexity of the waist interface. The multiple tabs and fasteners at the waist caused confusion and must be fastened properly and in sequence to avoid breaches. Additionally, the removable integration panel can be attached upside-down.
- Bulk at waist. This bulk is a result of the design of the waist interface. The height and weight of the secured integration panel allows the panel to fall forward and away from the body, creating bulk at the waist. Test participants were aware of the bulk at all times. It caused one TP discomfort when crawling due to pressure on the material from the IOTV. The bulk will likely cause many users discomfort over time.
- Breaching occurred at the top of the head when the balaclava/mask was donned. The balaclava easily slides off the top of the mask. The rubber of the mask is soft and easily compressed, which allows the top of the balaclava to move off the mask lip. TPs were unable to tell the balaclava was not secured on the lip of the mask, and a buddy would likely be needed to re-seat the balaclava.
- In certain cases, the garment hood brim may not fully seal at the sides of the face without intervention from a second person. Feeling and bending the brim was not possible for one TP when he wore CB gloves.
- The SPM garment needs improvements to the neck area in order to achieve and maintain full CB protection. The neck area had a breach any time the head was raised.

4.2 Positive HF Features

- Compatibility. The garments were compatible with all of the equipment items expected to be used with them: M4 rifle, IOTV body armor, loaded rucksack, grenade throwing, and a canteen.
- Ease of donning and doffing. All of the undergarments were easy to don and doff. After receiving training and donning trials, the shells were also easy to don and doff, both as a one piece and as a two piece system. (Note that “donning and doffing” does not include securing closures.)
- Range of Motion. The Gen 6 prototypes offered good range of motion regardless of which undergarment or shell was worn. Most of the restriction experienced was a result of wearing the IOTV, rather than from the garments. Side to side neck mobility was also good; it was affected mostly by the IOTV, an improvement from Gen 5.
- Acceptability. The test participants found all of the garments acceptable for mission use for MOPP 2 and MOPP 4, and the evaluator concurred.
- Security. No breaches in the garment occurred (assuming proper closure of the waist interface) except at the mask, when the mask brim was not adjusted properly. The wrist, waist, and leg closures stayed fully secured without moving throughout the mobility task sessions for all three types of overgarment.

5.0 RECOMMENDATIONS

Reduce the complexity of the waist closure.

- Simplify the closure by reducing the number of flaps. Consider a maximum of one vertical flap (similar to flap A and the inner flap) and one wide horizontal flap similar to flap D. A drawstring closure at the bottom of the jacket may assist in providing CB protection in conjunction with a reduction in flaps, and would be easy for wearers to use and understand.
- If the closure retains multiple flaps as part of the closure design, permanent lettering or other means of identifying the proper order would assist wearers in aligning and closing the flaps properly.
- Eliminate the integration panel by creating an inner skirt on the jacket, or an extended (higher) waistline on the trousers. Two zippers and a separate panel not only increase complexity but also allow removal and loss of the panel. Without the panel, the current design prevents the jacket and trousers from being connected. Also, in its current configuration, the integration panel can be attached upside-down, an orientation which is incorrect.

Reduce the bulk of material present at the waist.

- Simplifying the waist closure with the above suggestions will reduce bulk in that area.
- If the integration panel is retained, its size (height) should be reduced so that the fastened material does not sag forward and create an excess of material at the midsection. This may mean that there are multiple sizes of integration panel, in order to accommodate wearers of varying heights without creating either excess bulk when secured or a garment that is too short with trousers and jacket connected.
- If the panel is not retained, ensure that the waist closure interface between jacket and trousers minimizes the bulk that can become uncomfortable when the IOTV is worn.

Modify the balaclava so it stays in place on the mask.

- If the balaclava is critical to chemical protection, soldiers will need training to ensure that they keep the balaclava in place fully at the top of the mask and that they do not have a gap once the mask and balaclava are donned.
- A second option is to modify the balaclava so that it does not slide off the mask when installed or when donned. Possible modifications include using a less stiff elastic banding around the top of the balaclava (to avoid squeezing the mask lip inward), or incorporating a second skin type of lip to better grasp the mask.
- If the garment hood is sufficient to provide chemical protection to the head without the balaclava, consider eliminating the balaclava and incorporating the JSGPM mask hood with which every mask is issued. It would eliminate the problem of the slippage and the need for specific additional training. The donning process would remain the same, and wearers would tuck the hood into their garments instead of the balaclava.

Improve the sealing method of the mask brim.

- Training will be needed to teach users that they must check the temples for a proper seal without gapping. Provide some means or method where the wearer is able to determine

independently whether a proper seal has been achieved. Additionally, consider an alternate sealing method that facilitates quick sealing without need for multiple attempts.

Use a balaclava or mask hood with SPM garment.

- The neck is exposed frequently when wearers raise the head in the SPM garment. It should be worn with one of the balaclavas or the JSGPM mask hood. A balaclava or hood is the simplest remedy for this issue (versus redesign of the neck closure only for the SPM garment).

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Appendix B.

Human Factors Evaluation at Philadelphia University

B.1 Introduction

The long-term goal of the Laboratory for Engineered Human Protection (LEHP) project is to create a military garment prototype that provides an optimal protection profile while retaining sufficient comfort to enable the users to wear the protective garments under ambient conditions and “closed tight” during threats for the required amount of time. One important component in achieving this goal is obtaining psychophysical assessments of garment comfort from participants as they wear and use the garments. The overall objective of the testing reported here was to assess LEHP-designed and constructed garments before and after the completion of motion routines established to evaluate garment integrity and comfort of military and first-responder protective garments.

In the present study, we report on testing of the Generation 6 garment against the currently used JSLIST Lightweight Integrated Suit. Human participants completed the sequential steps of an established motion routine that simulates soldier movements to enable assessment of durability of seams and other features of the garment, and identifies pressure points and comfort/discomfort features.

B.2 Methods

B.2.1 Participants

Participants were eight median-size male individuals recruited from the Philadelphia University community. Participants were treated in accordance with the APA’s Ethical Principles of Psychologists and Code of Conduct. The studies were carried out with approval by the University’s Institutional Review Board (IRB) under a protocol sanctioned by the Human Research Protection Office at Fort Detrick.

B.2.3 Materials

Two protective garment ensembles were assessed: the LEHP Generation 6 garment against the currently used JSLIST Lightweight Integrated Suit.

B.2.4 Characteristics Evaluated

A seventeen-item Human Factors Evaluation Questionnaire (see B.2.5) was used to document participants' evaluation of the comfort of various aspects of the garments. Answers to all questions but one were provided along a seven-point, forced-choice, Likert-style scale along a comfort dimension particular to that question (ex., Very Uncomfortable to Very Comfortable). The other question was a qualitative question concerning areas of potential binding (Are there places in which the garment felt tight or was binding? Please list all areas that apply.).

Questions covered a broad range of sensory characteristics as follows:

- three questions concerned fabric characteristics (thermal comfort, scratchiness, stiffness);

Garment Characteristics

4. Please assess the comfort of the *seams* of the garment.

Very Uncomfortable		Neither Comfortable nor Uncomfortable				Very Comfortable
1	2	3	4	5	6	7

5. Please assess the comfort of the *closure at the front neck edge*.

Very Uncomfortable		Neither Comfortable nor Uncomfortable				Very Comfortable
1	2	3	4	5	6	7

6. Please assess the comfort of the *garment attachment to the gloves*.

Very Uncomfortable		Neither Comfortable nor Uncomfortable				Very Comfortable
1	2	3	4	5	6	7

7. Please assess the comfort of the *garment attachment to the boots*.

Very Uncomfortable		Neither Comfortable nor Uncomfortable				Very Comfortable
1	2	3	4	5	6	7

8. Please assess the comfort of the *weight* of the garment.

Very Light		Neither Light nor Heavy				Very Heavy
1	2	3	4	5	6	7

9. Please assess the *range of motion in the legs of the garment*.

Not at All Restricted						Extremely Restricted
1	2	3	4	5	6	7

10. Please assess the *range of motion in the arms of the garment*.

Not at All
Restricted

Extremely
Restricted

1 2 3 4 5 6 7

11. Please assess the *range of motion of the overall garment*.

Not at All
Restricted

Extremely
Restricted

1 2 3 4 5 6 7

12. Are there places in which the garment felt tight or was binding? Please list all areas that apply:

13. Please assess the comfort of the *hood*.

Very
Uncomfortable

Neither Comfortable
nor Uncomfortable

Very
Comfortable

1 2 3 4 5 6 7

14. Please assess the *range of motion in the hood area*.

Not at All
Restricted

Extremely
Restricted

1 2 3 4 5 6 7

15. Please rate the ease of putting on the garment.

Not at All
Difficult

Extremely
Difficult

1 2 3 4 5 6 7

Very Cool	Neither Hot nor cool					Very Hot
1	2	3	4	5	6	7

Very Cool	Neither Hot nor cool					Very Hot
1	2	3	4	5	6	7

B.2.5 Procedure

Participants were recruited from the Philadelphia University community. Upon arrival at the Human Factors Evaluation (HFE) Lab, each participant was briefed on the purpose and general procedures of the study. After signing the informed consent form, a participant provided demographic information and was measured on applicable body dimensions to determine the best fit sizes for ancillary items (chemical-biological (CB) and mission gear). The participant then changed into LEHP-supplied t-shirt and gym shorts.

All participants provided assessments of the JSLIST garment in the first half of the testing. LEHP staff provided the appropriately-sized JSLIST garment and assisted the participant in the donning of the garment. Donning was completed according to the prescribed donning procedure developed jointly by the LEHP Garment Team and NSRDEC. Participants then completed the seventeen-question Human Factors Evaluation Questionnaire.

Following completion of the questionnaire, participants performed two sets of the prescribed motion routine. The routines included specified movements such as standing, walking, bending, squatting, twisting, running in place, dropping to a prone position, and rolling over on the back. The motions—simulated common field motions—were designed to provide stress to the garment and to the various closures. The first routine, modeled after NSRDEC human factors testing, consisted of the followed specified movements:

Discrete Movements. Participants executed a series of discrete body movements designed to assess whether protective interfaces stay in place and if the overall CB ensemble was uncomfortable or restrictive. Participants were instructed to:

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2. Rotate head 90 degrees to right
3. Look up at ceiling
4. Look down at floor
5. Raise both arms above head simultaneously
6. Spread arms out fully to side, then raise above head, simultaneously
7. Place hands behind head and twist side-to-side at waist
8. Raise extended leg as high as possible, forward (left and right)
9. Raise extended leg as high as possible, backward (left and right)
10. Bend knee and raise as high as possible towards chest (left and right)

Participants then completed the second motion routine, a more demanding sequence of movements of greater complexity to determine whether protective interfaces stay in place.

Mission-Relevant Movements (Tasks). The Task Sequence consisted of the following movements:

1. Perform low crawl
2. Kneel on both knees and rise without using hands
3. Take a knee (i.e. kneel on one knee, and then rise)
4. Squat
5. Make climbing motion (using chair)
6. Step over 27-inch-high metal barrier, left foot first
7. Step over 27-inch-high metal barrier, right foot first
8. Hold and aim weapon in standing position (using realistically weighted mock M-4 carbine from HFE lab) (Optional)

During each motion sequence, participants were encouraged to identify any concerns about the garment, focusing particular attention to any clothing/gear slippage or breach at the interface points. LEHP staff provided a quick visual and tactile check of the garment following any reported slippage or breach at an interface. If participants became uncomfortable or fatigued, they were permitted to remove the mask and take a rest break at any point during evaluation activities. Participants were encouraged to hydrate between the Discrete Movement Sequence and the Task Sequence. LEHP staff provided constant monitoring for signs of fatigue or overheating (red face, labored breathing, copious sweating).

Following completion of the motion routines, the participant doffed all test items, solo, in proper doffing sequence. After doffing, the participant completed the HFE post-questionnaire.

Throughout testing, participants were encouraged to provide additional observations regarding comfort (such as pressure, confinement, rubbing, chafing, and thermal discomfort) and the experience of donning and doffing the garment. All supplemental information was recorded during discussion with the participants.

Participants were given a five-minute rest period. The procedure was then repeated in similar fashion for evaluation of the Generation 6 garment.

B.3 Results

B.3.1 Introduction

Survey items were used to create six summary variables reflecting dimensions of the garment. These summary variables included:

- **Fabric Characteristics**—Summary variable reflecting the three individual questions concerning thermal comfort, stiffness, and scratchiness.
- **Garment Characteristics**—Summary variable reflecting the five individual questions concerning comfort of the seams, neck closure, gloves attachment, boot attachment and overall garment weight.
- **Hood**—Summary variable reflecting the two individual questions concerning comfort of the hood, and range of motion with the hood.
- **Range of Motion**: Summary variable reflecting the three individual questions concerning range of motion of the arms and legs as well as ratings of overall motion.
- **Heat Factor**: Summary variable reflecting the two individual questions concerning the heat factor associated with wearing the garment (with and without the mask).
- **Donning Ease**: Summary variable reflecting the single question concerning the ease of donning and doffing the garment.

Multiple regression analysis was conducted on each of these summary variables to evaluate the influence of two independent variables: The test garment (either Generation 6 or JSLIST) and the time of evaluation (either at the start of testing following the initial donning of the garment or after the completion of the motion routine). A statistical comparison between Generation 6 and Generation 5 (obtained previously as reported in PHILA-LEHP-GT-TR-11-01, *Design and Testing of Chemical/Biological Protective Coverall System, Generation 5*) was also conducted.

B.3.2 Fabric Characteristics

Mean ratings of questions pertaining to fabric characteristics (thermal comfort, stiffness, and scratchiness) are presented in Figure B-1. Multiple regression analysis revealed significant differences by garment, but not by time of evaluation. The Generation 6 garment was rated significantly higher on its fabric characteristics than was the JSLIST garment ($t = 2.73, p <$

0.011). Both garments received comparable ratings following the initial donning of the garment and after completion of the motion routine ($t = 1.08, p < 0.29$; see Figure 1).

The Generation 6 garment was rated comparably to the Generation 5 garment tested previously (overall mean for Gen 5 = 14.7; $t = 0.70, p < 0.49$).

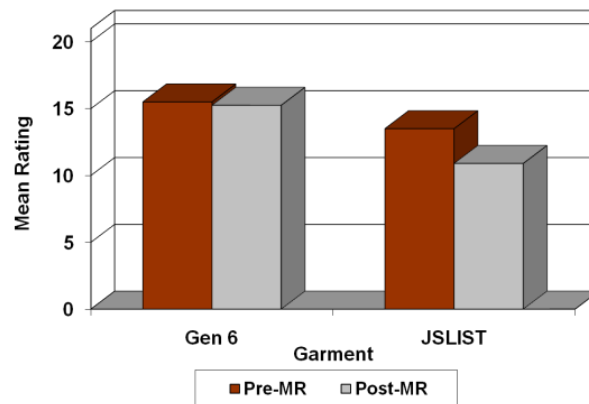


Figure B-1. Mean Ratings of Fabric Characteristics for the Generation 6 and JSLIST Garments after Initial Donning (Pre-MR) and Following Completion of the Motion Routine (Post-MR).

B.3.2 Garment Characteristics

Mean ratings of questions pertaining to garment characteristics (seam comfort, neck closure, glove attachment, boot attachment, and overall weight) are presented in Figure B-2. Multiple regression analysis revealed no significant differences by time of evaluation or garment. Both garments received comparable ratings on its garment characteristics ($t = 0.75, p < 0.46$), and no difference was noted for ratings following the initial donning of the garment and after completion of the motion routine ($t = 1.45, p < 0.176$; see Figure B-2).

Ratings of the Generation 6 garment in the current study were comparable to the ratings for the Generation 5 garment obtained in prior testing (overall mean for Gen 5 = 24.00; $t = 0.50, p < 0.62$).

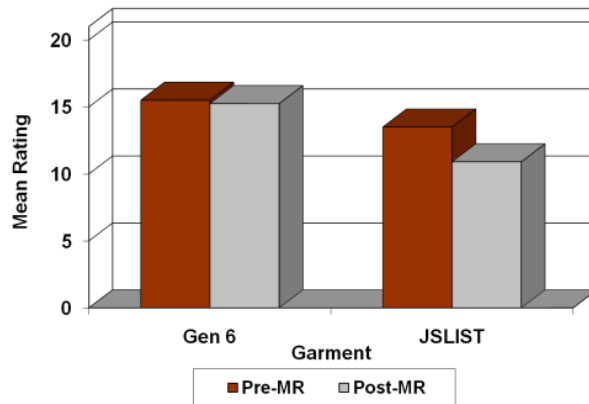


Figure B-2. Mean Ratings of Garment Characteristics for the Generation 6 and JSLIST Garments after Initial Donning (Pre-MR) and Following Completion of the Motion Routine (Post-MR).

B.3.3 Hood

Mean ratings of questions pertaining to the hood (hood comfort and hood motion) are presented in Figure B-3. Multiple regression analysis revealed no significant differences by time of evaluation or garment. Both garments received comparable ratings with respect to the hood ($t = 1.64, p < 0.11$).

The comparison between Generation 5 and Generation 6 likewise revealed no difference in comfort ratings of the hood (Generation 5 mean = 8.2; $t = 0.54, p < 0.59$).

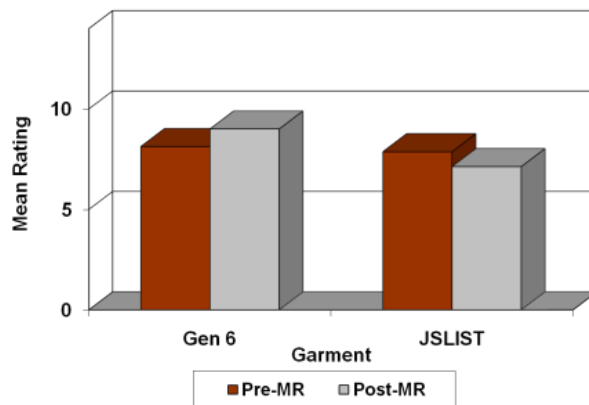


Figure B-3. Mean Ratings of the Hood for the Generation 6 and JSLIST Garments after Initial Donning (Pre-MR) and Following Completion of the Motion Routine (Post-MR).

B.3.4 Range of Motion

Mean ratings of questions pertaining to the range of motion of each garment (arm motion, leg motion, and overall motion) are presented in Figure B-4. Multiple regression analysis revealed no significant differences by either garment type ($t = 1.52, p < 0.14$) or time of evaluation ($t = 0.33, p < 0.75$).

The Generation 6 garment performed comparably to the previously-tested Generation 5 garment with respect to range of motion (Generation 5 Mean = 15.63; $t = 0.52, p < 0.61$).

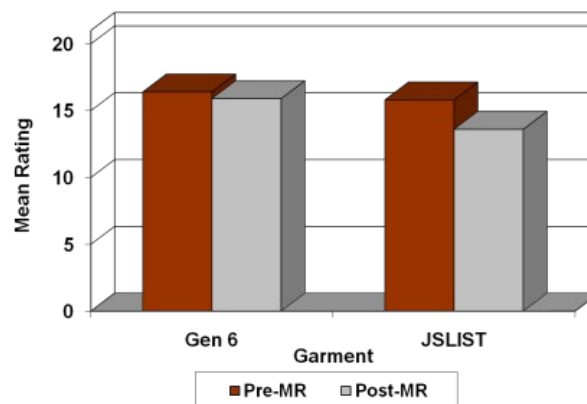


Figure B-4. Mean Ratings of Range of Motion for the Generation 6 and JSLIST Garments after Initial Donning (Pre-MR) and Following Completion of the Motion Routine (Post-MR).

3.3.5 Heat Factor

Mean ratings of questions pertaining to the heat factor of each garment (arm motion, leg motion, and overall motion) are presented in in B-5. No significant differences were noted for heat factor ratings between garments ($t = 0.94, p < 0.36$) or between pre-MR and post-MR testing of either garment ($t = 1.31, p < 0.20$).

The Generation 6 garment and the Generation 5 garments were rated similarly for heat factor (Generation 5 Mean = 7.1; $t = 1.50, p < 0.15$).

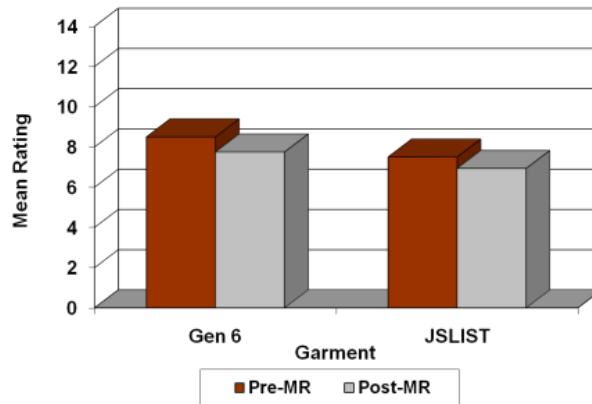


Figure B-5. Mean Ratings of the Heat Factor for the Generation 6 and JSLIST Garments after Initial Donning (Pre-MR) and Following Completion of the Motion Routine (Post-MR).

B.3.6 Donning Ease

The JSLIST garment (Mean rating of 4.87 out of 7) was judged to be significantly easier to don than the Generation 6 garment ($M = 3.1$; $t = 4.05$, $p < 0.001$). The Generation 6 and the Generation 5 garments were judged comparable in donning ease (Generation 5 Mean = 2.7; $t = 1.03$, $p < 0.31$).

B.4 Conclusions

The Generation 6 garment was judged to be significantly more comfortable than the JSLIST for the critical fabric characteristics (thermal comfort, stiffness, and scratchiness) that were assessed. This finding extends the LEHP previous work in which participants similarly judged the fabric characteristics of the Generation 5 garment to be significantly more comfortable than the JSLIST.

The fabrics used in the construction of both the Generation 5 and Generation 6 garments were selected from a pool of potential military fabrics that underwent extensive psychophysical evaluations for tactile comfort using the CALM and handfeel methodologies established by NSRDEC (For further information, see Pierce, Jr., J.D. [2008]. *Further Evaluation of the Reliability and Validity of the CALM scale for Assessing the Tactile Comfort of Fabrics*. Technical Report PHILA-LEHP-ME-TR-08-01. Philadelphia, PA: Philadelphia University Laboratory for Engineered Human Protection). The significantly higher ratings for fabric characteristics reflect, in part, the extensive psychophysical testing for comfort that influenced fabric selection for the Generation 6 garment.

The Generation 6 garment was further judged to be comparable to the JSLIST garment along the other critical dimensions that were assessed: garment characteristics (seam comfort, neck closure, glove attachment, boot attachment, and overall weight), the hood, the range of motion, and the heat factor associated with wearing the garment. The JSLIST garment was judged to be significantly easier to don than was the Generation 6 garment.

No significant differences emerged in the comfort evaluation of the Generation 6 garment compared to the previously tested Generation 5 garment, as each was rated similarly along the six summary variables. These findings demonstrate that the design improvements in the Generation 6 garment did not negatively impact the comfort of the overall garment. The improvement in comfort of the LEHP-designed garments over the JSLIST garment has now been demonstrated in two generations.

Appendix C

Philadelphia University LEHP FAST Testing Notes—April 5–8, 2011

Attendees:

LEHP: K. Hultzapple, J. Venafro

NCTRF: S. Proodian

DTRA: Tim Rittenhouse

RTI Test Team: James Hanley, Kathleen Owen and Clint Clayton.

Test participants (TPs):

TP-#8

- TP approved for testing based on availability: Weight 196 is inside JPACE Size 40 weight range (185-200). Height 69-1/2, which is inside the regular JPACE, size 40 height chart (68"-72").
- Subject measurements:

Body Location	Measurement
Neck	15 ½
Chest	30
High point to waist	21 ½
Waist—natural	34 ½
Hip	41 ½
CB—Sleeve Length—bent	31
CB—Sleeve Length—straight	30
Raglan Sleeve Length	30.5
Cross Shoulder	19
Back Length	20
Inseam	31
Outseam	40 1/2

TP-#7

- TP approved for testing based on availability. Weight 182 is slightly outside JPACE Size 40 weight range (185-200). Height is 69-1/2, which is inside the Regular height on JPACE prediction charts (68"-72").
- Subject measurements:

Body Location	Measurement
Neck	16
Chest	39
High point to waist	23
Waist—natural	35 1/2
Hip	40
CB—Sleeve Length—bent	33
CB—Sleeve Length—straight	31
Raglan Sleeve Length	30
Cross Shoulder	18
Back Length	22
Inseam	30
Outseam	40

TP-#9

- TP approved for testing based on availability. Weight 170 is below the range for JPACE Size 40 weight range (185-200). Height 67-1/2 which is 1/2-inch outside the Regular height on JPACE prediction charts (68"-72").
- Subject measurements:

Body Location	Measurement
Neck	16
Chest	39
High point to waist	23
Waist—natural	36 ½
Hip	38 ½
CB—Sleeve Length—bent	32
CB—Sleeve Length—straight	30 ½
Raglan Sleeve Length	28 ½
Cross Shoulder	17 ½
Back Length	21 ½
Inseam	29 ½
Outseam	38 ½

TP-#13

- TP approved for testing based on availability. Weight 154 is below the range for JPACE Size 40 weight range (185-200). Height 68-1/4 which is inside the Regular height on JPACE prediction charts (68"-72").
- Subject measurements:

Body Location	Measurement
Neck	14 $\frac{3}{4}$
Chest	36 $\frac{1}{2}$
High point to waist	19 $\frac{1}{2}$
Waist—natural	32
Hip	38
CB—Sleeve Length—bent	32 $\frac{1}{2}$
CB—Sleeve Length—straight	30
Raglan Sleeve Length	30 $\frac{1}{2}$
Cross Shoulder	21
Back Length	20
Inseam	29
Outseam	38 $\frac{1}{2}$

Test Schedule: Initial matrix was adjusted as testing proceeds.

	Tues	Tues	Tues	Wed	Wed	Wed	Thurs	Thurs	Thurs	Fri
	0920	1100	1330	0900	1100	1330	0830	1100	1330	0800
Gen 6 Fixed Hood-SPM	8								9	
Gen 6 Fixed Hood-31B			9	8						
Gen 6 Fixed Hood-78C		7			7					
Gen 6 Detachable Hood-31B								7		7
Gen 6 Detachable Hood-78C						13	8			
Gen 6 Carbon Undergarment-Collar 43Y			9					7		
Gen 6 Carbon Undergarment-Collar 63A		7				13			9	
Gen 6 Carbon Undergarment-Funnel 43Y				8						7
Gen 6 Carbon Undergarment-Funnel 63A					7		8			
Gen 6 Carbon Cuffs	8									
JSGPM mask and balaclava	X	X	X	X	X	X	X	X	X	X
7 mil butyl with cotton liner	X	X	X	X	X	X	X	X	X	X
AFS Overboot	X	X	X	X	X	X	X	X	X	X

Test Item Descriptions:

Gen6 Two-Piece—Fixed Hood (G6FH)

Design: Two-piece jacket and pant with attached hood. Designed to fit the JSGPM. Features include canister straps, two front neck flaps, an asymmetrical center front zipper, zip fly, articulated elbows and knees, knee-pad pocket with removable knee pad, elbow abrasion patches, waist cinch tabs, zipper pull tab, shoulder retention harness, and hood stowage system.

Materials: 78C, 31B and Natick supplied SPM

Gen6 Two-Piece—Detachable Hood (G6DH)

Design: Two-piece jacket and pant with a zippered removable hood. Designed to fit the JSGPM. Features include canister straps, two front neck flaps, an asymmetrical center front zipper, zip fly, articulated elbows and knees, knee-pad pocket with removable knee pad, elbow abrasion patches, waist cinch tabs, zipper pull tab, shoulder retention harness, and hood stowage system.

Materials: 78C and 31B

Gen6 Carbon Undergarment—Collared Neck (G6CCN)

Design: Fitted two-piece shirt and trouser with knit wrist and self ankle cuffs with center front asymmetrical zipper. The neck has a Velcro collar style. Trouser is pull on design with knit waistband.

Materials: 63A and 43Y (stretch)

Gen6 Carbon Undergarment—Funnel Neck (G6CFN)

Design: Fitted two-piece shirt and trouser with knit wrist and self ankle cuffs with center front asymmetrical zipper. The neck has funnel style with Velcro tab at zipper termination. Trouser is pull on design with knit waistband.

Materials: 63A and 43Y (stretch)

Gen6 Balaclava

Design: Balaclava style hood with elasticized opening at face to accommodate the JSGPM mask. Balaclava comes to mid upper chest and mid upper back with shaped areas for shoulders. Two covered neoprene inserts are sewn into the temple areas to fill in the

Materials: 63A and 43Y (stretch)

Gen6 Carbon Cuffs

Design: Carbon cuffs that Velcro into the SPM garment to compensate for the bellows effect. Carbon cuffs are attached at the ankle and wrist areas.

Materials: 63A (stretch)

Test #1 Tuesday – April 5th

0920 TEST

Configuration:

Gen6 Two-piece Fixed Hood SPM with Carbon Cuffs, Gen6 Balaclava (TP #8)

- TP wore 2007 JSGPM mask
- Butyl gloves with white cotton liner
- Combat boots with AFS overboots
- Knee pads worn in knee-pad pocket.
- Garment produced for FAST, never worn before.

Pre-Blacklighting: OK

Donning:

- Carbon wrist cuffs worn over cotton liner and under butyl glove. Shell is secured over butyl glove.
- Carbon ankle cuffs worn inside combat boot. Then overboot. Leg bottom of pant is secured on top of overboot.
- Gen4 balaclava positioned on JSGPM before donning. Once mask is secured in place, balaclava is pulled over head and then tucked inside jacket. Center front jacket zipper is closed to neck. Hook/loop of left and right flaps are secured and straps closed around filters.
- Fit: Hood, shoulders, torso (circ and length) are good fit. Also sleeve length and knee location are good. Crotch sagged a little bit but TP is on the shorter side. Good overall range of motion including head and shoulders.

Test: Test completed without issue. Subject covered completely with simulant

Doffing:

- Post-test/pre-doffing: possible little buckle in Velcro at left inside flap at top of integration channel panel.
- TP comments:

Black lighting:

- Left calf possible haze, sock line is barely visible.
- Arms look completely clean
- Haze on chest at left abdomen following possible breach at Velcro.
- About 6 small bright spots about the size of a pencil on right jaw line.
- 2 slightly larger bright spots on left jaw line and under chin area.

Recommendations for next run:

- Make sure integration panel is secured completely at waist area.
- Check Velcro tabs to be sure it's snug around the mask at the chin area.

Test #2 Tuesday – April 5th

1130 TEST

Configuration:

Gen6 Two-piece Fixed Hood 78C with 63A Carbon Collar Version, Gen6 Balaclava (TP #7)

TP wore 2007 JSGPM mask

Shell was worn 3 times for PhilaU human factors. Garment 1 of 2.

Carbon worn 3 times for PhilaU human factors.

Knee pads worn in knee-pad pocket.

Butyl gloves with white cotton liners.

Combat boots with AFS overboots

Pre-Blacklighting: OK

Donning:

- Wrist cuffs on carbon shirt worn over cotton liner and under butyl glove. Shell is secured over butyl glove.
- Ankle cuffs on carbon trouser worn inside combat boot. Then overboot. Leg bottom of pant is secured on top of overboot.
- Gen6 balaclava positioned on JSGPM before donning. Once mask is secured in place, balaclava is pulled over the head and then tucked inside jacket. Center front jacket zipper is closed to neck. Hook/loop of left and right flaps are secured and straps closed around filters.
- Fit: Hood, shoulders, torso (circ and length) are good fit. Also sleeve length and knee location are good. Good overall range of motion including head and shoulders.

Test: Test completed without issue. Subject covered completely with simulant

Doffing:

- Made sure that the helpers did not touch the bare neck of the test participant with contaminated gloves while removing the mask.

Black lighting:

- Legs and arms look completely clean.
- On the small of the back a very slight about 6" high oval shaped haze was present. (May be TP's skin, see notes for test#5).
- Small smudge about sized of fingerprint on right temple above the eyebrow.
- Haze over right ear.
- On the left neck clean areas where the mask straps were.
- Smudging under neck following the edge of the mask.
- Haze of simulant inside left ear.
- Small spot of simulant above left eye.
- TP said the garment was very comfortable and didn't have any complaints.

Recommendations for next run:

- Make sure Velcro flaps around neck are attached securely around mask.

Test #3 Tuesday – April 5th**1400 TEST****Configuration:****Gen6 Two-piece Fixed Hood 31B with 43Y Carbon Collar Version, Gen6 Balaclava (TP #9)**

TP wore 2007 JSGPM mask
Shell and carbon made for RTI 2 of 2.
Knee pads worn in knee-pad pocket.
Butyl gloves with white cotton liners.
Combat boots with AFS overboots

Pre-Blacklighting: OK**Donning:**

- Wrist cuffs on carbon shirt worn over cotton liner and under butyl glove. Shell is secured over butyl glove.
- Ankle cuffs on carbon trouser worn inside combat boot. Then overboot. Leg bottom of pant is secured on top of overboot.
- Gen6 balaclava positioned on JSGPM before donning. Once mask is secured in place, balaclava is pulled over the head and then tucked inside jacket. Center front jacket zipper is closed to neck. Hook/loop of left and right flaps are secured and straps closed around filters.
- Fit: Hood, shoulders, torso (circ and length) are good fit. Also sleeve length and knee location are good. Good overall range of motion including head and shoulders.

Test: Test completed without issue. Subject covered completely with simulant.

Doffing:

- Right sleeve shaped extension is folded up about 1.5”, must have flipped up during chamber exercises.
- Legs stayed in place.
- Wire brim appears to have stayed in place.
- Balaclava has visible sweat marks.
- Carbon shirt is visibly soaked in sweat.
- Temple pouches may be creating a little lift at above the jaw and creates a possible channel to the skin.

Black lighting:

- Entire body is clean except two pencil eraser sized spots on cheeks above jaw line. Spots are symmetrical on face.

- Test participant noted that this is the most comfortable suit he's worn so far and really tried to put it to work in the chamber. He is the first repeat participant for the prior generations. TP seemed impressed not to find any simulant on his body.

Recommendations for next run:

- On balaclava, tack one pouch to the elastic to see possible difference it makes in protection.

Test #4 Wednesday – April 6th

0900 TEST

Configuration:

Gen6 Two-piece Fixed Hood 31B with 43Y Funnel Neck Version, Gen6 Balaclava (TP #8)

TP wore 2007 JSGPM mask
 Shell and carbon made for RTI 1 of 2.
 Knee pads worn in knee-pad pocket.
 Butyl gloves with white cotton liners.
 Combat boots with AFS overboots

Changes made to garment:

- On balaclava the left temple pouch was tacked down on either end to the elastic.

Pre-Blacklighting: OK

Donning:

- Wrist cuffs on carbon shirt worn over cotton liner and under butyl glove. Shell is secured over butyl glove.
- Ankle cuffs on carbon trouser worn inside combat boot. Then overboot. Leg bottom of pant is secured on top of overboot.
- Gen6 balaclava positioned on JSGPM before donning. Once mask is secured in place, balaclava is pulled over the head and then tucked inside jacket. Center front jacket zipper is closed to neck. Hook/loop of left and right flaps are secured and straps closed around filters.
- Fit: Hood, shoulders, torso (circ and length) are good fit. Also sleeve length and knee location are good. Good overall range of motion including head and shoulders.

Test: Test completed without issue. Subject covered completely with simulant

Doffing:

- Hazing on the neck, clear line where the edge of the carbon suit stopped
- Haze slightly more on right than left.

Black lighting:

- Body completely clean, nothing on cheeks this time.
- About ½ inch haze band on neck edge on right to about 2” on back neck to vague haze on left.

Recommendations for next run:

- Tack right temple pouch to mimic what was done with the left temple pouch on the balaclava.

Test #5 Wednesday – April 6th**1130 TEST****Configuration:****Gen6 Two-piece Fixed Hood 78C with 63A Funnel Neck Version, Gen6 Balaclava (TP #7)**

TP wore 2007 JSGPM mask
Shell and carbon made for RTI 2 of 2.
Knee pads worn in knee-pad pocket.
Butyl gloves with white cotton liners.
Combat boots with AFS overboots

Garment Changes:

- Both temple pouches on the balaclava were tacked down to the elastic.

Pre-Blacklighting: OK

- Slight bright spot on chest visible prior to testing

Donning:

- Good fit.

Test: Test completed without issue. Subject covered completely with simulant

Doffing:

- Prior to doffing balaclava visible orange powder is seen on the inside of the balaclava

Black lighting:

- Subject’s skin naturally fluoresces more than the other test participants.
- Two small light spots of simulant on each side of face along mask edge just above the jaw line. Positioned the same as test #3, but fainter spots.
- Very vague haze mid jaw to Adam’s apple concentrated on left side.
- Oval shaped brighter spot on back—this is the same as test #2 when the test participant participated before. May be the TP’s skin.

- No haze above funnel neck like seen in prior tests, tacking the temple pouches on the balaclava may have helped this.
- Best test results so far.

Recommendations for next run:

- None

Test #6 Wednesday – April 6th

1330 TEST

Configuration:

Gen6 Two-piece Detachable Hood 78 with 63A Carbon Collar Version, Gen6 Balaclava (TP #13)

TP wore 2007 JSGPM mask
 Shell and carbon made for RTI 2 of 2, carbon was washed and dried on low heat.
 Knee pads worn in knee-pad pocket.
 Butyl gloves with white cotton liners.
 Combat boots with AFS overboots

Garment Changes:

- Both temple pouches on the balaclava were tacked down to the elastic.

Pre-Blacklighting: OK

Donning:

- Slight off set on the integration panel left channel Velcro positioning.

Test: Test completed without issue. Subject covered completely with simulant

Doffing:

- Everything looks secure coming out of chamber.
- Bottom strap on left overboot is undone.
- Face looks clean during black light when hood is rolled up around mask.

Black lighting:

- Body completely clean.
- Small spot on left side of neck at mask edge near Adam's apple, possibly from doffing.
- Very faint haze under chin.
- Fainter haze above collar on back neck, clean line from carbon garment.

Recommendations for next run:

- None

Test #7 Thursday – April 7th

0900 TEST

Configuration:

Gen6 Two-piece Detachable Hood 78C with 63A Carbon Funnel Neck, Gen6 Balaclava (TP #8)

TP wore 2007 JSGPM mask

Shell and carbon made for RTI 1 of 2, carbon was washed and dried on low heat.

Knee pads worn in knee-pad pocket.

Butyl gloves with white cotton liners.

Combat boots with AFS overboots

Garment Changes:

- Both temple pouches on the balaclava were tacked down to the elastic.

Pre-Blacklighting: OK

Donning: No issues.

Test: Test completed without issue. Subject covered completely with simulant

Doffing: Everything seems to have stayed in place.

Black lighting:

- Body completely clean.
- Very faint silver dollar sized haze on right neck, possibly mask straps are contacting skin during doffing. Carbon balaclava was clean in same area on inside.
- Possible faint haze on left neck, this appears to be under the mask butyl extension at the neck.
- TP says he wouldn't say that the garment is uncomfortable, but he wouldn't say that it's comfortable because it's not regular clothing.

Recommendations for next run:

- None

Test #8 Thursday—April 7th

1130 TEST

Configuration:

Gen6 Two-piece Detachable Hood 31B with 43Y Carbon Collar Version, Gen6 Balaclava (TP #7)

TP wore 2007 JSGPM mask

Shell and carbon made for RTI 2 of 2, carbon was washed and dried on low heat.

Knee pads worn in knee-pad pocket.

Butyl gloves with white cotton liners.

Combat boots with AFS overboots

Garment Changes:

- Both temple pouches on the balaclava were tacked down to the elastic.
- Lower mask straps were duct taped to the back of the mask to cut down on movement and reduce risk of skin contact during doffing.

Pre-Blacklighting: OK

Donning: Good fit.

Test: Test completed without issue. Subject covered completely with simulant

Doffing:

- Everything seemed to have stayed in place.
- During doffing black light haze of simulant was visible on jaw area of the inside of the balaclava.

Black lighting:

- Body seems clean, same oval shaped spot on TP's back that has been seen in his other test. Probably natural skin occurrence.
- Slight haze under Adam's apple.
- Best test thus far.

Recommendations for next run:

- None

Test #9 Thursday – April 7th

1420 TEST

Configuration:

Gen6 Two-piece Fixed Hood SPM with 63A Carbon Collar Version, Gen6 Balaclava (TP #9)

TP wore 2007 JSGPM mask

Shell and carbon made for RTI 1 of 1, shell was washed and air dried once after test #1.

Carbon was washed and dried on low heat twice

Knee pads worn in knee-pad pocket

Butyl gloves with white cotton liners

Combat boots with AFS overboots

Garment Changes:

- Both temple pouches on the balaclava were tacked down to the elastic.
- Lower mask straps were duct taped to the back of the mask to cut down on movement and reduce risk of skin contact during doffing.

Pre-Blacklighting: OK

Donning:

- Suit seems softer after washing once from prior test.
- No delamination of the fabric was seen after washing and air drying.
- The garment seems to be slightly discolored possibly from the orange simulant powder, as the coloration is orange/pinkish.
- Garment seems to fit well.

Test: Test completed without issue. Subject covered completely with simulant

Doffing:

- Haze of simulant visible on carbon shirt near hem on left side of body just right of the zipper.
- Small pencil eraser sized spots on cheeks where lower mask buckles are. Left side—only on top of buckle, right side—both above and below buckle.

Black lighting:

- Slight haze of simulant on top of left calf.
- Corresponding haze on abdomen where haze was seen on carbon shirt.
- Bright spots on left and right sides where mask edge is.
- Bright spots on left above and below buckle, also right below edge of side burn.
- Clearer line where the mask edge is on the right side.
- Three small bright spots on right side, above and below mask buckle and down on neck.
- Haze around both ears.
- TP says it's uncomfortable at zipper terminus at neck where it pushes onto the neck.

Recommendations for next run:

- None

Test #10 Friday – April 8th

0830 TEST

Configuration:

Gen6 Two-piece Detachable Hood 31B with 43Y Carbon Funnel Neck, Gen6 Balaclava (TP #7)

TP wore 2007 JSGPM mask
Shell and carbon made for RTI 1 of 2, carbon undergarment washed and dried on low heat
Knee pads worn in knee-pad pocket
Butyl gloves with white cotton liners
Combat boots with AFS overboots

Garment Changes:

- Both temple pouches on the balaclava were tacked down to the elastic.
- Lower mask straps were duct taped to the back of the mask to cut down on movement and reduce risk of skin contact during doffing.

Pre-Blacklighting: OK

Donning:

- Good fit.
- Velcro needs extension on the under side neck tab.

Test: Test completed without issue. Subject covered completely with simulant.

Doffing:

- On left arm the wrist extension flipped up about 1/2". Have seen this before in the same fabric.
- Sweat soaked under the chin on the balaclava.
- Haze under chin all way to about mid jaw on balaclava.
- Bright spot on right jaw right below mask buckle.
- Right temple pouch was sitting about 1/2" lower on mask and may be creating a slight lift over the buckle and creating the spot.

Black lighting:

- Similar spot on back as seen before with this test participant.

- One small spot on abdomen about 4” above belly button, possibly a drip from the sweat under mask area, no haze present around spot.
- Small spot on right jaw right below mask buckle, three small spots under chin around Adam’s apple.

Recommendations for next run:

- This is the final run at FAST

Overall recommendations for Gen6 system:

- Tacking the temple pouches on the balaclava may have improved protection. Recommend keeping this addition.
- Garment performed well, really no additional recommendations.

Appendix D

Philadelphia University Fluorescent Aerosol Screening Tests (FAST) Test Report—May 17, 2011.

(Reprint of original)

RTI International	
Fluorescent Aerosol Screening Tests (FAST)	
Test Report	
Purchase Order Number: P0014523 RTI Project Number: 0212534.036	
Prepared by: James Hanley RTI International 919-541-5811; hanley@rti.org	
Prepared for: Kristen Hultzaple Laboratory for Engineered Human Protection (LEHP) Philadelphia University	
1	May 17, 2011
RTI INTERNATIONAL	

Test Series

- Ten aerosol challenge FAST tests for Philadelphia University's Laboratory for Engineered Human Protection (LEHP) were performed at RTI International.
- Tests focused on evaluating the overall performance of prototype garment ensembles.
- Testing was conducted on April 5-8, 2011.
- Black light (UV) photographs were taken to document areas of aerosol deposition on the skin of the test participants.
- LEHP, DTRA and Natick representatives were on-site to observe the tests and to assist with proper and consistent donning and doffing of the test ensemble.

2



Test Conditions

- Fluorescent challenge aerosol:
 - "nuisance dust"
 - Amorphous silica tagged with two tracers:
 - Sodium fluorescein (quantitative analysis)
 - Tinopal (visual response under black light)
 - 2.5 μm aerodynamic mass median diameter
 - Solid-phase (i.e., dry, not liquid)
- 10 mph wind speed
- 30 minute exposure time
- $\text{CT} = \sim 5,000 \text{ mg m}^{-3} \text{ min}$
- "JSLIST" motion routine

3



Exposure Chamber; (photo from prior testing)



25' x 50'
10 mph
~ 70° F
~ 50% RH
~ 170 mg/m³
2.5 µm MMD

4

Motion Routine; (Same as used on JSLIST)

- Standing
 - Walking
 - Bending
 - Reaching
 - Squatting
 - Twisting
 - Running in place
 - Prone firing position
 - Laying on back

5

Black Light Photographs

- In the black light photographs:
 - Areas of heavy aerosol deposition appear as relatively bright green.
 - Areas of lighter deposition appear blue.
- The following areas of the skin have a bright natural fluorescence even in the absence of aerosol deposits. Brightness in these areas does not indicate a problem with the garment system:
 - Backs of the elbows
 - Palms and soles of the feet
 - Toenails and fingernails
 - White lint from garment or underclothing
- Pre-test black light photos of each test participant are included for comparison to post-test photos.

6



Ensemble Components

The following items were common to all of the tested garment configurations:

- Briefs and black athletic socks
- Butyl gloves with liners
- Combat boots with AFS overboots
- JSGPM mask
- Balaclava

7



Test Schedule (10 tests over 4 days)

Date	Day 1 Tuesday 4/5/2011			Day 2 Wednesday 4/6/2011			Day 3 Thursday 4/7/2011			Day 4 Friday 4/8/11
Sequence Number	1	2	3	4	5	6	7	8	9	10
RTI Test #	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
Test Participant	#8	#7	#9	#8	#7	#13	#8	#7	#9	#7

8



Detailed Test Matrix (from LEHP)

	Tues 0920	Tues 1100	Tues 1330	Wed 0900	Wed 1100	Wed 1330	Thurs 0830	Thurs 1100	Thurs 1330	Fri 0800
Gen 6 Fixed Hood-SPM	8							9		
Gen 6 Fixed Hood- 31B			9	8						
Gen 6 Fixed Hood- 78C		7		7						
Gen 6 Detachable Hood- 31B								7		7
Gen 6 Detachable Hood- 78C						13	8			
Gen 6 Carbon Undergarment- Collar 43Y			9					7		
Gen 6 Carbon Undergarment- Collar 63A		7				13			9	
Gen 6 Carbon Undergarment- Funnel 43Y				8						7
Gen 6 Carbon Undergarment- Funnel 63A					7		8			
Gen 6 Carbon Cuffs	8									
JSGPM mask and balacava	X	X	X	X	X	X	X	X	X	X
7 mil butyl with cotton liner	X	X	X	X	X	X	X	X	X	X
AFS Overboot	X	X	X	X	X	X	X	X	X	X

9

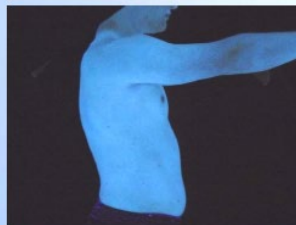


Background UV Photos Test Participant #7



10

Background UV Photos; Test Participant #7



11

Background UV Photos; Test Participant #8

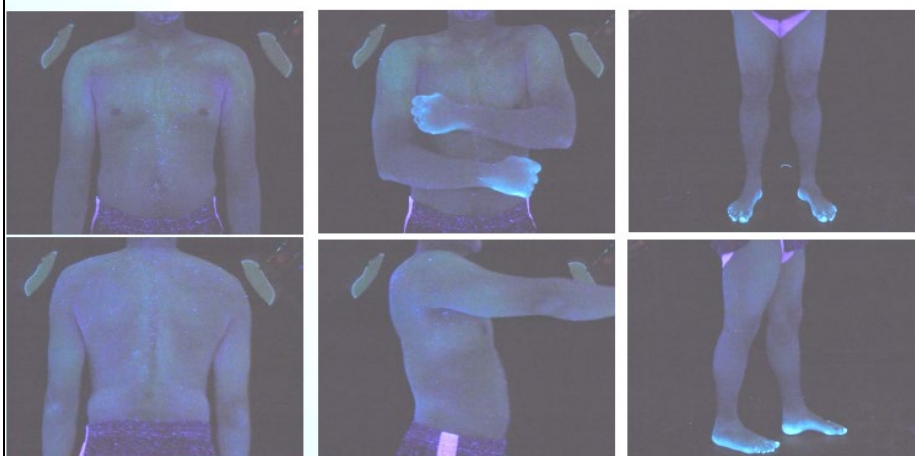


12

Note the presence of lint on the head and face. Also note a slight yellowing that should not be confused with aerosol deposits in the post-test photos.



Background UV Photos; Test Participant #8



13

Pre-test photos. Lint visible on body. Also note a slight yellowing that should not be confused with aerosol deposits in the post-test photos.



Background UV Photos; Test Participant #9



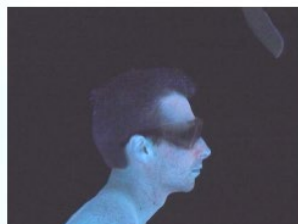
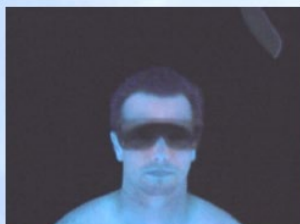
14

Background UV Photos; Test Participant #9



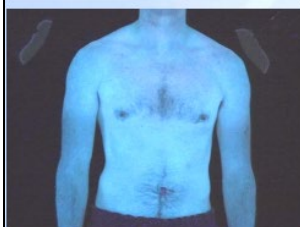
15

Background UV Photos; Test Participant #13



16

Background UV Photos; Test Participant #13



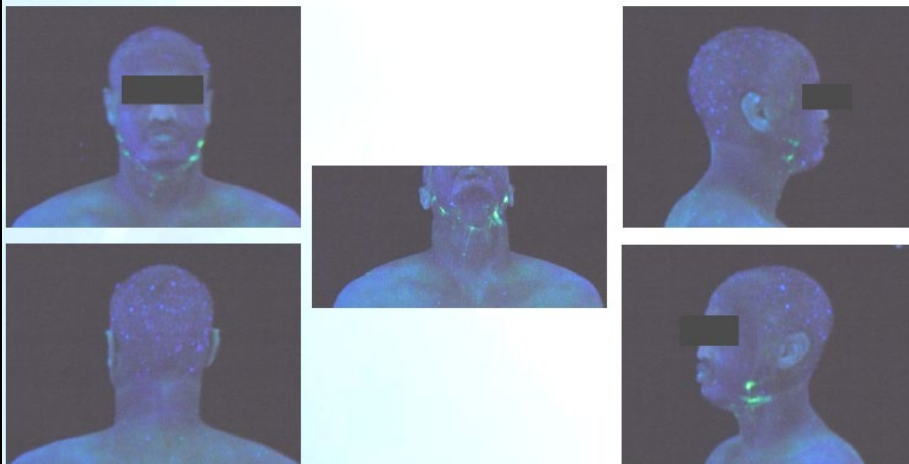
17

Test 1 (RTI 1958); Pre-Test Photos



18

Test 1 (RTI 1958); UV Photos: Head and Neck



Several areas of high aerosol deposition are visible on neck, side of face and head.

19

Test 1 (RTI 1958); UV Photos: Torso and Arms

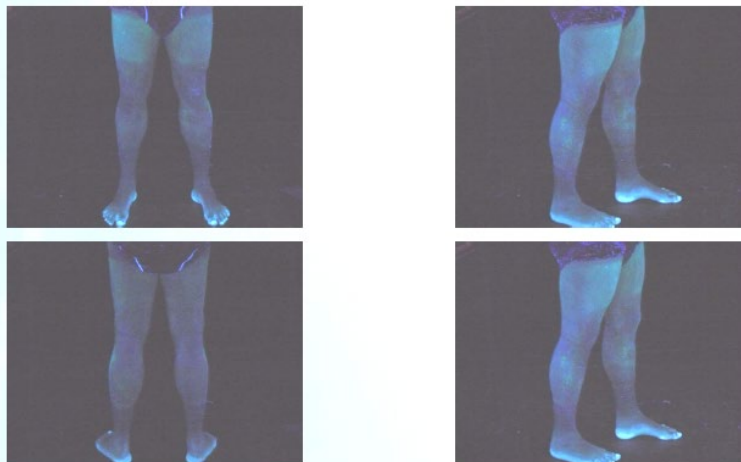


20

Aerosol deposition was clearly evident on the torso; heaviest on lower left abdomen. After doffing, LEHP personnel discovered that there was a small breach on the integration panel because the Velcro was closed improperly.



Test 1 (RTI 1958); UV Photos: Legs



21

Aerosol deposition was evident on the lower and upper legs.

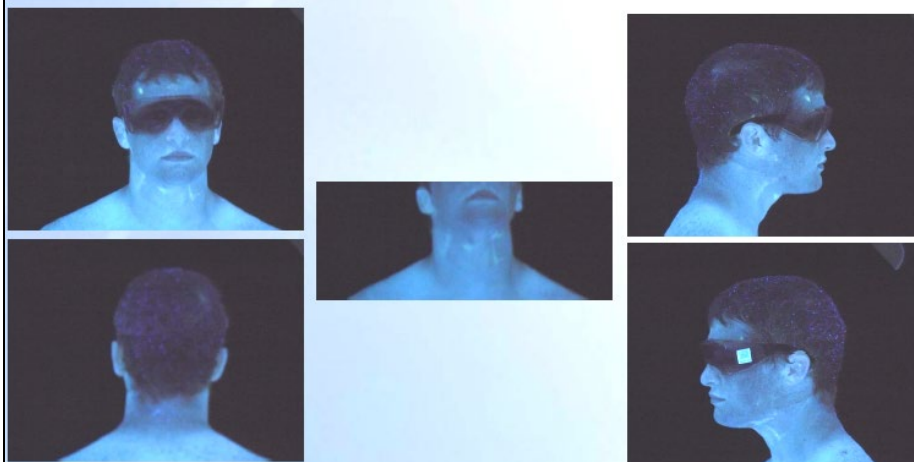


Test 2 (RTI 1959); Pre-Test Photos



22

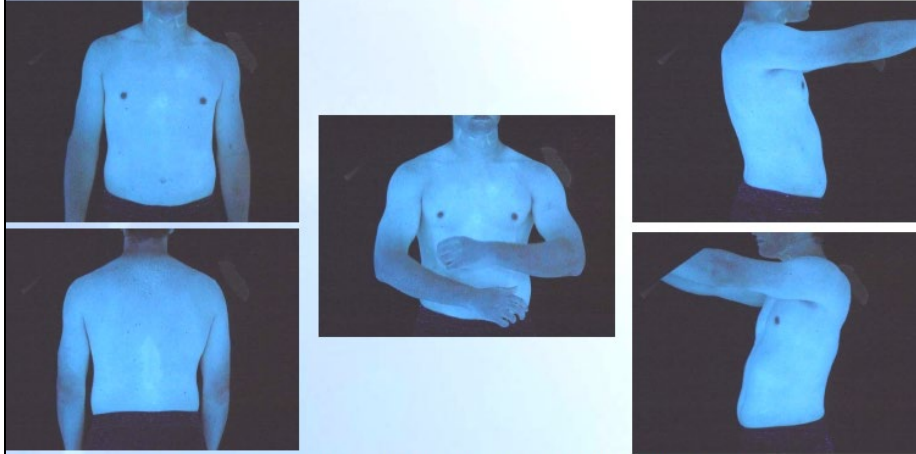
Test 2 (RTI 1959); UV Photos: Head and Neck



23

Various areas of aerosol deposition evident on neck and head. Note the outline of the mask strap is evident below the ears.

Test 2 (RTI 1959); UV Photos: Torso and Arms



24

Torso and arms were relatively clean; brightness at small of back may denote low level of aerosol deposition.



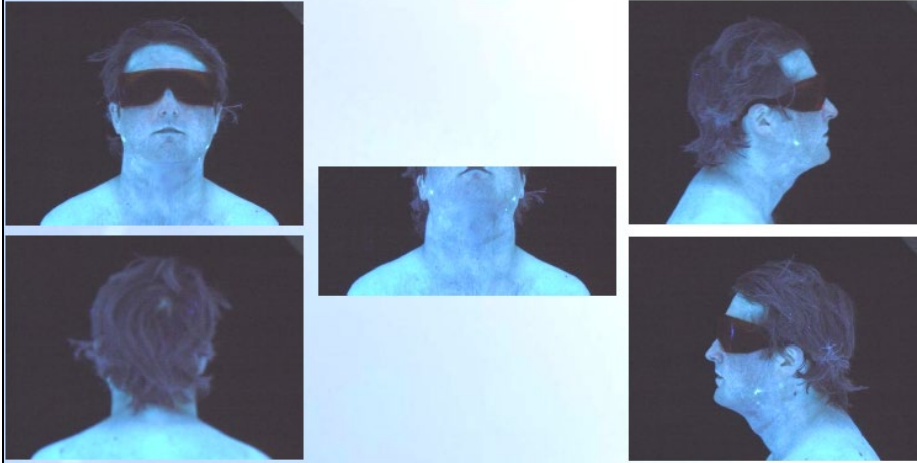
Test 3 (RTI 1660); Pre-Test Photos



26



Test 3 (RTI 1660); UV Photos: Head and Neck

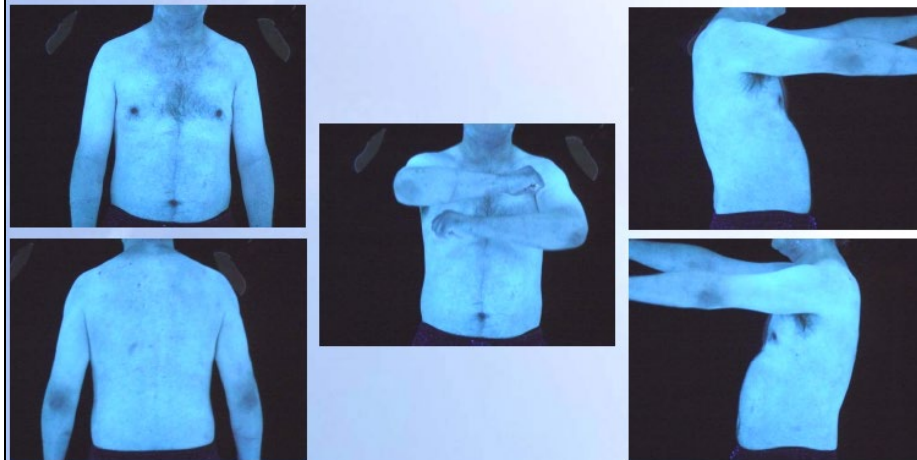


27

Some aerosol deposition is evident along the mask line.



Test 3 (RTI 1660); UV Photos: Torso and Arms

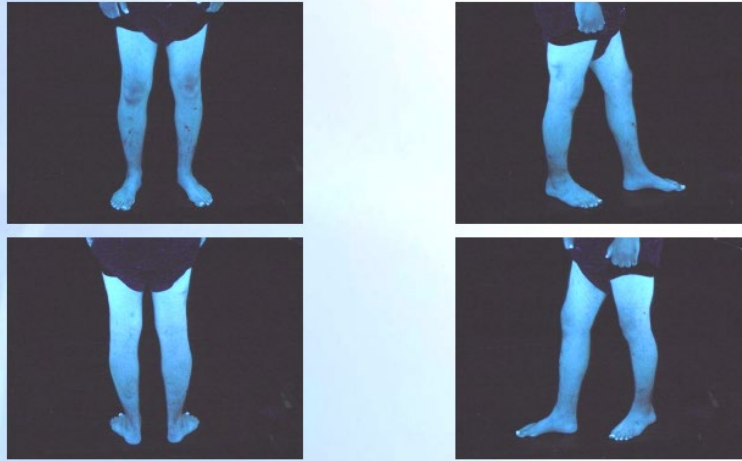


28

The arms and torso appeared clean.



Test 3 (RTI 1660); UV Photos: Legs



The legs appeared clean.

29

Test 4 (RTI 1661); Pre-Test Photos



30

Test 4 (RTI 1961); UV Photos: Torso and Arms

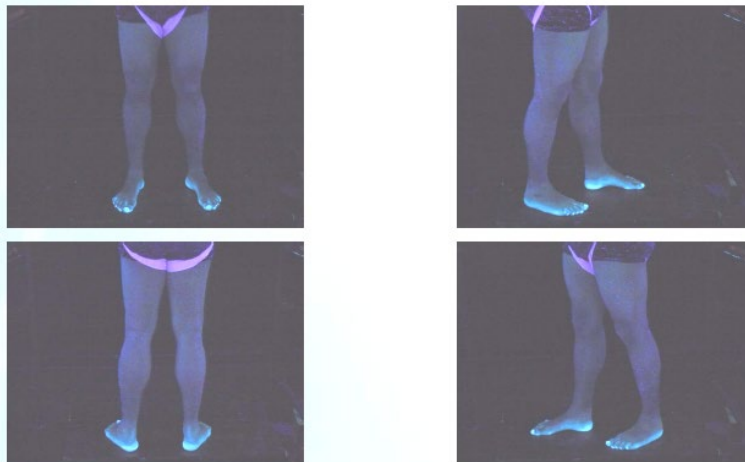


32

Torso and arms look clean. (Note that yellow cast on torso was observed in the pre-test background photographs.)



Test 4 (RTI 1961); UV Photos: Legs



33

The legs appear clean.



Test 5 (RTI 1962); Pre-Test Photos



34

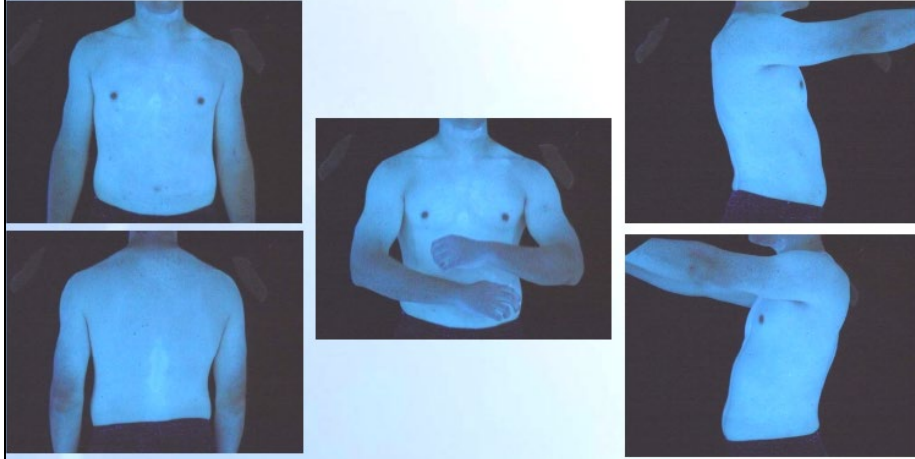
Test 5 (RTI 1962); UV Photos: Head and Neck



35

Some small areas of light deposition evident along mask line.

Test 5 (RTI 1962); UV Photos: Torso and Arms

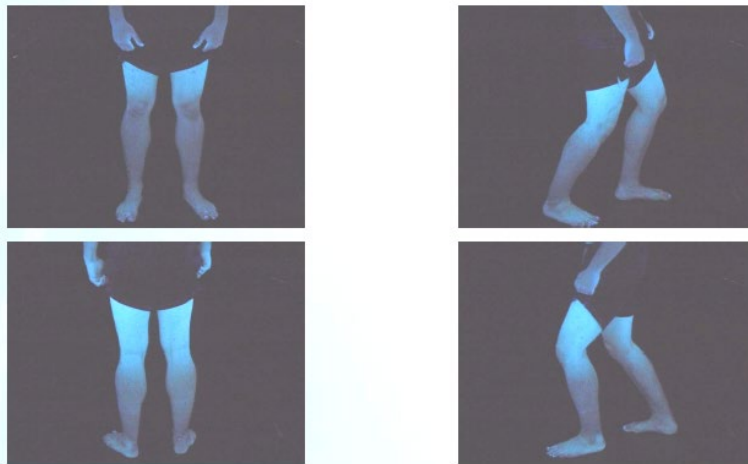


36

Torso and arms were relatively clean; brightness at small of back may denote low level of aerosol deposition.



Test 5 (RTI 1962) UV Photos: Legs



37

The legs appeared clean.

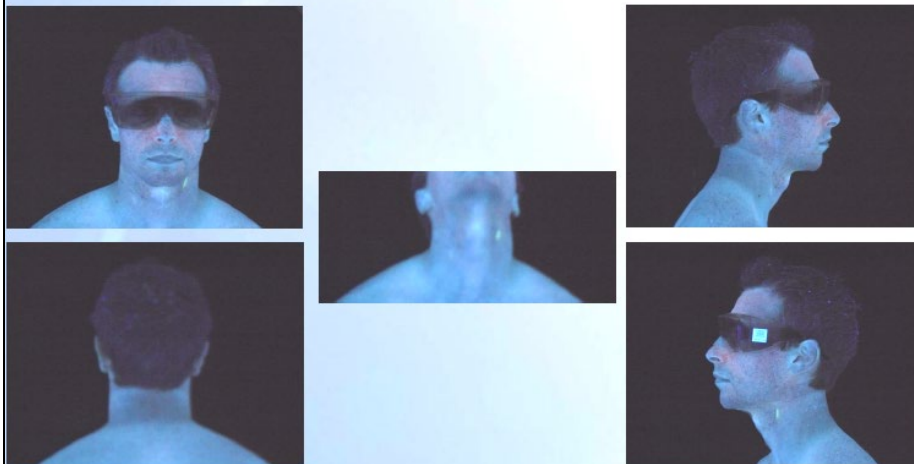


Test 6 (RTI 1963); Pre-Test Photos



38

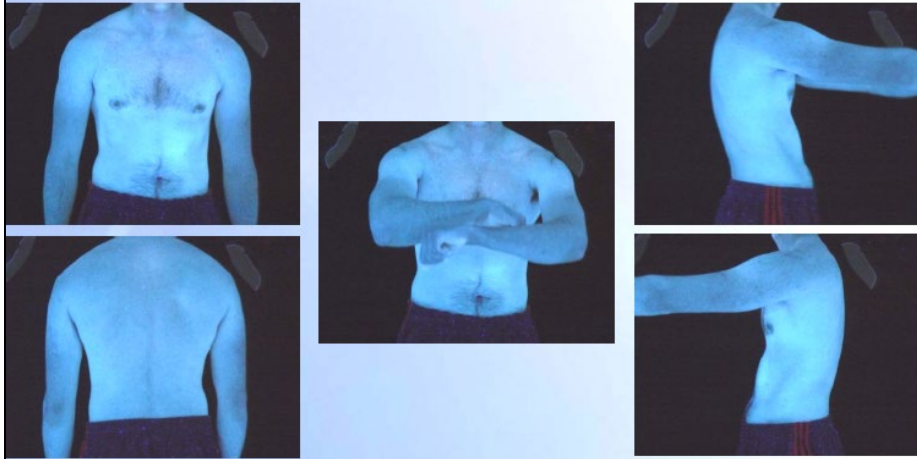
Test 6 (RTI 1963); UV Photos: Head and Neck



39

Aerosol deposition was evident on the neck with a small spot on the left side of neck.

Test 6 (RTI 1963); UV Photos: Torso and Arms

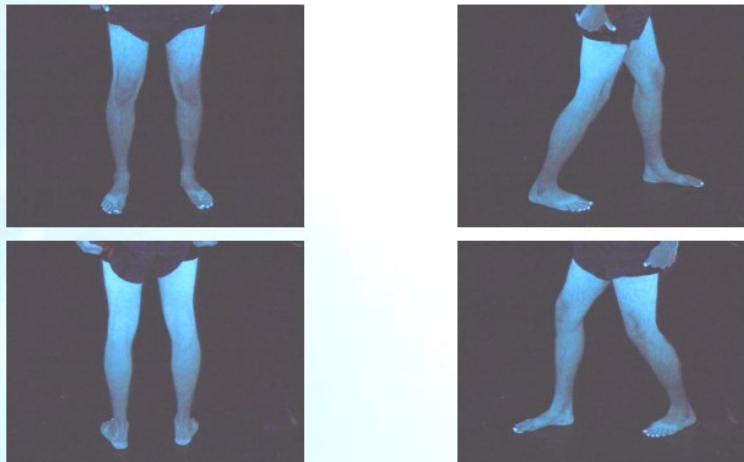


40

The torso and arms appeared clean.



Test 6 (RTI 1963); UV Photos: Legs



41

The legs appeared clean.

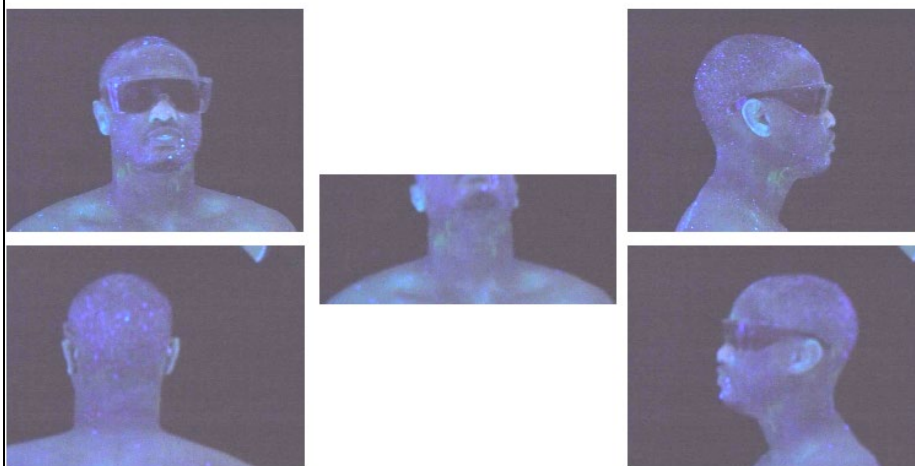


Test 7 (RTI 1964); Pre-Test Photos



42

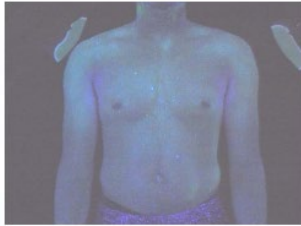
Test 7 (RTI 1964); UV Photos: Head and Neck



43

Some aerosol deposition evident on front of neck.

Test 7 (RTI 1964); UV Photos: Torso and Arms

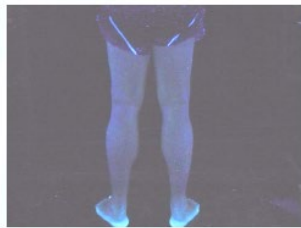


44

The torso and arms look clean. (The yellowing on the torso was noted in the pre-test background photographs.)



Test 7 (RTI 1964); UV Photos: Legs



45

The legs appeared clean.

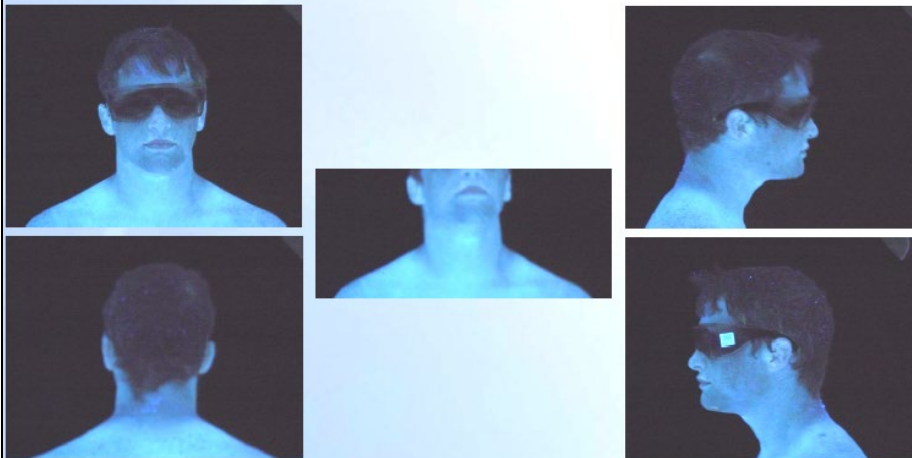


Test 8 (RTI 1965); Pre-Test Photos



46

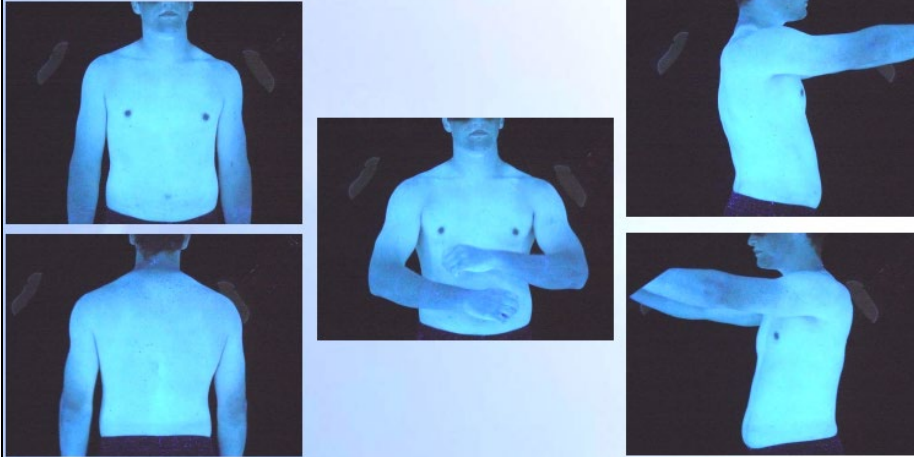
Test 8 (RTI 1965); UV Photos: Head and Neck



47

Head and neck appeared clean with perhaps a small amount of aerosol deposition at front of neck.

Test 8 (RTI 1965); UV Photos: Torso and Arms

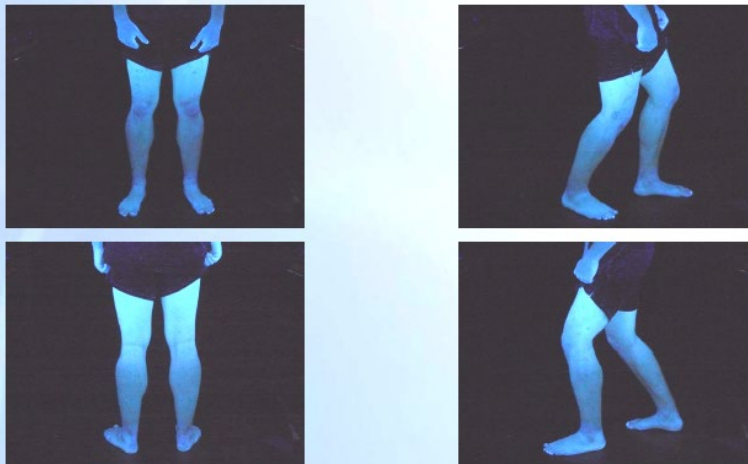


48

The torso and arms appeared relatively clean.



Test 8 (RTI 1965); UV Photos: Legs



49

The legs appeared clean.

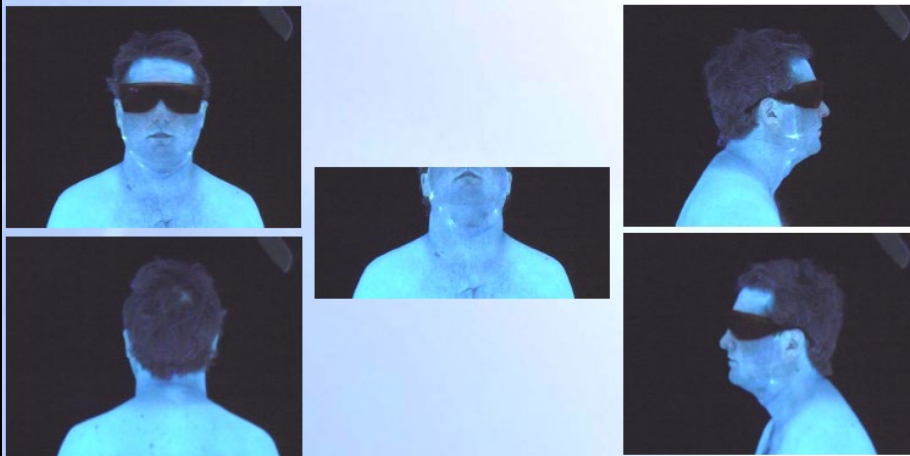


Test 9 (RTI 1966); Pre-Test Photos



50

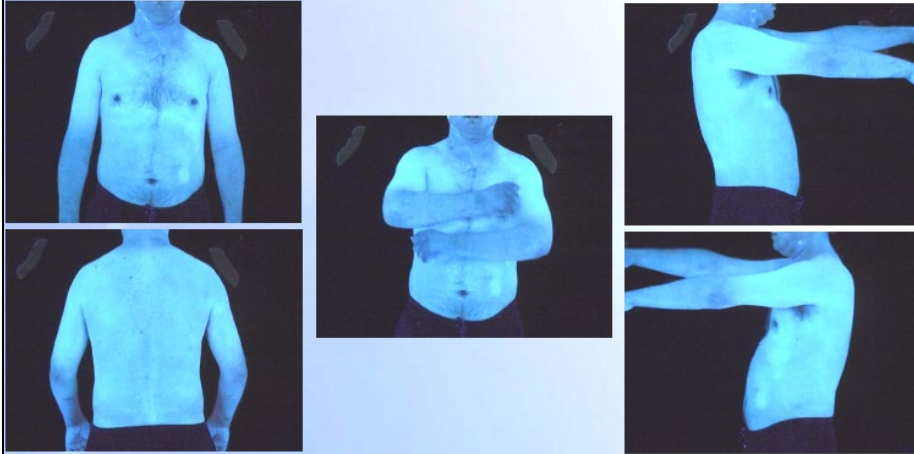
Test 9 (RTI 1966); UV Photos: Head and Neck



51

Several areas of aerosol deposition evident along hood/mask interface.

Test 9 (RTI 1966); UV Photos: Torso and Arms

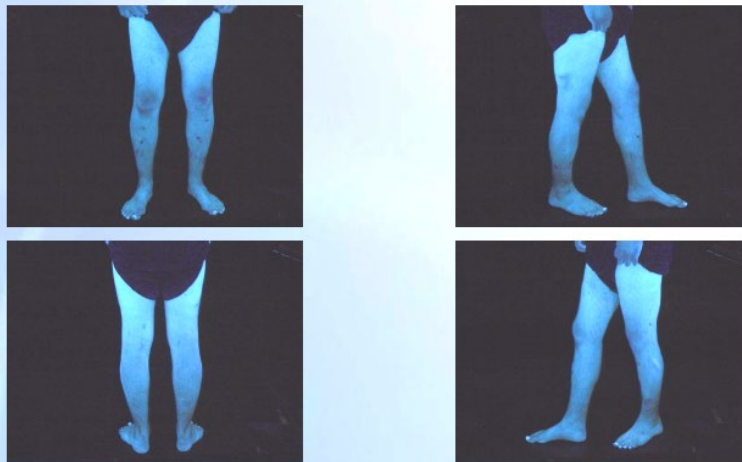


52

The torso and arms appeared relatively clean; light deposit at lower left chest.



Test 9 (RTI 1966); UV Photos: Legs



53

Some aerosol deposition evident on lower left leg.

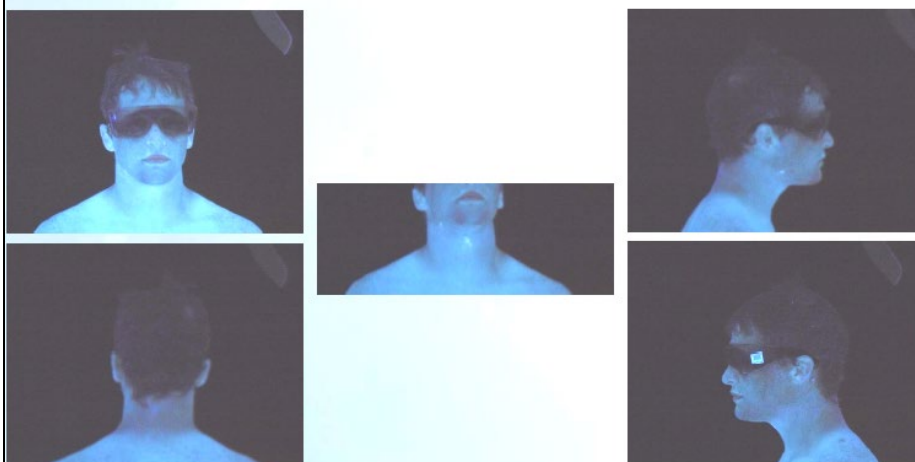


Test 10 (RTI 1967); Pre-Test Photos



54

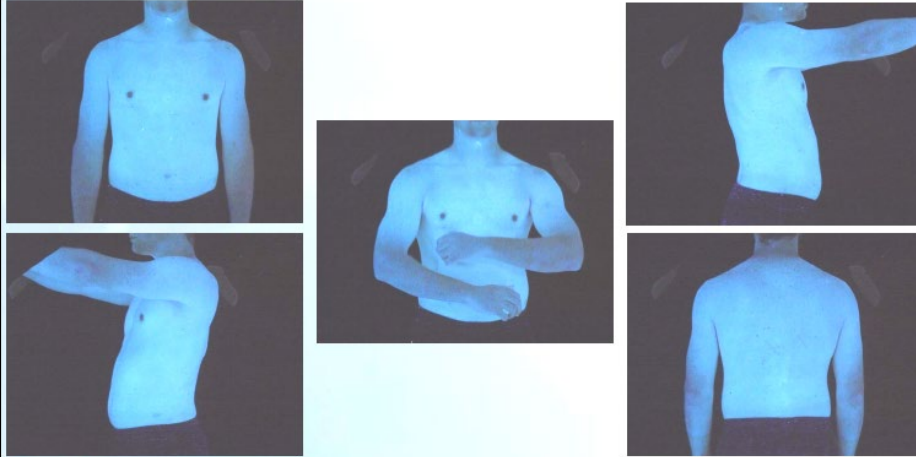
Test 10 (RTI 1967); UV Photos: Head and Neck



55

Aerosol deposition at front of neck was evident.

Test 10 (RTI 1967); UV Photos: Torso and Arms

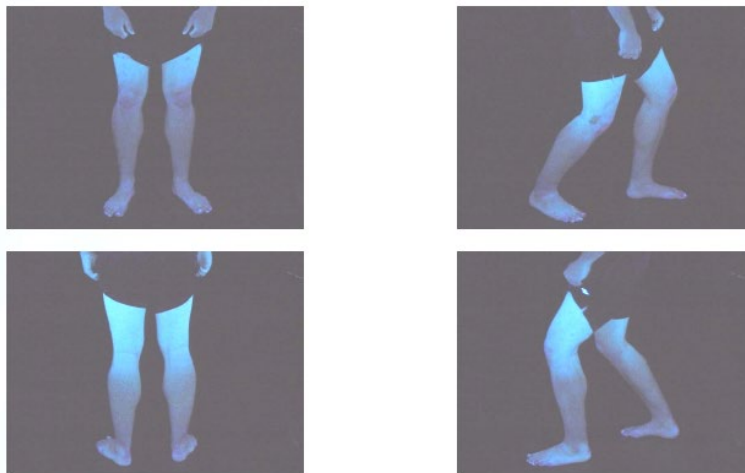


56

The torso and arms appeared relatively clean.



Test 10 (RTI 1967); UV Photos: Legs



57

The legs appeared clean.



Summary

- The tests ran smoothly with no significant donning, doffing or test condition issues.
- Overall, the two-layered configurations (Tests 2-10) were characterized as having very low aerosol deposition over most of the underlying body (based on black light viewing only). Without the inner layer (Test 1), aerosol deposition on the body was evident.
- For the head and neck areas, varying degrees of deposition were seen ranging from heavy in Test 1 to very light deposition (e.g., Test 8).

58



Donning Procedures; general approach

1. Don the briefs and socks.
2. Don the black inner layer trousers (not used in Test 1).
3. Don the outer layer trousers.
4. Put on the combat boots positioning the cuffs of the black liner inside combat boots. Lace and tie combat boots.
5. Don AFS overboot and secure the AFS closures.
6. Position outer layer garment legs over the AFS and secure the hook and loop closures.
7. Test participant inserts earplugs.
8. Don glove liners
9. Don inner layer coat (not used in Test 1).
10. Don the outer layer coat; secure the coat and trouser zipper and closures.
11. Don butyl rubber gloves. Carbon wrist cuff worn over cotton liner and under butyl glove. Shell is secured over butyl glove.
12. Balaclava hood positioned on JSGPM before donning.
13. Don JSGPM. Once secured in place, balaclava is pulled over head and tucked inside jacket.
14. Pull up the outer hood and secure.

59



Doffing Procedures; general approach

1. Spray the entire ensemble with a light water mist.
2. Using damp sponges, decon the ensemble from head to toe.
3. Open the hook and loop wrist and ankle closures.
4. Remove butyl gloves.
5. Undo the ankle closure and unhook the loops securing the AFS.
6. Starting with the right, the test subject steps out of the AFS.
7. De-lace the combat boots.
8. Open hook and loop closures at the neck, and unhook the filter retention straps.
9. Decon along the coat zipper flap.
10. Unzip the coat zipper completely.
11. With an outward turn, remove the hood over the head.
12. Doff the coat and trousers in one motion by pulling the coat off the shoulders and arms and down to the ankles.
13. Starting with the right, the test subject steps out of the trousers and combat boots.
14. Starting from the back, roll the balaclava over head and position on top of JSGPM face piece.
15. Unzip the black inner layer shirt completely and pull shirt off the shoulders and arms.
16. With an outward roll, pull the inner layer pants down to the ankles.
17. Starting with the right, the test subject steps out of the pants.
18. Encapsulate the mask in the balaclava, then loosen the lower mask straps, and remove the mask over the head.
19. Remove the glove liners and re-glove with disposable gloves.

Appendix E

LEHP Contaminated Doffing Planning Notes

Attendees:

LEHP: K. Hultzapfle, J. Venafro

NCTRF: S. Proodian

Hazmat Test Team: Miguel Vigil, Fred Bolton

Test participants (TPs):

TP-#1

- TP approved for testing based on availability: Weight 192 is within JPACE Size 40 weight range (185-200). Height is 74", which is two inches above the regular JPACE, size 40 height chart (68"-72").
- Subject measurements:

Body Location	Measurement
Neck	17
Chest	42
High point to waist	25
Waist—natural	36
Hip	41
CB—Sleeve Length—bent	35
CB—Sleeve Length—straight	33 ½
Raglan Sleeve Length	30
Cross Shoulder	20 ½
Back Length	22 ½
Inseam	34
Outseam	42

TP-#2

- TP approved for testing based on availability: Weight 170 JPACE Size 40 weight range (185-200). Height is 67", which is one inch below the regular JPACE, size 40 height chart (68"-72").
- Subject measurements:

Body Location	Measurement
Neck	16
Chest	43 ½
High point to waist	23 ½
Waist—natural	35
Hip	30
CB—Sleeve Length—bent	32
CB—Sleeve Length—straight	31
Raglan Sleeve Length	29
Cross Shoulder	19
Back Length	20 ½
Inseam	33 ½
Outseam	39 ½

Test Schedule: Initial matrix was adjusted as testing proceeds.

	Tues	Tues	Tues	Wed	Wed	Wed	Thurs	Thurs	Thurs
	Dry Run	1400	1700	1100	1400	1530	0830	1100	1100
Gen 6 Fixed Hood-31B	1	1		1					
Gen 6 Fixed Hood-78C			1					2	
Gen 6 Detachable Hood-31B							2		2
Gen 6 Detachable Hood-78C					1	1			
Gen 6 Carbon Undergarment-Collar 43Y	1	1					2		
Gen 6 Carbon Undergarment-Collar 63A			1		1				
Gen 6 Carbon Undergarment-Funnel 43Y				1					2
Gen 6 Carbon Undergarment-Funnel 63A						1		2	
JSGPM mask and balaclava	X	X	X	X	X	X	X	X	X
JB1GU Glove	X	X	X	X	X	X	X	X	X
AFS Overboot	X	X	X	X	X	X	X	X	X

Test Item Descriptions:

Gen6 Two-Piece—Fixed Hood (G6FH)

Design: Two-piece jacket and pant with attached hood. Designed to fit the JSGPM. Features include canister straps, two front neck flaps, an asymmetrical center front zipper, zip fly, articulated elbows and knees, knee-pad pocket with removable knee pad, elbow abrasion patches, waist cinch tabs, zipper pull tab, shoulder retention harness, and hood stowage system.

Materials: 78C and 31B

Gen6 Two-Piece—Detachable Hood (G6DH)

Design: Two-piece jacket and pant with a zippered removable hood. Designed to fit the JSGPM. Features include canister straps, two front neck flaps, an asymmetrical center front zipper, zip fly, articulated elbows and knees, knee-pad pocket with removable knee pad, elbow abrasion patches, waist cinch tabs, zipper pull tab, shoulder retention harness, and hood stowage system.

Materials: 78C and 31B

Gen6 Carbon Undergarment—Collared Neck (G6CCN)

Design: Fitted two-piece shirt and trouser with knit wrist and self ankle cuffs with center front asymmetrical zipper. The neck has a Velcro collar style. Trouser is pull on design with knit waistband.

Materials: 63A and 43Y (stretch)

Gen6 Carbon Undergarment—Funnel Neck (G6CFN)

Design: Fitted two-piece shirt and trouser with knit wrist and self ankle cuffs with center front asymmetrical zipper. The neck has funnel style with Velcro tab at zipper termination. Trouser is pull on design with knit waistband.

Materials: 63A and 43Y (stretch)

Gen6 Balaclava

Design: Balaclava style hood with elasticized opening at face to accommodate the JSGPM mask. Balaclava comes to mid upper chest and mid upper back with shaped areas for shoulders. Two covered neoprene inserts are sewn into the temple areas to fill in the

Materials: 63A and 43Y (stretch)

Test #1 Tuesday – April 19th

1000 TEST – Dry Run

Configuration:

Gen6 Two-piece Fixed Hood 31B with 43Y Carbon Collar version, Gen6 Balaclava (TP # 1)

TP wore 2004 JSGPM mask

JB1GU

Combat boots with AFS overboots

Knee pads worn in knee-pad pocket.

Garment worn at FAST once, 2/2.

Donning: N/A

Test: N/A

Doffing:

- Slight changes made to the doffing procedure from FAST.
- Overall procedure seems good.

Black lighting:

- N/A

Recommendations for next run:

- Use updated doffing procedure.

Test #1 Tuesday – April 19th

1400 TEST –

Configuration:

Gen6 Two-piece Fixed Hood 31B with 43Y Carbon Collar version, Gen6 Balaclava (TP # 1)

TP wore 2004 JSGPM mask

JB1GU

Combat boots with AFS overboots

Knee pads worn in knee-pad pocket.

Garment worn at FAST once, 2/2.

Donning:

- Subject is on the tall side, medium regular is a little short.
- Jacket sleeves slightly short.
- Pants seem long enough.
- Less bulk is observed at the waist because the subject is taller.

Test: Subject covered in simulant.

Doffing:

- Right pant leg is rolled higher than left, and is above the combat boot.
- Integration panel was opened after the fly was wiped down and opened.
- Lowered the hood before opening the center front Velcro.
- Assistant 1 realized that the jacket could not be pulled off and returned to front of subject to open center front Velcro.
- Balaclava is pulled all the way over the face, not rolled up at head like directed.
- After doffing trouser subject stepped on the contamination line, not over it.

Black lighting:

- Face looks clean
- Hands clean
- Specks of orange on the body but not concentrated to one area, are believed to be fibers.
- Smudge of blue on arm pit area on left and right, may be sweat.

Recommendations for next run:

- Split up directions for opening the center front zipper, fly and center front Velcro.

Test #2 Tuesday – April 19th

1700 TEST –

Configuration:

Gen6 Two-piece Fixed Hood 78C with 63A Carbon collar version, Gen6 Balaclava (TP #1)

TP wore 2004 JSGPM mask

JB1GU

Combat boots with AFS overboots

Knee pads worn in knee-pad pocket.

Garment worn at FAST once, garment 1/2.

Donning:

- Fit similar to test 1.

Test: Subject covered in simulant.

Doffing:

- Attendant 1 appeared to spray the garment very heavily with water.
- Check to see if there is water in the second shuffle pit.
- Balaclava rolled correctly this time.

Black lighting:

- Very bright spot of blue decon solution on top of head, probably soaked through the garment during the spray down. Spot was also visible on the balaclava and the skullcap of mask.

Recommendations for next run:

- Only do a quick spray down of the test participant, do not soak the participant.
- Second shuffle pit needs about 2” of soapy water in.

Test #3 Wednesday – April 20th

1130 TEST

Configuration:

Gen6 Two-piece Fixed Hood 31B with 43Y Carbon funnel neck version, Gen6 Balaclava (TP #1)

TP wore 2004 JSGPM mask

JB1GU

Combat boots with AFS overboots

Knee pads worn in knee-pad pocket.

Garment worn at FAST once 1/2.

Donning:

- Residual spot on top of head and on skullcap after washing from test #2.
- Canisters from test #2 are being reused, so they are put on the mask after the test subject dons the entire garment in MOPP 4.
- Stitching is coming off slightly on right Velcro on skull cap of mask.

Test: Subject covered in simulant.

Doffing:

- Assistant only used a light spray in station 1 this time.

Black lighting:

- Small smudges on left back shoulder, test participant said he felt the helper brush his shoulder during the removal process of the carbon shirt.

Recommendations for next run:

- Garments are coming out remarkably clean, perhaps try to remove the garment without conducting gross decon to see the ability to doff without this step.
- Could also set a time limit for doffing to see what can be accomplished in a limited amount of time.
- Another option would be to do a self decon.

Test #4 Wednesday – April 20th

1400 TEST –

Configuration:

Gen6 Two-piece Detachable Hood 78C with 63A Carbon collar version, Gen6 Balaclava (TP #1)

TP wore 2007 JSGPM mask

JB1GU

Combat boots with AFS overboots

Knee pads worn in knee-pad pocket.

Garment worn at FAST once 1/2.

Donning:

- First test with the detachable hood, everything fit the test participant well, just a little short like first three tests.

Test: Participant covered in simulant.

Doffing:

- Visible puddle of water on top of participant's head, sprayer may have more water coming out than usual.
- Test participant said he could feel a little water leaking onto his shoulders.

Black lighting:

- Four small drip spots on the right shoulder area. Two on front shoulder and two on back.
- One small drip spot on left back shoulder.

Recommendations for next run:

- None

Test #5 Wednesday – April 20th

1600 TEST –

Configuration:

Gen6 Two-piece Detachable Hood 78C with 63A Carbon Funnel Neck, Gen6 Balaclava (TP #1)

TP wore 2007 JSGPM mask
JB1GU
Combat boots with AFS overboots
Knee pads worn in knee-pad pocket.
Garment worn at FAST once 2/2.

Donning:

- Fits same as test #4.

Test: Subject covered in simulant.

Doffing:

- No water in the shuffle pit.
- Zipper on integration panel, part that zips to pant came unzipped from front to a little past the side. Zipper probably was not closed properly.
- The separation zipper on the integration panel to pant came apart from the center front stop starting point across center front to approximately 16-18 inches, when the assistants were opening the center front inner Velcro flap from the neck to the waist. There was no simulant contamination on the body from this issue.

Black lighting:

- Nothing seen on the body.

Recommendations for next run:

- Make sure there is water in the second shuffle pit.

Test #6 Thursday – April 21st

0915 TEST –

Configuration:

Gen6 Two-piece Detachable Hood 31B with 43Y Carbon collar version, Gen6 Balaclava (TP #2)

TP wore 2007 JSGPM mask

JB1GU

Combat boots with AFS overboots

Knee pads worn in knee-pad pocket.

Garment worn at FAST once 2/2.

Donning:

- This test participant is smaller than test participant #1.
- The fit is pretty good. A little more ease in the body than participant #1.

Test: Subject covered in simulant.

Doffing:

- Subject put his head down to look at the floor while just wearing the mask. Look for possible contamination on the chest.
- It was noted that the fan in the decontamination chamber

Black lighting:

- Nothing observed on the body.
- Test participant said that the garment felt very comfortable, hardly even started sweating. No restrictions from garment movement. Also didn't feel any moisture penetration on like other test participant did in some tests.

Recommendations for next run:

- Due to the success of the first six runs, do not perform gross decon on test #7 to see the ability to remove the subject from the garment without performing this operation. The assistant will still wipe down the critical areas with a damp sponge.

Test #7 Thursday – April 21st

1100 TEST –

Configuration:

Gen6 Two-piece Fixed Hood 78C with 63A Carbon Funnel Neck, Gen6 Balaclava (TP #2)

TP wore 2007 JSGPM mask

JB1GU

Combat boots with AFS overboots

Knee pads worn in knee-pad pocket.

Garment worn at FAST once and three times at PhilaU human factors 2/2.

Donning:

- Fit the same as test #6.
- Pull tabs on canister cords were left sticking out for easier doffing.

Test: Subject covered in simulant.

Doffing:

- No gross decon was done on this run. The subject was only wiped down when instructed in the regular doffing procedure.

Black lighting:

- There seemed to be more re-aerosolization onto the assistants, but nothing was seen on the test participant at first black light.
- Only one speck of orange simulant was seen on right side between the shoulder and pectoral muscle.
- Test participant noted no movement restrictions, the fabric felt stiffer than 31B suit. But the comfort levels are comparable in both suits.

Recommendations for next run:

- Conduct decon procedure using self decon to see the possibility of a soldier deconning himself in an emergency situation. No gross decon will be used. Damp sponges will simulate the decon wipes a soldier is issued.

Test #8 Thursday – April 21st

1400 TEST –

Configuration:

Gen6 Two-piece Detachable Hood 31B with 43Y Carbon Funnel Neck, Gen6 Balaclava (TP #2)

TP wore 2007 JSGPM mask
JB1GU
Combat boots with AFS overboots
Knee pads worn in knee-pad pocket.
Garment worn at FAST once 1/2.

Donning:

- Fit similar to test 1 and 2.

Test: Subject covered in contaminant.

Doffing:

- Test participant self doffed the garment, without conducting gross decon. He used only damp sponges to decon specific areas.
- Subject was able to remove overboots without using the hands.
- He had a little trouble removing the left canister strap.
- Subject seemed to have a little trouble removing this second foot from the combat boot while the garment was around his ankles.
- Balaclava was rolled nicely up to head.
- Had a little trouble removing the carbon trouser from the feet.
- Subject said the garment is very comfortable.

Black lighting:

- Two specks of orange near center front above pectoral muscle on right side.
- One speck further right below the pectoral muscle.
- One speck at front of shoulder.
- One specks on left elbow.
- Overall very clean.

Recommendations for next run:

- This was the last run.

Appendix F

Philadelphia University Contaminated Doffing Test [Report]—April 19-21, 2011.
(Reprint of original)

**PHILADELPHIA UNIVERSITY
CONTAMINATED DOFFING TEST
April 19-21, 2011**

Prepared by:

**Fredric N. Bolton
Miguel A. Vigil
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Hazmat Science Applications
Northern New Mexico College
Santa Fe, New Mexico
505-471-1515**

Report Date: May 31, 2011

CONTAMINATED DOFFING TESTING FINAL REPORT: PHILADELPHIA UNIVERSITY PROTOTYPE GARMENTS

April 19 – 21, 2011

EXECUTIVE SUMMARY

Hazmat Science Applications (HSA), a division of Northern New Mexico College, performed Contaminated Doffing Testing (CDT) of two PhilaU protective ensemble (PE) prototype configurations during the period April 19 – 21, 2011. CDT uses a proprietary mixture of water-soluble and -insoluble particulate materials to test the extent to which a PE can prevent or minimize contamination transfer to the wearer during decontamination and doffing. For this series of tests, the PE was fitted and donned by a test subject, and the mixture was then applied to the PE outer surfaces. Following PE removal of the ensemble according to a PhilaU-supplied script, the subject was examined for evidence of the particulate materials on head, neck, face, hands and the surface of a test undergarment worn beneath the protective ensemble.

Eight ensembles in two configurations were tested following garment familiarization review with the HSA staff. Decontamination and doffing was performed for each test run using a PhilaU-provided script. The seventh test run was performed with minimal gross decon, and the final run required the test subject to remove the contaminated ensemble without assistance.

All of the PhilaU PE prototypes effectively prevented or minimized contamination simulant transfer to unprotected skin and/or duty uniform beneath the ensemble protective barrier. Three ensembles were found to be entirely free of contamination transfer, while the remaining displayed limited and faint evidence of contamination simulant transfer. Relative to nearly 10 years of experience, HSA staff concluded that the PhilaU prototypes performed as well as or better than any other PE configuration subjected to HSA CDT protocols to date.

This CDT report includes: 1) digital images of the protective ensemble configuration; 2) digital images of the HSA test garments used for evaluation purposes; 3) scanned images of the PhilaU CDT data sheets; and 4) video records of several test runs, which are included as separate attachments/deliverables.

CONTAMINATED DOFFING TESTING FINAL REPORT: PHILADELPHIA UNIVERSITY PROTOTYPE GARMENTS

April 19 – 21, 2011

INTRODUCTION

This report presents the results of contaminated doffing testing (CDT) activities performed at Santa Fe, NM for several PhilaU prototype protective ensembles. Other report items, e.g., photographs and video records, are provided separately.

The purpose of CDT was to determine the extent to which the prototype protective ensembles can be doffed while minimizing the amount of contamination transferred to unprotected skin or duty uniform beneath the protective ensemble barrier.

This work was performed by Hazmat Science Applications of Northern New Mexico College.

TEST METHODOLOGY

Evaluation Methodology

The HSA evaluation methodology seeks to qualitatively identify the presence of simulant residue patterns on unprotected skin or duty uniform, which could be attributed to specific actions or events that take place during implementation of scripted decontamination procedures. The HSA test undergarment can display a variety of end states with respect to transferred contaminants in both wet and dry form: smears, smudges, or touches by contaminated hands or fingers; drags or brushes from inadvertent rubbing between contaminated and uncontaminated surfaces; drips, runs, or dots attributed to leaks or other transfer of wetted contaminant onto unprotected surfaces; "dotting" in the form of individually identifiable particles of dry, colored simulant; "hazing" in the form of faint areas of dry simulant visible under black light illumination and having little or no discernible pattern; or "clean" with respect to a noticeable lack of any of the states previously described.

Test Schedule

All the PhilaU CDT testing was performed during the period April 19 – 21, 2011.

Test Subjects

The use of human beings in testing is regulated by 45CFR46, and Northern New Mexico College (NNMC) is registered with the U.S. Office of Human Research Protection (OHRP) under Assurance Number IORG0005540. The protocols (including provisions for subject recruiting informed consent, confidentiality, and privacy) used in this study were reviewed and approved by the NNMC Institutional Review Board.

Test Protocol

The HSA test protocol, HSA11-002:TP, is summarized below:

1. The HSA co-Principal Investigator completed the Informed Consent process.



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CONTAMINATED DOFFING TESTING FINAL REPORT: PHILADELPHIA UNIVERSITY PROTOTYPE GARMENTS

April 19 – 21, 2011

2. The participant donned a test undergarment (disposable white coverall).
3. The donned test undergarment was marked in several areas (e.g., shoulders, elbows, navel, and knees) for post-test evaluation purposes.
4. The participant was assisted in donning the prescribed protective ensemble (ensemble components, boots, over-boots, respirator, and gloves).
5. Digital images were taken of the dressed participant.
6. The participant was placed in an enclosure and the simulant material was applied to the protective ensemble.
7. The participant was escorted to the HSA processing line.
8. Decontamination processing was completed according to the PhilaU-provided script.
9. The participant and test garment were inspected and evaluated.
10. Data records were collected and photographs taken of the evaluated undergarment.

Digital Photography and Video Recordings

Still and moving images included:

1. Pre-test images of the participant to document the protective ensemble configuration.
2. Video recordings of decontamination processing line activities.
3. Post-test images of the marked test undergarments following UV examination.

Test Data

Test data include a review of residual contamination simulant found to be present on either the test subject's skin (head, neck, face, hands) or on the test garment worn beneath the protective ensemble. Scans of the data sheets are presented as a part of this report. Other data include images and/or video records.

TEST RESULTS

Introduction

HSA used a proprietary mixture of water-soluble and –insoluble fluorescent components for this evaluation. In solution, the water-soluble component exhibits a distinct color change under black light illumination, while the optical properties of the insoluble component remain unaffected. The insoluble component imparts the characteristic orange hue to the dry simulant mixture. Upon wetting, the water-soluble component exhibits a marked color change, which makes it possible for certain conclusions to be drawn about the nature of residual contamination on the test undergarments, as well as the possible source(s) of that contamination. Following simulant application, the characteristic hue of the simulant was clearly visible on protective ensemble surfaces at the start of each test run.

Test Results

Refer to Table 1, Summary of Test Results, which appears at the end of this report.



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**CONTAMINATED DOFFING TESTING FINAL REPORT:
PHILADELPHIA UNIVERSITY PROTOTYPE GARMENTS
April 19 – 21, 2011**

Discussion of Test Results

Over the course of the three testing days, the processing time (in mm:ss, beginning with introduction into the doffing chamber and ending with removal of the respirator) ranged from a high of 46:13 to a low 19:50; the bulk of test runs were between 25 and 30 minutes. Most of the subjects and participants for this test are currently employed in either Santa Fe or Sandoval County Fire Departments, New Mexico, and serve as both firefighters and EMS. For the purpose of this test, HSA did not ask them to work on achieving “combat speed” with respect to decontamination and doffing procedures; however, several individuals clearly felt that the entire process could easily be performed more quickly without sacrificing effectiveness.

1. In general, each test run resulted in an undergarment that was relatively free of visible contamination (see the “Evaluation Methodology” section), whether wet or dry:
 - a. Run 1 exhibited very faint evidence of “dotting” on the lower extremities.
 - b. Runs 2, 5, & 6 were rated “clean” i.e., free of any forms of visible contamination.
 - c. Runs 3, 4, & 8 were virtually clean with faint evidence of wetted material transfer on the chest and shoulders.
 - d. Run 7 exhibited a single, small “dot” of material on the upper right shoulder, which was determined to be dry simulant material.
 - e. Hazing was not observed on any of the 8 test run undergarments.
2. Run 2 resulted in a V-shaped, quarter-sized spot of wetted material in the subject’s hair at the top of the head just behind the mask face-piece sealing surface.

CONCLUSIONS

Under test conditions, the PhilaU prototype garments performed consistently and provided substantial protection against transfer of simulant materials, either wet or dry, to unprotected skin or duty uniform surfaces:

1. The prototype ensembles can be decontaminated and doffed with minimal contaminant transfer to unprotected surfaces beneath the protective ensemble barrier.
2. By comparison with the 2009 PhilaU tests, these results strongly suggest that multiple layers (e.g., a separate, layered carbon suit beneath the protective ensemble) are beneficial in achieving wearer cleanliness upon completion of the D&D processes.
3. As seen in run #2, the ensemble interface between the jacket hood and mask face-piece is capable of being breached by the decontamination solution; it appears that the balaclava became soaked in a small area at the top of the head. The exact source of the contamination is uncertain. However, the test director and others noted that gross decon actions were extensive during this run, which also was the longest of the test runs at a total time of 46:13. A procedural change to wipe the ensemble hood of free-standing decon solution might be sufficient to eliminate this type of breach (with the assumption that the top of the hood itself was leak-free).

CONTAMINATED DOFFING TESTING FINAL REPORT: PHILADELPHIA UNIVERSITY PROTOTYPE GARMENTS

April 19 – 21, 2011

Subjectively, it is noted that the PhilaU protective ensembles performed exceptionally well. CDT methodology has been employed in various forms dating back to the 1980s, and HSA staff have been directly engaged in those activities since 2002. During this time, a variety of military PE configurations have been the subject of CDT activities, including bomb suits, coveralls, and multi-piece ensembles. Several of these configurations have performed reasonably well with respect to CDT goals (to test the ability of the PE to prevent or minimize contamination transfer to unprotected skin/uniform beneath the protective barrier); nonetheless, HSA concluded that the PhilaU prototypes performed as well or better than other PE configurations subjected to the CDT process.

SUGGESTIONS / RECOMMENDATIONS

HSA has no recommendations with respect to the test results and overall performance of the PhilaU prototype ensembles. If possible, it would be informative to formally review the performance of the PhilaU ensembles in comparison with that of other ensembles previously studied by HSA staff.

With respect to future studies, it would be logical and/or useful to perform a series of follow-on tests:

1. Using military personnel with draft procedures, such as FM 3-11.5, or equivalent. This would allow the system (people, procedure, and equipment) to be validated with respect to its ability to protect the wearer as intended.
2. With the objective of ensuring that appropriate “combat speeds” can be achieved for D&D actions under field conditions.
3. To challenge the ensemble performance under abnormal conditions, such as a “man-down”, injured, or isolated warfighter(s).
4. To investigate whether D&D actions can be improvised under field conditions when standard D&D materials are either limited or unavailable.

TABLES

1. Summary of Results

APPENDICES

1. PhilaU CDT Data Sheets
2. Post-Donning Images
3. Test Undergarment Post-Doffing Images
4. Miscellaneous CDT Images

OTHER DELIVERABLES

1. PTZ video files for runs 1, 4, 7, & 8 (CD format with embedded player)
2. Digital images and files (CD)



Page 6 of 8
June 3, 2011



2011 PhilaU CDT Data Sheet Images

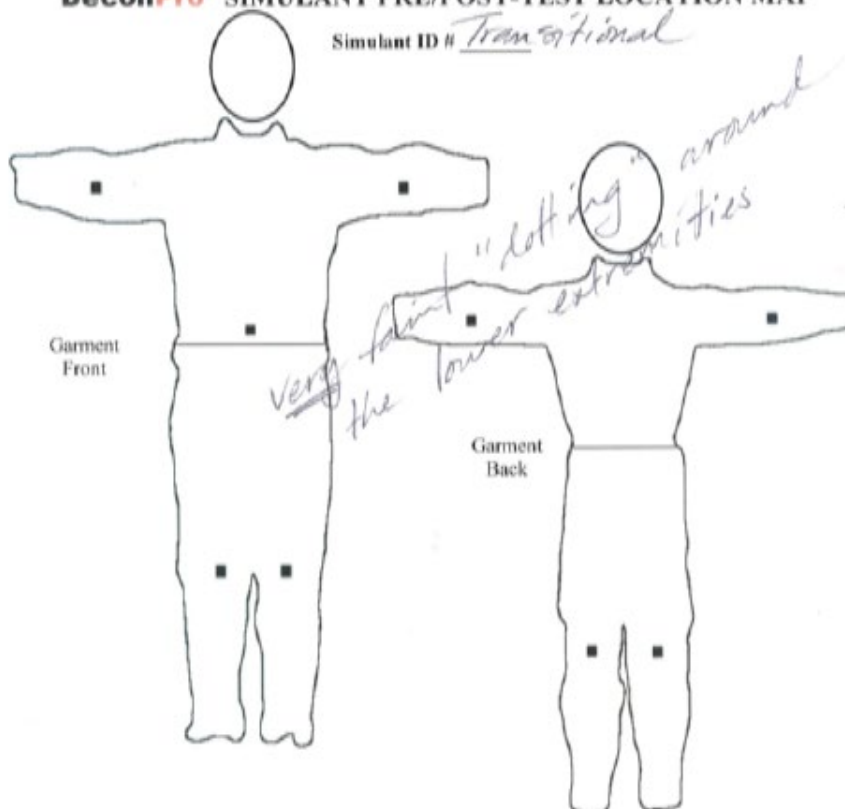


Hazmat
Science
Applications

Department/Agency: Thick U LOP Date: 4/19/11 Run # 1

DeconPro® SIMULANT PRE/POST-TEST LOCATION MAP

Simulant ID # Transitional



Note relative size and location of residual contaminants by marking the figures. Add other comments as needed:

Head, neck, & hands are clean. There is very faint evidence of dotting of orange particles, esp. lower half of body.

Checklist actions completed by (initials): JAB Date: 4/19/11

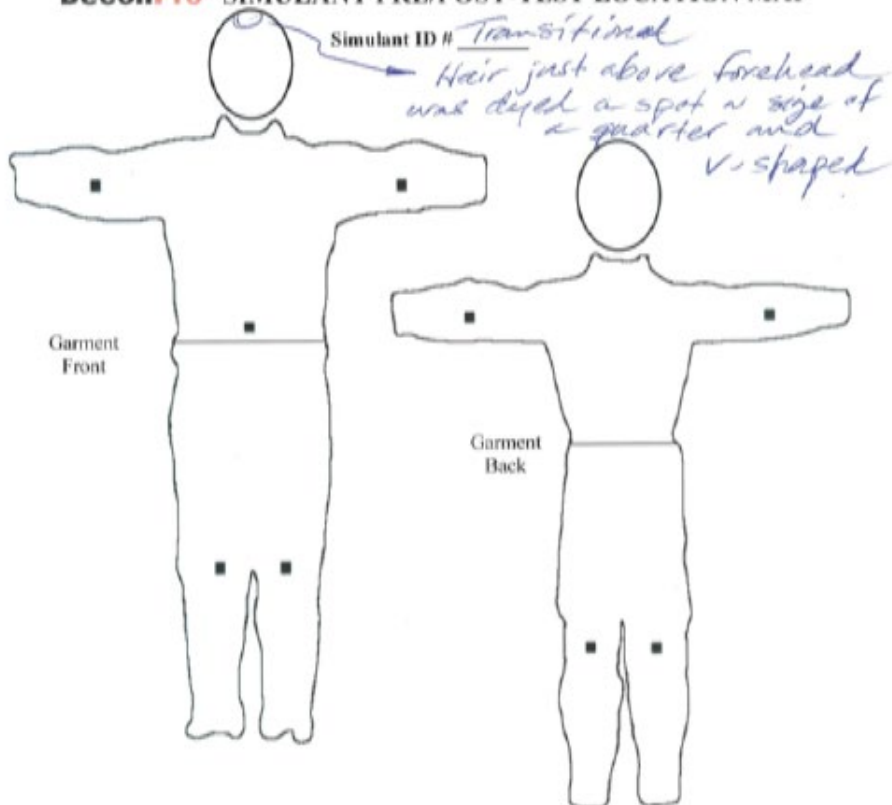
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Proprietary and Confidential (Revised 09/1908)



Hazmat
Science
Applications

Department/Agency: Philak LEAP Date: 4/19/11 Run # 2

DeconPro® SIMULANT PRE/POST-TEST LOCATION MAP



Note relative size and location of residual contaminants by marking the figures. Add other comments as needed: face, neck, & hands are clean; note the presence of v-shaped area in the hair (above); front and back appear to be free of contamination and almost no dotting.

Checklist actions completed by (initials): Jul Date: 4/19/11

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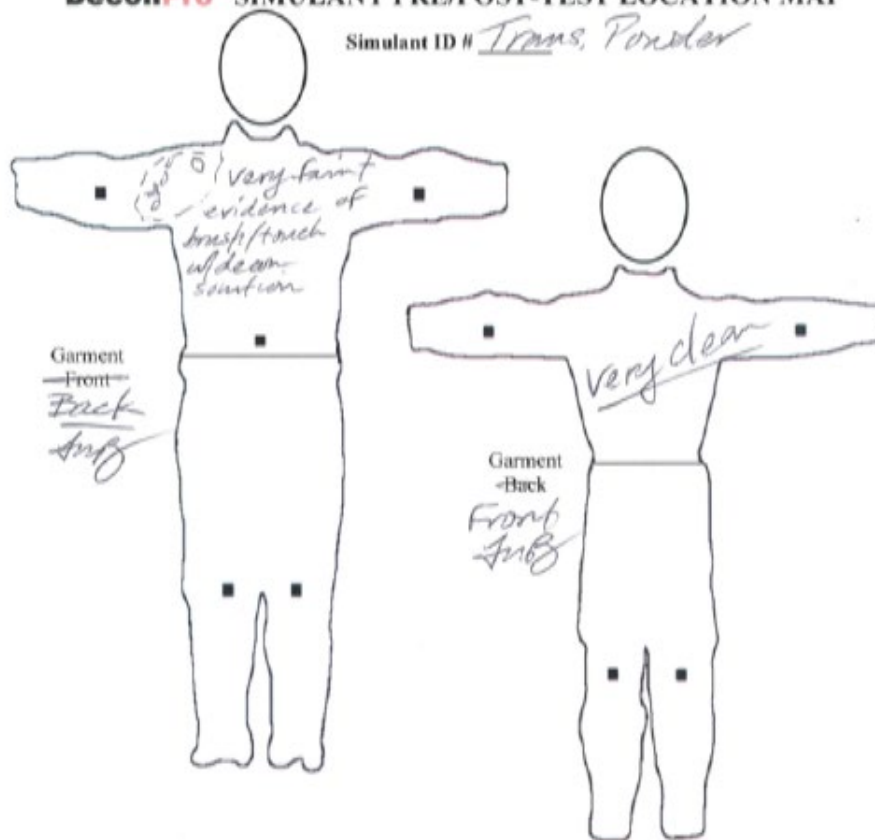


Hazmat
Science
Applications

Department/Agency: Phital/LOHP Date: 4/20/2011 Run # 3

DeconPro® SIMULANT PRE/POST-TEST LOCATION MAP

Simulant ID # Trans. Powder



Note relative size and location of residual contaminants by marking the figures. Add other comments as needed:

Head, face, & neck are clean.
very clean w/ exception of noted brush/touch
of decon solution on back of left shoulder

Checklist actions completed by (initials): JNB Date: 4/20/2011

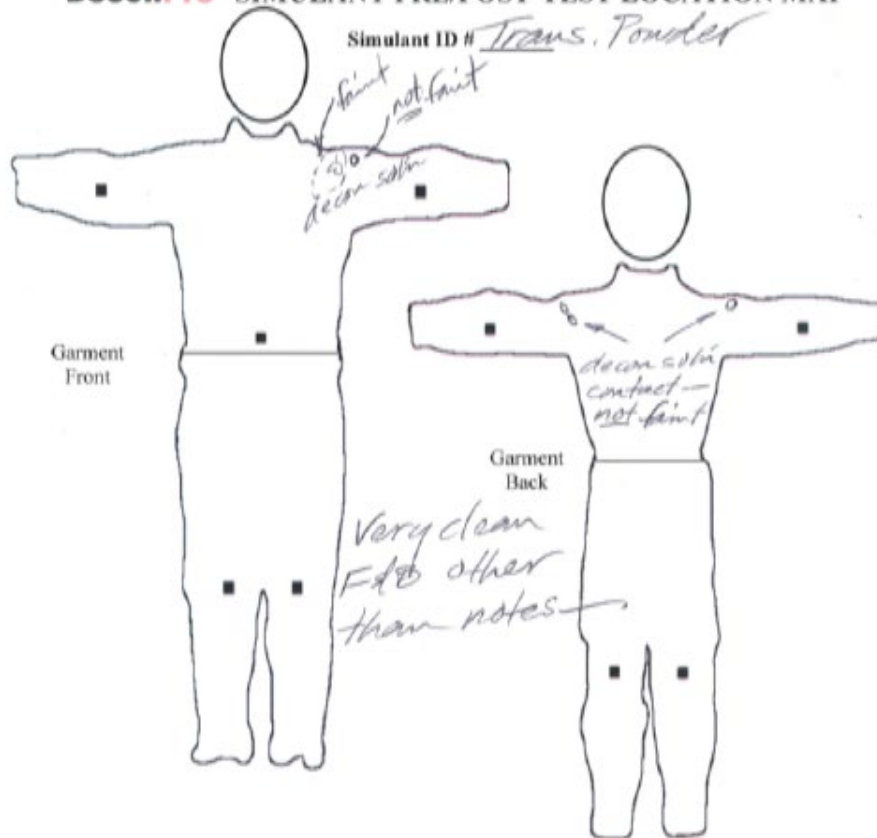
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Hazmat
Science
Applications

Department/Agency: Phila U LOHP Date: 4/20/2011 Run # 4

DeconPro® SIMULANT PRE/POST-TEST LOCATION MAP



Note relative size and location of residual contaminants by marking the figures. Add other comments as needed: Head, neck, & face are all clean.
No "doffing" on either front or back. Each
shoulder has evidence of decon solution (blue
only - no orange). See foot subject post-decon PRQ

Checklist actions completed by (initials): JR.D Date: 4/20/2011

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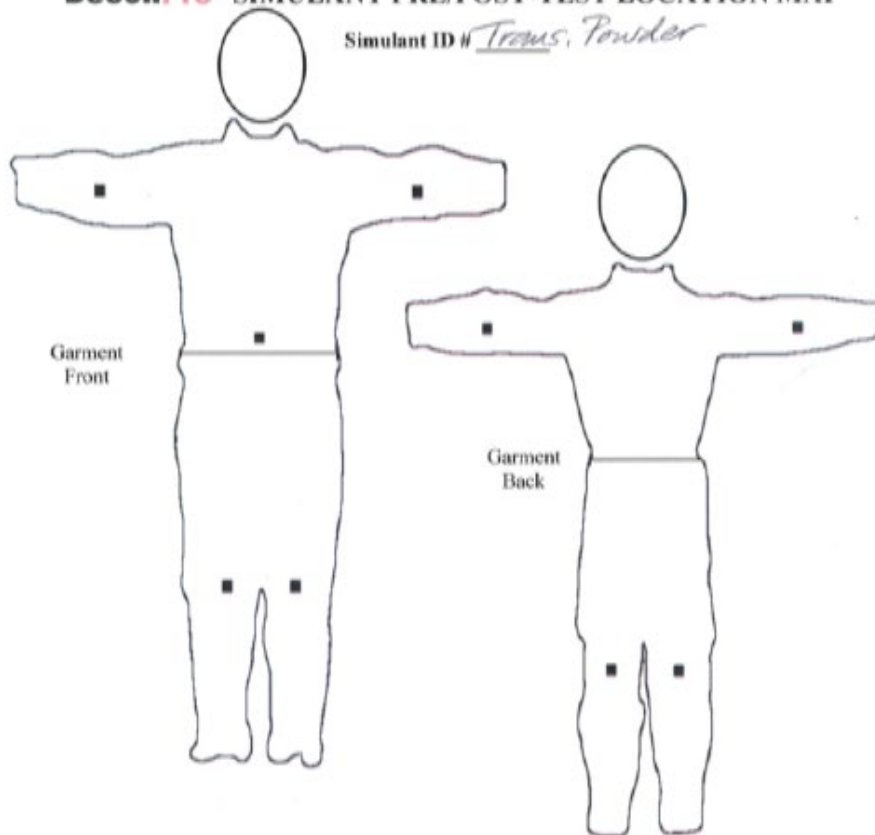


Hazmat
Science
Applications

Department/Agency: Phelan L&HP Date: 4/20/2011 Run # 5

DeconPro® SIMULANT PRE/POST-TEST LOCATION MAP

Simulant ID # Trans. Powder



Note relative size and location of residual contaminants by marking the figures. Add other comments as needed: Head, neck, & face are clean. Both
front and back sides of the garment are free
of visible contamination.

Checklist actions completed by (initials): JLB Date: 4/20/2011

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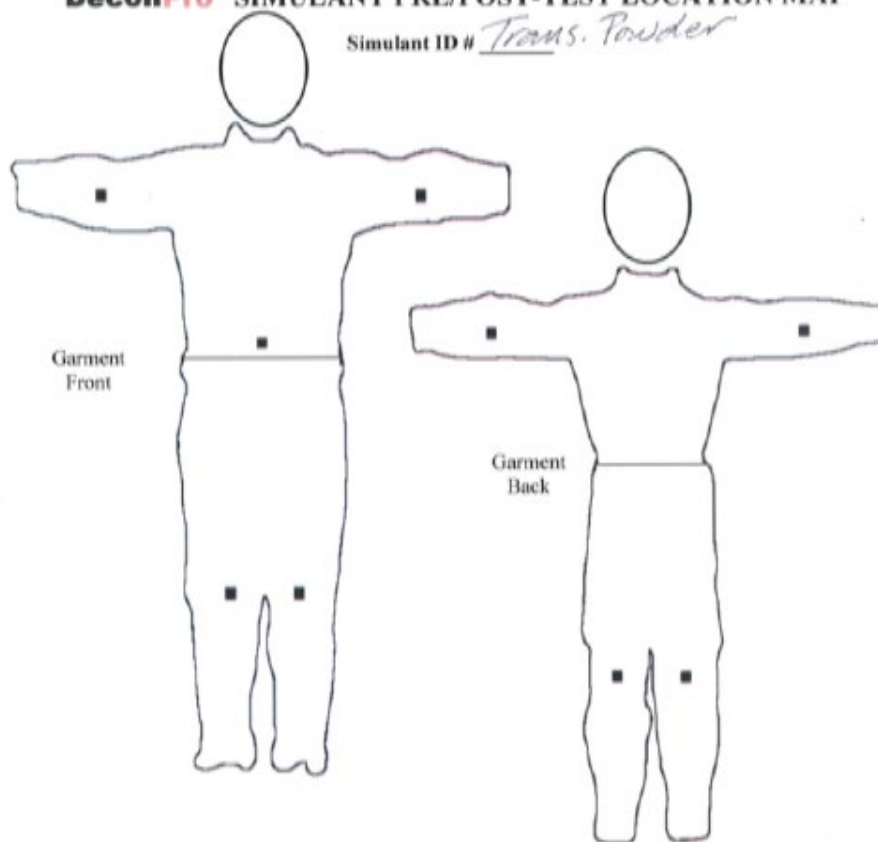


Hazmat
Science
Applications

Department/Agency: Thibault LEHP Date: 4/21/2011 Run # 6

DeconPro® SIMULANT PRE/POST-TEST LOCATION MAP

Simulant ID # Trans. Powder



Note relative size and location of residual contaminants by marking the figures. Add other comments as needed: face, neck, head & hands are clean. Both the front and back of the under-garment are free of visible contamination.

Checklist actions completed by (initials): JWR Date: 4/21/2011

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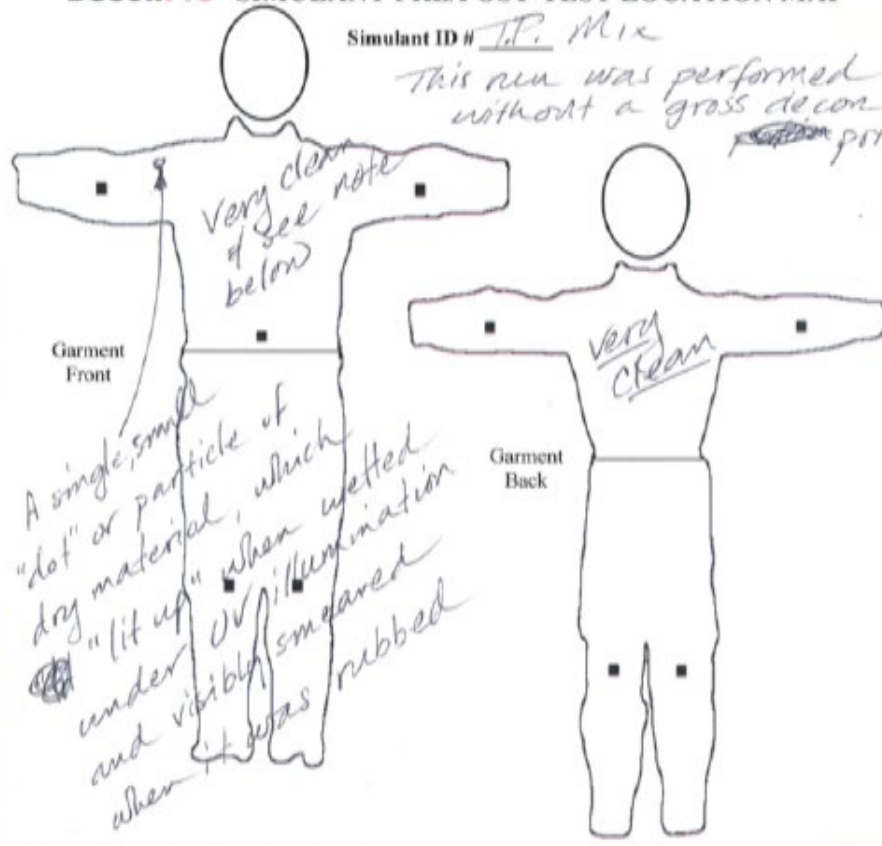
Hazmat
Science
Applications

Department/Agency: Phila U LEHP Date: 4/21/2011 Run # 7

DeconPro® SIMULANT PRE/POST-TEST LOCATION MAP

Simulant ID # J.P. Mix

This run was performed without a gross decon portion-



Note relative size and location of residual contaminants by marking the figures. Add other comments as needed: Head, neck, face, & hands are clean. Under garment is very free of contamination with the exception of the note above for the garment front.

Checklist actions completed by (initials): MLB Date: 4/21/2011

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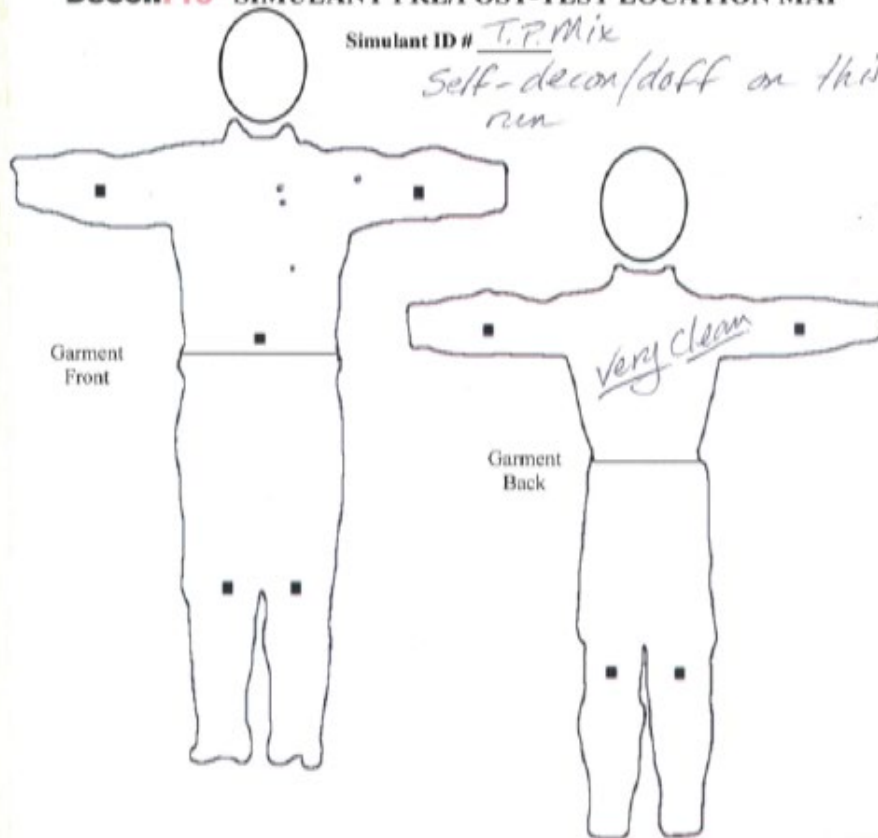
Hazmat
Science
Applications

Department/Agency: Phila U LCHP Date: 4/21/2011 Run # 8

DeconPro® SIMULANT PRE/POST-TEST LOCATION MAP

Simulant ID # T.P. Mix

Self-decon/doff on this run



Note relative size and location of residual contaminants by marking the figures. Add other comments as needed: Face, neck, head, & hands clean.
Undergarment is quite free of contamination
except as noted above for the left front.

Checklist actions completed by (initials): JNB Date: 4/21/2011

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2011 PhilaU Run #1

Post-Don Images









2011 PhilaU Run #2

Post-Don Images



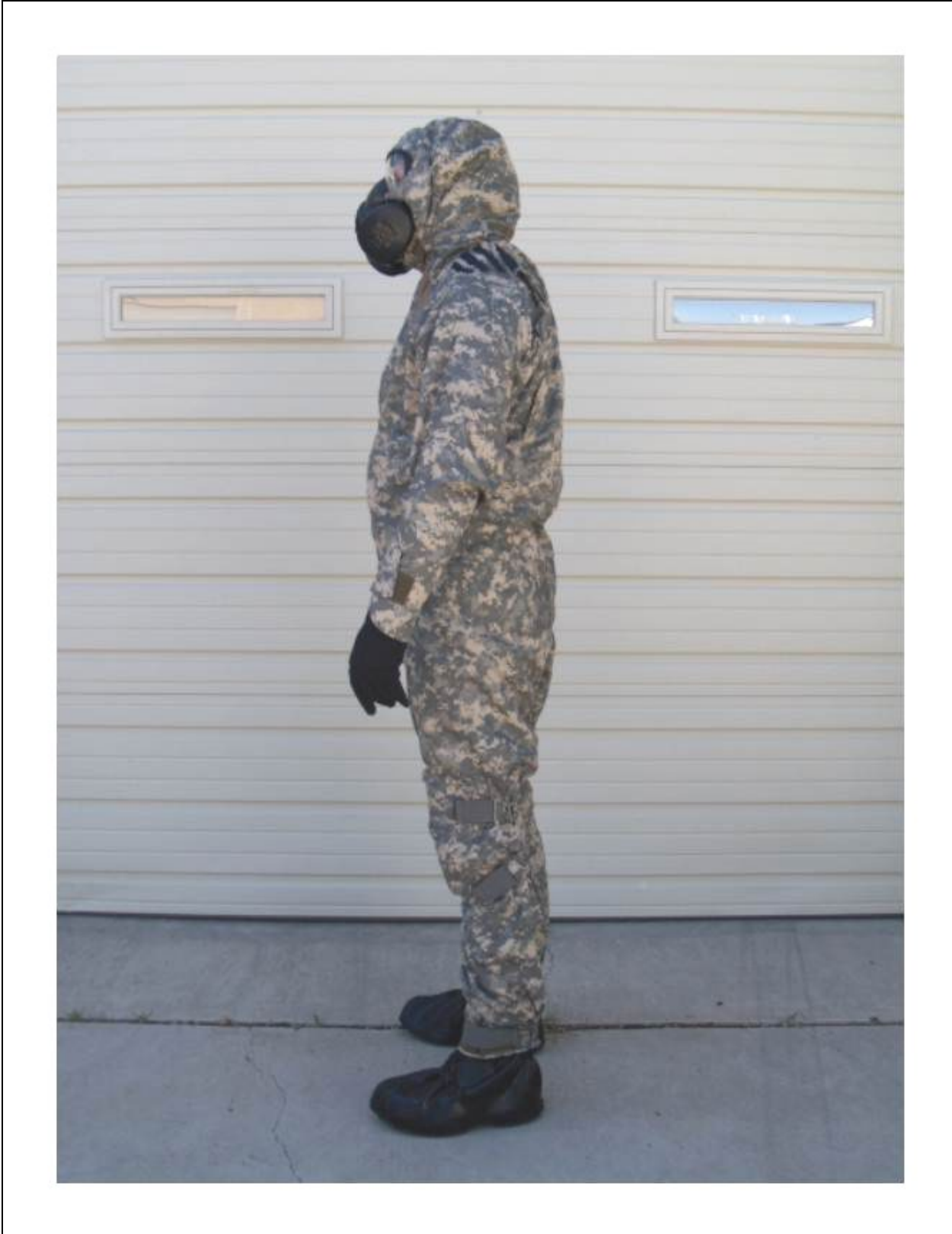






2011 PhilaU Run #3 Post-Don Images









2011 PhilaU Run #4 Post-Don Images









2011 PhilaU #5

Post-Don Images









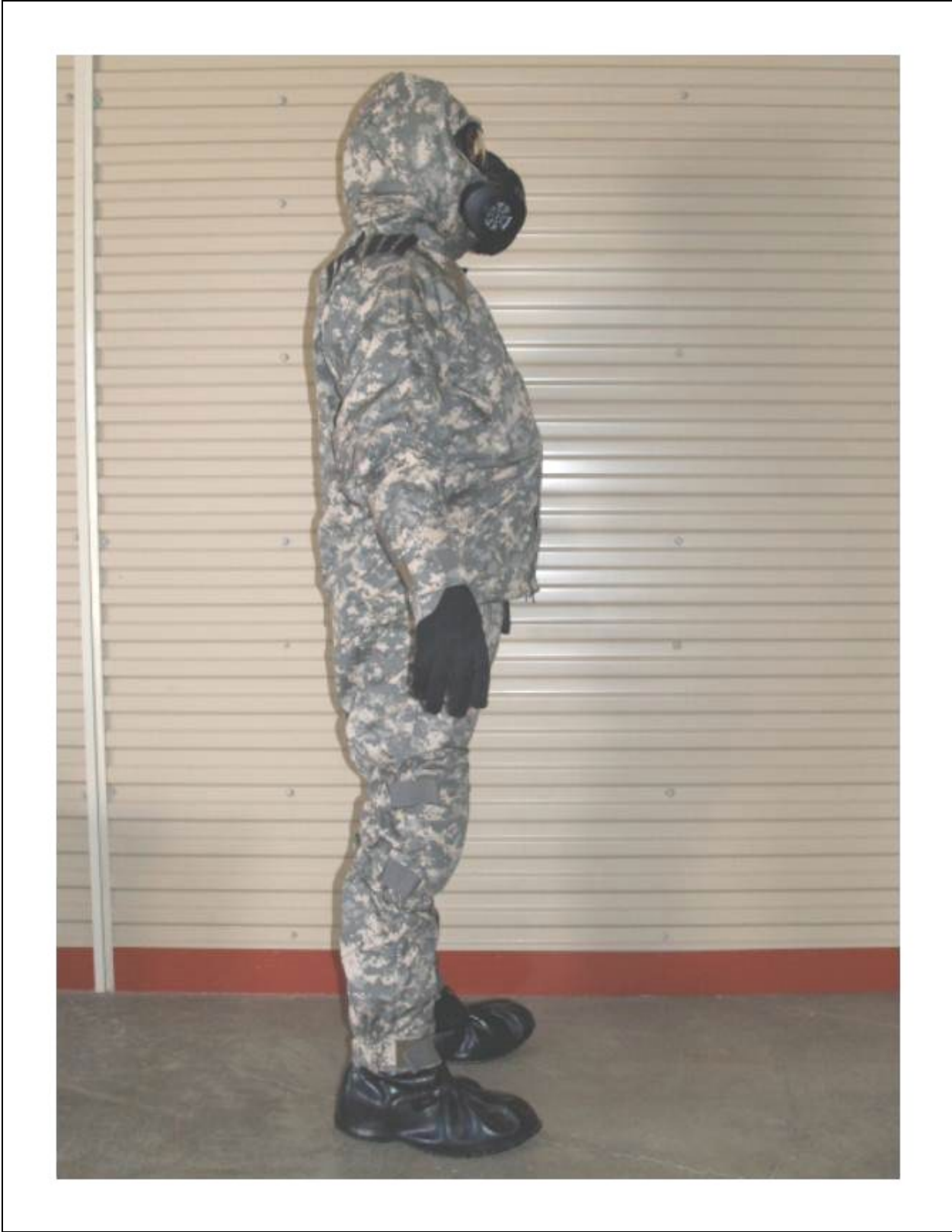
2011 PhilaU Run #6

Post-Don Images









2011 PhilaU Run #7

Post-Don Images



11.00 in



11.00 in



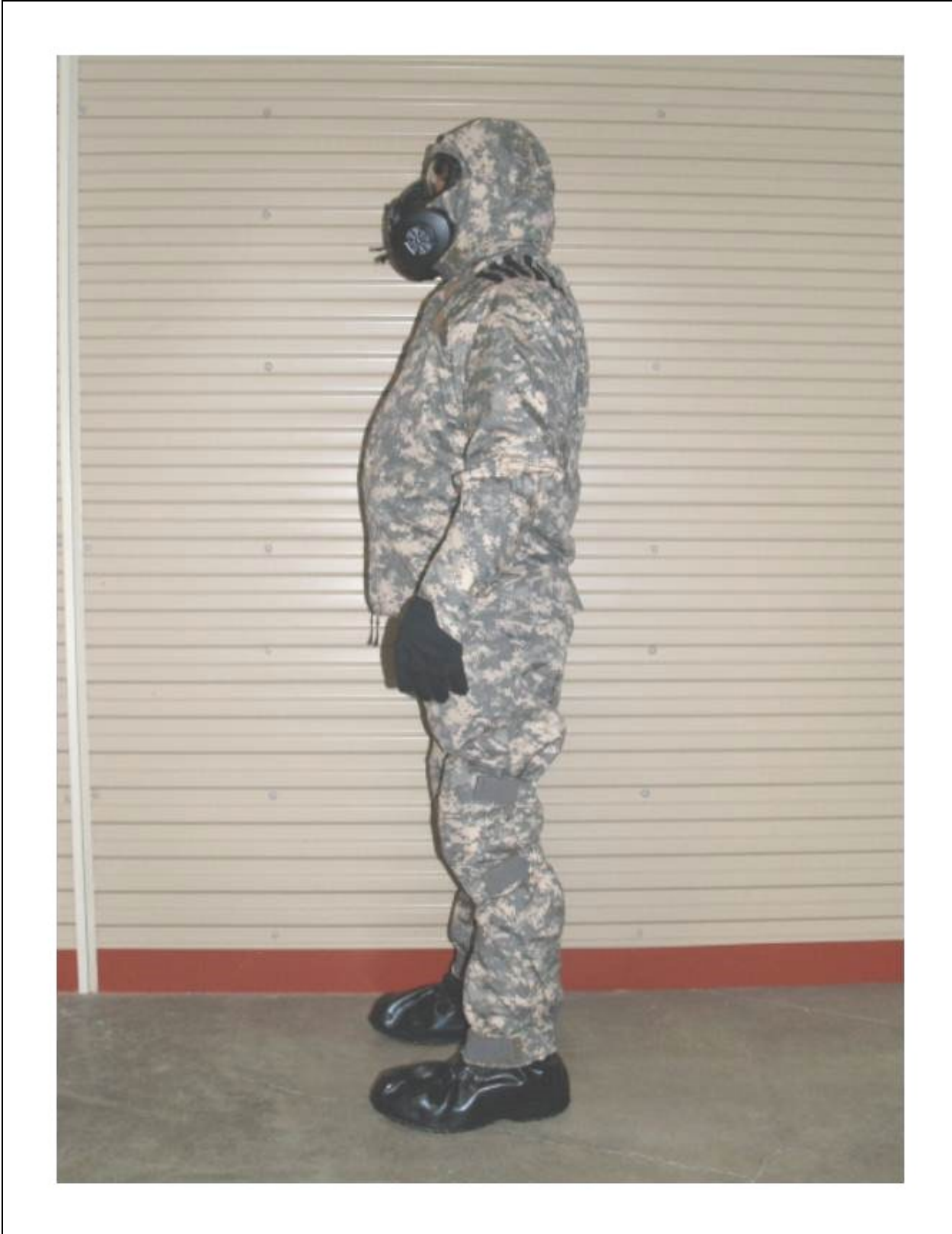




2011 PhilaU Run #8

Post-Don Images



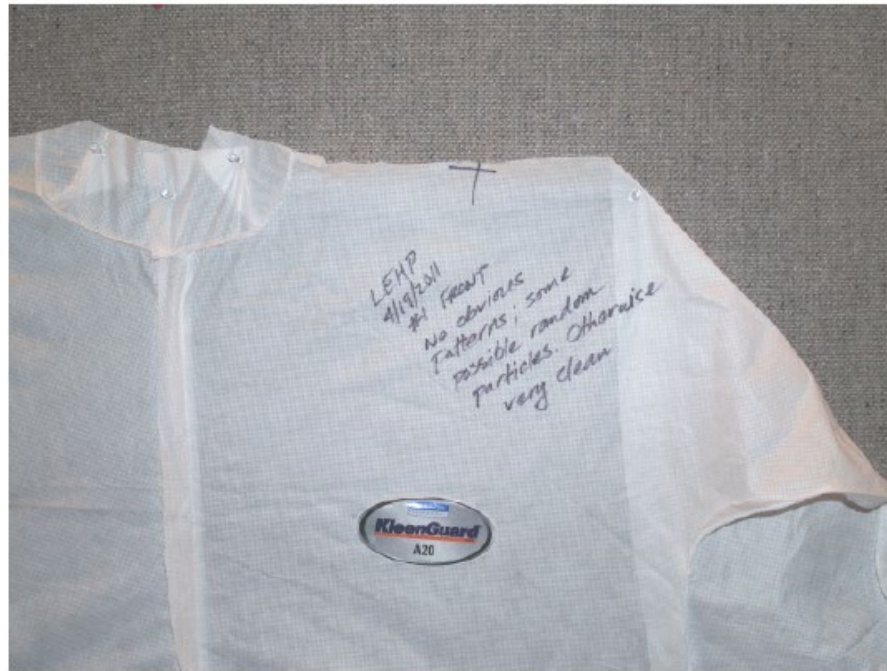


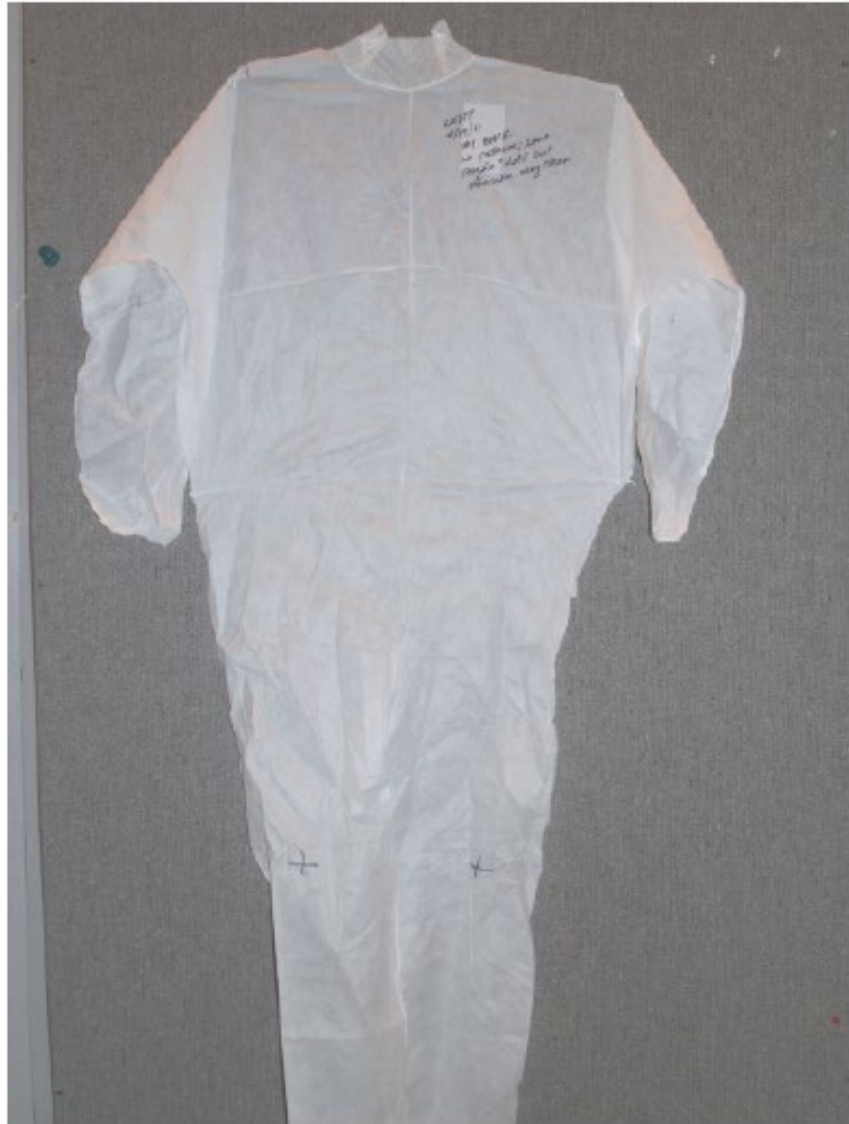


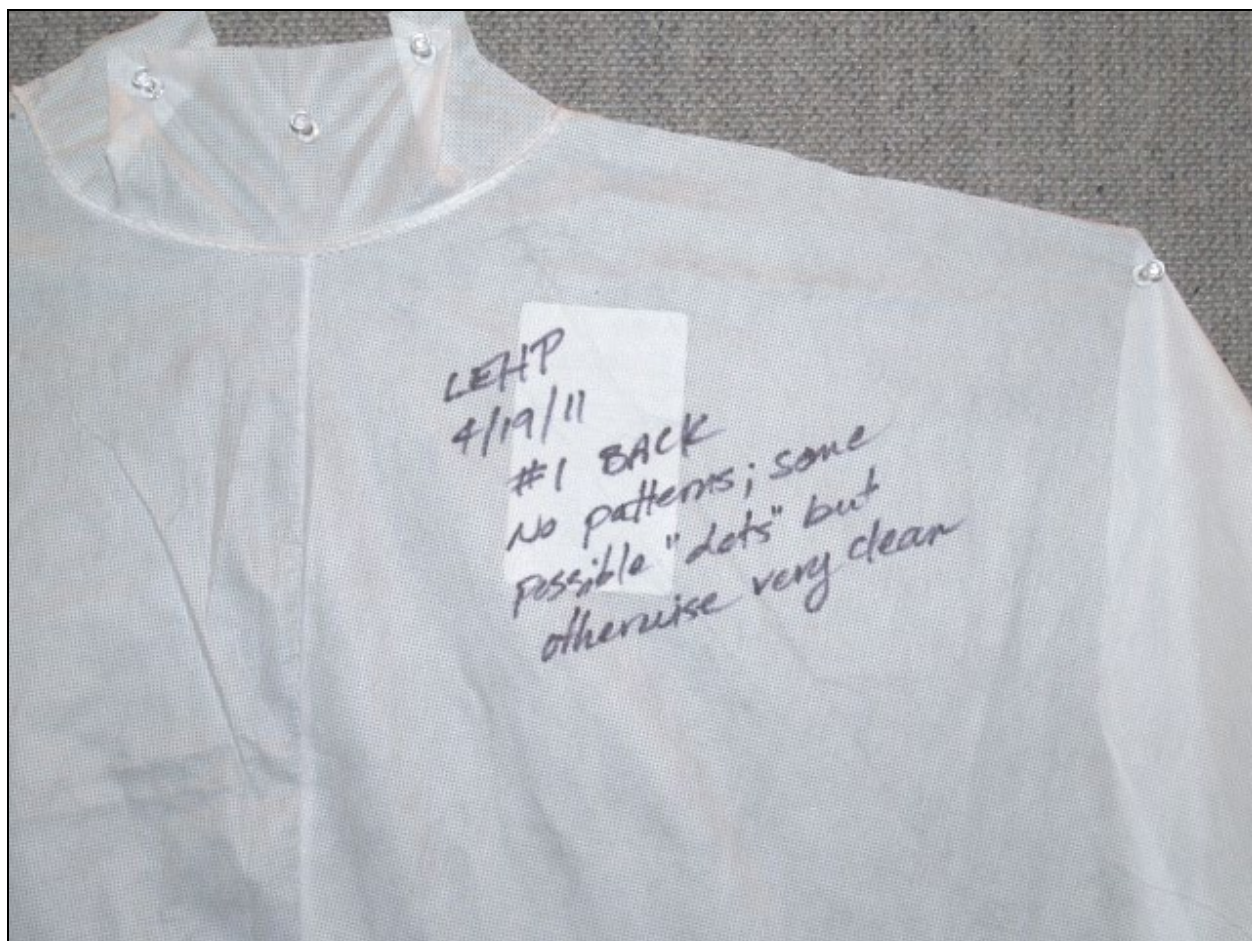


2011 PhilaU Run #1 Undergarment Images





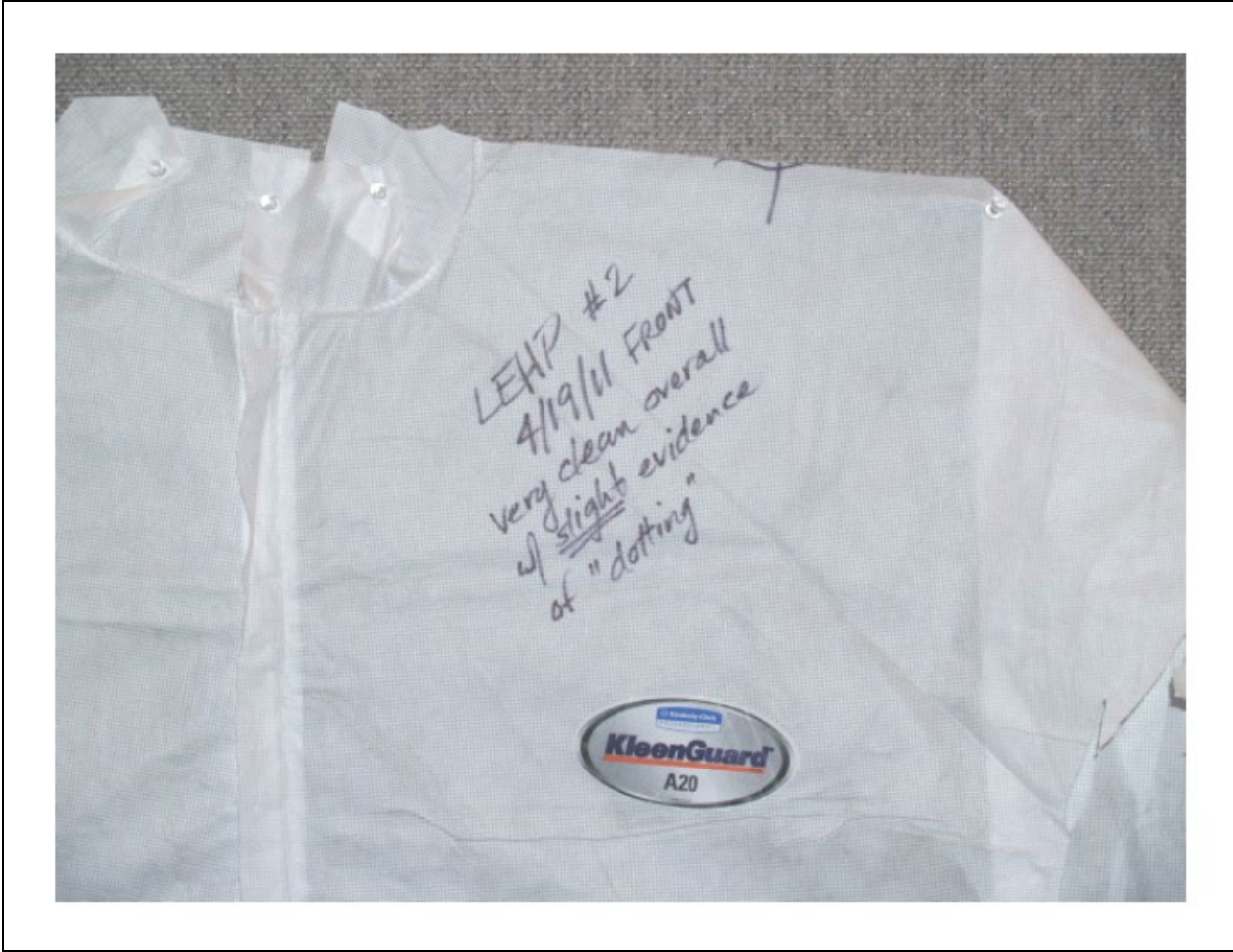




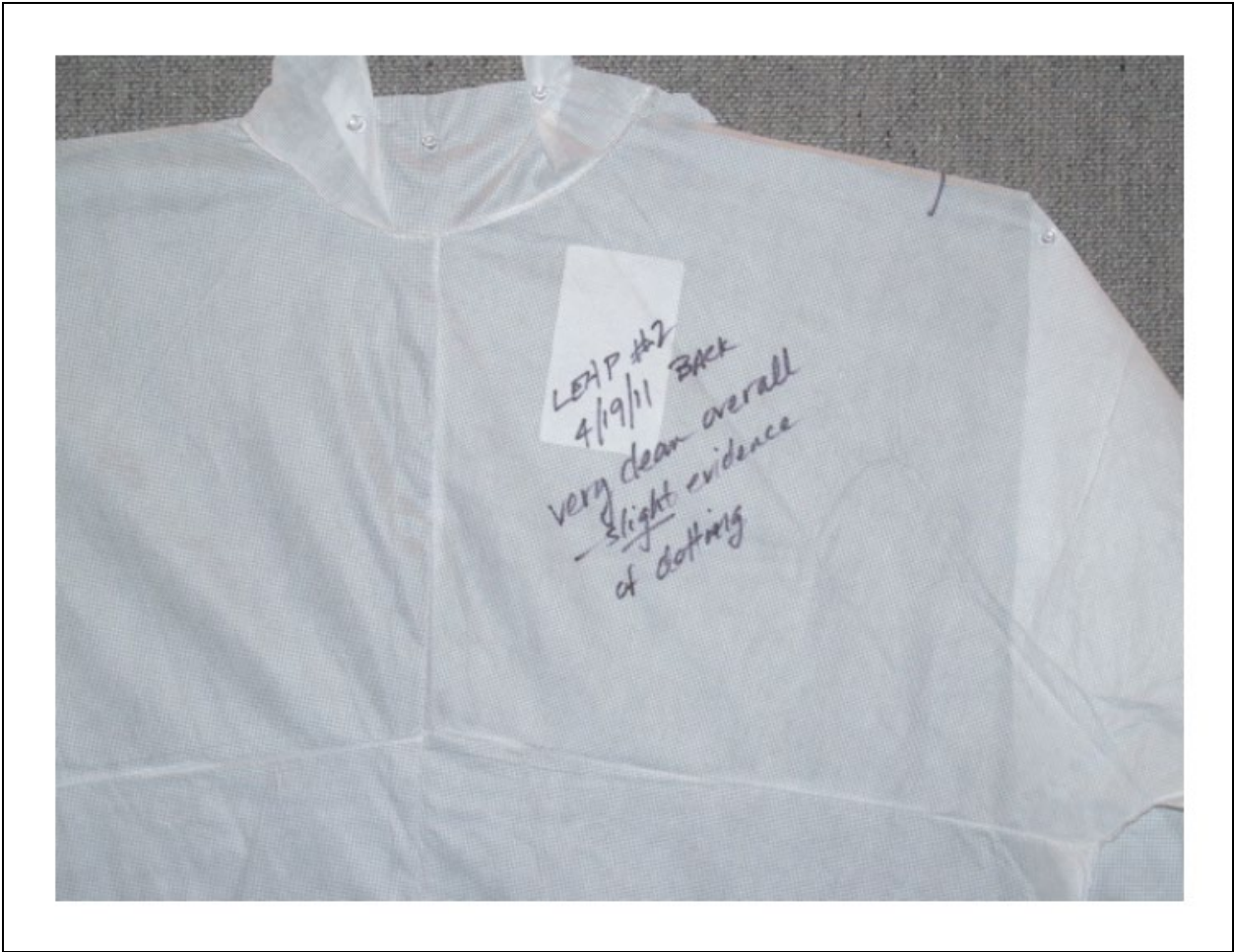
LEHP
4/19/11
#1 BACK
No patterns; some
possible "dots" but
otherwise very clean

2011 PhilaU Run #2 Undergarment Images





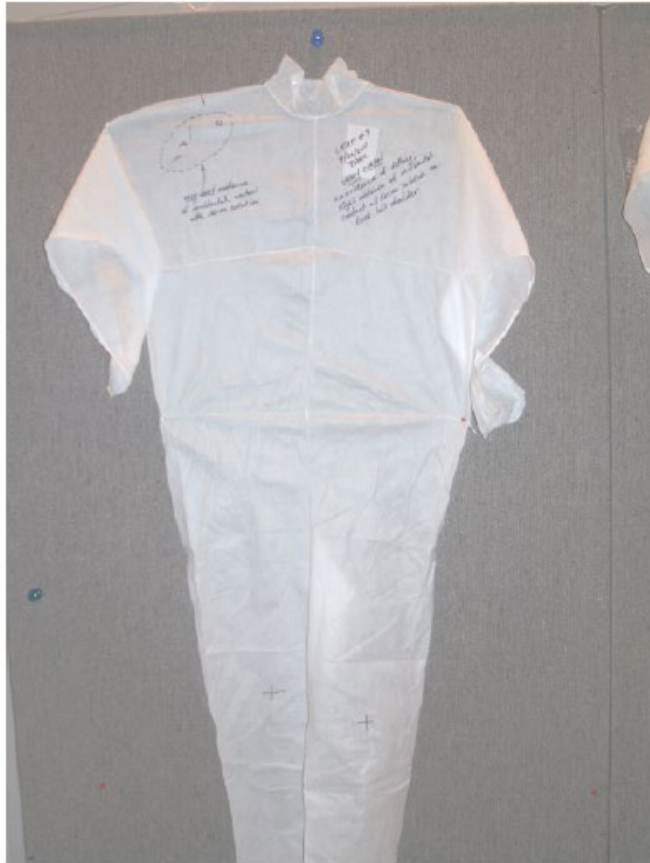


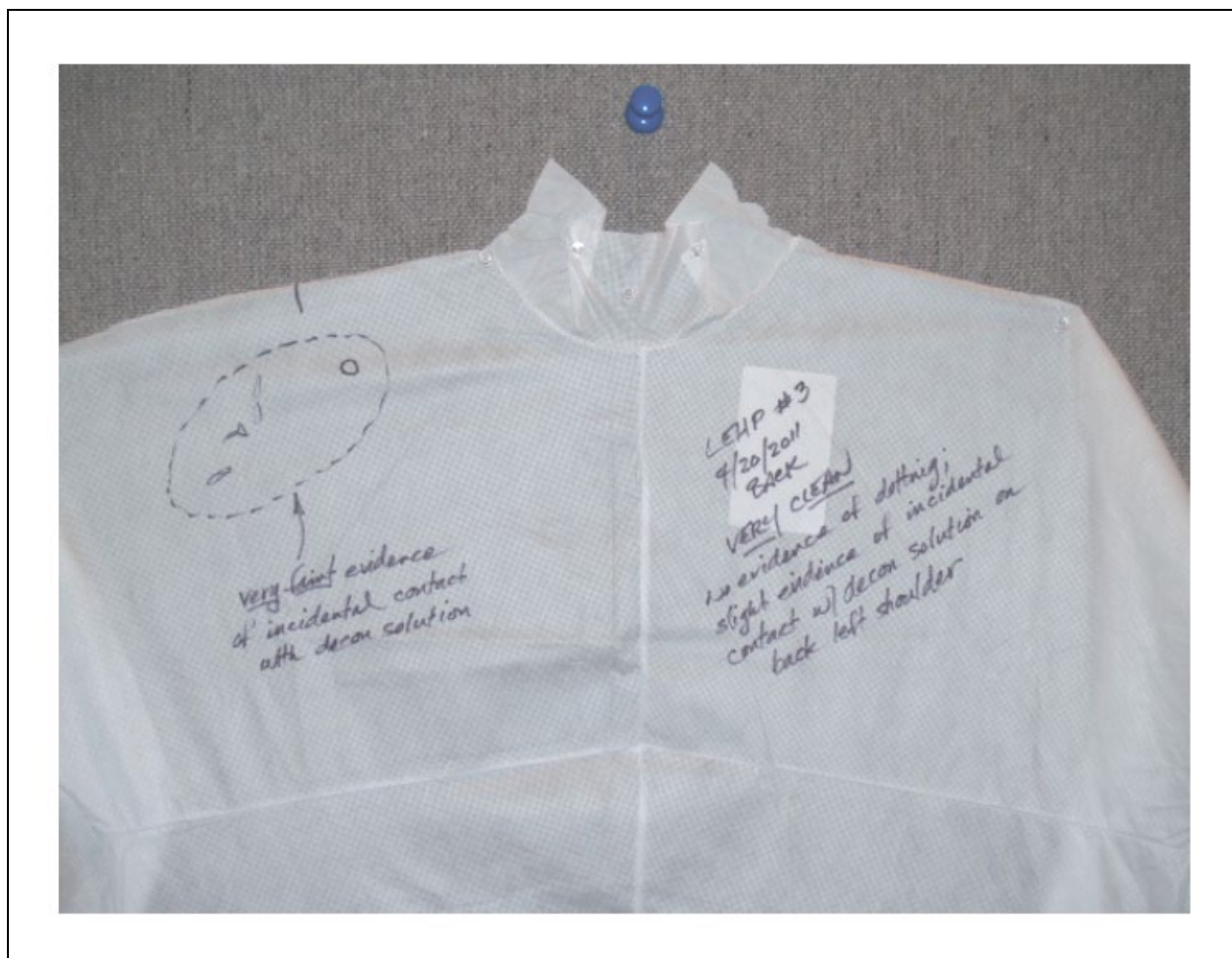


2011 PhilaU Run #3 Undergarment Images







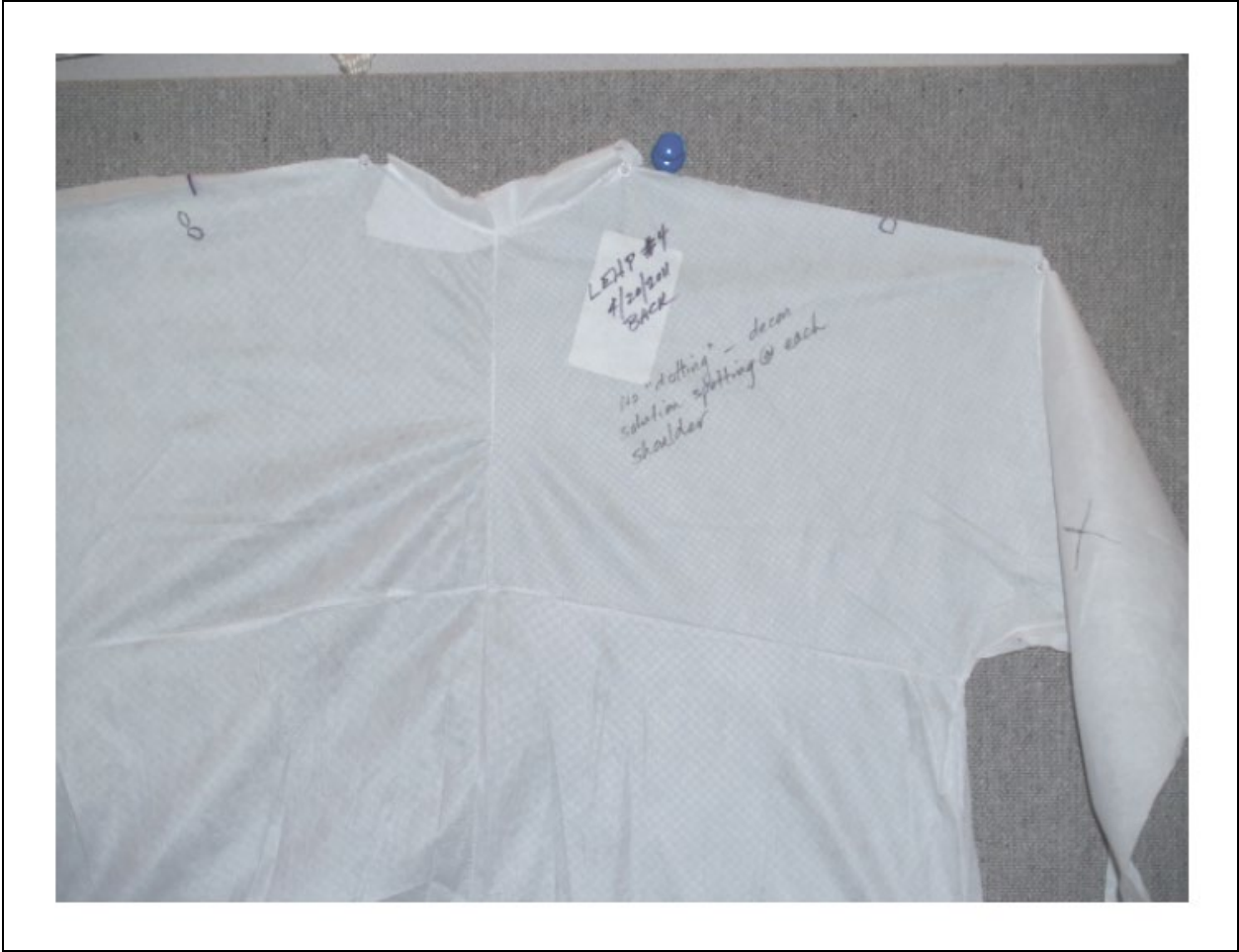


2011 PhilaU Run #4 Undergarment Images





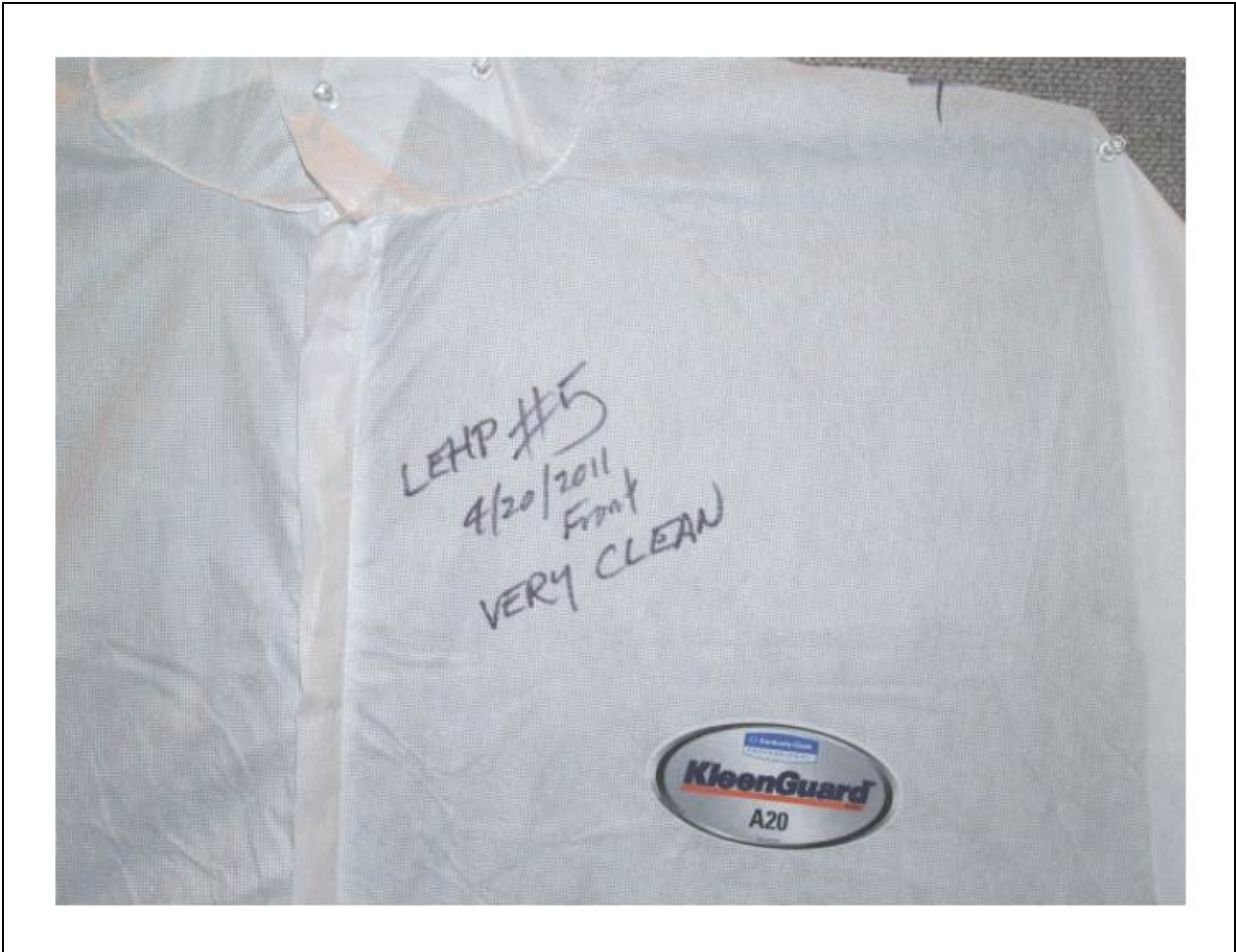




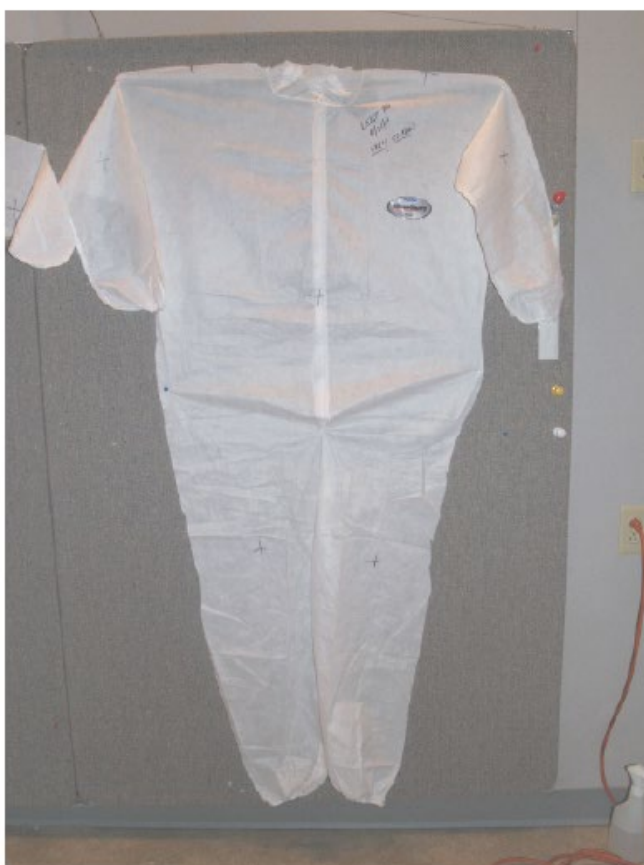
2011 PhilaU Run #5 Undergarment Images







2011 PhilaU Run #6 Undergarment Images

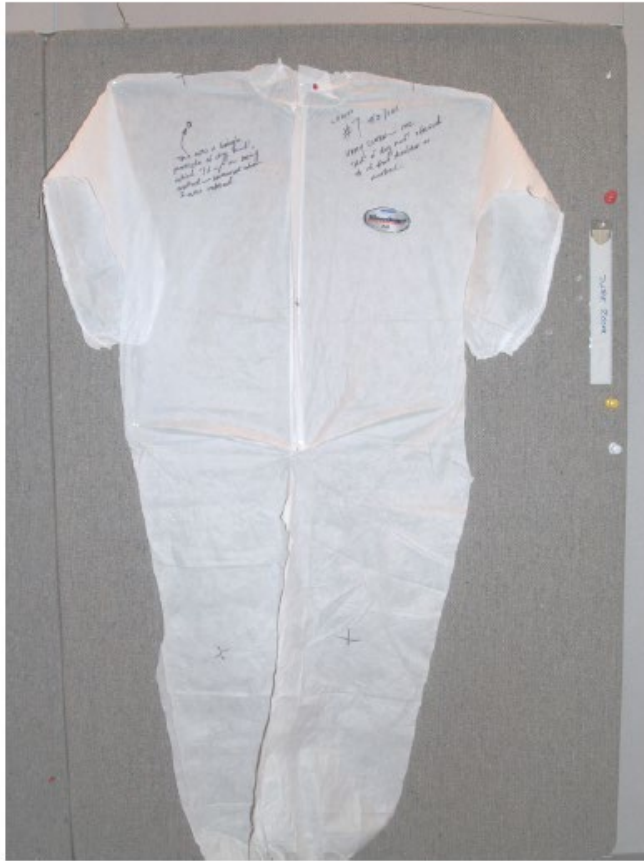


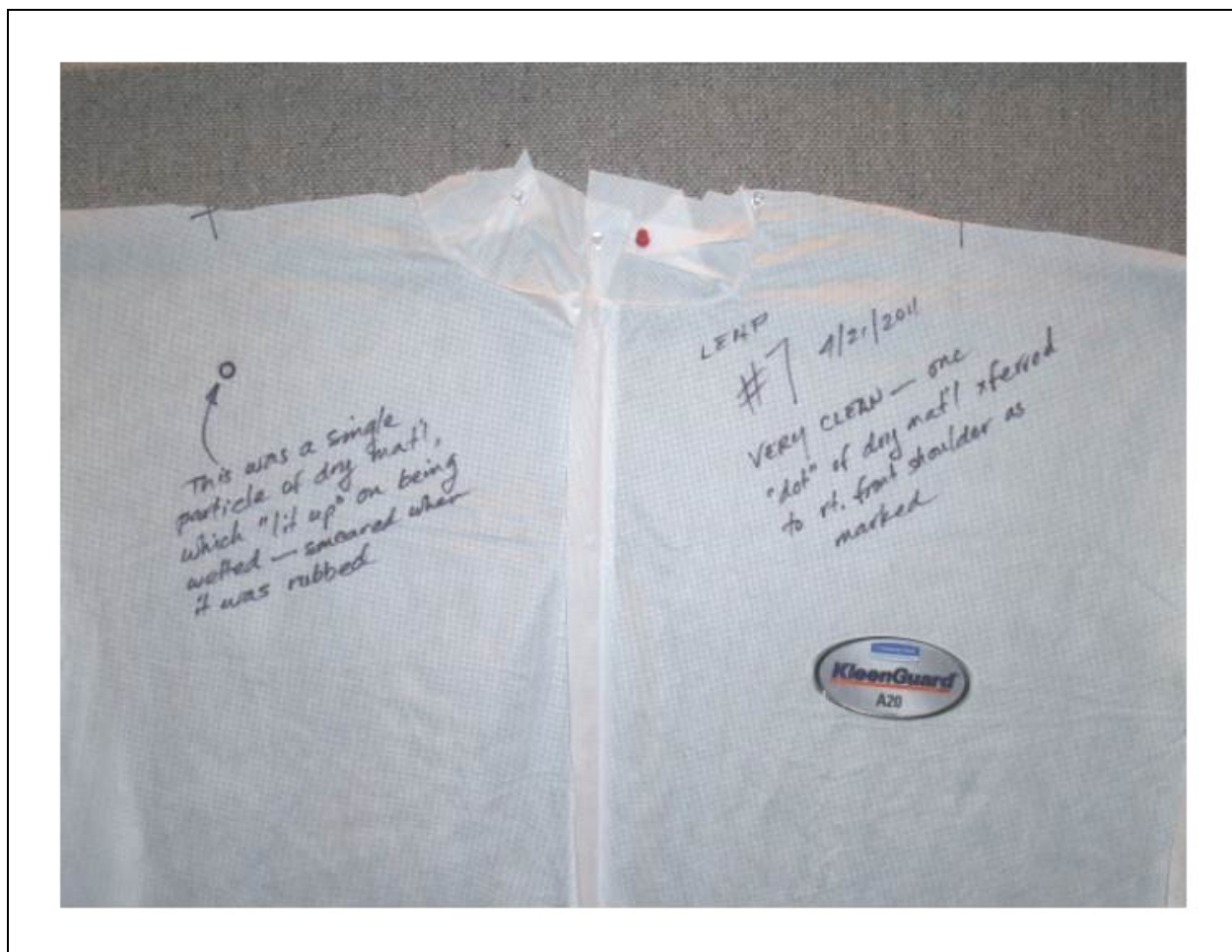






2011 PhilaU Run #7 Undergarment Images



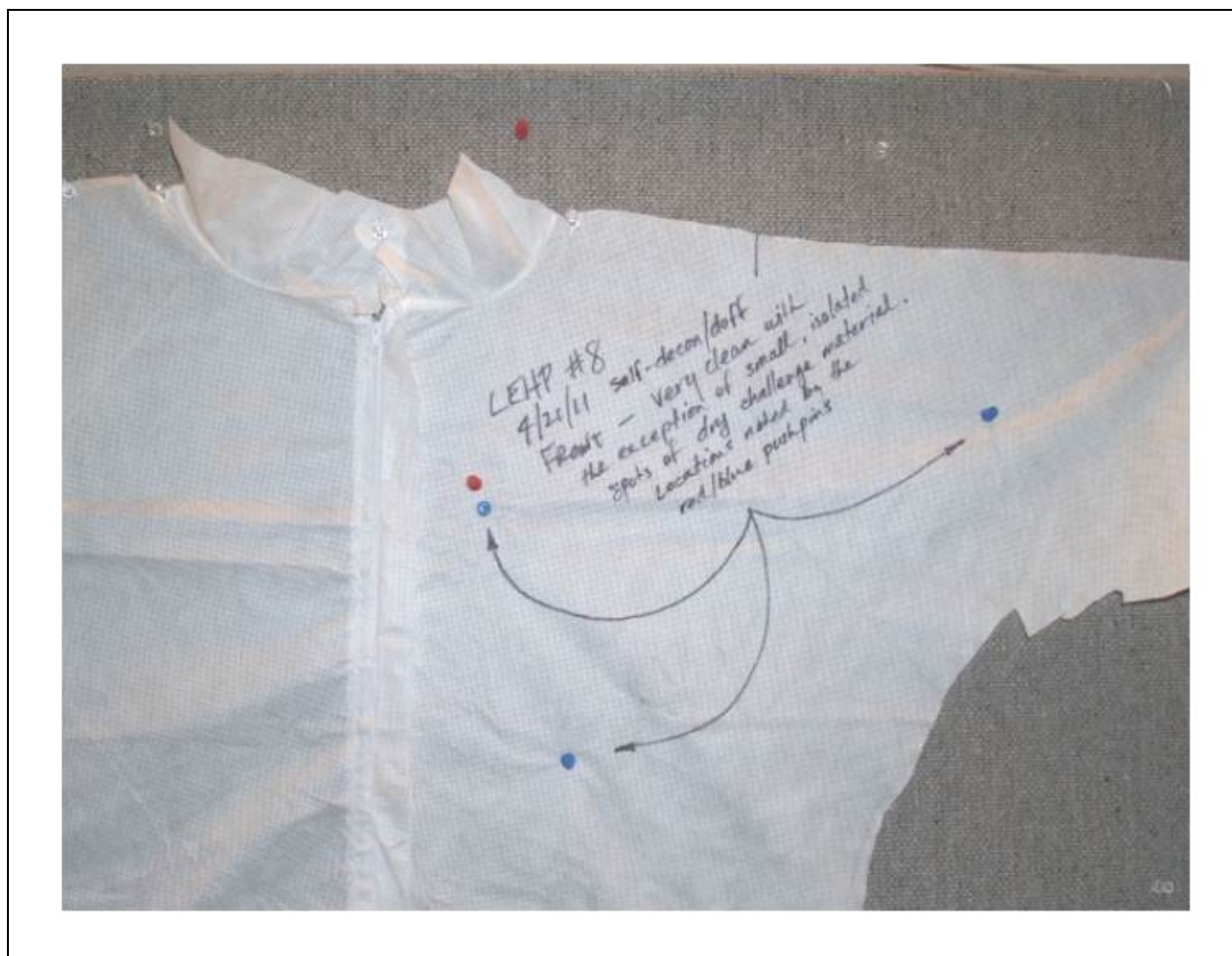




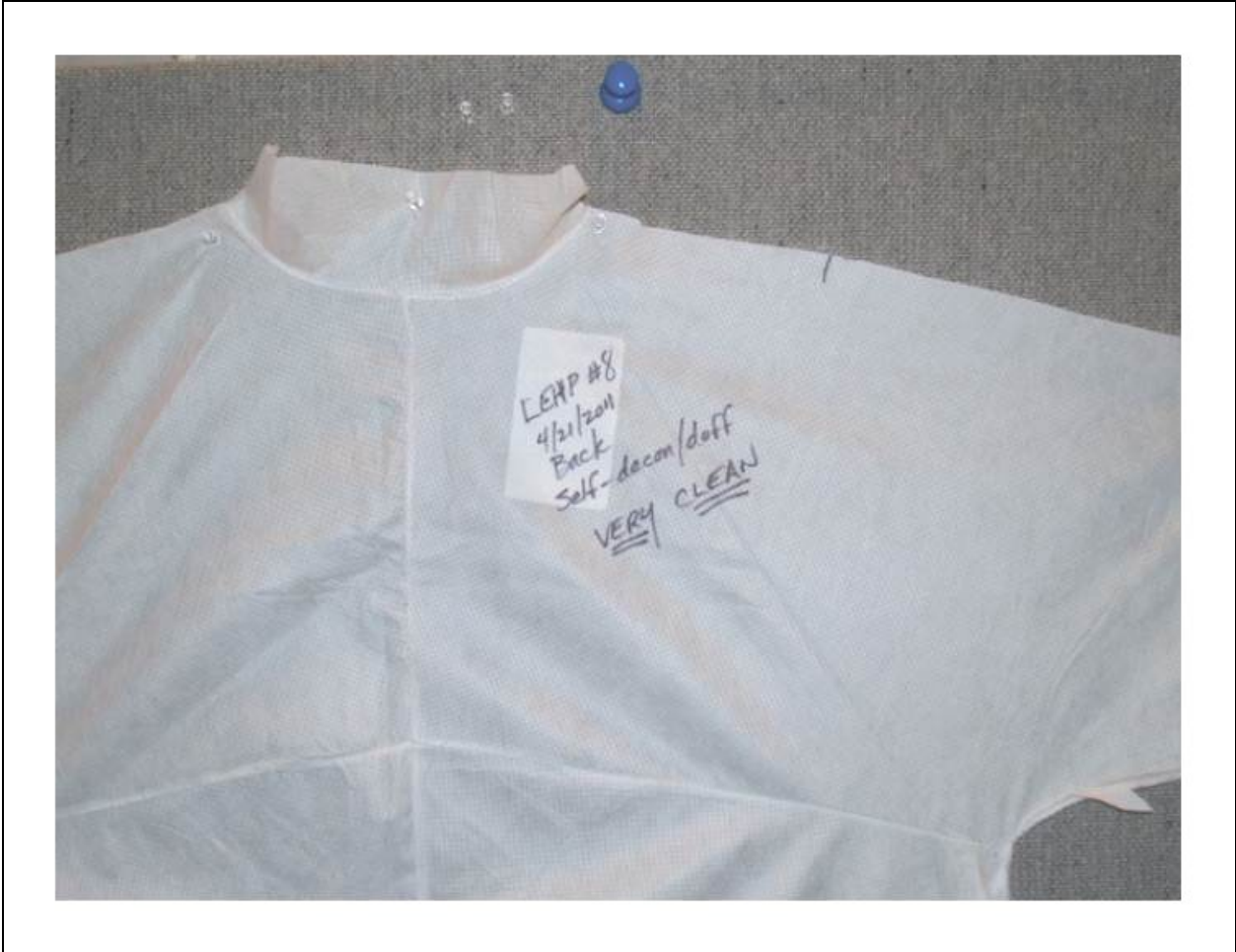


2011 PhilaU Run #8 Undergarment Images



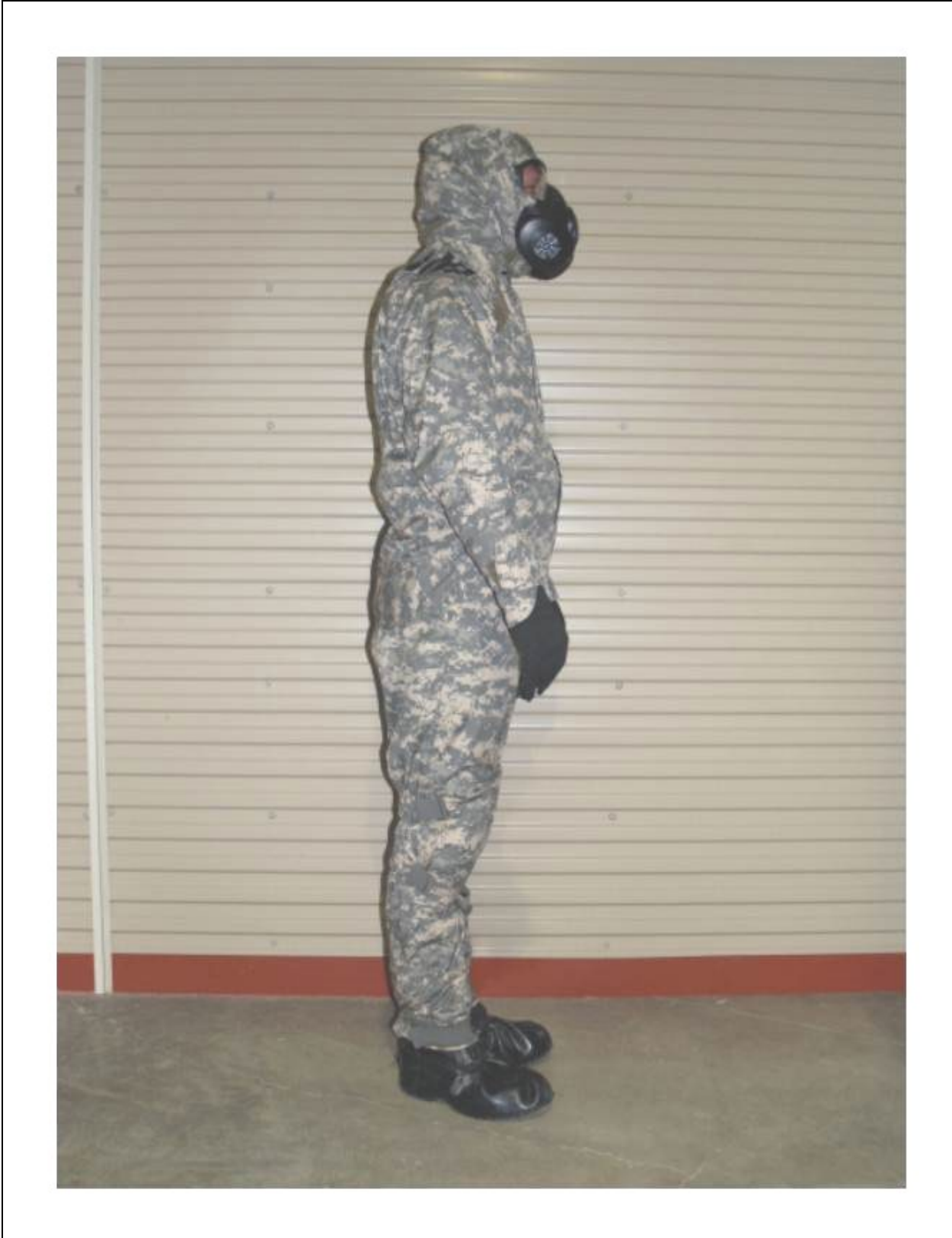




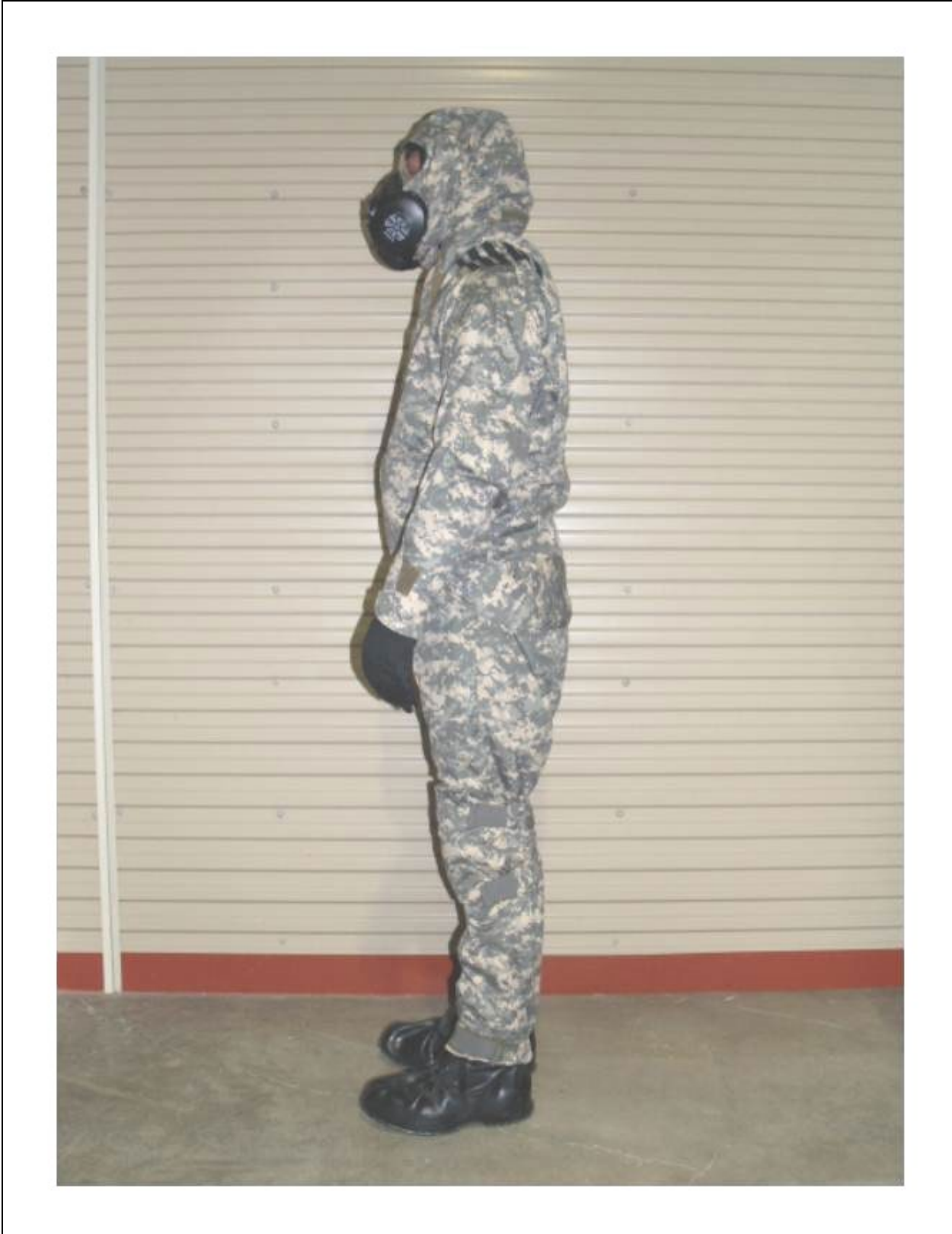


2011 PhilaU Dry Run Images

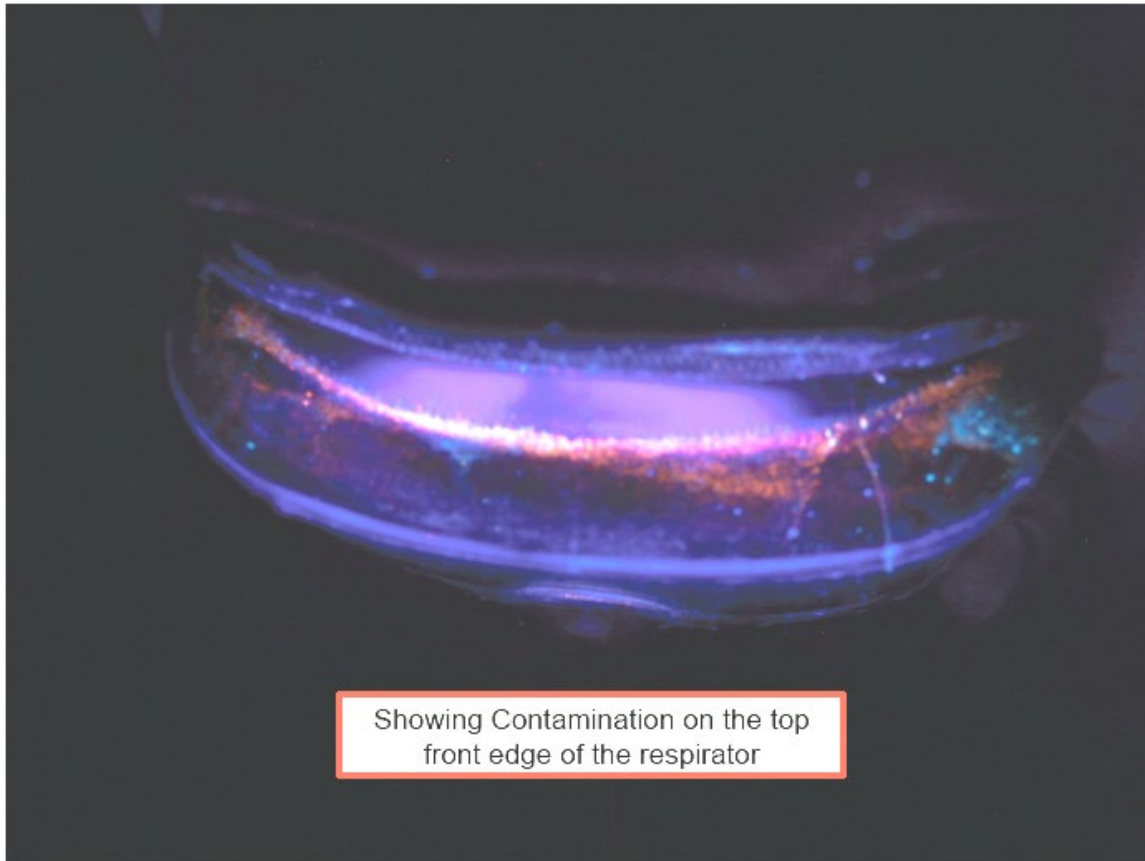




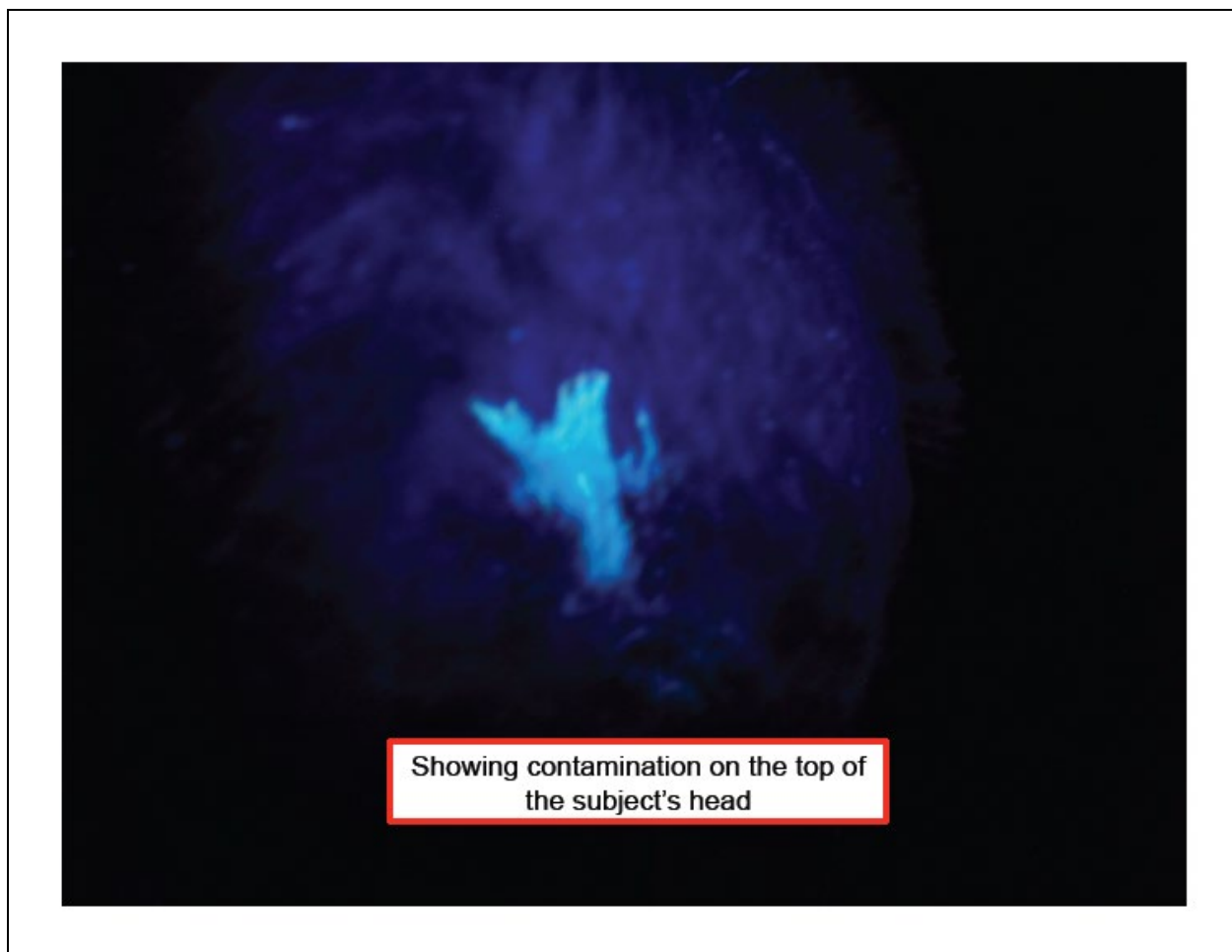




2011 PhilaU Run #2 Miscellaneous Images



Showing Contamination on the top front edge of the respirator



2011 PhilaU CDT Run #3 Miscellaneous Images

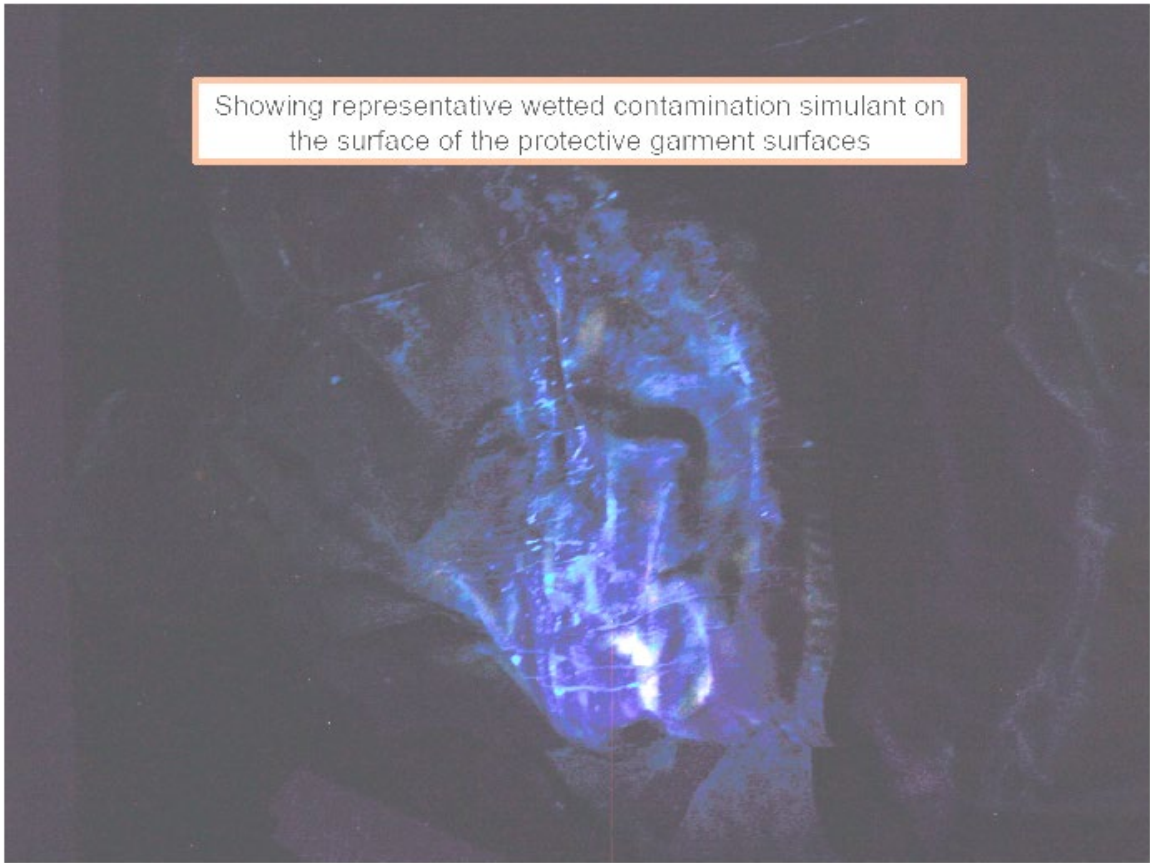






2011 PhilaU Run #5
Dirty Protective Garment Image

Showing representative wetted contamination simulant on the surface of the protective garment surfaces



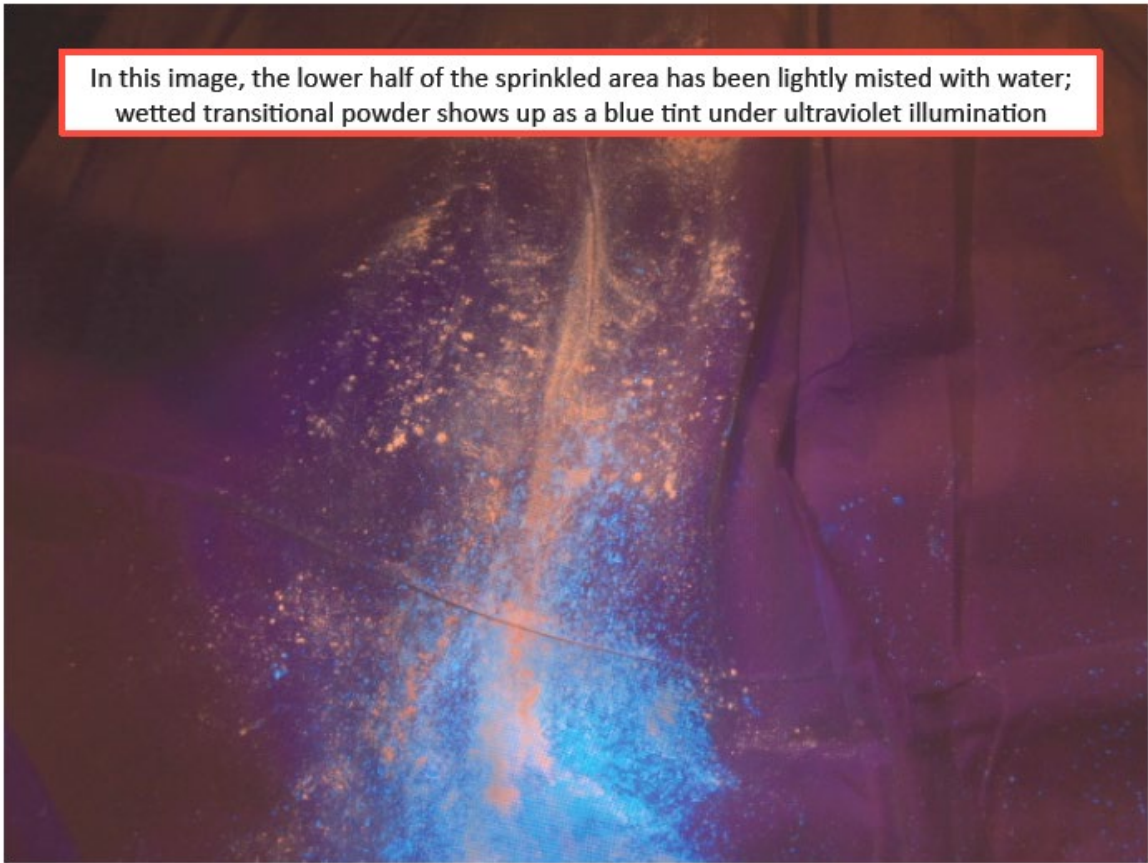
Hazmat Science Applications

Transitional Powder Images

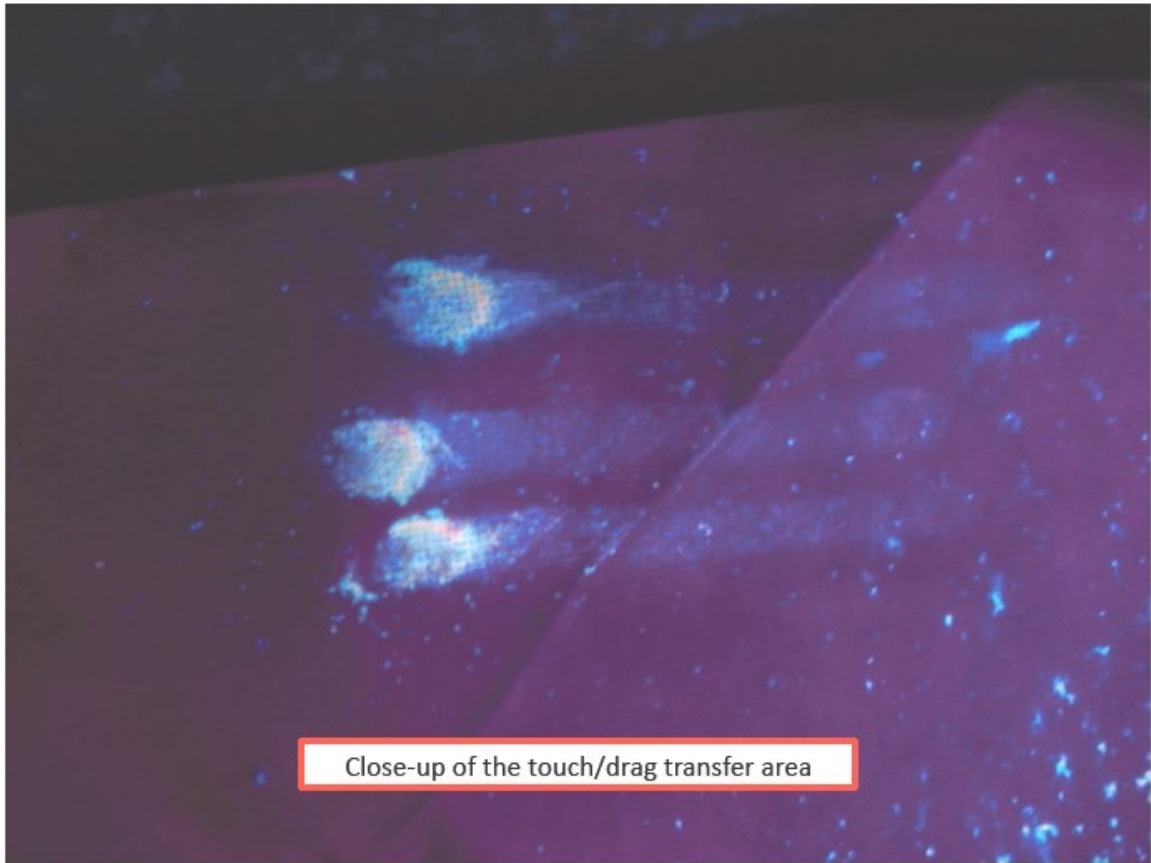


Dry transitional powder sprinkled on the back of a representative test undergarment used for contaminated doffing testing; the orange tint is imparted by the insoluble component

In this image, the lower half of the sprinkled area has been lightly misted with water; wetted transitional powder shows up as a blue tint under ultraviolet illumination







Close-up of the touch/drag transfer area