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DESIGN AND TESTING OF CHEMICAL/BIOLOGICAL PROTECTIVE GARMENT SYSTEM—GENERATION 5

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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 downselecting 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 5 garments. Assessments were conducted at LEHP, and at DEVCOM Soldier Center (NSRDEC) and other DoD facilities, and at contractors' sites where specialized equipment and expertise was available. Results of the assessments are included in other technical reports that are appended to this report. LEHP work supports the Warrior Systems Technology Program.					
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FABRICS	CLOTHING	COVERALLS	CONTAMINATION	PROTECTIVE CLOTHING	
TEXTILES	UNIFORMS	PROTOTYPES	MILITARY CLOTHING	CHEMICAL PROTECTION	
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DESIGN AND TESTING OF CHEMICAL/BIOLOGICAL PROTECTIVE GARMENT SYSTEM—GENERATION 5

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. This report describes the iterative design process and materials used by the GT, summarizes the construction, the test methods and the test results for three ensembles, and presents conclusions drawn from the results. The work described was performed between February 2009 and August 2010 under Department of Defense University Research Initiative Grants (numbers W911QY-09-1-0001 and W911QY-10-1-0002) administered by the U.S. Army Combat Capabilities Development Command – Soldier Center ((Natick Soldier Research, Development and Engineering Center (NSRDEC))), in support of the Warrior Systems Technologies Program.

The overall objectives of LEHP's research included:

- Develop a modular two-piece ensemble with a fixed-hood coat and trouser, and separate two-piece carbon undergarments.
- Optimize garment design for fit, functionality, ease-of-movement, performance, 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 5 garment. The Generation 5 garment is the fifth iteration of the LEHP prototypes and is the first two-piece garment to be made.

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

2. Garment Design and Materials

2.1 Generation 5 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 designs. Those four 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* and PHILA-LEHP-GT-TR-09-01, *Design and Testing of Chemical/Biological Protective Coverall System, Generation 4*. Results from earlier generations influenced the design of subsequent generations.

During work on the Generation 4 coverall, at the request of NSRDEC staff, the GT began work on the Generation 5 two-piece design; see Figure 1. Figure 2 shows the timeline for Generation 5 and for events that influenced its development, as well as overlapping events from Generation 4.

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 was designed to be worn under the two-piece shell.



Source: RTI.¹

Figure 1. Generation 5 Garment.

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

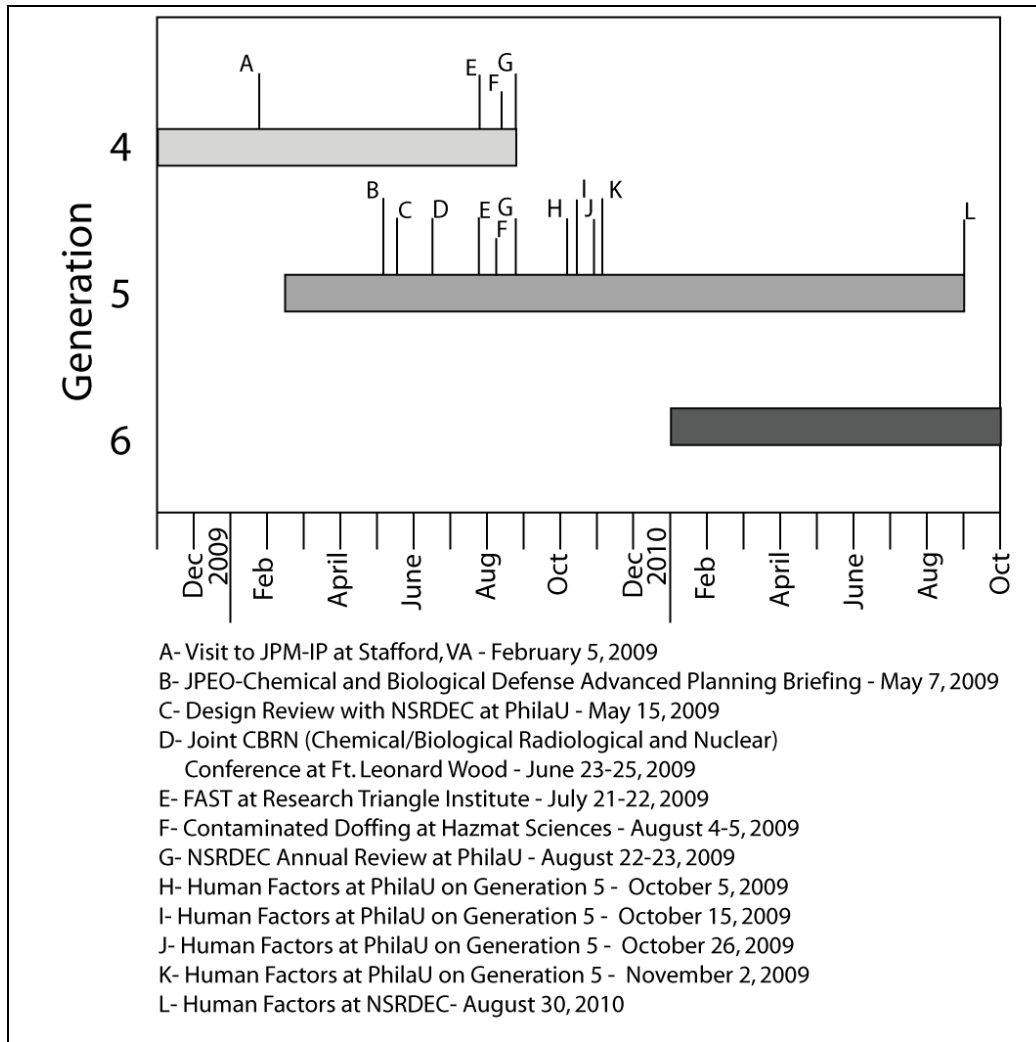


Figure 2. Timeline for Generation 5 of GT-Designed Protective Garments.

For a comparison of Generations 4 and 5, see Table 1. Figures 3 through 7 show the Generation 5 design.

As described in previous reports the Generation 5 garment was sent for outside evaluation at Research Triangle Institute (RTI) for the Fluorescent Aerosol Screening Test (FAST), Hazmat Science Applications (HSA) for Contaminated Doffing (CD), and the NSRDEC for Human Factors (HF) 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 past four prototype garment systems.

Table 1. Comparison of Generations 4 and 5 Features.

Generation 4 vs. Generation 5			
Generation	Shell Fabric	Carbon Fabric	Design Overview
4	78C- 330d Cordura® shell with microporous ePTFE membrane and tricot backing	63A- active carbon filter material, polyester/ elastane 2-way stretch jersey knit material	One-piece coverall design with integrated belt, asymmetric front zipper, left-sleeve doffing zipper, field-relief zipper, knee-pad pockets with removable knee pad, knee-control straps, reinforced elbow-to-shoulder patch, hood-retention flap, hood brim wire and elastic canister loops to fit JSGPM. Separate one-piece fitted carbon bodysuit to be worn under shell. Balaclava-style carbon head protection worn under the outershell hood.
5	78C- 330d Cordura shell with microporous ePTFE membrane and tricot backing	63A- active carbon filter material, polyester/ elastane 2-way stretch jersey knit material	Two-piece zip-together jacket (see Figures 2 and 3) and pant (see Figures 4 and 5) design with asymmetric front zipper, zip fly, bi-swing back, articulated elbow, grip material at shoulder, knee-pad pockets with removable knee pad, knee-control straps, reinforced elbow-to-shoulder patch, hood-retention flap, hood brim wire and elastic canister loops to fit JSGPM. Separate two-piece fitted carbon undergarments; top features high neck and asymmetric zipper; pant is long-underwear style. Balaclava-style carbon head protection worn under the outershell hood.

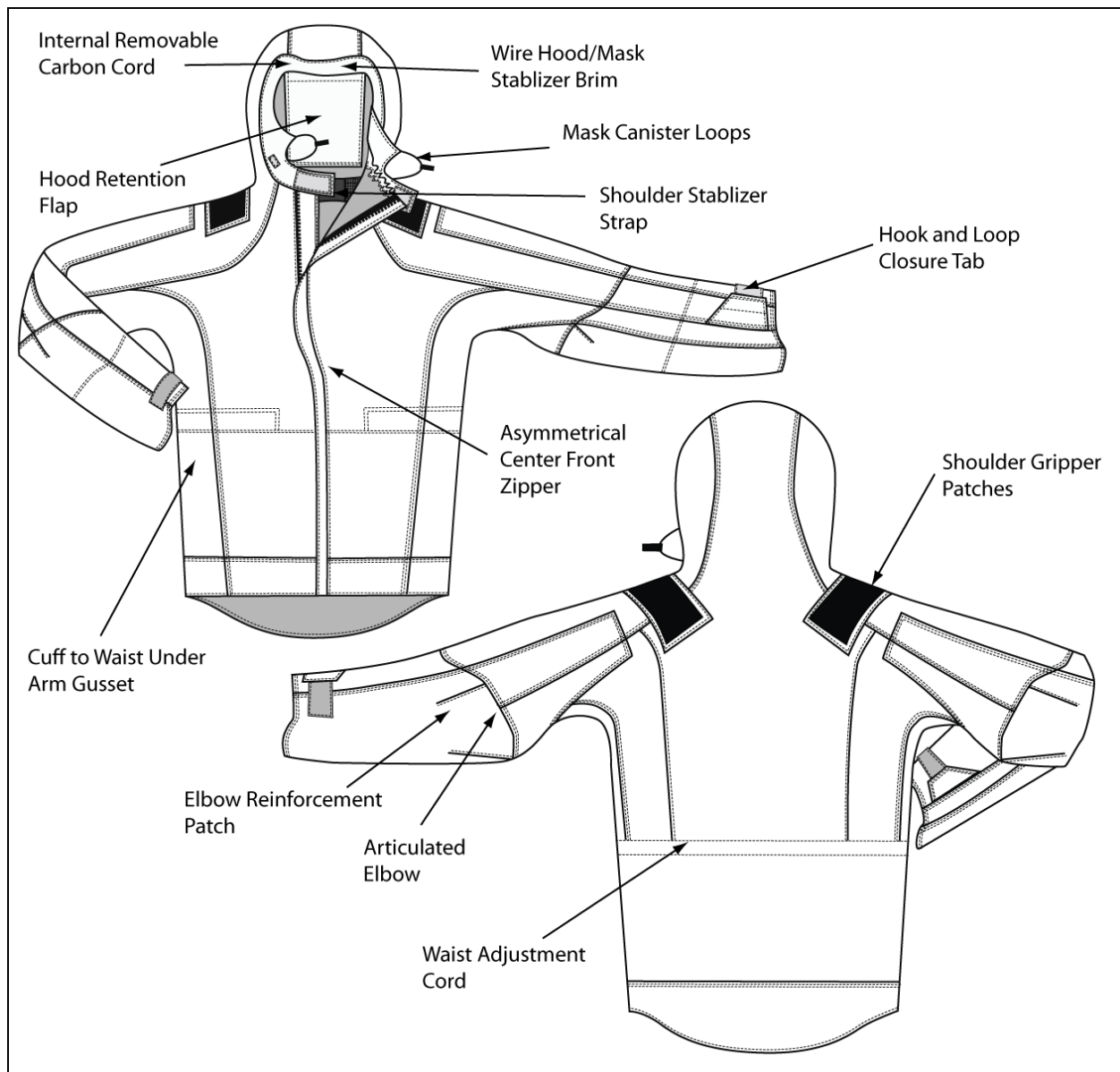


Figure 3. Generation 5 Jacket Shell Flat Sketch.

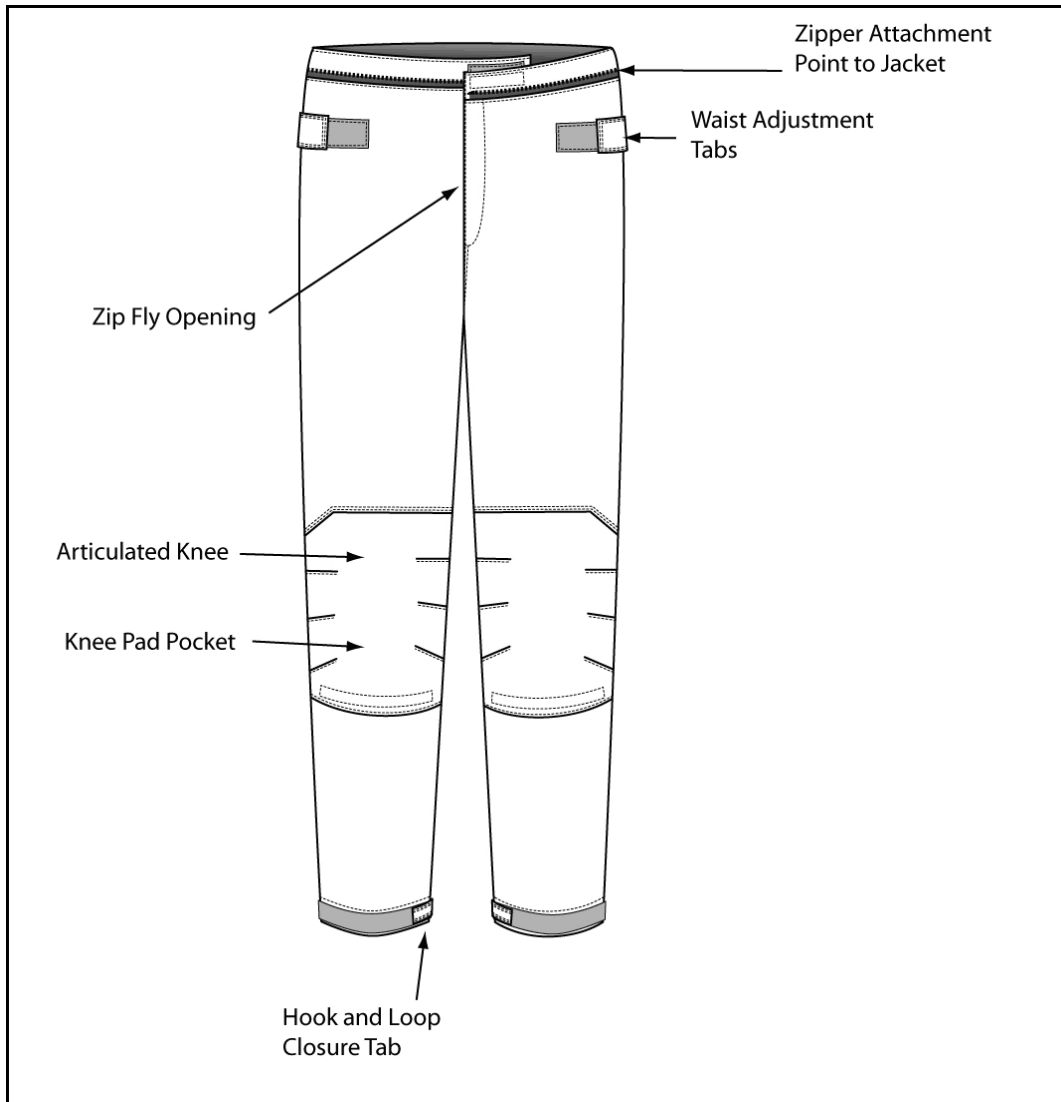


Figure 4. Generation 5 Pant Shell Flat Sketch—Front.

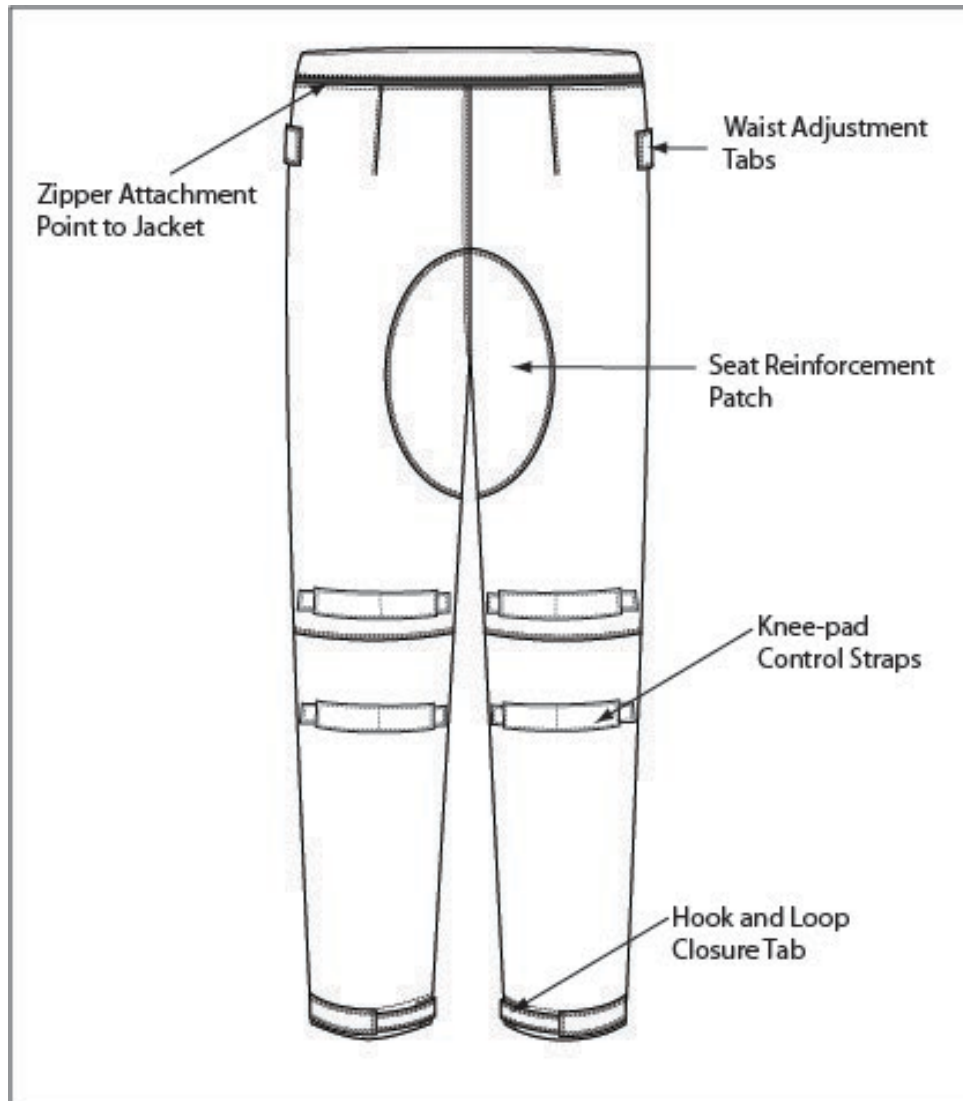


Figure 5. Generation 5 Pant Shell Flat Sketch—Back.

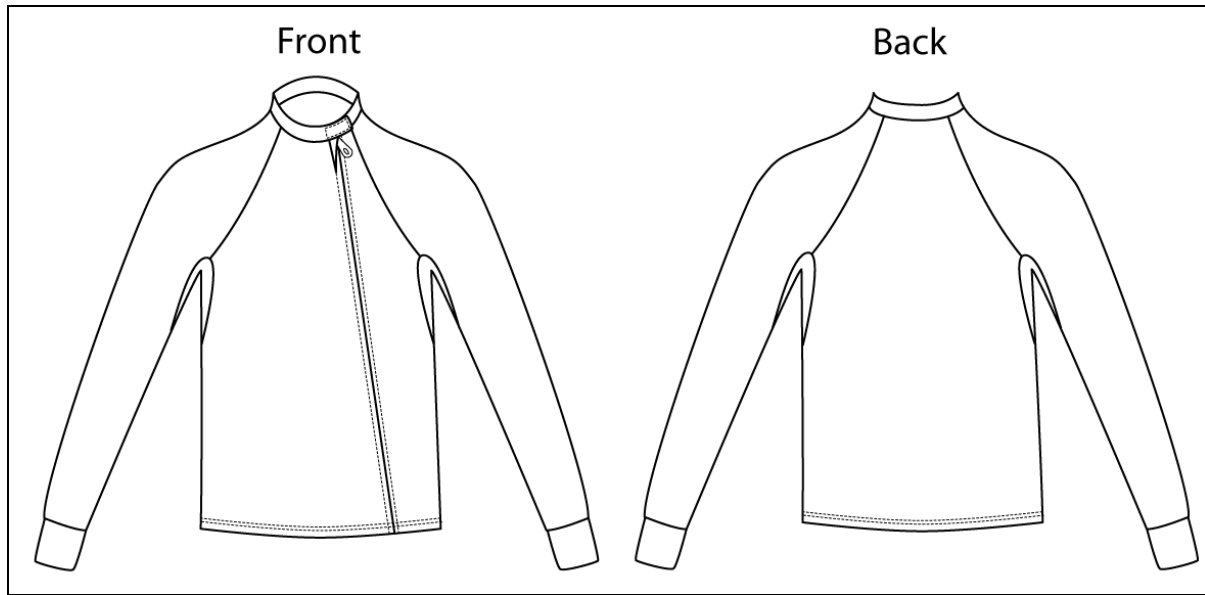


Figure 6. Generation 5 Carbon Shirt.

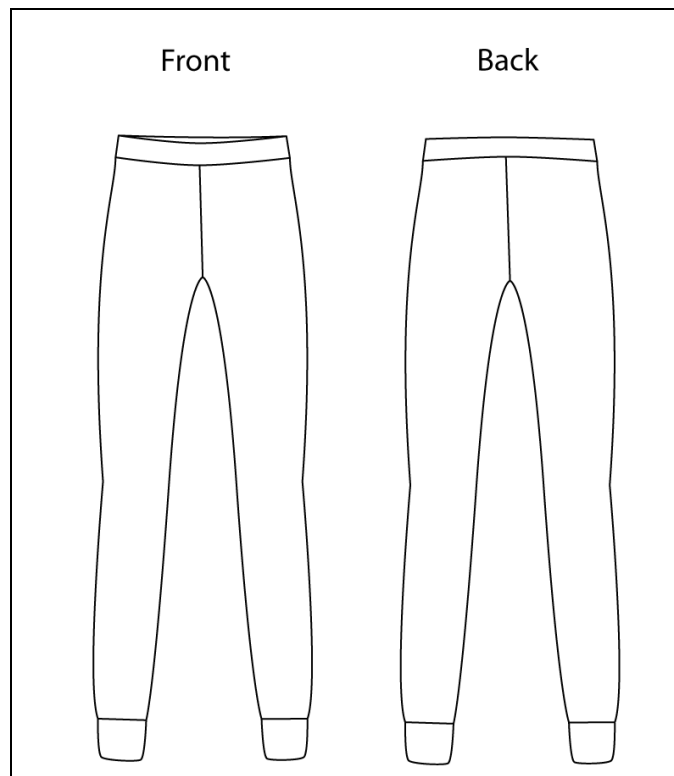


Figure 7. Generation 5 Carbon Drawer.

2.2 Design Process

The GT investigated and the Materials Evaluation Team (MET) selected and evaluated 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 the construction of the Generation 5 garment. This process also included the use of novel manufacturing techniques and innovative garment design concepts.² After the GT evaluated the FAST results described in section 3, modifications were made to the carbon bodysuit and to the jacket and pant ensemble. These modifications are documented in the relevant “Results” subsections and summarized in 3.11.

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 liner, and a durable water- and oil- repellent outer shell fabric. In collaboration with NSRDEC and NCTRF, the GT created a fixed-hood two-piece shell with separate carbon undergarments to eliminate the need for a sewn-in carbon-containing layer.

The Generation 5 was designed to be worn directly over undergarments (without a duty uniform) and with ability for the shell to be worn as a duty uniform. The garment was designed taking into consideration interfaces with the JSGPM, CB gloves, and CB boots. It maintained the need for field relief with a fly zipper and the ability of the garment to be donned individually or with a partner, and also considered the doffing process after the garment had been contaminated.

Principal considerations included maximizing 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 proposed design of the LEHP Generation 5 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. LEHP has not conducted studies on the reusability of the shell after it has been contaminated with chemical warfare agents.

For the purpose of clarity additional garment design challenges will be addressed later in the report.

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.

3. Methods and Test Results

Obtaining testing data was critical to the spiral development process of the LEHP garment. Various in-house and off-location facilities provided feedback on comfort and protection of the garments. The Generation 5 ensemble was evaluated as summarized below.

- HF (external)—This test was completed at NSRDEC by Dr. Karla Allan. It included donning the garment in various Mission Oriented Protective Posture (MOPP) levels, while performing a preselected motion routine. Five soldier participants were used, all of whom were familiar with the JSLIST garment. Participants wore ancillary equipment including helmets, backpacks, and body armor. This evaluation provided an outside evaluation of the garment using soldiers who have been trained to use the JSLIST and could provide appropriate feedback and comparisons. Selected results are presented in the body of this report. The complete test report is in Appendix A.
- HF (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 the preceding Generation prototype. 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 expensive testing. More information about the human factors evaluations conducted at LEHP is in Appendix B.
- FAST - This test was performed at 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 penetrated the garments and reached 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.

After evaluating the FAST results, the GT made minor changes to the ensemble. For details see 3.12.

- CD—This test took place at HSA in Santa Fe, NM. HSA is now a unit of Northern New Mexico College. This test assesses the ease of doffing a contaminated garment. During this evaluation the test participant was covered in a fluorescent fingerprint powder and then taken through a decontamination line. Once the garment had been completely doffed a black light was used to show any “contaminant” that had been transferred onto the body. The process could also be stopped at any point, and a black light used to examine specific steps. Selected results are presented in the body of this report. The complete test report is in Appendix E. LEHP CD Testing Notes are in Appendix F, and the final script for contaminated doffing of Generation 4 garments is in Appendix G. For

changes made to the garments between FAST testing and CD evaluation, see subsection 3.11.

This chapter discusses the construction and evaluation methods, and the results of the evaluations for the 10 components of the Generation 5 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 human factors testing are also included in each section.

3.1 Fabric

Because fabrics that provide chemical protection generally have had low air permeability (and sometimes additional shortcomings such as bulk and stiffness), CP clothing can be hot and uncomfortable. Throughout the LEHP design process effort was made to optimize comfort while maintaining or improving protection. Fabric decisions for the Generation 5 garment were made concurrently with the Generation 4 garment. The fabric chosen for the Generation 5 prototype is a permeable system, which does not require fabric with seam sealing. This change in fabric would allow production to take place at any sewing facility.

Generation 5 fabric selection was completed in conjunction with the Generation 4 garment. Much of the decision-making process took place after the Generation 4 garment prototype was completed and during design of the Generation 5 garment muslin (initial prototype). Because the garments in the Generation 4 and 5 design would be tested concurrently at FAST and Contaminated Doffing the GT decided to use the same fabric pairings for both.

During fabric evaluation, samples were sourced from leading textile suppliers. Table 2 provides a description of the coded fabrics that were considered by the GT and evaluated by the Materials Evaluation Team.

Table 2. Fabrics Considered by the GT for Generations 4 and 5.

LEHP Code	Fabric Structure	Cloth Characteristics					
		Structure Type	Fiber Blend	Coloration Method	Functional Treatment	Weight (oz/sq. yard)	Air Permeability ft ³ /ft ² /min See Note 1.
31B shell	woven	plain weave	multiple fibers	universal camou-flage print	durable water- and oil-repellent (non-flame-retardant)	5.20	9.02
61U shell	woven	n/a	flame-resistant	dyed green	durable water- and oil-repellent	5.30	16.48
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
85M shell	laminate	330d Cordura shell with microporous ePTFE membrane	100% nylon 6,6 330 denier (Cordura)	jet dyed green	microporous ePTFE membrane, durable water repellent finish	5.00	11.39
40C liner	laminate	spherical carbon with multiple fabrics	fiber combination with carbon	dyed green	N/A	5.84	172.87
54M liner	laminate	spherical carbon	multiple fibers with carbon	dyed black	N/A	6.74	148.42
63A liner	knit	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 liner	laminate	Spherical carbon with multiple fabrics	Fiber combination with carbon	dyed grey	N/A	11.42	21.74

Note 1. 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.

3.1.1 Methods

Multiple layers of material that are laminated tend to have a reduced air permeability and increased thermal burned in CP garments. The GT acquired the following materials for evaluation and Table 3 shows shell and carbon pairings that were selected for evaluation by the LEHP teams:

- Two versions of Cordura to evaluate the viability of using an unprotected membrane system. One version (85M) featured a Cordura shell with an aerosol barrier membrane, unprotected, and the second version (78C) featured the same structure with a tricot backer laminated onto the membrane to protect its fragile structure. Plans were made to test 85M shell fabric in internal HF to assess how well the membrane would hold up with real-world use. In the event that 85M was not deemed useable, 78C would replace it for further garment development.
- Another supplier provided a fabric (63A) with unprotected carbon powder adhered to a stretch knit.
- Another supplied two non-membrane shells (31B and 61U) and three carbon bead laminated fabrics (40C, 54M, and 96X). Two of the carbon fabrics 40C and 54M were non-stretch while 96X was an updated version of the stretch fabric used in the Generation 3 undergarment. This supplier required that their carbon fabrics only be used with their shells, which limited pairing with other suppliers' fabrics.

Table 3. Pairings of Shell and Carbon Materials by the GT for Generation 5

Fabric Pairings	
Shell	Carbon
31B	96X
31B	40C
31B	54M
61U	54M
85M	63A
78C	63A

3.1.2 Results

After multiple HF trials on the Generation 4 garment and various model fittings, 85M was evaluated and deemed unusable for LEHP's Generation 4 garment based on the significant membrane wear was observed at key stress points such as the knees, elbows and center front chest area, along with many other areas on the body. Test participants in the in-house and NSRDEC HF trials experienced no significant difference while trying on garments constructed from 85M and 78C. During production of the garment, degradation of the membrane was also

observed from simply sewing two layers of fabric together. (For pictures of the wear patterns please see Technical Report PHILA-LEHP-GT-TR-09-01, *Design and Testing of Chemical/Biological Protective Coverall System, Generation 4.*)

It was also observed after multiple HF trials that the carbon liner fabric 63A showed some degradation of integrity of the attached carbon powder. Visible wear on the knees and selected seams caused concern, although it is unknown how this wear affects performance of this vital layer. A possible solution might be as simple as reinforcing key areas such as the knees and elbows with an additional layer of the carbon fabric but this was not investigated. This fabric was the most comfortable carbon layer per comments from the Generation 4 NSRDEC HF trial in November 2008 (report issued March 30, 2009). “Between the two long underwear garments featured in this evaluation (63A and 96X), they [test participants] both preferred 63A, which they perceived as lighter weight and therefore cooler.”

Because the GT was not authorized to carry out chemical agent testing on the individual fabric and/or pairs, the level of protection that each fabric provided was not known. All fabrics used were deemed by the supplier to be suitable for chemical defense. Because a principal objective of the LEHP undertaking was to improve comfort, the GT focused on fabrics that provided the greatest comfort as determined by the data collected on fabrics made available to LEHP.

Despite visible wear on 63A the GT chose to continue moving forward with this fabric because its thermal resistance (R_{ct}) and water vapor resistance (R_{et}) were much lower than most of the other carbon fabrics³. This testing was conducted by the LEHP MET using a Sweating Guarded Hot Plate and the procedure in ISO 11092. The 63A was also more breathable and received a very favorable response during HF trials; it was generally well regarded by the GT researchers, as well, because of its light weight and perceived comfort. Further support for 63A came from the regression analysis developed and evaluated by the LEHP Artificial Intelligence (AI) Team. The regression analysis was used to predict Comfort Affect Labeled Magnitude (CALM) scores for tactile comfort.⁴ Fabric 63A scored very favorably in this assessment; this score, combined with all the favorable responses to this fabric during Generation 4 HF evaluation, provided support for 63A to become the front-runner of the carbon fabrics to prototype test garments for FAST and CD evaluations. Because of fabric combination restrictions by certain suppliers, 78C was chosen to be paired with 63A for all future FAST, CD, and HF evaluations of the Generation 4 and 5 garments.

In September 2010, the Generation 5 garment completed HF evaluations at NSRDEC. All five subjects noted the combined LEHP ensemble (undergarment and shell) weighed less than the JSLIST. They also agreed that the ensemble seemed to be less hot than the JSLIST, whether the JSLIST was worn with or without a duty uniform underneath.

³ For more information about fabrics mentioned in this report, see Technical Report PHILA-LEHP-ME-TR-08-02, *Consolidated Data on Fabric Construction*.

⁴ For information about the analysis process, see “Identification of the Most Significant Properties Influencing Tactile Fabric Comfort Using Regression Analysis.” Les M. Sztandera. February 2009. *WSEAS Transactions on Computers*. Issue 2, Volume 8. 302–311.

3.2 Dual-Layer System

During evaluations of the previous LEHP garments it had been noted that a separate carbon and shell system proved very successful in both FAST and especially CD testing. For Generation 5 it was decided that GT would continue to design a garment comprised of two parts: an outer shell that could alternately be worn as a substitute duty uniform, and a separate disposable inner carbon liner. An important issue with any item using carbon technology for CP is the shelf life. Once the carbon's wear or shelf life expires, the item no longer provides the needed protection and disposal is necessary, resulting in much unnecessary 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 discarded only because the protection provided by the carbon has expired. In addition, it was discovered during CD at HSA testing of the Generation 3 garment that outer garment/undergarment ensembles were doffed more successfully. Minimal contaminant was found on the body after completion of the doffing procedure in comparison to the identical shell garment worn with carbon cuffs instead of the separate carbon undergarment.

3.2.1 Methods

The GT complied with NSRDEC's request to streamline the design, making it closer-fitting to the body. This design change included eliminating the loose fitting carbon undergarment seen in the prior generation and retaining use of only the close-fitted version. MET evaluations on the articulated manikin confirmed this was a superior choice. Their data suggested that a tighter fitting undergarment design can reduce the intrinsic clothing insulation value by as much as 32% compared to a loose-fitting design, thus reducing thermal burden. During prior HF evaluations the tightly fitting stretch bodysuit was found to be more comfortable than the loose, non-stretch bodysuit.⁵

The Generation 5 carbon undergarment was modified into a two-piece undergarment to correspond with the two-piece shell. The fitted undergarments (Figures 8 and 9) were made from a knitted stretch carbon fabric (63A). Because this carbon and shell combination is intended to be worn in place of 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 5 ensemble would likely prove more comfortable than options that require the duty uniform to be worn underneath.

The fitted carbon undershirt features a raglan sleeve design with a small 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. A mock-turtle neck and hook-and-loop closure complete the shirt. The carbon drawers are long-underwear style with a ribbed stretch waistband

⁵ Details of the study that resulted in this conclusion are available in "Comparison of Thermal Resistance between Two Garment Designs Driven by Material Characteristics Using a Thermal Manikin" by J. L. Brady, N. Rao, T. Rioux, C. Winterhalter, and published in *Proceedings of the 13th International Conference on Environmental Ergonomics*, August 2–7 2009, Boston, MA.

that can be easily pulled down for field relief, and feature non-elasticized carbon cuffs and a cotton elastic-ribbed waistband. The ensemble also includes a carbon hood (balaclava, see Figure 10) to be worn over the head; this hood interfaces with the JSGPM.

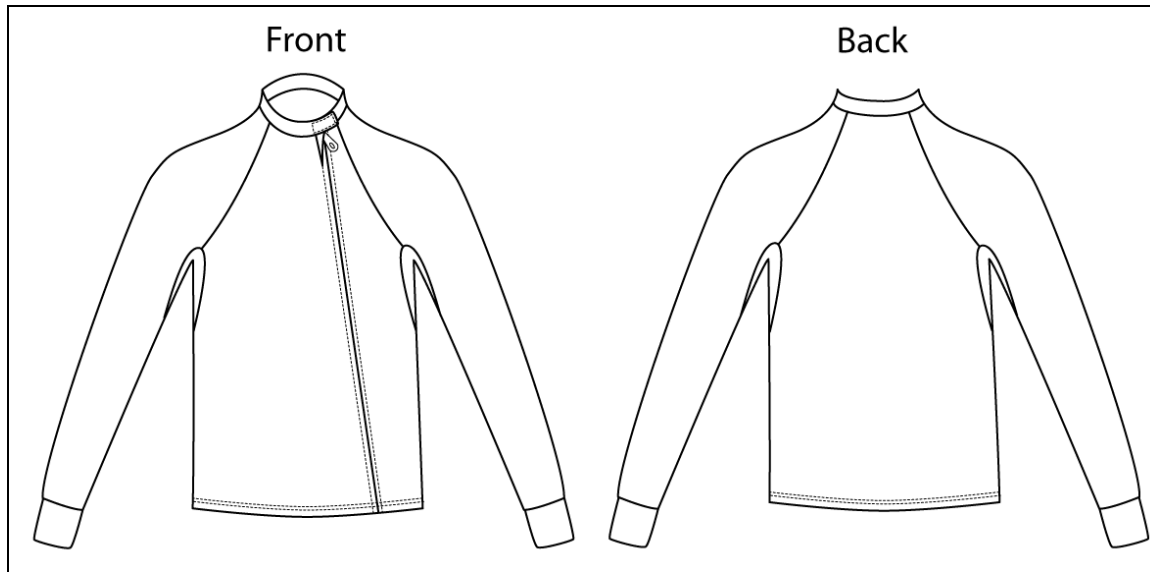


Figure 8. Generation 5 Carbon Shirt.

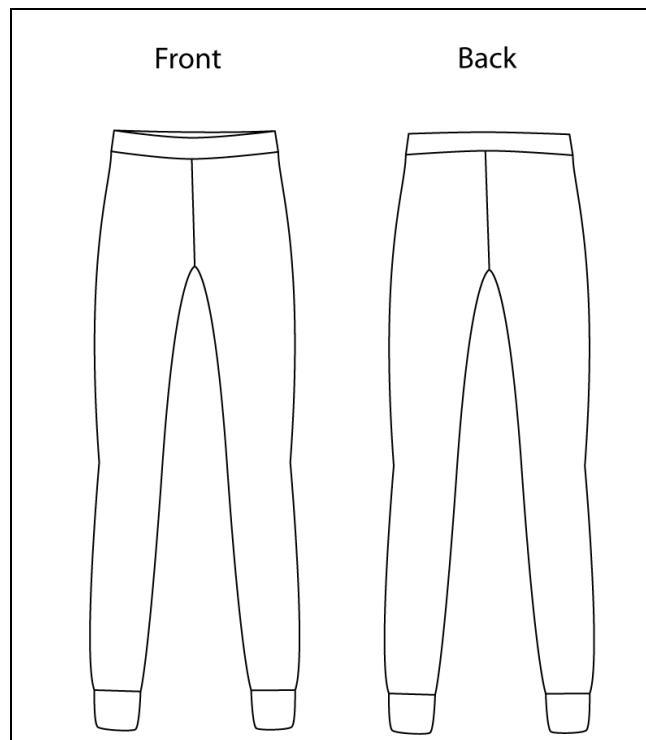


Figure 9. Generation 5 Carbon Drawer.

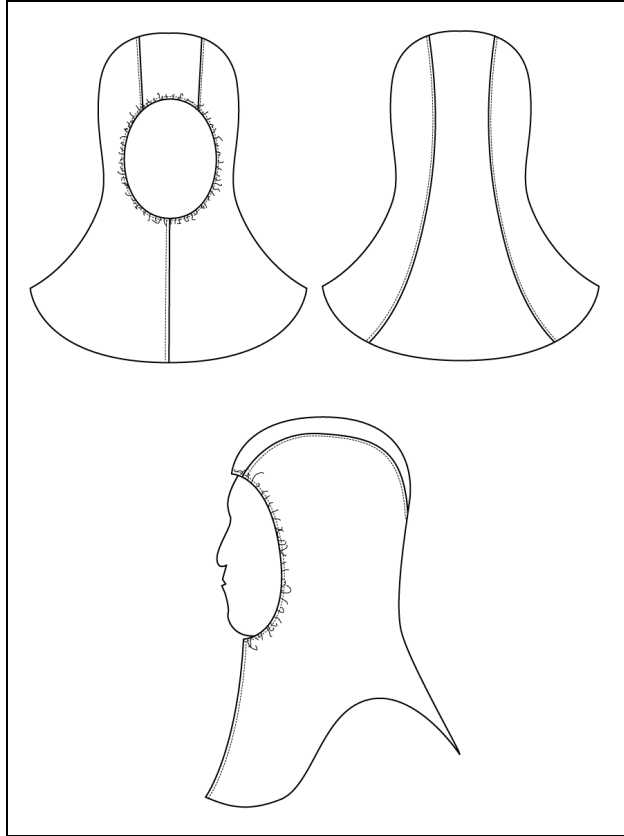
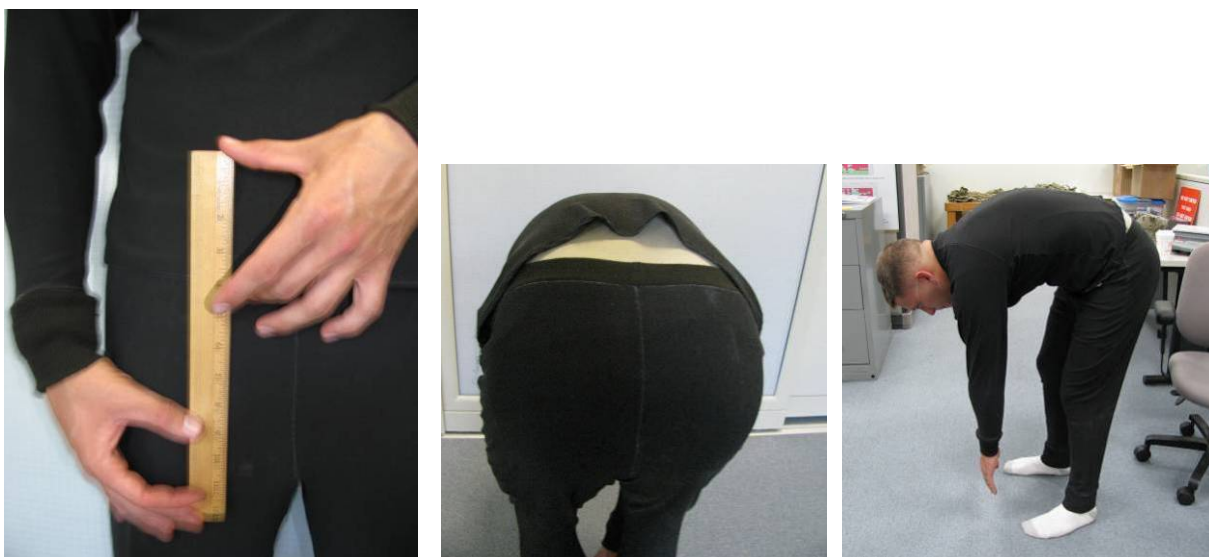


Figure10. Generation 5 Carbon Hood Flat Sketch.

3.2.2 Human Factors Results

During HF evaluations at NSRDEC it was noted that when four of the five test participants bent over to touch their toes while wearing only the carbon undergarments a breach was observed at the lower back between the shirt and drawer. For example, Figure 11 panel A shows a test participant whose carbon shirt overlapped the carbon drawers by 2.5 inches when he was standing. Figure 11 panel B shows the bodysuit breach when the same participant bends at the waist. Figure 11 panel C shows the bodysuit breach when another participant bends at the waist.



A. Overlap of Carbon Bodysuit Pieces.

B. Bodysuit Breach for Participant Shown in Panel A.

C. Bodysuit Breach for Another Participant

Source: NSRDEC

Figure 11. Breach Points on Carbon Bodysuit. A. 2.5-Inch Overlap of Carbon Bodysuit Pieces. B. Bodysuit Breach for Participant Shown in Panel A. C. Bodysuit Breach for Another Participant.

Despite the shirt's being short in the back for most participants, the participants liked the feel and flexibility of the fabric of the carbon undergarment. Only one participant noted discomfort at the neck. Some chafing was observed (see Figure 12), most likely due to the exposed carbon adjacent to the skin, as this is the only place on the garment that such chafing was mentioned.



Source: NSRDEC

Figure 12. Neck Chafing, Apparently from Carbon Bodysuit.

3.2.3 FAST Results

Undergarment fabric 63A was used for all three FASTs performed at RTI. No significant difference in protection was found, regardless of whether the carbon drawer leg cuffs were

tucked into the combat boot or worn outside. See Appendix C for LEHP planning notes for FAST and Appendix D for FAST results.

3.2.4 Contaminated Doffing Results

Undergarment fabric 63A was used for all three CD trials.

After the GT evaluated the FAST results, the following changes were made to the carbon undergarments prior to CD evaluations.

Shirt:

- Lengthened 4 inches
- Repositioned front shirt zipper to left side of waist with curved shape to the neck reducing discomfort from layer stacking
- Reinforced inside zipper flap with three vertical stitch rows to stiffen and eliminate fold back
- Reworked band collar with grab extension

Drawers:

- Removed non-carbon ribbed ankle cuffs from pant legs and replaced with cuffs made of the same carbon fabric used for the rest of the undergarment

Balaclava:

- Added temple filler to carbon hood: one with neoprene, one with rib knit, and one with cording filler and brim edge piped with one-quarter-inch cord
- Reshaped carbon hood lens/front opening shape to conform to the contour of the CB respirator

The test participants preferred that the leg cuffs on the drawers be tucked into the combat boot. They believed that tucking the lower legs into the boot made doffing easier; the carbon drawers did not get stuck on the combat boot. As a result, clean doffing was more likely. For details of the CD trials, see Appendices E, F, and G.

3.3 Hood/Mask Interface

The interface between the hood and the mask remains a critical area for maintaining the protective interface to prevent penetration of contaminants. Because of the concave shape of the JSGPM at the temple areas, the GT attempted to improve the interface with filled pouches, a wired hood brim, and elastic canister loops. In the efforts to optimize this interface, the GT has implemented numerous design changes in the past four years while providing optimal comfort and no restriction of movement.

The outer garment's attached hood covers the wearer's head and fastens around the mask. Therefore, the challenge areas are at the forehead and eye/temple where a tightly closed interface is needed. Bellowing is also a concern at this area; this effect can pull air and contaminants inside the hood and/or garment. Additionally, at this interface the hood/neck area of the outer

garment wraps around and closes under the chin covering the front zipper, providing additional sealing at this crucial interface.

3.3.1 Methods

The GT has continually revised and modified the under-chin area of the garment to improve the comfort and reduce or eliminate restricted movement while bending and twisting the neck. The neck flaps were reduced to a small hook-and-loop tab to maintain a snug fit around the mask. This design was an improvement over the larger flaps seen in the Generation 4 garment. For a comparison of the under-chin area of Generations 4 and 5, see Figure 13. After evaluation of FAST results, the GT added hook-and-loop tape to this neck flap to secure it during doffing.

After evaluating the FAST results, the GT reduced the fullness of the hood by a maximum of 1 inch at a point 16 inches from the brim. This reduction was accomplished by taking in the two front-to-back seams. The change was graded from 0 at the front to 0.5 inch (at the 16-inch point) and back to 0 at the shoulder end of the seam.



A. Generation 4.

B. Generation 5.

Figure 13. Reduction in Bulk in Under-Chin Area. A. Generation 4. B. Generation 5.

Generation 5 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).

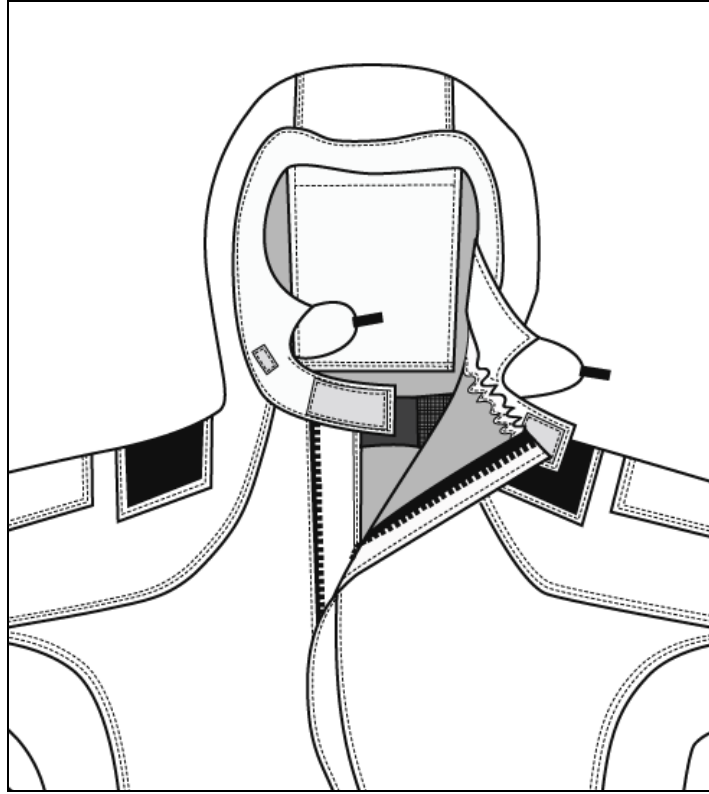


Figure 14. Generation 5 Hood/Mask Interface.

During Generation 5 development, much of the design effort was focused under the chin area to lessen bulk while improving flexibility, range of motion and fit. The neck flaps were reshaped and significantly reduced to provide more comfort for head movements and a better field of vision. In Generation 4 the wire brim was one piece; for Generation 5 this wire brim was split in the center, and elastic was placed in the two-inch gap between the wires. The split brim provides for easier stowage of the hood when not in use.

A removable carbon brim rope cord was employed at the center front brim inside the hood on the forehead area above the mask lens to create an additional layer of protection and to prevent liquid contamination of the wearer. Such liquid contamination was seen during the Generation 3 during CD tests. After evaluation of the FAST results, the circumference of the hood brim internal carbon cord was reduced to 0.5 inches in an attempt to cut down on bulk at the forehead area. The cord was also lengthened 1.5 inches so that it could be tucked away behind the temple pouches on the carbon hood.

The hood was designed with a construction seam over the crown (see Figure 15). This seam ran from the neck area around the hood and over the crown of the head to the neck area on the adjacent side. This modular feature allowed 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 production and/or 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 may benefit economically by producing large numbers of the uniforms without the mask panel; by sewing only one seam the basic uniform may be fitted to different masks. Once the mask frame panel is attached it's 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.

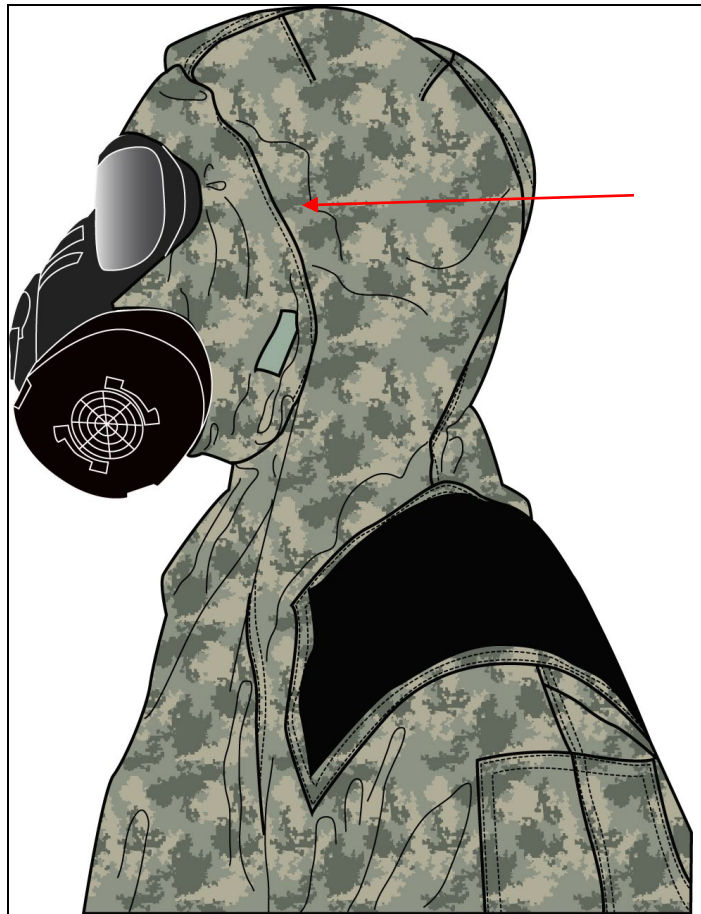


Figure 15. Generation 5 Hood Seam.

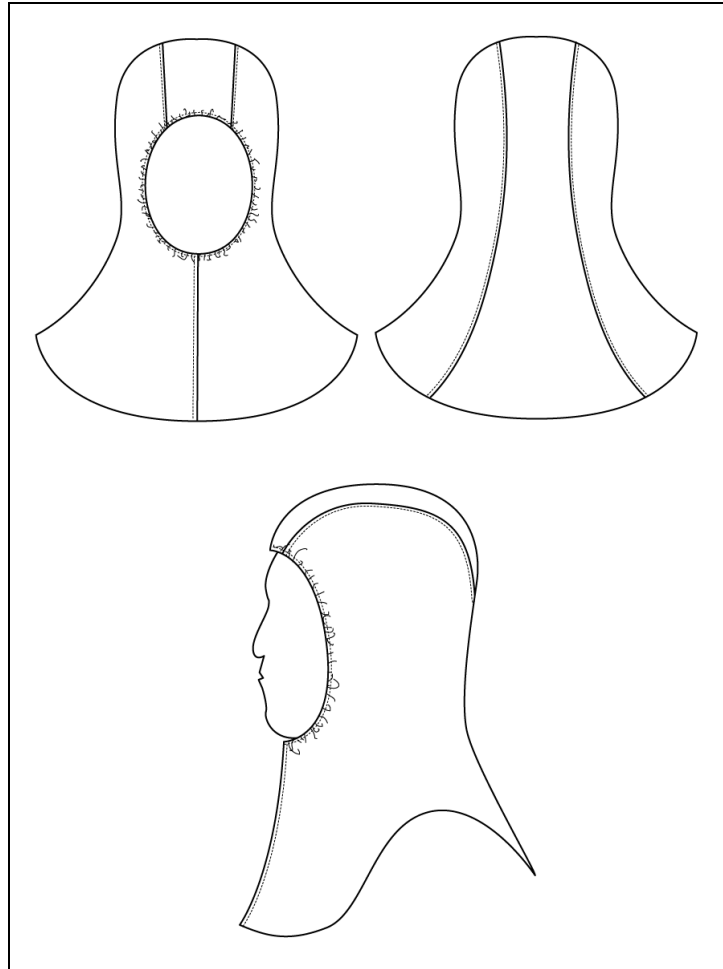


Figure 16. Generation 5 Carbon Balaclava (Pullover Hood) Flat Sketch.

The outer 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. An initial design was used during HF evaluation and the first two tests at FAST of Generation 4 (see Figure 17, panel A.). After using a knitted insert on the third test for Generation 4, it was decided that all three FAST tests for Generation 5 would employ the knitted insert (see Figure 17, panel B) to potentially reduce simulant penetration at the temple area where the JSGPM's concave shape creates issues with forming a protective interface in that specific area. During CD evaluation three different inserts were used: knit, neoprene (see Figure 17, panel C), and filled pouches with an additional carbon cord around the opening (not pictured).



A. Without Modifications. B. With Knitted Insert C. With Neoprene Insert

Figure 17. Carbon Hood Modifications to Improve Snug Fit with JSGPM, A. Without Modifications. B. With Knitted Insert. C. With Neoprene Insert.

3.3.2 Human Factors Results

In-house HF testing showed some minor restriction in the neck area while turning the head side-to-side, as well as while looking at the ceiling. However, this minor restriction did not impact the test subject's ability to complete any of the motion routine.

Participants in these HF evaluations rated the closure at the front neck edge to be relatively comfortable. (See Appendix B for more details of this and other LEHP HF Evaluation results.)

Some restriction was observed while the test participants at NSRDEC's HF evaluations tried to turn their necks. One test participant also expressed some discomfort at the neck while wearing the Generation 5 garment in MOPP 4 with the Improved Outer Tactical Vest (IOTV). No visible breaches in this area were observed during the testing.

3.3.3 FAST Results

Excerpts from the July 2009 RTI FAST report are below. For more information about the report results, see Appendix D. With the exception of Figure 18, the photographs in this subsection are from that report.

The JSGPM was used in all the July 2009 FAST tests. The hood and mask configuration used for those test is shown in Figure 18.



Figure 18. Generation 5 Hood/Mask Interface with JSGPM.

Test 1.⁶: “A light level of aerosol deposition was visible on the right cheek and in the hair just above the middle mask strap” [Figure 19].

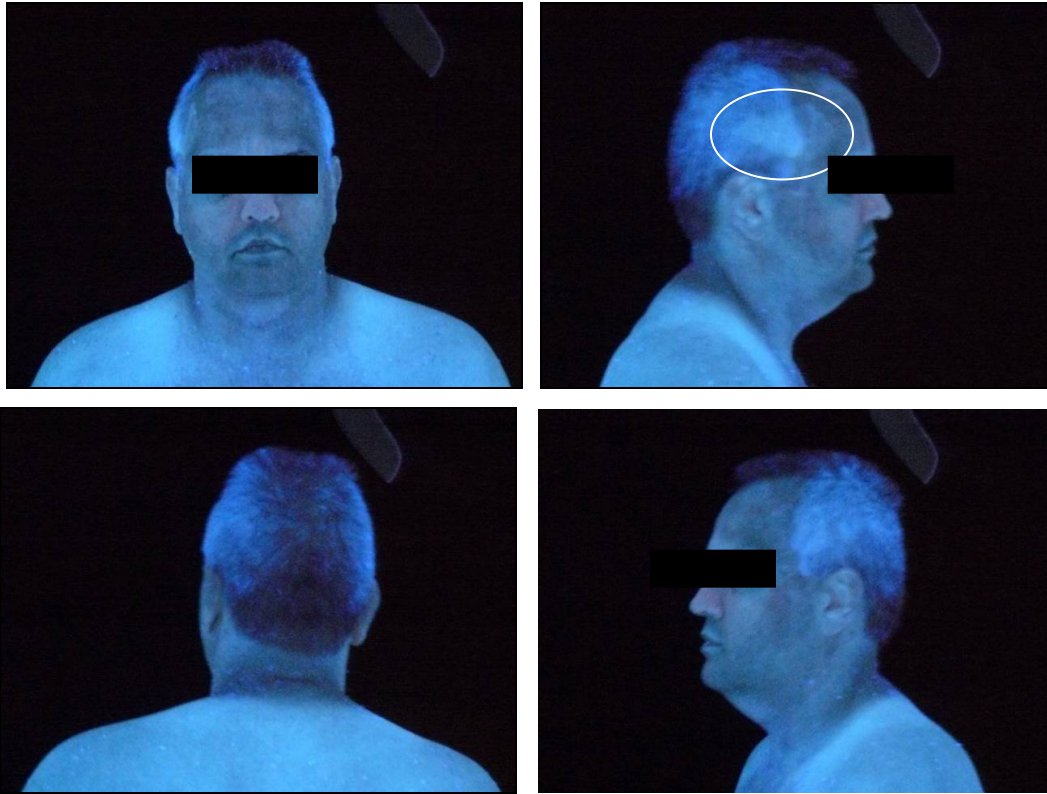


Figure 19. Generation 5 Hood/Mask Interface (with Knit Inserts) FAST Test 1 Results—Light Deposits on Cheek and Hair.

⁶ In the RTI report, this test is identified as Test 1815.

Test 2⁷: “There was a blue haze on the cheeks and around the ears. Additionally, there was a small yellow hotspot on both sides of the face. The cause of the hotspots was not immediately apparent. The lower mask straps are visible below the hotspots” [Figure 20].

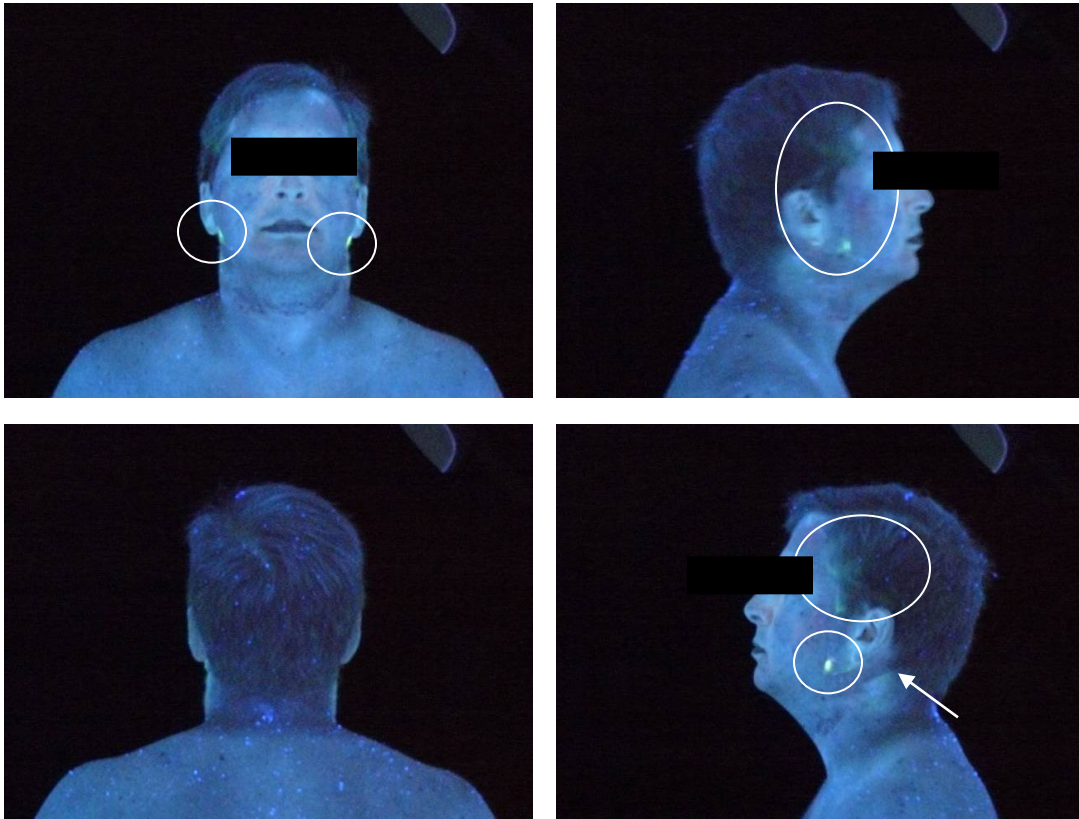


Figure 20. Generation 5 Hood/Mask Interface (with Knit Inserts) FAST Test 2 Results—Haze on Cheeks and around Ears; Small Hotspots on Sides of Face.

⁷ In the RTI report, this test is identified as Test 1816.

Test 3⁸: “Light to moderate levels of aerosol deposition were visible on the cheeks and under the chin, including a line of moderate deposition on the left cheek” [Figure 21].

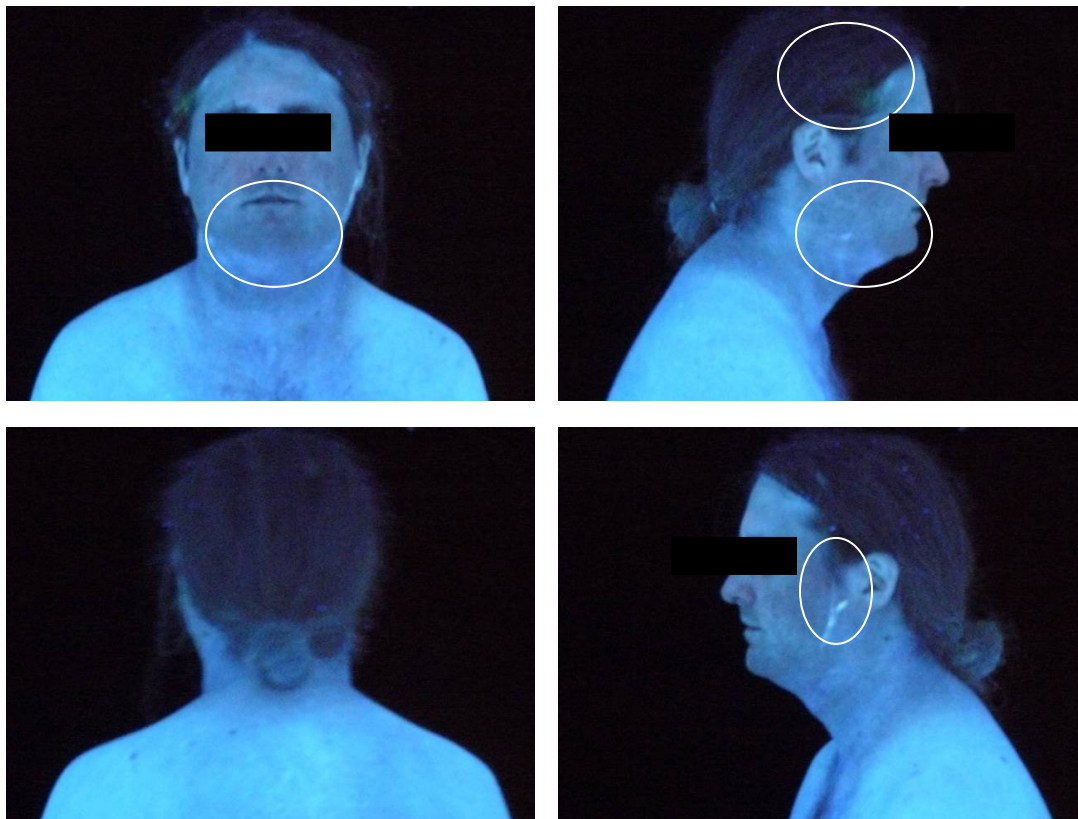


Figure 21. Generation 5 Hood/Mask Interface (with Knit Inserts) FAST Test 2 Results—Light to Moderate Deposits on Cheeks and under Chin.

3.3.4 Contaminated Doffing Results

During FAST the participant performs a series of motion routines while subjected to aerosolized simulant in a chamber for approximately 30 minutes. For CD, the participant keeps movement to a minimum and is exposed to aerosolized simulant for five minutes to coat the subject and minimize any penetration onto the body due to the bellows effect.

During Run 1 simulant was noticed on the top of the right ear. The subject noted at one point he felt a “breeze” on his head, which is likely the cause of the noted simulant. It is unknown at this time if the wire brim was shifted out of place while the dusting occurred. Inspection of the mask under the black light showed simulant present on the mask underneath the carbon hood.

Run 2 showed a bright spot around the size of a pencil eraser was detected on the right temple as was a slight haze at the mask edge in this same area.

⁸ In the RTI report, this test is identified as Test 1817.

At the culmination of Run 3, faint hazing of simulant on the left temple area was observed. Inspection of the mask under the black light showed simulant on the temple area of the mask underneath the carbon hood; on the right side it appeared that the neoprene inserts stopped most of the simulant from penetrating. However, simulant entered the hood at the point the insert stops and was deposited onto the upper jaw line of the subject.

3.4 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 outr garment pant. The knee-pad pocket is attached to the outside of the garment so that an extra layer of protection is provided with removable neoprene knee pads (see Figure 22).

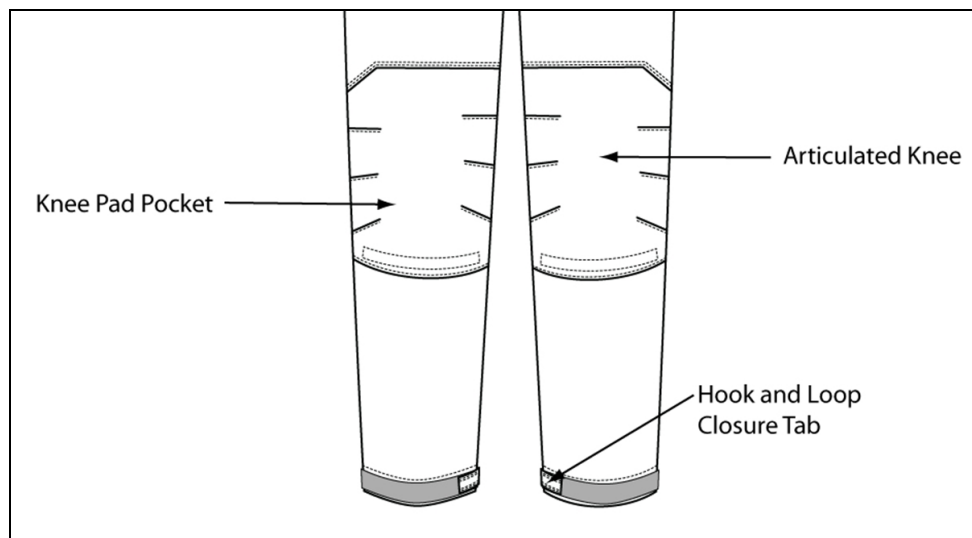


Figure 22. Generation 5 Articulated Knees with Knee-Pad Pocket.

3.4.1 Methods

The knee area of the Generation 5 garment was slightly redesigned from the Generation 4 coverall style. A seam was placed behind the knee, and most of the seams in the front of the knee were removed and replaced with darts. This change to the knee area allows the knee to bend more easily and provides less bulk while squatting.

The knee-pad pocket continued to mimic the shape of the knee on the pant and the design feature of the removable knee pad was carried into the Generation 5 garment. The pocket continues to open at the bottom to remove the chance of liquid pooling in the pocket. Hook-and-loop tape keeps the pocket closed, preventing loss of the kneepad.

Knee-pad control straps that were designed during the Generation 4 garment were incorporated again in the Generation 5 garment resulting from favorable findings during LEHP human factors testing on the Generation 4 coverall. The positive response led the GT to continue with the knee-pad control straps in this design (see Figure 23).

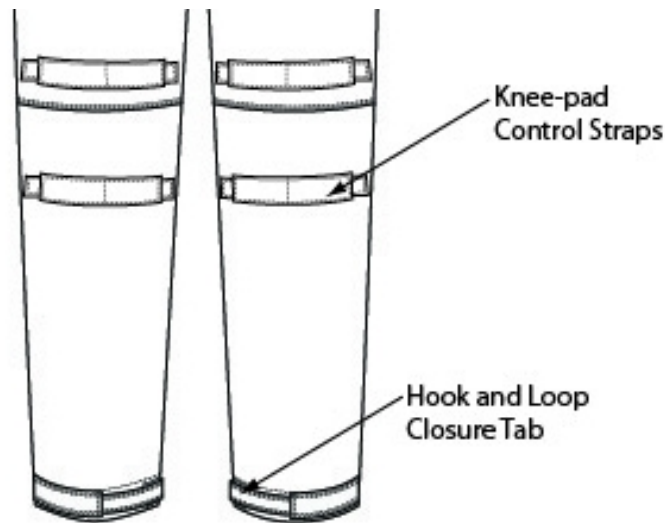


Figure 23. Knee-Pad Control Straps.

3.4.2 Human Factors Results

Slight restriction in the top knee area was reported while lifting the knees to the chest during HF at Philadelphia University. The GT has observed that the test participants seem to have less restriction since incorporation of the knee-pad-retention straps.

During testing at NSRDEC, a possible snag hazard was observed due to the knee-control straps sticking out between the legs. The tabs could get stuck to each other or be snagged on nearby objects.

3.5 Articulated Sleeve and Elbow Reinforcement

3.5.1 Methods

To provide the wearer with better comfort while bending at the elbow, the GT shaped this portion of the Generation 5 jacket to create a more ergonomic design (see Figure 24). A seam and two darts were added to increase the elbow area and to allow even better articulation while bending this joint. The elbow area is reinforced with an additional layer of fabric to prevent wear. The elbow reinforcement (see Figure 25) continues to mimic the shape of the articulated sleeve and provides an extra layer of protection to high-abrasion areas.



Figure 24 Articulated Sleeve—Front View.



Figure 25. Articulated Sleeve with Elbow Reinforcement Shown—Back View.

3.6 Torso and Zippered Integration Panel

It has been shown that there is potential for contaminant to penetrate at the waist area of two-piece garments (upper and lower pieces) and several have been evaluated to improve this interface and reduce and/or eliminate 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 5 ensemble has the potential to improve this interface.

3.6.1 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 zipper lengths are the same length. Unlike other designs, the Generation 5 ensemble 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.

The donning sequence for the integration panel is shown in Figures 26 through 29.



Figure 26. Ensemble before Donning Integration panel; Integration Panel Zipper on Pant Visible.



Figure 27. Integration Panel Zipped First to Jacket and then to Pant.



Figure 28. Integration Panel Zipped to Both Jacket and Pant.



Figure 29. Integration panel tucked up under Jacket.

To give the jacket a snugger fit at the waist a stretch cord was set into a channel inside the jacket (see Figure 30). This cord can be tightened and held in place by cord locks in the front of the jacket to reduce bellowing. The wearer can choose how tightly or loosely to wear the jacket. This function does not interfere with the integration panel's attachment to the pant.

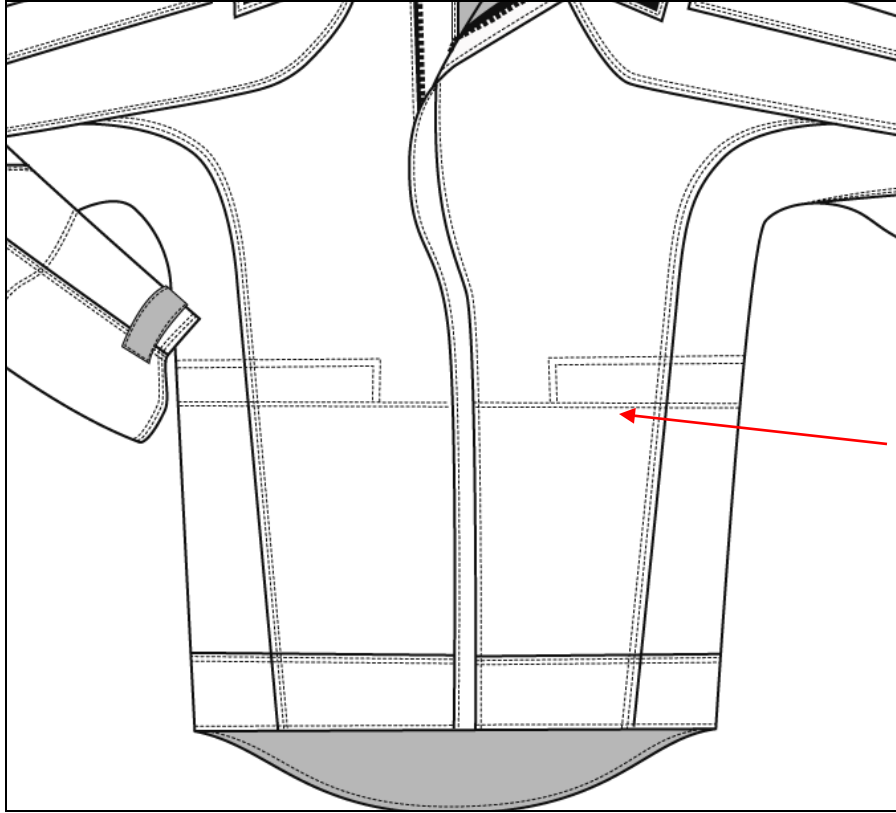


Figure 30. Close-Up of Stretch Cord Channel (Positioned inside Jacket).

After the GT evaluated the FAST results, the internal jacket/pant retention flap was extended and hook-and-loop tape was added at center front on the integration panel to close gaps. Hook-and-loop tape was also added to the jacket's outer zipper flap; the tape was added from the retention flap to the hem edge. The front zipper's pull tab was lengthened 0.5 inch to a finished length of 2 inches.

3.6.2 Human Factors Results

During HF trials at Philadelphia University it was noted by some participants that extra bulk seemed to be in the area of the integration panel. Discomfort was expressed when participants were in the prone position; this discomfort resulted from lying on the cord locks. No participant felt the need to pull the stretch cord to tighten the jacket at the waist; test participants actually preferred that the cord not be tightened.

Evaluations at NSRDEC found that while the circumferential zipper on the integration panel was easy for the test participants to zip unassisted, they found it difficult to align the hook-and-loop fastener panels smoothly. The area was reported to be complicated, but despite this perception, no instances of loosened hook-and-loop fasteners or breaches during movement were observed.

3.6.3 FAST Results

The following results are from Philadelphia University Fluorescent Aerosol Screening Tests (FAST) Test Report, July 31, 2009 (Appendix D). The photos are from the RTI report.

Test 1: “There was a light level of aerosol deposition on the central chest and downward along the centerline of the torso, generally in the area of the shirt zipper” [Figure 31].

Hazing on the chest was seen for the first time on the LEHP garments since the implementation of the separate carbon bodysuit. This penetration of simulant was not unexpected as the Generation 5 garment is the GT’s first two-piece garment, and one of the challenges was to provide a two-piece garment that could attach at the waist, taking into account the front zipper and fly on the shell, which provided obstacles for maintaining a secure seal. As reported, a light hazing was on the chest with a distinct “clean” area that followed the line of the zipper and additional zipper flap of the carbon shirt, noted by the arrow in Figure 31.



Figure 31. Generation 5 Torso FAST Test 1 Results—Light Deposit on Chest.

Test 2: “There was a light blue haze on the central chest, indicating a low level of aerosol deposition” [Figure 32].

Hazing was seen again on Test 2 in nearly identical patterns to Test 1.

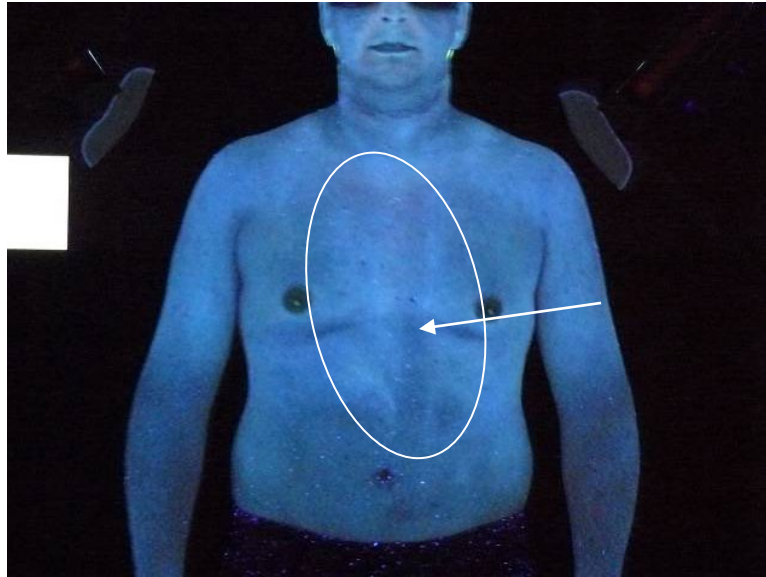


Figure 32. Generation 5 Torso FAST Test 2 Results—Light Deposit on Chest Similar to Test 1.

“There was a light blue haze on the central chest, indicating a low level of aerosol deposition.”

Hazing was seen again on Test 2; the patterns of hazing were nearly identical to those in Test 1.

In an effort to eliminate aerosol penetration onto the torso area, after Test 2 the GT used copious amounts of duct tape to reduce the aerosol penetration where it was suspected the zippered integration panel was allowing penetration onto the body (see Figure 34).



Figure 33. Duct Tape Added to Integration Panel Area before Generation 5 Torso FAST Test 3.

Test 3: “The torso and arms appeared relatively clean.”

Finding no aerosol hazing on the torso demonstrated to the GT that the hazing seen earlier was a result of a breach in the outer garment at the area of the zippered integration panel as theorized from the first two tests. Considering that this ensemble was the first prototype of a two-piece design, the GT was satisfied with the results and planned to use this information for design changes in the future. Because the hazing was seen on the first two tests (see Figure 34) and not the third where the interface was taped closed, the GT assumed that the simulant was breaching the area where the zippered integration panel and the garment shell’s front zipper crossed. The GT theorized that the aerosol simulant is penetrating through the carbon fabric after penetrating the outer garment interface; this observation was substantiated by the fact that the zipper flap area with its extra two layers of fabric was observed as a clean area among the aerosol hazing on the chest in Tests 1 and 2. It is unclear to the GT how this would affect a soldier in a real-world situation as NSRDEC has requested no penetration data be run on these fabrics. In keeping with the scope of the original LEHP program, fabric choices from the protective fabrics sourced were made largely based on comfort.



Figure 34. Torso Test 2.

3.6.4 Contaminated Doffing Results

Faint hazing on the chest was seen in two of the three tests done at HSA. This hazing was much like that seen at FAST. These CD results support the supposition that simulant breached the interface between the pant and jacket at center front.

3.7 *Bi-Swing Back and Shoulder Grips*

3.7.1 Methods

A bi-swing (“action”) back allows the user an improved range of motion rather than as seen with a garment with a plain back. The large pleats running from shoulder to waist provide increased flexibility, especially while wearers cross their arms (Figure 35).

Material that has a grip face was attached on the jacket shoulder area in this new design to help prevent gear slippage. These grip areas provide extra protection to a high-abrasion location 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.

3.7.2 Human Factors Results

No instances of restriction in the shoulder area were reported during HF at Philadelphia University.

Only one participant during NSRDEC's evaluations noted restriction while bending to touch his toes (see Figure 36); he was the tallest of the group.



Figure 36. Restriction at Shoulders While Bending.

3.8 Closures

3.8.1 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, underarm-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 (both SPM and breathable) 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 one-piece carbon undergarment is YKK continuous coil zipper size #5.

3.8.2 Results

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.

3.9 Shoulder Stabilizer Strap

3.9.1 Methods

During a September 2007 visit to Cherry Point Marine Air Station, NC base the Generation 3 garment was shown to a group of pilots and crew. During a gear-donning demonstration and discussion, uniform shoulder displacement of the currently 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 eliminating restriction of head movement. Incorporating elastic into this gear strap helped to prevent any movement restriction.

Because of favorable response to this design, the internal shoulder stabilizer strap has been carried over to the Generation 5 garment.

3.10 Hood Retention Flap

3.10.1 Methods

When a soldier is not required to be in MOPP 4, the hood on the garment is not worn. To provide a way to stow the hood the GT designed a flap to allow the hood to be rolled up and held in place with the flap and hook-and-loop closures. After evaluation of FAST results, the hook-and-loop closure's length was increased by 5.5 inches.

3.10.2 Human Factors Results

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

3.11 Summary of FAST vs. Contaminated Doffing

Table 3 shows the small changes made to the garments between FAST and CD assessment.
Table 4 summarizes and contrasts the results of FAST and CD assessment.

Table 3. Modifications Made to Generation 5 Garments after FAST but before CD Assessment.

Carbon Undergarments	Shell Ensemble
Shirt: Lengthened 4 inches Repositioned front shirt zipper to left side w/curved shape to the neck reducing discomfort from layer stacking Reinforced inside zipper flap with three vertical stitch rows to stiffen and eliminate fold back Reworked band collar with grab extension Added temple filler to carbon hood: one with neoprene, one with rib knit, and one with cording filler and on-quarter-inch cord piped brim edge Reshaped carbon hood lens/front opening shape to match the contour of the gas mask Pant: Removed rib ankle cuffs from pant legs and replaced with self fabric	Jacket: Extended internal jacket/pant retention flap; added hook-and-loop tape to close gap voids Added hook-and-loop tape to front outer jacket zipper/ flap and from retention flap down to hem edge Lengthened zipper and filter cord pull tabs 0.5 inch to finished length of 2 inches Reduced hood fullness by one inch at point 16 inches from brim; change was graded to zero at front and shoulder Increased hook-and-loop tape length by 1.5 inch (to total of 7 inches) on back hood for stow away tab Reduced hood brim internal carbon cord circumference to 0.5 inch and lengthened it 1.5 inches to tuck away behind temple pouches Added hook-and-loop tape to neck flap for hold-back control during doffing Pant: Lengthened legs 1.25 inches Reworked hook-and-loop pull tab at leg cuff to recess into the channel smoothly; widened channel Added hook-and-loop tape to increase and secure closure and eliminate gap voids in jacket/pant zip-off integration panel

Table 4. Simulant Penetrations Observed on Test Participant's Bodies after FAST and CD Assessment.

Test	FAST	Contaminated Doffing
1	Haze of aerosol visible on right cheek bone and in hair above ear with visible "clean" areas where mask straps were Hazing of aerosol on mid to upper chest with "clean" area following the zipper and zipper flap on carbon suit Extremely faint hazing above sock line	Small drip marks of decon solution on upper back neck and back shoulder Three faint smudges of decon solution on left leg below knee Simulant at right top of ear; subject noted that while donning he could feel a breeze in temple area Suit front appears completely clean; no haze on chest as in FAST On left tricep small smudges from decon solution A couple of orange simulant particles on right side waist
2	Haze of aerosol around cheek bones and ears on both sides Small yellow deposits on both sides of face on the jaw line at the mask edge Clean area visible where mask straps were Hazing of aerosol on mid to upper chest with "clean" area following the zipper and zipper flap on carbon suit Light haze on left shin above sock line	Faint hazing on left abdomen to left navel area Small bright spot about the size of a pencil eraser, on right temple and slight haze at mask edge; edge clearly visible
3	NOTE: Integration panel on shell was duct taped to try to minimize aerosol penetration at this interface Light to moderate hazing on both cheeks and under chin Moderate line of deposition on left cheek along mask line Extremely faint hazing above sock line	Faint hazing and decon smudges on waist/abdomen area Faint haze of orange at left temple Under black light, orange simulant was visible on left side at temple on mask right below mask hook; on right side neoprene stopped most of the simulant from penetrating but simulant could clearly be seen where it came in below the insert and deposited on the jaw line of the subject

4. Conclusions

4.1 Fabric

The GT is satisfied with the choice of the 78C/63A fabric pairing and feels the feedback from all test participants was very positive. Further support for 63A came from the regression analysis developed and analyzed by LEHP AI team. The regression analysis was used to predict CALM scores for tactile comfort.⁹ Fabric 63A scored very favorably in this assessment; this score, combined with all the favorable responses during human factors evaluation, caused 63A to become the front-runner for carbon fabrics to be sent to FAST and CD evaluations. Because of fabric combination use restrictions, 78C (outershell) was chosen to be paired with 63A for the undergarment.

The only note of discomfort was at the neck on the carbon shirt, which irritated the neck of one participant, most likely due to the fact that the exposed carbon (rough) side of the fabric was against the skin. In the future the carbon shirt will not have the exposed carbon side against the skin.

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 undergarment 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 undergarment (bodysuit or two-pieced ensemble). When the outer garment is doffed with a carbon undergarment, the risk of accidentally brushing bare skin with the contaminated outer garment is significantly lower. As the wearer moves through the doffing process, the carbon undergarment will be removed in a relatively clean environment, which is more desirable to the user.

The efficacy of a separate carbon undergarment was supported during CD assessment of the Generation 5 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 ideas and improvements for protection. The Generation 5 interface shows increased protection, as documented through FAST, and is comfortable to wear, as shown by the HF evaluation. The novel addition of the two-piece wire brim and the elastic cord canister loops has contributed to the improved protection seen at this time. Though this interface has seen many changes through the generations, including Generation 5, this interface continues to be an area where the GT seeks improvement. The temple region, due to the shape of the JSGPM, is a difficult interface to maintain.

⁹ For information about the analysis process, see “Identification of the Most Significant Properties Influencing Tactile Fabric Comfort Using Regression Analysis.” Les M. Sztandera. February 2009. *WSEAS Transactions on Computers*. Issue 2, Volume 8. 302–311.

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 5 changes were well received by HF evaluation participants.

4.5 Articulated Sleeve and Elbow Reinforcement

The shaped elbow reinforcement was 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 wear to the main body of the outer garment. The improved shape of the articulated sleeve in the Generation 5 has improved flexibility in the elbow area.

4.6 Torso and Zippered Integration Panel

The Generation 5 ensemble was the first two-piece trouser and jacket system designed by the GT. The integration panel was successful in keeping out most of the contaminant, although work still needs to be done to improve this area to eliminate any contaminant and cut down on the bulk provided by the hook-and-loop tape and zippers.

Test participants did not regard the stretch cord at the waist as necessary; some participants expressed discomfort while in the prone position because of cord locks became pressure points under their bodies. For this reason the stretch cord waist drawstring will be removed for the Generation 6 garment.

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 will continue in the next generation.

4.9 Hood Retention Flap

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

5. Recommendations

Following are the recommendations of the Garment Team based on complete testing of the Generation 5 garments, together with the design and scheduled testing of Generation 6.

1. Continue using spiral development to create the Generation 6 two-piece ensemble while evaluating both fixed and removable hood systems.
 - a. Simplify the interface between the outer garment jacket and trouser.
 - b. Extend hook-and-loop tape on the trousers at knees to prevent knee-pad control straps from sticking out.
 - c. Reduce restriction while turning the neck on the outer garment jacket.
 - d. Lengthen carbon under shirt to eliminate breach at waist while bending over.
2. Conduct the following tests on garments:
 - a. FAST at RTI to provide information on aerosol penetration at interfaces such as wrists, ankles, hood/mask, and zippers while motion routines are performed in a controlled environment.
 - b. Contaminated doffing at Hazmat Science Applications to provide information on contaminant transferred onto the body during doffing of the contaminated garments. This is an important test as it validates design of the garment system and ensures its clean removal after exposure to contaminants.
 - c. Human factors evaluations at both NSRDEC and Philadelphia University so that motion routine studies can provide significant data about human subjects' perceived comfort, and about the ability of wearers to perform discrete and mission-relevant movements. This evaluation also provides for observation of ease of donning and doffing procedures.
 - d. User evaluations in real warfighter scenarios.

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Appendix A

Test Report Human Factors Evaluation of LEHP CB Protective Garment—Generation 5 Prototype

(Reprint of original)

TEST REPORT

HUMAN FACTORS EVALUATION OF LEHP CB PROTECTIVE GARMENT -- GENERATION 5 PROTOTYPE

Submitted to:

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Natick Soldier Research, Development and Engineering Center

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October 21, 2010

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EXECUTIVE SUMMARY

Background

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. After several years of designing 1-piece overgarments, LEHP was asked to explore ideas for a 2-piece (shirt and trousers) garment.

Test Items and Concept of Wear

For CB protection, this ensemble features a 2-piece undergarment consisting of a carbon shirt and carbon drawer that provide protection against chemical agents in vapor form. These are worn beneath the shell, consisting of a separate shirt and trouser for MOPP 2 wear that fasten together when MOPP 4 protection is needed. 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. A carbon-based protective balaclava is also part of this ensemble; it is stowed in the CB mask case, already attached to the mask, and donned as the mask is donned. The ensemble is designed to form a protective interface with the Joint Service General Purpose Mask (JSGPM) and with current issue CB protective gloves and boots.

According to the lead designer (e-mail communication), the Gen 5 is suitable for situations where Soldiers are operating under CB threat possibility with advanced warning; in such situations, the Soldier would don the undergarment and shell to the MOPP 2 level and could wear it all day or for many days. He/she would be ready to transition quickly to MOPP 4 from MOPP 2. The ensemble is not applicable for true emergencies. For that, one concept the designers have envisioned is a lightweight, disposable garment that could be quickly thrown on over all gear, including body armor and backpack. At this time, however, the designers have been asked to focus on the shell and undergarment concept (Gen 5).

Evaluation Objective and Method

The objective of this evaluation was to conduct an initial human factors assessment of the Gen 5 CB protective ensemble developed by LEHP. As the basic approach, five Active Duty Soldier Test Participants (TPs) donned and wore the ensemble at MOPP 2 and MOPP 4 levels. Three of these Soldiers had been in the theater of combat, though they had only carried, not worn CB protection while deployed. All five TPs have experience wearing the Army's current ground Soldier CB uniform, the JSLIST, during training.

TPs were required to don garment components and adjust to fit, perform specified movements in MOPP 2 with military gear, form protective interfaces within the Gen 5 ensemble for waist protection and between the ensemble and CB protective accessories to achieve MOPP 4; and perform specified movements in MOPP 4. When donning, adjusting, and forming interfaces, the level of challenge was evaluated. When performing movements, the level of restriction was evaluated and any breach in CB protection was noted. TPs provided ratings of comfort at

milestone points during the evaluation. A complete evaluation session required about 3.5 hours per TP.

Human Factors Findings

I. Areas of Concern

Breach between waist and shirt of undergarment during movements. All TPs were judged to have an acceptable fit in the Gen 5 prototype, for the size that was available. At a resting, standing position, the undergarment shirt overlapped with the waistline of the undergarment pants between 2.5 and 4.5 inches, depending on size of TP. During movements, however, while wearing only the undergarment, bare skin was revealed at the waist for all but one TP; this happened when they bent to touch toes and when they raised both arms. The amount of revealed skin was not measured but it was observed to vary in inverse proportion to the amount of initial overlap of shirt over pants. For the TP with the most overlap when upright (4.5 inches), no breach was observed. Once the shell was donned, the undergarment shirt was never observed to pull out and form a breach with the shell pants.

Shell sleeve too short. For three of the five TPs, the Tester felt that the shell sleeves were too short at the inside of the wrists, falling about 1 inch below wrist level when Soldiers raised their arms. (Note: the length at the back of the hands – where the sleeve design featured an extension – was sufficient for all TPs). The minimal shell sleeve length did not adversely impact wrist interface during MOPP 4 because the cinching of the shell sleeve over the undergarment and glove gauntlet revealed no breaches.

Snag hazard from leg cinch tabs. For some TPs, after cinching the tabs to a comfortable position, the tabs stuck out considerably between the legs. This presents a clear snag hazard for legs getting stuck to each other or tabs getting snagged on the environment.

Neck irritation/chafing. Neck irritation and chafing were observed for one of the five TPs after he doffed from MOPP 4.

Restriction at neck in MOPP 4. A sequence of 14 movements was executed during MOPP 4. Neck restriction when looking left and right was the only motion that was consistently restricted, affecting all TPs. As the Tester observed, they could swivel their neck only slightly. In order to see fully to the left or right, they had to turn their upper bodies; this appeared to be due, at least in part, to the inability to turn their necks very far, but was likely also due to limited field of view from the mask.

Flap connectors for waist protection confusing and cumbersome. To enhance protection at the midriff area requires the wearer to attach 3 pairs of flaps. Attachment of the largest pair of flaps was relatively simple for the TPs; but locating and properly attaching two smaller pairs of flaps was challenging. Although the challenge became easier with practice, the TPs did not like having to fasten so many flaps and they did not fasten the small flaps with good alignment. Once everything was fastened properly with Tester assistance, the TPs were left with a feeling of bulkiness and a visible bulge in their shell jacket in this area.

II. Positive Human Factors Features

Ensemble is lightweight. All TPs agreed that the LEHP undergarment and shell are lightweight. Based upon their memories of wearing the JSLIST, they felt that the LEHP undergarment and shell, together, weigh less than the JSLIST (which is true; weights are listed under Point III, below). Related to garment weight, all TPs felt that the Gen 5 ensemble is less hot to wear than the JSLIST, whether the JSLIST is worn with or without ACUs beneath it. It is important to recall however, that no TPs wore the JSLIST during this evaluation and when they did wear it, it may have been in warmer temperatures or under more physical exertion.

Zipper connecting shell trousers and jacket is easy to use. The zipper that connects the shell trousers to the jacket worked easily and effectively; both left- and right-handed TPs could work the zipper easily.

Balaclava works well. In accordance with the designers' vision, the balaclava is stored in the mask case, attached to the front of the mask, inside out. After the mask is donned, the balaclava is flipped over the head, into position. This storage and donning approach – which is similar for the currently fielded JSGPM with hood combination -- was effective and easy to accomplish.

Easy to don (with one exception). It was easy to don the Gen 5 components: undergarment pants and shirt, shell trousers and jacket, and balaclava. *Attaching* shell trousers to the shell jacket was also easy except for fastening three pairs of flaps at the midriff area; this was slightly to moderately challenging and the outcome was often not smooth.

No consistent restriction in range of motion (with one exception). Through 14 movements involving the head/neck/torso, the knees/legs/ankles, and upright actions, the ensemble did not consistently restrict motion except for swiveling the neck from side-to-side in MOPP 4; it has been anecdotally reported to the Tester that a hallmark of existing CB ensembles is that the wearer must turn their whole body to see directly left or right. Whether this is due to movement restriction at the neck or to limited field of view from the mask is not clear.

Undergarment and shell are comfortable (with one exception). The Gen 5 prototype was generally seen as comfortable – from extremely comfortable (undergarment alone), to moderately comfortable (in MOPP 2 configurations). One TP rated it as extremely comfortable at every configuration, including MOPP 4, but the other TPs rated comfort lower for MOPP 4 (either Neutral or Slightly Uncomfortable). The only source of discomfort noted by more than one TP was pressure against the neck from the bulk of the many layers of fabric there: undergarment collar, balaclava stuffed into upper shell, shell hood, and IOTV. Purely from a fabric comfort perspective, the undergarment fabric against the skin was rated favorably, between Moderately Comfortable and the Greatest Imaginable Comfort.

Strong CB interfaces. No breaches observed (with one exception). Throughout movements, no breaches were reported by TPs or observed by the Tester at the ankles, shell waistline, wrists, neck, face, or scalp. In fact, no movement of any kind was observed at the various breach points as is sometimes the case in CB ensembles (for example, trousers creeping upward at the ankles). The shell blocked the view of one important breach location, however, which was at the waistline of the undergarment during movements, as noted above.

Soldiers acceptance was high. All TP's rated this Gen 5 prototype as acceptable for the concept for which it is intended: situations where Soldiers are operating under CB threat possibility with advanced warning.

III. Subjective Comparisons to JSLIST

Note: JSLIST was not worn during the evaluation, but it was present for TP's to look at – as a reminder of its features -- and handle – as a reminder of its fabric characteristics. All five Test Participants had worn it before and made comparisons, listed below, all favorable to the Gen 5. These comparisons should be qualified in that the TP's experience and activities while wearing the JSLIST may have been much different (e.g., hotter climate, more rigorous activities).

- Gen 5 is cooler to wear. TP's consistently said that the two layers of the Gen 5 (undergarment and shell) are definitely cooler to wear than the JSLIST worn over the ACU or the JSLIST worn over t-shirt and briefs.
- Gen 5 is lighter in weight. All TP's judged that the Gen 5 ensemble (undergarment and shell, together) are lighter in weight than the JSLIST garment. The Tester confirmed this by weighing the ensembles in the HF lab. The JSLIST Type 2 (hooded) shirt and pants together weighed 5.99 lbs. for size Medium-Regular and 6.1 lbs. for Large-Regular. The Gen 5 undergarment and overgarment shirt and pants together weighed 5.34 lbs. (The shell was 3.6 lbs. and the undergarment was 1.74 lbs. Lighter weight is an advantage for Soldiers carrying the Gen 5 in their pack.
- Gen 5 appears to require less volume for stowage in pack. The flexibility of the shell fabric and the thinness and flexibility in the undergarment would appear to make the Gen 5 easier to pack tight for stowage, compared to the JSLIST.
- Gen 5 fabric is more flexible. The relative flexibility of the Gen 5 fabric compared to the JSLIST was seen as an advantage for stowage (noted above) and for maneuverability and comfort when wearing CB protection.
- Gen 5 ensemble is more comfortable. The fabric is more comfortable and flexible on the Gen 5, leading to more comfort. Gen 5 is less bulky than the JSLIST. One TP who had worn the JSLIST for up to 8 hours at a time said that the heaviness and stiffness of the JSLIST made him feel claustrophobic, even at MOPP 2 level. The Gen 5 did not make him feel claustrophobic, though it should be noted that he did not wear it for 8 hours.
- Means of connecting jacket to trousers. Zipper method is preferable to JSLIST suspenders because the elastic in the suspenders often becomes slack. Also, the Soldiers prefer a garment without the crotch retention cord featured on the JSLIST.

Recommendations for Further Ensemble Development

Regarding Undergarment breach at waistline

- Alter the cut of the undergarment shirt or pants or change the interface to eliminate breach at waist when Soldiers are active (e.g., bending forward, raising arms).

Regarding waist protection flaps

- Simplify system of connecting hook and loop flaps so that only a single thick flap at the midriff needs to be affixed when transitioning to MOPP 4 (like “flap A” in current design.) Eliminating B and C but adding an outer drawstring like those found on parka jackets might protect equally well against CB penetration and be more familiar and easier for Soldiers to operate.
- If more than one pair of flaps must be attached at the midriff area, the use of formal lettering is encouraged. Several TPs remarked that the handwritten letters (A, B, and C) were helpful or even necessary to them aligning the flaps properly. The lettering was especially helpful when aligning these flaps while wearing the CB mask.
- Currently, the zipper mechanism for attaching shell trousers to jacket and the multiple hook and loop flaps for extra waist protection reside on a detachable panel, like a cummerbund. It is detachable due to the two circumferential zippers at the lower and upper edges of this cummerbund. The HF analyst sees no advantage to this detachability; in fact it is viewed as a disadvantage, because the cummerbund may become separated/lost and would need to be located in the event of MOPP 4 threat. It is recommended that the top zipper be eliminated; instead, the top of the cummerbund section would be sewn to the inside of the jacket, forming a jacket lining from lower chest to waist.

Regarding leg cinches:

- To avoid snag hazard, the hook and loop patches *on the trousers* must be longer to prevent excess leg tabs dangling with no attachment to the trousers.
- Recommend experimenting with a single cinching tab above and a single cinching tab below each knee pad instead of two tabs above and two tabs below; this would take less time to execute, require only one, not two hands, and result in fewer total tabs per leg, which would minimize snag hazard.

Regarding restriction at neck

- All TPs experienced restriction at the neck in MOPP 4 when looking side-to-side, but the analyst has learned that Soldiers in the field expect this restriction and learn to turn their whole body when looking side-to-side while encapsulated. As an option, however, for eliminating this restriction, it may be possible to add length to the bottom of the hood in the form of accordion style, rigid fabric. The accordion dimension would provide leniency at the neck and the rigid style for this extension would prevent excess fabric from overhanging the jacket collar, which would cause a snag-hazard.

Regarding neck tabs on shell hood

- When the TPs attached the neck tabs, the tabs were not well aligned without Tester verbal or physical intervention. Instead, the natural movement of the TPs led to the tabs being attached in a criss-cross fashion, forming an X, with only a small portion of the hook and loop engaged. Soldiers can be trained to take more care to align these tabs. Alternately, a design solution could be to thicken the width of these extensions to the hood so they are more like panels than tabs, and employ larger, square hook and loop patches. It is envisioned that Soldiers will align hook and loop more naturally and effectively, in this case.

Executive Summary Concludes

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**TEST REPORT:
HUMAN FACTORS EVALUATION OF
LEHP CB PROTECTIVE GARMENT, GENERATION 5 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 5 prototype is the first 2-piece garment developed by LEHP to receive a human factors assessment at NSRDEC. 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 5 (Gen 5) CB protective ensemble developed by LEHP.

2.0 METHODOLOGY

2.1. Scope of Assessment

The following HF dimensions were investigated for the Gen 5 protective ensemble:

1. Adequacy of fit.
2. Comfort: Subjective reports of fabric comfort, thermal comfort, and overall 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 gear, 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 5 (Gen 5)

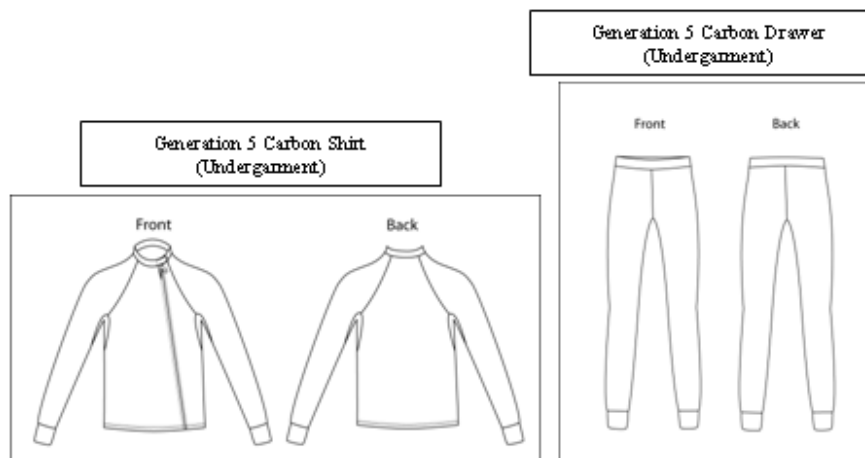
As indicated above, the Generation 5 garment concept involves a CB protective carbon shirt and carbon drawer (undergarment) worn beneath a jacket-trouser set overgarment (shell). A balaclava is worn with the JSGPM mask when MOPP 4 protection is needed along with the attached hood of the overgarment jacket. Fabric and design characteristics of the prototype are provided in the table, text and drawings, below.

Table 2-1. Fabric Description for Generation 5 Prototype Components

LEHP Code	Supplier	Cloth Characteristics						
		Manufacturer Style Number	Fabric Structure	Structure Type	Fiber Blend	Coloration Method	Functional Treatment	Weight (oz/sq. yard)
63A: Undergarment & Balaclava	Purification Products	PR6479/1B	knit	active carbon filter material, polyester/elastane 2-way stretch jersey knit material	polyester/Elastane carbon	dyed black knit	N/A	8.60
78C: Shell	Stedfast USA	Job# 253	laminated	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 (provides aerosol protection), durable water repellent finish	6.12

2.2.1 Undergarment 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.



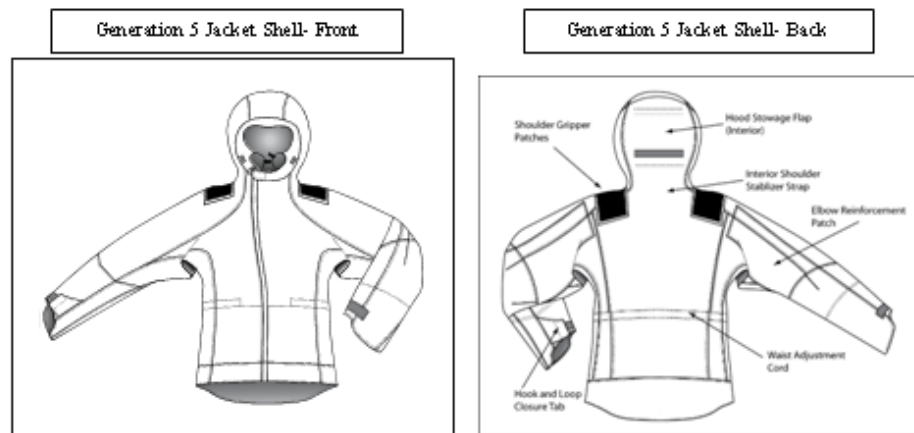
The shirt of the undergarment features a zipper that runs diagonally (from lower left side to center of neck). There is a tab-over (hook and loop) closure at the neckline. This is a change from the Gen 4 undergarment where the central zipper went to the top of the garment neck with no tab-over. The ankle 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.

2.2.2 Shell 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.

Shell Jacket

The jacket closes at the front using a zipper up the midline of the torso. Inside the jacket there is a waist adjustment cord for active adjustment by the wearer. There is also a passive adjustment, shoulder stability elastic band which conforms to the width of the wearer's back and holds the garment shoulders and back in position (not shown in drawing). A swath of black gripper fabric has been added to the outside of the shell on each shoulder. It is there 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 have been added to 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.

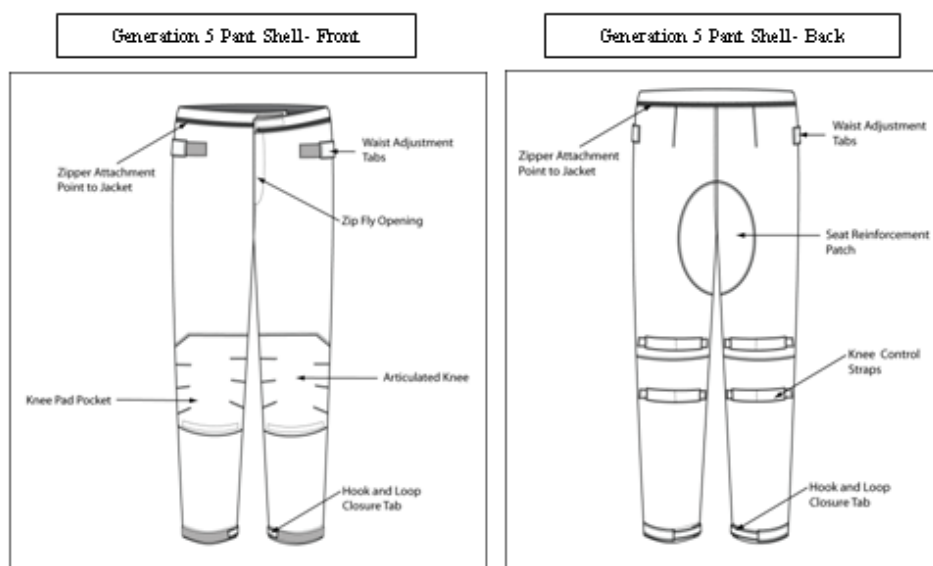
The jacket includes an attached hood, similar in style to earlier LEHP prototypes. The top, front contours of the hood are formed by firm, encapsulated wire that conforms to the contours of the eye protection area of the JSGPM mask. Elastic cords extend from the hood on either side to

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. A new feature is the break/interruption at the top center of the encapsulated wire at the hood's front edge; this allows for better folding of the hood when storing the jacket. Finally, the hood now 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, which resembles a cummerbund when donned, does not appear in the drawings, above.

Shell Trousers

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. No extended zipper for solid waste relief is needed because the overall garment is now a 2-piece compared to earlier prototypes. The back of the trousers feature a seat reinforcement patch in the crotch/upper thigh area.



There are horizontal zipper feet slightly above the waistline encircling the torso. These match up to the zipper feet on the jacket, permitting the trousers and jacket to be connected.

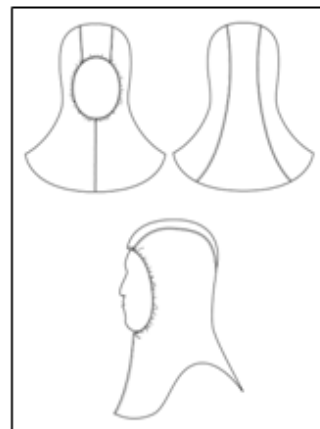
As in prior garment versions, there is a knee pad pocket and knee pad that slips into the pocket. On the lower thigh and upper shin, just above and below the knee pad pocket, there are now adjustment tabs that cinch the trouser to a comfortable width and permit flexible positioning of

the knee pads, vertically, on the leg. Hook and loop cinching is also available at the ankles for cinching trousers over CB protective boots.

Balaclava

Gen 5 features a balaclava made from the same CB protective material as the undergarment. It 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 kept inside 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.



2.2.3 Protective Interface Points on Prototype

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

- Waist: A horizontal circumferential zipper was added to 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 form a cummerbund shape and are located just above the navel like the cummerbund on a tuxedo.



Two views of the hook and loop flaps which must be fastened on the cummerbund for MOPP 4 protection (TP2)

- Ankles: Operational opinions are varied with regard to how the cuff should be worn for optimal protection during MOPP 4. The Tester instructed TPs to place the undergarment ankle cuff outside of the duty boot; a CB protective overboot was worn over the cuff and the Gen 5 shell trouser was cinched around the overboot with hook and loop at the ankle. For the record, the ankle cuff lay easily and smoothly over the duty boot and remained in

place; it appears that it could alternately be tucked into the duty boot with no interface problem.

- 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 5 undergarment for optimal protection and to facilitate an orderly decontaminated doffing process.
- 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. Inner wiring on the front of the hood 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. This is a change from prior garments where the hood was cinched off-center, just beneath the right ear.

2.2.4 CB Protective Gear Accessories

The CB gear items that are needed, along with a garment, to provide head-to-toe CB protection will be featured in the interface assessment. These include:

1. CB overboots: Alternative Footwear Solution (AFS) which is the current standard-issue CB protective overboot for the Army and other Services.
2. 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
3. JSGPM mask: includes integrated respirator and eye protection. It comes with an optional hood which will not be needed due to the balaclava and shell hood on the Gen 5 prototype

2.2.5 Military Gear Accessories

To assess compatibility between the CB garment prototype and commonly worn Soldier military gear, the following items will be featured in the evaluation:

1. Improved Outer Tactical Vest (IOTV) with realistically weighted protective plates. For realism, two realistically weighted ammo pouches were attached to the front of the vest. A mock grenade was also attached – this was used in the grenade throw activity executed in MOPP 2 and MOPP 4
2. Mock M4 rifle
3. Backpack, Type 1: large, square rucksack weighted to 40 lbs. Requires waist strap and chest strap to stabilize.
4. Backpack, Type 2: long, narrow rucksack weighted to 30 lbs. Requires only chest strap to stabilize. Note: the backpacks were worn one at a time, in turn.
5. Canteen. This was employed to assess operational arm range of motion needed for lifting the canteen above head to drink (simulated – canteen was empty).
6. Helmets were not featured 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. The first participant in the current evaluation donned his own ACH helmet during MOPP 4 but could not strap it closed. The helmet toppled off of his head after each movement, and was, thereafter, abandoned for him and the subsequent TPs. This situation will not likely improve until a strap extender is developed for wearing during MOPP 4.

2.3 Garment Fit-Sizing

The shell size available for testing is 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. Because the Gen 5 garment is a 2-piece, however, it was unknown if the size accommodation would vary from the earlier prototypes. With this in mind, candidate Subjects were considered in a wider range of heights (68 to 74 inches) and weights (150 to 215 pounds). Only Subjects with an adequate fit in the Gen 5 were selected for participation in this evaluation.

2.4. Test Participants, Location, and Schedule

Five Active Duty Soldiers were selected to be Test Participants (TPs). Their weights ranged from 180 to 200 lbs. and their heights from 69-72 inches. For reference, TP height, weight, and predicted JPACE size are listed in Table 2-2, below. Note that TPs are listed in order from tallest to shortest, not by TP ID.

Table 2-2. Physical Characteristics of Participating TPs

TP ID	Height (inches)	Weight (lbs.)	Predicted JPACE Size
3	72	192	40-R
2	71	196	40-R
1	71	180	38-R
5	70	200	40-R or 42-R
4	69	170	38-R

During the selection process, four other individuals tried on the garment but it did not fit them. For future reference in fit-sizing and as sizing feedback to the designers, a log was maintained of the heights and weights of these personnel. The Gen 5 prototype was too small all over for 2 individuals. The first one was 73 inches tall and weighed 210 lbs. The second one was 72 inches tall and weighed 205 lbs. Note that both of these individuals predict into JPACE size 42-L.

The Gen 5 prototype was too large all over for 2 individuals. The first one was 69 inches tall and weighed 165 lbs. He predicted into JPACE size 38-R. The second one was 67 inches tall and weighed 145 lbs. He predicted on the borderline between JPACE 36-S and JPACE 34-S.

As further pertinent information about the TPs, three Soldiers had served in the theater of combat (Iraq, Afghanistan, Haiti), though they had only carried, not worn CB protection while deployed. All five TPs had experience wearing the Army's current ground Soldier CB uniform, the JSLIST, during training, most for periods of an hour or less (i.e., for donning practice); TP4 wore the JSLIST for several 8-hour periods during training. For the record, none of the TPs had experience wearing a 1-piece CB protective garment – such as the JPACE.

The TPs with combat experience were more sensitized to issues of CB ensemble concept of wear, carrying, and storage volume. For reference, the table below indicates by TP number, which TPs had prior combat experience.

Table 2-3. Combat Experience of Participating TPs

TP ID	Yes	No
1	✓	
2		✓
3	✓	
4		✓
5	✓	

The evaluation took place during August 2010 in NSRDEC's Human Systems Integration Laboratory.

2.5 Assessment Approach

As the basic approach, all TPs dressed and wore the Gen 5 ensemble at MOPP 2 and MOPP 4 levels. To be more specific, the sequence of activities was as follows:

- Familiarization and practice donning and adjusting the prototype to fit at MOPP 2 and to form CB protective interfaces at MOPP 4
- 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 military gear. TP was now fully dressed in MOPP 2 plus IOTV and was asked to perform 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; accessing and 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. For every individual act of donning, etc., the TP was asked to rate the degree of challenge. For every movement activity, the TP was asked to rate the level of restriction. TPs provided ratings of comfort at five milestone points during the evaluation, and they 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 also completed short questionnaires after activities in MOPP 2, after activities in MOPP 4, and after doffing the prototype. Meanwhile, throughout the session, the Tester recorded her own observations of anything problematic or unusual/unexpected in ease/difficulty of donning, restriction in movement, or breach in CB protection. A complete evaluation session required about 3.5 hours per TP. The information gathered has been integrated and is presented below in the Results Section.

3.0 RESULTS

3.1 Findings according to HF Dimensions

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

3.1.1 Adequacy of Fit

Table 3-1, below, provides fit information for the participants in this evaluation. Two fit issues were (1) undergarment shirt was too short to cover waistline when arms were raised for 4 of 5 TPs and (2) shell sleeve length was approximately 1 inch too short on the inner wrist when arms were raised for 3 of 5 TPs. Due to the common occurrence of these fit limitations, Soldiers were considered to have an acceptable fit for participation, if the undergarment and shell fit well except for the two limitations just noted. In Table 3-1, the two columns at the right of the table indicate for which TPs these conditions existed, with the "Yes" displayed in bold typeface for emphasis. Note that TPs are listed in order from tallest to shortest, not by TP number.

Table 3-1. Adequacy of Prototype Fit

TP ID	Height (inches)	Weight (lbs.)	Predicted JPACE Size	Adequacy of Fit	Shirt-pant Overlap at Waist of Undergarment	Breach at Waist?*	Shell sleeve Length was Short?*
3	72	192	40-R	Excellent fit, except see column at right	4.0 inches	Yes	No
2	71	196	40-R	Excellent fit, except see column at right	2.5 inches	Yes	No
1	71	180	38-R	Acceptable fit. Undergarment tight at neck; Shell trousers tight at groin; And see rightmost column	4.5 inches	No	Yes
5	70	200	40-R or 42-R	Acceptable fit. Shell jacket tight across chest and back, shell trousers tight at groin; and see columns at right	3.5 inches	Yes	Yes
4	69	170	38-R	Excellent fit, except see columns at right	2.5 inches	Yes	Yes

* Yes = Breach at waist for undergarment when raise arms or bend to touch toes

** Yes = Sleeve fell about 1 inch below wrist line when arms were raised.

As the Table, above, depicts, three TPs had an excellent fit and two were judged to have a sufficiently adequate fit that the Gen 5 prototype could be fairly evaluated when they wore it. Although there were no alternate, adjacent sizes to try on, the TPs were down-selected from among other individuals who did not have an adequate fit, and the provided size appeared to be the correct size for the individuals participating in the evaluation. As noted, TP1 had the greatest shirt-pant overlap (4.5 inches) when standing still in the undergarment and he was the only TP who did not experience a breach at the undergarment waistline when touching toes and raising arms.

A view of the predicted JPACE sizes indicated in Table 3-1 suggests that the Gen 5 is likely to fit personnel who predict into sizes 38-R and 40-R. As an aside, the Generation 4 LEHP prototype – when it was evaluated at NSRDEC -- also fit Soldiers who predicted into sizes 38-R and 40-R JPACE. For the record, the Generation 4 ensemble consisted of a 1-piece undergarment and 1-piece overgarment

3.1.2 Overall Comfort

Overall comfort of the Gen 5 ensemble was rated by the TP five times during the experimental session: (1) upon arrival, while still wearing one's Army Combat Uniform (ACU); (2) wearing undergarment only; (3) wearing shell jacket and trousers unattached and without the IOTV; (4) wearing shell jacket and trousers attached, with the IOTV over the shell; and (5) fully encapsulated. Ratings were made on a 7-point scale with 1 = Extremely Uncomfortable, 7 = Extremely Comfortable, and 4 = Neither Comfortable or Uncomfortable. Due to missing data, ratings are available for four TPs and are depicted in the table, below. The only rating below the midpoint, i.e., Slightly Uncomfortable, is depicted in bold typeface for emphasis. For readers with a color printer, cells containing neutral or negative comfort ratings are shaded in blue. The consistent responses of TP4 are shaded in lavender.

Table 3-2. Ratings of Overall Comfort

TP ID	In ACUs	Undergarment Only	Measured after movements/activities		
			Undergarment + Shell	Connected Shell + IOTV	MOPP 4
1	Extremely Comfortable	Extremely Comfortable	Moderately Comfortable	Moderately Comfortable	Neither Comfortable Or Uncomfortable
2	Extremely Comfortable	Extremely Comfortable	Moderately Comfortable	Moderately Comfortable	Neither Comfortable Or Uncomfortable
3	Moderately Comfortable	Extremely Comfortable	Slightly Comfortable	Slightly Comfortable	Slightly UNcomfortable
4	Extremely Comfortable	Extremely Comfortable	Extremely Comfortable	Extremely Comfortable	Extremely Comfortable

As the table, above, illustrates, all TPs rated their ACUs at the highest rating possible, Extremely Comfortable, except for TP3 who rated comfort in his ACUs as Moderately Comfortable. The lowest column of the table shows that TP4 rated the Gen 5 in every configuration as Extremely Comfortable. TPs 1 and 2 rated the undergarment as Extremely Comfortable, and then lowered their ratings by one level to Moderately Comfortable when wearing the undergarment and shell with jacket and pants unattached or with jacket and pants attached plus IOTV worn over the jacket. They then lowered their ratings by two labels to Neither Comfortable nor Uncomfortable for comfort in Gen 5 during full encapsulation. TP 1 felt uncomfortable pressure from bulk around the neck once he had donned the IOTV and even more so when he had stuffed the balaclava into his jacket, raised the hood around the neck, and fastened the hood for secure encapsulation. TP 2 did not explain any source of discomfort.

TP 3 followed a different pattern of comfort ratings, rating the undergarment as more comfortable than his ACUs, then lowering his rating by two labels to Slightly Comfortable for the two MOPP 2 configurations, and then lowering his rating two more labels to Slightly Uncomfortable when in MOPP 4. Like TP 1, TP 3 verbally expressed discomfort from bulk and pressure at the neck during MOPP 2 wear (with the IOTV), and stronger discomfort, to the point of irritation/chafing at the neck during MOPP 4. Indeed, when he removed his mask, hood, and balaclava for transitioning back to MOPP 2, his neck was visibly irritated with red chafing marks [see photo, at right]. TP3 was not sure of the cause of the chafing, but suspected it was from pressure of the undergarment fabric just behind the zipper – he felt that he could feel the zipper pressing through the fabric against his neck. Based upon the location and range of irritation across the front of his neck, however, it's unlikely that the zipper, alone, caused this irritation; it appears possible that the entire front collar of the undergarment irritated the front of his neck.



The chafing was observed across entire front of his neck, following MOPP 4, but was most pronounced at the left side (TP3)

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TP5 did not provide comfort ratings, but he commented that “uncomfortable pressure at the neck would definitely cause irritation over time.”

Although TPs 1, 3, and 5 all complained of neck discomfort, TP 3 was the only one to experience skin irritation. He may have more sensitive skin than the others, because he was the only TP to also report that the bunched material from the upper leg cinch -- was causing sweat accumulation and irritation at the back of his knee.

3.1.3 Fabric comfort

After donning the undergarment, TPs were asked to consider the fabric, only, and rate fabric comfort according to the Comfort Affect Labeled Magnitude (CALM) Scale which was designed for rating fabric comfort (Cardello, et. al, 2003). Labeled anchor points are Greatest Imaginable Comfort and Greatest Imaginable Discomfort with a midpoint of Neither Comfortable nor Uncomfortable. The table below shows the undergarment fabric comfort ratings which are available, again, for TPs 1-4.

Table 3-3. Ratings of Undergarment Fabric Comfort

TP ID	Fabric Comfort Label (Undergarment)
1	Extremely Comfortable
2	Greatest Imaginable Comfort
3	Between: Very Comfortable & Moderately Comfortable
4	Extremely Comfortable

3.1.4 Thermal comfort

As an overview, all TPs had worn the JSLIST before -- at some point in their careers -- and the garment was on hand in the laboratory for those wanting to refresh their memory of its features, weight, or feel. Unanimously, TPs reported that the Gen 5 was cooler than the JSLIST. There was no waffling -- they appeared to have no doubt of the truth of this statement, even though they had not compared them under similar conditions. They felt that the two layers of the Gen 5 were far cooler than wearing the JSLIST over the ACU, and would also be cooler than wearing the JSLIST over simple T-shirt and briefs.

True thermal impact of a CB garment can only be determined via physiological measurement or thermal manikin testing. Given this caveat, the perceptions of the TPs while they wore the Gen5 prototype at MOPP 2 and MOPP 4 levels are reported, below. For the record, across all sessions collectively, temperatures in the laboratory ranged between 67 and 72 degrees Fahrenheit and humidity between 55 and 62%. Ratings are reported first for perceived sweat and then for perceived heat.

Sweat

The rating scale employed for sweat is provided, below. After rating their sweat level, TPs indicated, where they sweated, if anywhere, on a drawing of the body. Summary information is presented in the Table, below the rating scale.

How wet or dry does your skin feel right now? (Circle the number)

0	1	2	3	4	5	6
Very Dry			Neutral/ Normal			Soaking/ Dripping Wet

Table 3-4. Subjective Impressions of Sweating while Wearing the Gen 5 Prototype

TP ID	Ratings After Performing Activities in:		MOPP 2 Sweat Locations	MOPP 4 Sweat Locations
	MOPP 2	MOPP 4		
1	4	5	Forehead, neck, shoulders, waist, torso, hips, thighs, feet, lower back, buttocks, back of thighs, back of knees.	Same as MOPP 2, plus: Face, chest, hands, wrists, back of head, upper back, and calves.
2	2	4		
3	4	5		
4	Not rated	3		

As the left hand columns indicate, no one employed the anchor values of Very Dry or Soaking/Dripping Wet. As expected, each TP felt more sweat in MOPP 4 than in MOPP 2. The right hand columns show that while in MOPP 4, TPs sweated in the same locations as in MOPP 2, plus additional ones.

Body heat

A modified ASHRAE rating scale was employed to assess subjective impressions of body heat following activities performed in MOPP 2 and MOPP 4. The ASHRAE scale was developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (hence, the acronym: "ASHRAE"). It is a 7-point scale with anchors of Hot and Cold (see Rohles and Nevins, 1972). Extra label options at the ends of the scale are considered appropriate when evaluating outdoor, more extreme temperatures compared to indoor, and seemed equally appropriate for the extreme heat that may be experienced when wearing MOPP gear. Therefore, the 9-point scale version was used which has anchor points of Very Hot (1) and Very Cold (9). The midpoint is labeled Neutral.

After performing activities in MOPP 2 and MOPP 4, TPs provided ratings of body heat on the ASHRAE scale and subsequently indicated on a drawing, the body locations where they felt warm, if any. Summary information is presented in Table 3-5, below. Because each numeric scale value had a label, the labels are presented instead of the numeric values, for the convenience of the reader.

Table 3-5. Subjective Impressions of Body Heat while Wearing the Gen 5 Prototype

TP ID	Ratings After Performing Activities in:		Warmth Locations in MOPP 2	Warmth Locations in MOPP 4
	MOPP 2	MOPP 4		
1	Slightly warm	Warm	Forehead, face, neck, armpits, shoulders, waist, torso, hips, thighs, lower back, crotch, buttocks, legs, ankles, feet, back of thighs, back of knees, and calves.	Same as MOPP 2, plus: Back of head, upper back, chest, hands, and wrists.
2	Slightly warm	Warm		
3	Warm	Hot		
4	[Not rated]	Neutral		

For body warmth, each TP rated himself as one label warmer after MOPP 4 wear compared to MOPP 2 wear. Compared to reports of sweat locations, there were many more locations of warmth during MOPP 2 wear. As the right-most column shows, the back of the head, upper back, chest, hands, and wrists felt warm only in MOPP 4, not MOPP 2.

3.1.4 Range of motion

Table 3-6, below, lists 14 movements involving the head/neck/torso, the knees/legs/ankles, and upright actions that TPs performed first in MOPP 2 and then in MOPP 4. For each movement, the TP rated the level of restriction as None, Some, or Not Possible to Perform Movement; the Tester logged her own observation if it differed from the TP's report.

Table 3-6. Military-Relevant Movements Performed During Evaluation

Head, Neck, Torso	Knees, Legs, Ankle	Upright Actions
• Look to each side • Look up/look down • Raise both arms • Bend to touch toes • Access and toss mock grenade • Use canteen to simulate drinking	• Kneel to fire • Perform low crawl with weapon • Fire from prone position • Access and toss mock grenade	• Climb & reach motion • Jog across the room and back • Move forward to fire weapon • Don, adjust-to-fit, and remove backpack #1 • Don, adjust-to-fit, and remove backpack #1

The most notable finding is that all TPs were restricted in swiveling their necks from side-to-side in MOPP 4; this restriction, however, is a hallmark of existing CB ensembles and the Tester has been told by a Soldier who wore MOPP gear in Iraq that one quickly learns to turn the shoulders or body when looking side-to-side while in MOPP 4 posture. For two TPs there was one additional movement, each, that was restricted by the ensemble. First, TP 1 was restricted in the climb and reach movement during MOPP 2 and MOPP 4 when the shell jacket and trousers were connected: the lower back of the side he was reaching upward with was tight, restricting his movement. But, when the shell trousers and jacket were worn disconnected as a true 2-piece garment in MOPP 2, he experienced no restriction. Secondly, for TP3 when touching toes or performing the climb and reach motion in MOPP 2 (with jacket and trousers connected or not connected) or in MOPP 4, he felt a restriction starting from his upper back and extending through his shoulders and under his arms (see photo, below). In search for a cause, the Tester

checked the fit adjustment band on the back, inside of his shell jacket but it was not cinched at all, suggesting some other, unknown cause for the restriction.

Shell garment causes restriction while touching toes for TP3, only



Aside from these two instances of restriction and the restriction in swiveling the neck, there were no other restrictions across 14 movements performed both in MOPP 2 and MOPP 4. Of the 14 movements performed, the low crawl engages the most body parts: shoulders, elbows, waist, hips, knees, and ankles; observing TPs perform this movement in MOPP 2 and in MOPP 4 -- flexibly and without restriction -- suggests good overall range of motion when wearing the Gen 5 prototype.

3.1.5 Donning and Doffing

For every action involved with donning, doffing adjusting fit, and adjusting to achieve protective interface, TPs rated the challenge level as No Challenge, Slight to Moderate Challenge, or Not Possible without more training or design change. The Tester logged her own observation if it differed from the TP's report.

The Gen 5 was easy to don in every respect: undergarment trousers and shirt, shell trousers, shell jacket, and attaching shell trousers to the shell jacket were all easy with the exception of fastening protective flaps at the midriff area. Positioning balaclava and hood properly were also easy. For the record, the balaclava was stored in the mask case attached to the mask. It never once became detached or tangled; it was always ready to don as intended. Donning/fastening the midriff flaps and the balaclava and hood are discussed immediately below, under Protective Interfaces.

3.1.6 Protective Interfaces

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.

At the waist

Just above the waistline of the shell trousers, TPs could easily and competently employ the circumferential zipper to attach the shell trousers to the jacket. They also could affix the large panels (labeled "A") to one another, smoothly, with just a few practice trials.

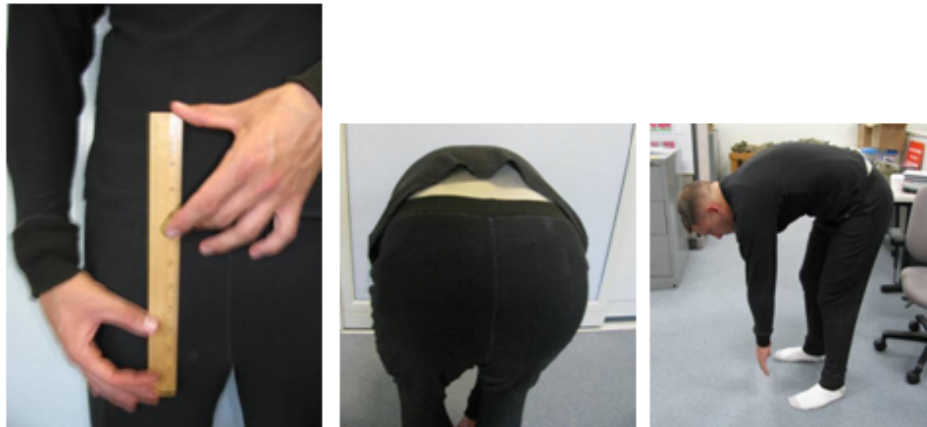
Attaching the remaining, smaller flaps ("B" and "C") was rated as a Slight to Moderate Challenge by three TPs, and even those TPs who claimed it was No Challenge did not achieve good alignment. Even a



TP1 attaching the smaller flaps on the cummerbund. The large flap in center is attached but not well-aligned.

sub-optimal alignment of hook and loop, however, appeared to hold, as none of the waist connectors loosened at all or caused a breach during movements in MOPP 4.

The shell component of Gen 5 may have hidden from view a breach in the undergarment at the waistline. At a resting, standing position, with no shell worn, the undergarment shirt overlapped with the waistline of the undergarment pants between 1.5 and 4.5 inches depending on size of TP. For the TP with the longest overlap -- 4.5 inches -- no breach was observed; but for the other four TPs with shorter overlap, bare skin was revealed at the back of the waist when they bent to touch toes and at the front of the waist when they raised both arms.



TP2 has a 2.5 inch overlap between shirt and trousers when standing, but loses this overlap on his back when he touches his toes (1st two photos). In photo at far right, the same condition is depicted for TP5.

At the wrists

Wrist interface: The JB2GU non flame resistant CB protective glove was employed in this evaluation for hand protection. This glove consists of a CB-protective butyl glove worn over a cotton sweat absorption liner. After donning the cotton liner onto bare hands, the butyl is donned in accordance with doctrine by placing the gauntlet against the skin, or, in this case, beneath the cuff of the undergarment. There is, however, *operational* disagreement about whether the butyl can be alternately placed between an inner CB cuff and an outer garment sleeve; so both methods were employed in this evaluation, one on each hand.

Evaluation of other CB garments has shown that it is more challenging to tuck the CB glove gauntlet beneath -- compared to outside of-- an inner cuff, and the same held true for the Gen 5. All TPs were able to fully don the JB2GU glove ensemble using either method of layering, but they said that it was somewhat challenging to tuck the gauntlet up under the undergarment cuff while it was no challenge to don the butyl *between* the undergarment and shell sleeves. Two TPs half-joked that inserting the gauntlet up inside the undergarment sleeve was the hardest part about preparing for MOPP 4! The Gen 5 design accommodates either method, however, and there are no HF concerns regarding glove interface.

Earlier, it was noted that the shell sleeve was short, on the inner wrist, for 3 TPs (when they raised their arms). This had no impact on the security of the protective wrist interface. Once the butyl was in place beneath the shell sleeve or beneath the shell and undergarment sleeves, the hook and loop cinching mechanism on the shell sleeve was easy to use and held the gloves firmly in place. Throughout the 14 activities, no glove movement was observed by TPs or Testers.

At the ankles

The AFS CB protective boot was donned over the duty boot and the shell trousers were cinched over it with a hook and loop closure. For all TPs, trouser length was adequate for cinching the boot at the optimal location (beneath the top fastener) and this interface action was easy for all TPs. In the Tester's experience, trousers often creep up during MOFP 4 as movements are performed, especially low crawl and climb and reach movements. No such movement was observed during the Gen 5 evaluation. Once the trousers were cinched over the CB boots they remained in place without fail.

At the necks, face, and head

Securing the neck, face, and head involved the JSGPM mask and several components of the Gen 5 ensemble. The sequence performed during this evaluation is listed, below. HF findings are noted with each step.

- Remove JSGPM mask from mask case with Gen 5 balaclava attached to it. The balaclava stayed attached to the mask while it was in the case; it was, therefore, ready to go, as planned.
- Clap mask onto face and follow prior training to clear and seal the mask. It was possible to do this right through the balaclava as it hung down in front of the mask.
- Flip the balaclava over the head and adjust into place. This movement was very easy but two TPs initially pulled the balaclava onto their heads with too much "gusto," exposing the front of their scalp without realizing it. Once informed, it was easily self-correctable and they did not make the same mistake twice.
- Tuck the balaclava into the open neckline of the jacket. This action presented some challenge, because the neckline of the jacket was not large or flexible at this point. That is because TPs were wearing their IOTVs with their shell jackets zipped nearly to the top, with just 2 to 3 inches open. Though challenging, all TPs could satisfactorily accomplish this step. TP5 complained, however, that it "was a pain" and all TPs rated this step as a Slight to Moderate Challenge.
- Raise the hood and work it carefully across the top and sides of the contours of the JSGPM mask. Fasten the canister cords. The Tester observed that 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 protrusions at the temples. For that reason, she encouraged TPs to fasten the canister cords first, and then tuck the sides of the hood behind those protrusions.
- Zip the shell jacket up to the top and fasten the hook and loop neck tabs. TPs considered this step to be easy but their neck tabs were generally not well aligned without Tester verbal or physical intervention. The natural movement of the TPs led to the tabs being attached in a criss-cross fashion, forming an X, with only a small

portion of the hook and loop engaged. With Tester verbal instruction, they could self-correct.

3.1.7 Compatibility with Military Gear

As a reminder, the military gear items employed in this evaluation were: the IOTV with mock ammo pouches and a mock grenade attached to it, the mock M4 rifle, two types of backpacks, and a standard 2-qt canteen. The IOTV was donned as part of the dress-up to MOPP 2 level. In order to be ready to transition to MOPP 4 without removing the IOTV, TPs fastened their shell trousers to the jacket prior to donning the IOTV; they also needed to zip up the shell almost to the neck line, so that they would be able to reach into the collar opening of the IOTV to grab the zipper pull when they were ready to go to MOPP 4.

Given this sequence, there was no incompatibility between the IOTV and the Gen 5 prototype. Although TPs found it slightly to moderately challenging to tuck the balaclava into the jacket collar and zip up the jacket collar while wearing the IOTV, it was achievable and the Tester does not view this as an incompatibility.

The remaining gear items were all employed in one or more of the movements performed during MOPP 2 and MOPP 4 (see Table 3-6 to review these movements). No incompatibilities with the Gen 5 ensemble were observed.

3.1.8 Safety

There were no urgent Safety issues observed. Potential safety/health hazards observed during this evaluation were:

1. Snag hazard from the protruding leg tabs
2. Irritation/chafing/rash at the neck from the pressure of multiple garment and protective items that converge there
3. Potential abrasion, puncture, or tearing of undergarment wrist cuff on inner wrist due to insufficient length of shell sleeve. This would compromise CB protection.

3.1.9 User Acceptance

User acceptance of this prototype was unanimous. The following table lists the questions that participants were asked with regard to acceptance and indicates their responses.

Table 3-7. Acceptability of the Gen 5 Ensemble

Asked when?	Question Asked	Response
After MOPP 2 activities	<i>All things considered, would this garment be Acceptable for performing your duties in a CB threat environment requiring you to be at MOPP 2?</i>	Unanimous Yes
After MOPP 4 activities	<i>All things considered, would this garment be Acceptable for performing your duties in a CB threat environment requiring you to be at MOPP 4?</i>	Unanimous Yes
After doff at end of session	<i>All things considered, would you accept this undergarment-shell-balaclava combination as your CB protection for MOPP Level 4?</i>	Unanimous Yes

As the table reveals, there was 100% Acceptance among the respondents. TPs were also asked if they would accept the ensemble for a cold climate (below 32 F), a warm climate (75-90 F) and a hot climate (above 90 F). All TPs said they would accept both the MOPP 2 and MOPP 4 configurations for all three environments.

The combat-experienced participants expressed some uneasiness that the Gen 5 ensemble would not be useful in an emergency; but, *given the proposed concept of wear*, the ensemble was acceptable and well-liked. Many spontaneous comparisons to the JSLIST were expressed, all of them favorable to the Gen 5 (see next section).

3.2 Comparisons to JSLIST

JSLIST was not worn during the evaluation, but all five Test Participants had worn it before and made the following comparisons, all favorable to the Gen 5.

- Gen 5 is cooler to wear. TPs consistently said that the two layers of the Gen 5 (undergarment and shell) are definitely cooler to wear than the JSLIST worn over the ACU or the JSLIST worn only over personal undergarments (e.g., t-shirt and briefs).
- Gen 5 is lighter in weight. All TPs judged that the Gen 5, both layers together, are lighter in weight than the JSLIST garment. This would be an advantage for carrying the Gen 5 in their pack.
- Gen 5 requires less volume for stowage in pack. The flexibility of the shell fabric and the thinness and flexibility in the undergarment would make the Gen 5 easier to pack tight for stowage, requiring less volume than the JSLIST.
- Gen 5 fabric is more flexible. The relative flexibility of the Gen 5 fabric compared to the JSLIST was seen as an advantage for stowage (noted above) and for maneuverability and comfort when wearing CB protection.
- Gen 5 ensemble is more comfortable. The fabric is more comfortable and flexible on the Gen 5, leading to more comfort. Gen 5 is less bulky than the JSLIST. TP4, who had worn the JSLIST several times for 8-hour periods, said that the JSLIST made him feel claustrophobic, even at MOPP 2 level but that the Gen 5 does not.
- Means of connecting jacket to trousers. Zipper method is preferable to JSLIST suspenders because the elastic in the suspenders often becomes slack and the plastic mechanisms on

the suspenders break. Also, the TPs prefer a garment without the crotch retention cord featured on the JSLIST.

4.0 CONCLUSIONS

To recap, the HF areas of concern are:

- Breach between trousers and shirt of undergarment during movements, exposing bare skin
- Shell sleeve too short on the inside of the wrist when arms are raised
- Snag hazard from leg cinch tabs
- Possibility for irritation and chafing at neck when fully encapsulated, especially for individuals with sensitive skin
- Restriction at neck in MOPP 4 – inability of all TPs to swivel neck from side-to-side
- Flap connectors for waist protection are complicated, making them challenging to align properly, they are bulky to wear

The positive HF features are:

- Both undergarment and shell are lightweight with comfortable and flexible fabric
- Zipper connecting shell trousers and jacket is effective and easy to use for both left- and right-handers
- Balaclava approach to storage, donning, and wear is easy to use and effective
- Ensemble is easy to don to MOPP 2 and easy to transition to MOPP 4 with the exception of the connector flaps at the midriff.
- Ensemble permits excellent range of motion, allowing many military-relevant movements except for side-to-side movement of neck
- According to wearers, both the undergarment and the shell are comfortable except for the bulkiness and pressure at the neck when fully encapsulated
- CB interfaces at wrists, ankles, and neck were strong and did not breach or even budge during activities
- The TPs unanimously accepted the Gen 5 prototype ensemble for situations where there is advanced warning of chemical threat.

5.0 RECOMMENDATIONS

Regarding Undergarment breach at waistline

- Alter length or cut of undergarment shirt or pants to eliminate breach at waist when Soldiers are active (e.g., bending forward, raising arms).

Regarding waist connecting flaps

- Simplify system of connecting flaps so that a single thick flap at the midriff needs to be affixed when transitioning to MOPP 4 (like “flap A” in current design.) This flap would be similar to the belly band on an IOTV, something all Soldiers are familiar with. A single flap would add less bulk, be easier to attach, and be more acceptable to Soldiers than the current arrangement requiring 3 pairs of flaps to be attached. The analyst understands that the smaller flap attachments (B and C) were designed in direct response to tests showing CB penetration in that area of the torso. Eliminating B and C but adding an outer drawstring like those found on parka jackets might protect equally well against CB penetration and be easier for Soldiers to operate.
- If more than one pair of flaps must be attached at the midriff area, the use of printed lettering on the fabric of the cummerbund is encouraged. Several TPs remarked that the handwritten letters (A, B, and C) were helpful or even necessary for them to align the flaps properly.
- Recommend that the cummerbund that houses the circumferential zippers and flap attachments be non-removable and remain as a short lining inside the shell jacket. In this case it would be one less item to become lost or separated from the prototype and one less item to locate when donning to MOPP 4 posture.

Regarding leg cinches:

- Given current design, the hook and loop patches on *the trousers* must be longer to prevent excess leg tabs dangling with no attachment to trousers, which is a snag hazard;
- Recommend experimenting with a single cinching tab above and a single cinching tab below each knee pad instead of two tabs above and two tabs below; this would take less time to execute, require only one, not two hands, and result in fewer total tabs per leg, which would minimize snag hazard.

Regarding restriction at neck

- All TPs experienced restriction at the neck in MOPP 4 when looking side-to-side, but the analyst has learned that Soldiers in the field expect this restriction and learn to turn their whole body when looking side-to-side while encapsulated. As an option, however, for eliminating this restriction, it may be possible to add length to the bottom of the hood in the form of accordion style, rigid fabric. The accordion dimension would provide leniency at the neck and the rigid style for this extension would prevent excess fabric from overhanging the jacket collar, which would cause a snag-hazard.

Regarding neck tabs on shell hood

- When the TPs attached the neck tabs, the tabs were not well aligned without Tester verbal or physical intervention. Instead, the natural movement of the TPs led to the tabs being attached in a criss-cross fashion, forming an X, with only a small portion of the hook and loop engaged. Soldiers can be trained to take more care to align these tabs. Alternately, a design solution could be to thicken the width of these extensions to the hood so they are more like panels than tabs, and employ square hook and loop patches. It is envisioned

that with this design, Soldiers will overlap hook and loop more completely and effectively.

6.0 REFERENCE LIST

Creation of CALM Scale:

Cardello, A.V., Winterhalter, C., & Schultz, H.G. (2003). Predicting the Handle and Comfort of Military Clothing Fabrics from Sensory and Instrumental Data: Development and Application of New Psychophysical Methods. *Textile Research Journal*, 73 (3), 221-227.

Use of ASHRAE Scale:

Rohles, F.H., & Nevins, R.G. (1972). Thermal Comfort: New Directions and Standards. *Aerospace Medicine*, July 1973.

Report Concludes

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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 5 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 5 garment against the currently used JSLIST Lightweight Integrated Suit.

B.2.3 Characteristics Evaluated

A seventeen-item Human Factors Evaluation Questionnaire (see B.2.4) 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);

- ### B.2.4 Questionnaire

[illegible]

Now, please answer the following questions by circling the appropriate number.

Fabric Characteristics

1. Please assess the *thermal comfort* of the fabric.

Very Cool			Neither Cool nor Warm			Very Warm
1	2	3	4	5	6	7

2. Please assess the *stiffness* of the fabric.

Very Soft						Very Stiff
1	2	3	4	5	6	7

3. Please assess the *scratchiness* of the fabric.

Very Smooth						Very Itchy
1	2	3	4	5	6	7

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

16. Please rate the heat factor while wearing the full suit (including mask).

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

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, the 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.

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:

1. Rotate head 90 degrees to left
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, and 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 5 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 Characteristic—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 5 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).

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 and time of evaluation. The Generation 5 garment was rated significantly higher on its fabric characteristics than was the JSLIST garment ($t = 2.84, p < 0.008$). Both garments received higher ratings following the initial donning of the garment than after completion of the motion routine ($t = 2.54, p < 0.017$; see Figure B-1).

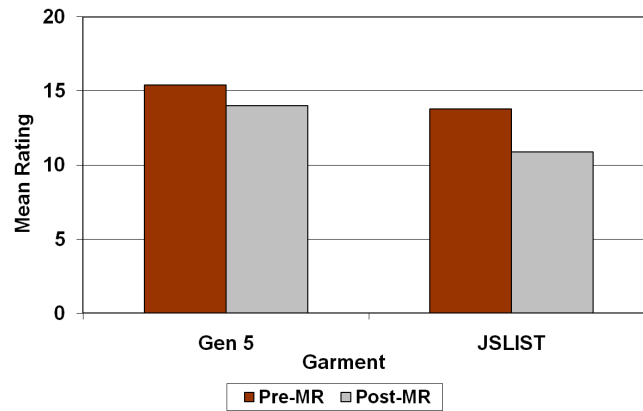


Figure B-1. Mean Ratings of Fabric Characteristics for the Generation 5 and JSLIST Garments after Initial Donning (Pre-MR) and Following Completion of the Motion Routine (Post-MR).

B.3.3 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 following the initial donning of the garment and following completion of the motion routine ($t = 0.61, p < 0.55$; see Figure B-2). The Generation 5 garment was rated higher on its garment characteristics than the JSLIST garment, although this difference fell just short of statistical significance ($t = 1.68, p < 0.10$).

See Table B-1 for a comparison of mean ratings for each of five garment characteristics for the Generation 5 ensemble and the JSLIST.

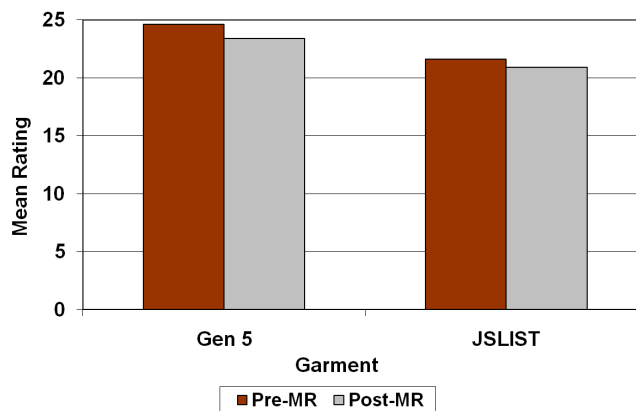


Figure B-2. Mean Ratings of Garment Characteristics for the Generation 5 and JSLIST Garments after Initial Donning (Pre-MR) and Following Completion of the Motion Routine (Post-MR).

Table B-1. Mean Ratings for Each of Five Garment Characteristics for Generation 5 Garment Configurations and the JSLIST Garment Configuration before and after Completion of the Motion Routines.

Characteristic	Generation 5 Mean (std.dev.)		JSLIST Mean (std.dev.)	
	Pre-Motion Routine	Post-Motion Routine	Pre-Motion Routine	Post-Motion Routine
Overall Garment Characteristics	24.6 (3.4)	23.4 (5.3)	21.6 (4.5)	20.9 (5.3)
Hood	8.0 (2.4)	8.4 (1.8)	7.9 (2.7)	7.5 (1.6)
Range of Motion	15.9 (2.4)	15.4 (2.3)	17.0 (1.3)	12.9 (3.4)
Heat Factor (Total)	7.6 (1.4)	6.5 (1.9)	7.0 (1.0)	6.9 (1.0)
Donning Ease	3.0 (1.1)	2.7 (1.1)	4.5 (1.7)	5.0 (1.6)

B.3.4 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 ($t = 0.66, p < 0.52$; see Figure B-3).

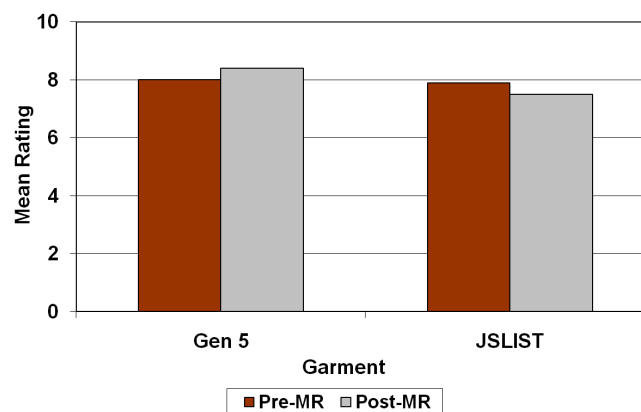


Figure B-3. Mean Ratings of the Hood for the Generation 5 and JSLIST Garments after Initial Donning (Pre-MR) and Following Completion of the Motion Routine (Post-MR).

B.3.5 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 garment, but a significant difference based on time of evaluation.

Although there was no significant difference in the range of motion ratings for the two garments ($t = 0.74, p < 0.46$), it is instructive to note that the JSLIST garment evidenced a sharp reduction in perceived range of motion as a consequence of the motion routine. The Generation 5 garment range of motion ratings following completion of the motion routine ($M = 15.9$) were comparable to the ratings it received following the initial donning of the garment ($M = 15.4$). However, the ratings of the range of motion for the JSLIST garment decreased significantly following completion of the motion routine ($M = 12.9$) compared to the ratings following the initial

donning of the garment ($M = 17.0$). Thus, a significant difference was noted in the pre-MR compared to Post-MR ratings ($t = 2.50, p < 0.018$; see Figure B-4).

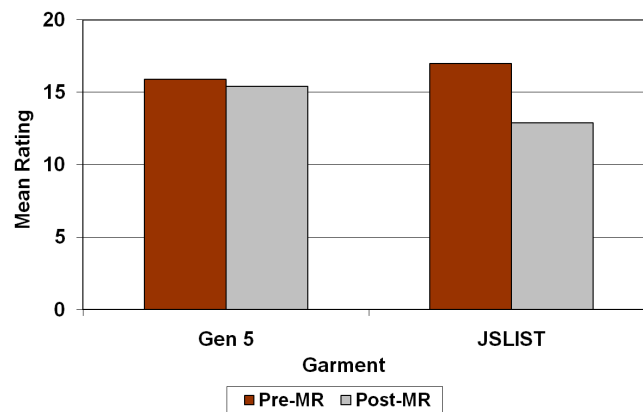


Figure B-4. Mean Ratings of Range of Motion for the Generation 5 and JSLIST Garments after Initial Donning (Pre-MR) and Following Completion of the Motion Routine (Post-MR).

B.3.6 Heat Factor

No significant differences were noted for heat factor ratings between garments ($t = 0.26, p < 0.80$) or between pre-MR and post-MR testing of either garment ($t = 1.29, p < 0.21$); see Figure B-5.

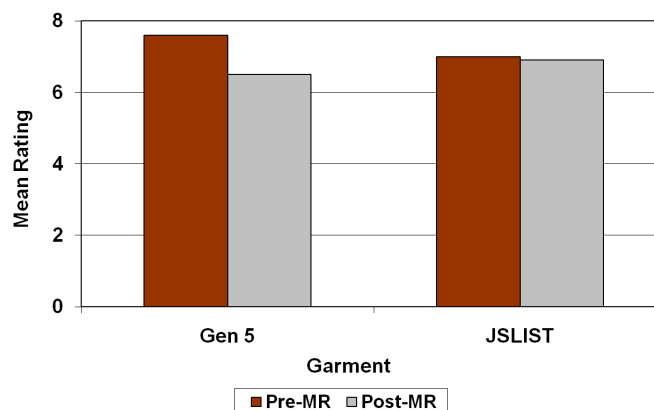


Figure B-5. Mean Ratings of the Heat factor for the Generation 5 and JSLIST Garments after Initial Donning (Pre-MR) and Following Completion of the Motion Routine (Post-MR).

B.3.7 Donning Ease

The JSLIST garment (Mean rating of 4.5 out of 7) was judged to be significantly easier to don than the Generation 5 garment ($M = 3.0$; ($t = 4.11, p < 0.001$).

B.3.8 Overall Comfort

Figure B-6 shows Generation 5 and JSLIST garments' mean ratings comparisons for overall comfort before and after motion routine.

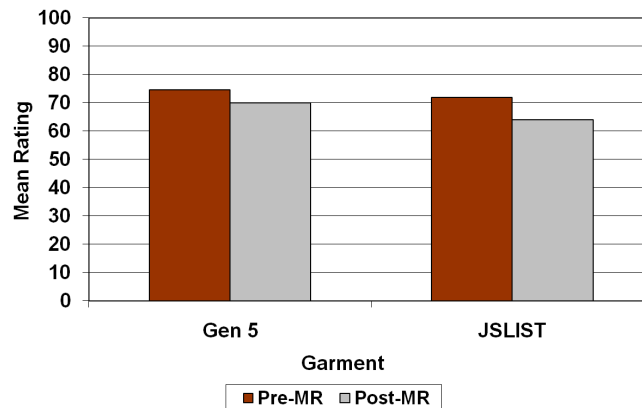


Figure B-6. Mean Ratings of the Overall Comfort for the Generation 5 and JSLIST Garments after Initial Donning (Pre-MR) and Following Completion of the Motion Routine (Post-MR).

B.4 Conclusions

The Generation 5 garment was judged to be significantly more comfortable than the JSLIST for the assessed critical fabric characteristics (thermal comfort, stiffness, and scratchiness). The fabrics used in the construction of the Generation 5 garment 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 Technical Report PHILA-LEHP-ME-TR-08-01, *Further Evaluation of the Reliability and Validity of the CALM Scale for Assessing the Tactile Comfort of Fabrics*.¹⁰) The significantly higher ratings for fabric characteristics reflect, in part, the extensive psychophysical testing for comfort that influenced fabric selection for the Generation 5 garment.

The Generation 5 garment similarly received higher mean evaluations than the JSLIST for the assessed garment characteristics (seam comfort, neck closure, glove attachment, boot attachment, and overall weight), although these differences fell just short of statistical significance. The failure to reach statistical significance for this summary variable is likely due to the small sample size ($n = 8$) used for evaluation. At the very least, these results suggest that the Generation 5 garment is comparable to the JSLIST for these critical garment characteristics.

No significant differences were noted between the Generation 5 garment and the JSLIST for three summary variables: The hood, the range of motion, and the heat factor associated with

¹⁰ Pierce, John D., Jr. *Further Evaluation of the Reliability and Validity of the CALM Scale for Assessing the Comfort of Fabrics*. Technical Report PHILA-LEHP-GT-TR-08-01. Philadelphia, PA: Philadelphia University Laboratory for Engineered Human Protection, 2008.

wearing the garment. The JSLIST garment was judged to be significantly easier to don than was the Generation 5 garment.

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Appendix C

Philadelphia University LEHP FAST Testing Notes—July 21-22, 2009

(Reprint of original)

PHILADELPHIA UNIVERSITY - LEHP FAST JULY 21-22, 2009

Testing Notes

Attendees:

LEHP: K. Hultzapfel, J. Venafro

NCTRF: S. Proodian

RTI Test Team: James Hanley, Jason Hill and Clint Clayton.

Test participants (TPs):

TP-#0

- TP approved for testing based on availability: Weight 147 is outside JPACE Size 40 weight range (185-200). Height 67-1/2 which is 1/4-inch outside the Regular height on JPACE prediction charts.
- Long hair is worn in a pony tail at nape of neck during testing
- This TP sweats profusely. His T-shirt is almost completely soaked when test is complete
- Subject measurements:

Body Location	Measurement
Neck	16
Chest	38
High point to waist	21-1/4
Waist band	35-1/4
Waist - natural	36
Hip	38-1/2
Center back- Sleeve Length	31-1/2
Raglan Sleeve Length	28
Cross Shoulder	17-1/2
Back Length	22-1/2
Inseam	28
Outseam	39

TP-#3

- TP approved for testing based on availability. Weight 213 is slightly outside JPACE Size 40 weight range (185-200). Height is 1/4-inch over Regular height on JPACE prediction charts.
- Subject measurements:

Body Location	Measurement
Neck	16-3/4
Chest	43-1/2
High point to waist	
Waist band	41
Waist - natural	41-1/2
Hip	44
Center back- Sleeve Length	36
Sleeve Length - bent arm	38
Raglan Sleeve Length	32-1/2

PHILADELPHIA UNIVERSITY - LEHP FAST
JULY 21-22, 2009

Testing Notes

Body Location	Measurement
Cross Shoulder	20
Back Length	22
Inseam	34-1/2
Outseam	43

- TP-#4
 - TP approved for testing based on availability. Weight 192 is within the range for JPACE Size 40 weight range (185-200). Height 67 which is 1-inch outside the Regular height on JPACE prediction charts.
 - Subject measurements:

Body Location	Measurement
Neck	16-1/4
Chest	41-3/4
High point to waist	22-1/2
Waist band	39-1/2
Waist - natural	40
Hip	42
Center back Sleeve Length	34-1/2
Raglan Sleeve Length	
Cross Shoulder	20-1/2
Back Length	20-3/4
Inseam	30
Outseam	38

Test Schedule: Initial matrix was adjusted as testing proceeds.

	Tues	Tues	Tues	Wed	Wed	Wed
	800	1100	1330	800	1100	1330
Coverall (Gen4) with Undergarment	3	4	9			
Coat/Trousers (Gen5) with 2-pieced Undergarment				3	4	9
JSGPM mask and butyl hood	X	X	X	X	X	X
7 mil butyl with cotton liner	X	X	X	X	X	X
GVO	X	X	X	X	X	X

Test Item Descriptions:

Gen4 Coverall

Design: One piece coverall with attached hood. Designed to fit the JSGPM. Features include canister straps, two front neck flaps, an asymmetrical center front zipper, a left sleeve doffing zipper, two way relief zipper, articulated elbows and knees, knee pad pocket with removable knee pad, elbow abrasion patches, interior waist belt, zipper pull tab, shoulder retention harness, and hood stowage system.

Materials: 78C

Gen4 Undergarment

Design: Fitted one piece body suit with knit ankle and leg cuffs with center front asymmetrical zipper and two way relief zipper.

Materials: 63A (stretch)

Gen4 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.

Materials: 63A (stretch)

Gen5 Uniform (Coat & Trousers) (note: used Gen4 Balaclava for this testing)

Design: The coat features a bi-swing back with gripper patches at the shoulders to prevent gear slippage. The sleeve includes an articulated elbow with a reinforcement patch and shaped wrist cuffs. The pant sits high on the waist and includes a zip fly and side size adjustment straps. Redesigned articulated knees improve movement, but still include the knee pad pocket with removable knee pad. Ankle cuffs are elastic with a Velcro pull tab. The coat and trousers form an integrated unit when zipped together at the waist. An internal removable skirt is attached to the coat that zips

Materials: 78C

Gen5 Undergarment (Shirt & Drawers)

Design: Undergarment shirt includes an asymmetrical center front zipper, with backup flap for comfort and knit cuffs. The drawers feature a high waisted style along with knit cuffs and waist band.

Materials: 78C

Tuesday – July 21st

0830 TEST

Design: Configuration:

Gen4 Coverall with Gen4 One-pieced Undergarment & Gen4 Hood (TP #3)

TP wore 2004 JSGPM mask

This specific garment has been through internal LEHP Human Factors

Pre-Blacklighting: OK

Donning:

- Leg bottom of UG drawers worn inside combat boot. Then GVO. Leg bottom of Coverall secured over GVO.
- When closing UG Shirt zipper, TP positioned end at front...top of zipper is off-set to the left as worn. Need to ensure the top of zipper is off-set when worn to reduce potential of irritation at Center front neck.
- TP had some difficulty closing front zipper on coverall...tab at bottom helped. Should/can that curve be flattened some?
- Gen4 balaclava positioned on JSGPM before donning. Once mask is secured in place, balaclava is pulled over head and then tucked inside coverall. Center front coverall 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. Leg length looks short (bottom of leg falls above middle GVO closure after movement). Good overall range of motion including head and shoulders.

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

Doffing:

- Post-test/pre-doffing: left bottom outer and top right outer knee retention strap were open. It looked like the bottom straps opened and reclosed. Leg bottoms settled at the top closure of the GVO. No tabs on filter straps
- Need more loop at CB to secure Hood neck flaps
- Yellow simulant on CF and left doffing zipper teeth which was visible to the naked eye. Also a significant deposit on the top of the mask eye lens and also on the balaclava along interface
- Need thong on undergarment zippers
- No visible simulant on the undergarment
- TP comments: overall one of the most comfortable CB Garments worn. Liked the fact that it stretches with movement. Garment is not restrictive, cool and light. Zipper pull at CB was mildly uncomfortable; it's unclear whether this is from the coverall or the undergarment.

Black lighting:

- Relatively clean. Only one spot at right temple even with top of ear.

Recommendations for next run:

- Sleeves – none
- Legs – undergarment leg bottom to be worn outside combat boots.

Tuesday – July 21st

1130 TEST

Design: Configuration:

Gen4 Coverall with Gen4 One-pieced Undergarment & Gen4 Hood (TP #4)

TP wore 2004 JSGPM mask

Coverall produced specifically for FAST- never worn

Pre-Blacklighting: OK

Donning:

- Leg bottom of UG drawers worn outside combat boot. Then GVO. Leg bottom of Coverall secured over GVO.
- Fit: Hood, shoulders and torso (circ and length) is loose. Also sleeve length and knee location are long. Leg length looks long also. Good overall range of motion including head and shoulders. Leg cuff on undergarment appears to be tight over combat boot.

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

Doffing:

- Post-test/pre-doffing: Outer neck flap flipped up. Knee straps did not open during test
- Cannot secure neck flaps to loop at CB until after filter straps are released.
- Visible yellow simulant on zipper teeth of both entry zippers
- GVOs doffed and coverall was doffed over the combat boots and then gloves were doffed. TP was re-gloved
- Balaclava was pulled over head. Test assistant gathered outer edges of balaclava around mask and doffed
- Combat boots unlaced and undergarment/boots doffed together
- Checked interface of balaclava to mask and there appears to be a potential path just below the temple area on each side (outer shape of JSGPM and stretching of balaclava creates this void). Team will “fill the void” with extra material at each side for next run
- TP stated the mask was comfortable.
- Void between balaclava and JSGPM may be causing the very slight contaminant hazing on temple area to upper neck where lower mask strap is located, barely visible. (hand held black light)

Black lighting:

- Legs/arms clean
- One spot on left front neck (perhaps from re-aerosolization)
- Head from temple area to back of ears slight haze (could see outline of straps). Slightly darker at each temple.

Recommendations for next run:

- Sleeves – none
- Legs – remove on leg cuff on undergarment and position outside combat boots.
- Head/Neck – Add temple inserts onto carbon balaclava to fill void with JSGPM

Tuesday – July 21st

1300 TEST

Design: Configuration:

Gen4 Coverall with Gen4 One-pieced Undergarment & Gen4 Hood (TP #9)

TP wore 2007 JSGPM mask

Coverall produced specifically for FAST- never worn

Modifications: Left leg bottom cuff removed (new circ of leg bottom = 13 inches), right cuff circ increased with duct tape (new circ = 13 inches). Original cuff circ = 10-1/4 inches. Folded stretch cuff material in semi circle shape added to each temple area of the balaclava.

Pre-Blacklighting: OK

Donning:

- Both undergarment leg bottoms worn outside the combat boot
- Fit: Undergarment fit OK. Outer garment is very loose over the TP. Sleeves 3 inches too long, legs at least 3 inches too long. Torso long – waist belt needed to be worn rather high to “take up” excess torso length. Knee on garment low on TP too.
- Interface of coverall hood to mask uneven from side to side. Left temple area of hood does not “match” mask. Added padding on balaclava seemed to “fill the void”

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

Doffing:

- Post-test/pre-doffing: GVOs bottom closures were mismatched...one higher than other. RTI checking to see if boots are same size.
- All knee straps stayed closed
- Need to make filter tabs longer (1/2-inch) on coverall hood
- No visible yellow stimulant on subject or undergarment

Black lighting:

- Legs clean – no real need for cuff. Also lower leg can be worn outside combat boot. Simple layering with GVO and outer garment creates block of aerosol
- Slight light bluish palm sized haze over back and shoulders between shoulder blades
- Slight light haze on upper neck to temple on both sides – added material in temple area of balaclava seems to improve protection here, better performance than test 1 and 2
- Clear light deposit on upper left forehead - rounded shape (could this be a finger transfer?)

Overall recommendations for Gen4 system:

- Coverall
 - o Work on tabs/velcro on knee pads
 - o Work to potentially eliminate cheek pads in hood
 - o Lengthen CB loop 2-inches for attachment of neck flaps during doffing.
 - o **Need to make filter tabs longer (1/2-inch) on coverall hood**

- o Add 2-inch thongs (fabric pulls) to zipper sliders
- Undergarment
 - o Add 2-inch thongs (fabric pulls) to zipper sliders
 - o Eliminate rib knit cuff on leg bottom. And replace with body material cuff 13 inch circ and same height as current cuff
 - o Add stops for zipper (center front waist and crotch zipper)
 - o Sleeve cuffs are OK
- Balaclava
 - o Add additional layer/s of material at temple area to "fill JSGPM void". Can't test a different mask because hood is custom to mask.

Above highlighted items to be incorporated into test items for Contaminated Doffing

Wednesday – July 22nd

0830 TEST

Design: Configuration:

**Gen5 Uniform (Coat/Trouser) with Gen5 Undergarment (Shirt & Drawers)
& Gen4 Hood (TP # 3)**

- Added additional layer/s of material at temple area to “fill JSGPM void”.
- TP wore 2004 JSGPM mask
- Specific Coat/ Trouser produced for FAST – never worn prior
- Added duct tape onto canister cord pull tabs to make longer

Pre-Blacklighting: OK

Donning:

- Undergarment drawers
 - o Leg cuff worn inside combat boots. GVOs worn over
 - o Appeared to fit OK and length was OK
- Undergarment shirt
 - o Too short (at least 4 inches and more in back) on this subject. Tucked shirt into drawers for this test to potentially eliminate bare skin
 - o Need to ensure that protective fly is in correct position during doffing. Should be flat under the zipper
 - o Circumference of shirt OK
 - o Sleeve length OK
- Uniform Trousers
 - o Very snug on this TP...he is outside the JPACE 40R dimensions (43 chest etc), he could have used about two more inches at waist
 - o Velcro at waist skirt opened when TP sat to don boots
 - o Length too short (after donning GVOs, closing leg tabs and moving around – leg bottoms shifted to just below top of GVOs
 - o Knee width appeared to be OK so knee pad straps were **NOT** engaged
- Uniform Coat
 - o Snug on this TP – again he is outside JPACE 40R dimensions
 - o Upper Coat (shoulders) OK (bi-swing was closed) on this TP but from under arm to hem a bit snug
 - o Chest circ was snug
 - o Inner skirt circ was snug and closed velcro pulled in standing position - after movement (sitting etc) the closure opened and had to be re-secured
 - o Lower back conforms well to body
 - o Sleeve length – OK After closing sleeve tab

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

Doffing:

- Uniform
 - o Left trouser leg bottom shifted up and just covers top closure. Right leg bottom shifted above top closure but not above the GVO. For this TP...legs should be about 3 inches longer
 - o Doffing assistants had difficulty opening the leg bottoms. Tab became caught on casing edge and it was difficult to get tab to retract into the casing. Solution: increase length of tab/reduce elastic or widen casing opening at top to accept tab.
 - o Longer tape on filter straps and duct tape color provided easier doffing of straps
 - o Hood doffing worked good – yellow simulant at R temple and less at L
 - o Under garment
 - Looks clean – no yellow
 - Shirt stayed under top of drawers. Doffing assistants folded top of drawers down to doff shirt. Shirt peeled off easily. This fold provided means to easily doff drawers
 - Leg bottoms remained in position at ankle– leg length OK for this subject. Doff easily
 - o TP notes: this ensemble warmer than coverall, but less restrictive while doing high reach. Only mild discomfort while lying on stomach from zippers.

Black lighting:

- Per TP
 - o Sleeves were very comfortable – no restriction when reaching high
 - o Some discomfort when lying on stomach from all layers
 - o Velcro at center opened at start of testing and remained open
- Faint haze at sock line on both front legs (left more than right)
- Front chest to just above waist haze of bluish simulant. Just left of median at top of inner skirt location long smudge of simulant. Appears that there was no simulant haze in the area on the zipper protective fly. Perhaps this UG material shouldn't be stressed? Is the simulant penetrating the carbon fabric?
- Right arm two parallel lines above wrist
- Head – right temple and above ear faint haze of simulant in a triangle shape from presumably the mask straps outline

Recommendations for next run:

- UG shirt to be worn outside drawers – ensure protective fly is flat and in place
- Sleeves – none
- Legs – remove leg cuffs
- Head/Neck – added material at temples to fill void
- Overall check fit of UG and Uniform

Wednesday – July 22nd

1130 TEST

Design: Configuration:

**Gen5 Uniform (Coat/Trouser) with Gen5 Undergarment (Shirt & Drawers)
& Gen4 Hood (TP # 4)**

TP wore 2004 JSGPM mask

- Specific Coat/ Trouser produced for FAST – never worn prior
- Added additional layer/s of material at temple area to “fill JSGPM void”
- Filter tabs longer (1/2-inch) on coverall hood
- Leg cuffs removed from Undergarment drawers and they will be worn outside the combat boot

Pre-Blacklighting: OK

Donning:

- Undergarment drawers
 - Length OK on this TP without the cuffs
 - Overall fit is OK – with material loose on the body
- Undergarment shirt
 - Protective fly is in correct position - flat under the zipper
 - Circ of shirt is OK – with material loose on the body
 - Back/Front Length – short. Need to add at least 3-4 inches
 - Sleeve length – a bit long but ok.
 - Shirt worn over drawers (not tucked in)
- Uniform Trousers
 - Waist/Hip – snug on this TP. High waist folded down when TP sat down. Upper trouser should have ease (increase circ) because there is adjustment with the waist tabs. The inner skirt should “float” a bit. Recommend increasing circ at waist and top of trousers at least 2-inches. Subject has 40-inch waist....needs more ease especially if worn over two layers of undergarment. Check JSLIST specs to confirm waist addition, perhaps TP is too large for Medium Male.
 - Knee length - OK
 - Leg Length – OK, covers second hook on GVO
- Uniform Coat
 - Chest circ – a bit tight.
 - Body length – overall good length for this subject – overlaps trouser by at least 12-inches
 - Inner skirt – circ needs to be increased so it closes properly (on this TP this closure was strained). Needs more refinement...there is a pathway to the inside of the garment where skirt attaches to itself...close with duct tape next run
 - Sleeve Length - OK
 - Hood – problems with elastic interface with mask in first garment. TP felt “air” at right forehead after attaching the canister straps, but not prior. Appears the elastic was too short and forced a fold or void in the mask for air to enter. Tried re-setting hood which didn’t work. Tried second garment which worked. Elastic lengths should be checked on all garments for consistent length.
 - Chest draw cord – not sure of function? Seems to conflict with inner skirt Recommend removing....adds more bulk/stiffness to torso area.

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

Doffing:

- Face seal was ok throughout test. Coat stands away from front torso when TP stands straight
- Same problem with trouser leg bottoms – tabs/casing needs to be fixed
- Mask filter strap caught under one filter – assistant able to remove for doffing
- Hood/mask doffed: yellow simulant on top of eye lens and also at temples
- Some yellow simulant visible at tope of inner skirt. Black light TP – some yellow on coat/inner skirt velcro and the retention flap
 - o Note: It appears that simulant does not show up on the black carbon undergarment under the hand held black light. Yellow simulant was visible in regular light on right temple of balaclava, but not visible under the black light. Unable to determine if simulant is transferring onto chest of carbon undergarment due to breach at skirt interface.
- Note: garment doffed to ankles before boots unlaced. Assistants lifted garment to unlace boots and doffed garment without issue
- Shirt remained over drawers with a 2 inch overlap

Per TP – this system more comfortable than coverall ensemble but warmer

Black lighting:

- Vague line of simulant at sock line of both front legs, darker on left
- Bright yellow simulant about ½ inch below and 1 inch forward of ears on jaw line – both sides unable to determine what this spot is from. Possible from opening lower mask straps??
Simulant too low on face to be from temple breach.
- Faint haze over top of torso and front arms. (presumably from voids in inner skirt) – will duct tape voids for next test.

Recommendations for next run:

- Sleeves – none
- Legs – remove cuffs
- Head/Neck – remove carbon cord
- Coat – duct tape voids on inner skirt

Wednesday – July 22nd

1330 TEST

Design: Configuration:

**Gen5 Uniform (Coat/Trouser) with Gen5 Undergarment (Shirt & Drawers)
& Gen4 Hood (TP # 9)** TP wore 2007 JSGPM mask

- Added additional layer/s of material at temple area to “fill JSGPM void”.
- Filter tabs longer (1/2-inch) on coverall hood

**PHILADELPHIA UNIVERSITY - LEHP FAST
JULY 21-22, 2009**

Testing Notes

- Remove carbon cord from hood
- Close void at top of inner skirt with duct tape

Pre-Blacklighting: OK

Donning:

- Drawers – length OK
- Shirt – length short overlaps only about 4-inches and should be more. Shirt worn over drawers for testing
- Trousers – overall a loose fit and ok in length. Tabs adjusted at waist to secure fit. Leg tabs secured so ends were inside casing...this should help doffing
- Coat – overall a loose fit and ok in length. Overlap with trousers is 12-14 inches.
- Inner skirt – still too tight. Recommend more Velcro for adjustment or different positioning. Closure was duct taped for this test (see photos).
- Per TP when filter straps are engaged...the configuration of the mask interface changes – nose cup as well as forehead area is different. Really need QF testing to ensure the face seal is not compromised. Passed fit integrity test per RTI.

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

Doffing:

- Right side of hood at top of filter – point is setting away from the mask.
- After doffing hood – yellow simulant visible on top of eye lens and along temples. Could see yellow along temple area and over front top of head on balaclava where elastic inside shell hood stopped simulant. Pulled balaclava over head and black light head – simulant visible at right temple.
- Black light – inner skirt duct tape...slight yellow haze and heavier deposits.
- Per TP
 - o Body hair on legs (knees) is pulled by undergarment material when TP moves. Painful at times
 - o Overall this ensemble is more comfortable with increased range of motion of body and arms over coverall ensemble
 - o Mask – if TP had suddenly moved he felt that seal at said areas at side forehead would have breached. Likes this mask because there is least pressure on the face. After donning mask – when filter straps on hood were engaged...configuration of mask went from vertical oval to more horizontal oval.

Black lighting:

- Possible haze at sock line
- Relatively clean. Only one spot at right temple even with top of ear.
- Clean at chest – tape must have blocked the pathway that the simulant was getting into. Skirt needs to be revised to provide a better seal.
- Slight haze on upper back between shoulder blades
- Bright mark on right jaw line on edge of mask.

Recommendations for next run:

- Sleeves – none
- Legs – none
- Head/Neck – optimize hood/mask interface

Overall recommendations for Gen5 system:

- Duty Uniform - Coat
 - o Need to make filter tabs longer (1/2-inch) on coverall hood
 - o Inner skirt closure – more Velcro/different position. Also look at sizing
 - o Hood sizing – review
 - o Look at sleeve hem contour – OK on last two subjects
- Duty Uniform - Trouser
 - o Add 2-inch thongs (fabric pulls) to zipper sliders
 - o Revisit sizing – is waist too small.
- Undergarment - Shirt
 - o Add 2-inch thongs (fabric pulls) to zipper sliders
 - o Add stops for zipper (center front waist and crotch zipper)
- Undergarment Drawers
 - o Eliminate rib knit cuff on leg bottoms. And replace with body material cuff 13 inch circ and same height as current cuff
 - o Sleeve cuffs OK.
- Balaclava
 - o Add additional layer/s of material at temple area to “fill JSGPM void”.

Above highlighted items to be incorporated into test items for Contaminated Doffing

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Appendix D

Philadelphia University Fluorescent Aerosol Screening Tests (FAST) Test Report—July 31, 2009
(Reprint of original)

Philadelphia University Fluorescent Aerosol Screening Tests (FAST) Test Report

Purchase Order Number: B0001250
RTI Project Number: 0210914.042

Prepared by:
Jason S. Hill
919-541-7443
jhill@rti.org

July 31st, 2009



| *turning knowledge into practice*

Test Series

- Six 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 two prototype garment ensembles.
- Testing was conducted on July 21st and July 22nd, 2009.
- Black light (UV) photographs were taken to document areas of aerosol deposition on the skin of the test participants.
- LEHP and Natick representatives were on-site to observe the tests and to assist with proper and consistent donning and doffing of the test ensemble.

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
- CT = $\sim 5,000 \text{ mg m}^{-3} \text{ min}$
- “JSLIST” motion routine

Exposure Chamber (photo from prior testing)



25' x 50'
10 mph
 $\sim 70^\circ \text{ F}$
 $\sim 50\% \text{ RH}$
 $\sim 170 \text{ mg/m}^3$
2.5 μm MMD

Motion Routine

(Same as used on JSLIST)

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

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.

Ensemble Components

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

- Briefs, PT shorts, and black athletic socks
- 14-mil butyl gloves and short cotton liners
- Combat boots and GVO overboots
- JSGPM mask

Test Matrix

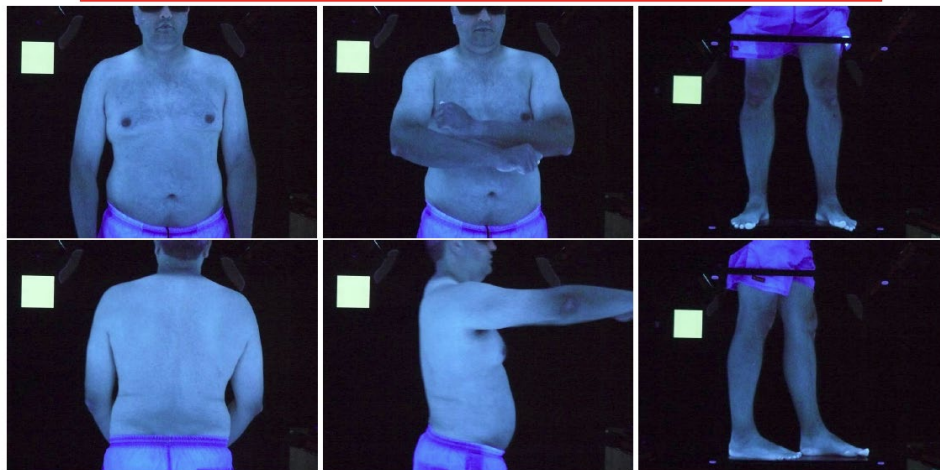
<i>Date & Time</i>	7/21/09 8:30	7/21/09 11:00	7/21/09 13:30	7/22/09 8:30	7/22/09 11:00	7/22/09 13:30
<i>RTI Test #</i>	1812	1813	1814	1815	1816	1817
<i>Test Participant</i>	3	4	9	3	4	9
<i>Configuration / Garment</i>	Coverall, inner and outer	Coverall, inner and outer	Coverall, inner and outer	Two- Piece, inner and outer	Two- Piece, inner and outer	Two- Piece, inner and outer
<i>Mask</i>	JSGPM	JSGPM	JSGPM	JSGPM	JSGPM	JSGPM
<i>Boots</i>	Combat & GVO	Combat & GVO	Combat & GVO	Combat & GVO	Combat & GVO	Combat & GVO
<i>Gloves</i>	Butyl w/ liners	Butyl w/ liners	Butyl w/ liners	Butyl w/ liners	Butyl w/ liners	Butyl w/ liners

Background UV Photos Test Participant #3



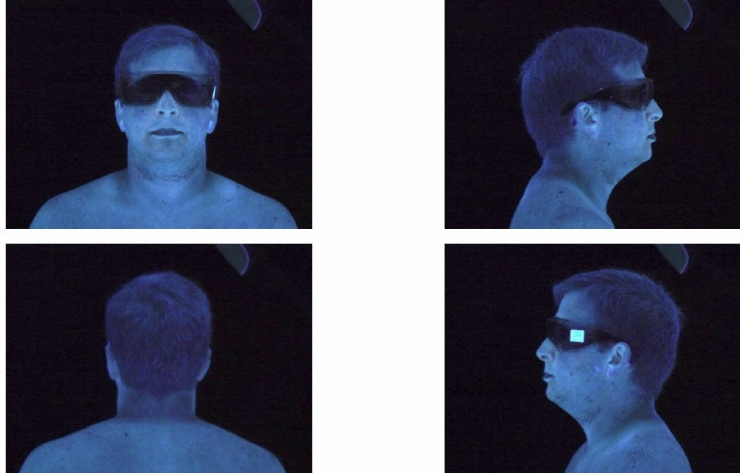
Pre-test photos. This test participant has light-colored hair on the sides of his head which appears white under UV light.

Background UV Photos Test Participant #3



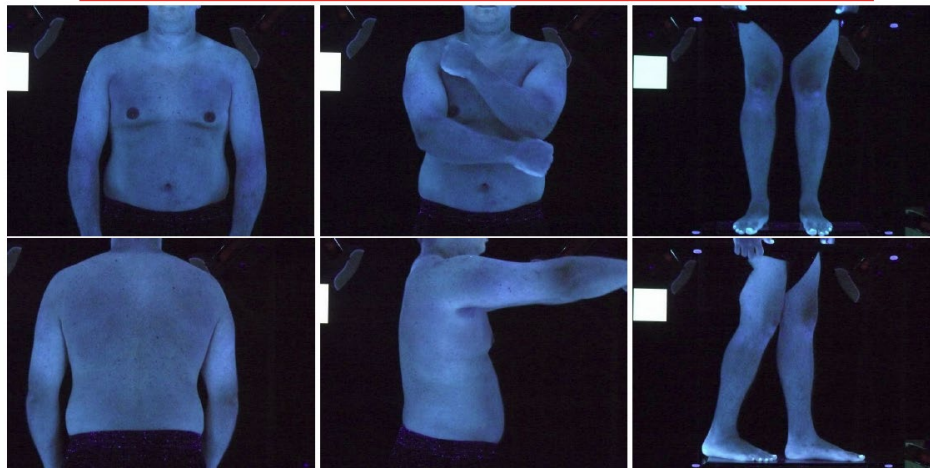
Pre-test photos. The test participant's forearms have a darker appearance than his upper arms under UV light.

Background UV Photos Test Participant #4



Pre-test photos. The back of this participant's neck has a fairly dark appearance under UV light due to the presence of a suntan.

Background UV Photos Test Participant #4



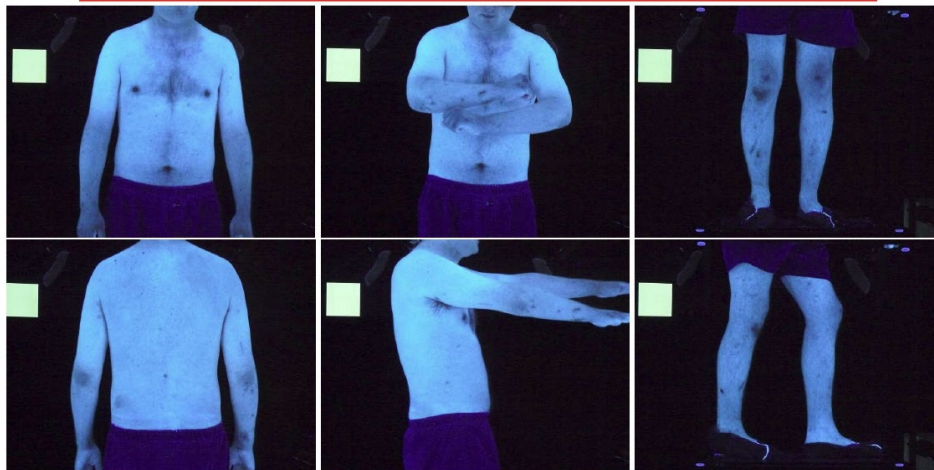
Pre-test photos. The forearms are noticeably darker in appearance than the upper arms and torso, again, due to suntan. Also, the thighs are somewhat brighter than the lower legs.

Background UV Photos Test Participant #9



Pre-test photos. This test participant has long hair which hangs farther down the back of the neck than on the other test participants. Notice the naturally bright spot on the forehead as highlighted by the red circle.

Background UV Photos Test Participant #9



Pre-test photos. With the exception of some bruises and body hair, this test participant's skin has a naturally bright and relatively uniform appearance under UV light.

Test #1812, Coverall Pre-Test Photos



For this test, the ensemble was donned without any modifications to the garment or the donning procedures.

Test #1812, Coverall UV Photos: Head and Neck



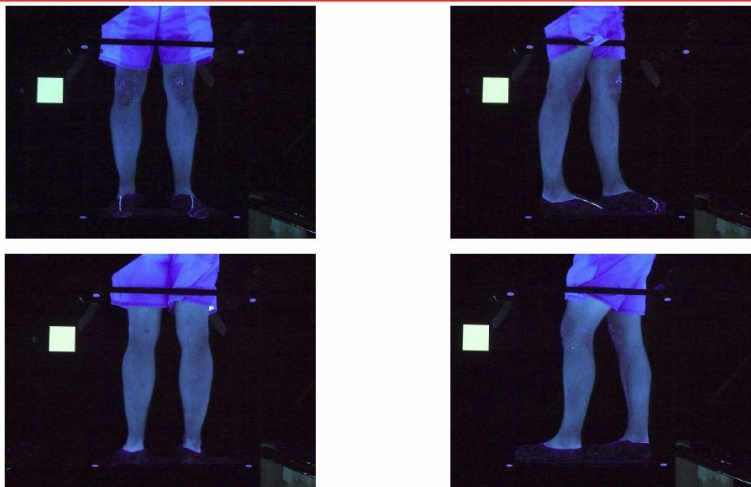
There was a distinct, bright line of deposited aerosol near the right temple, possibly indicating a localized breach of the hood-mask interface. The head and neck otherwise appeared clean.

Test #1812, Coverall UV Photos: Torso and Arms



The torso and arms appeared clean except for a light covering of lint, which appear as white specks.

Test #1812, Coverall UV Photos: Legs



The legs appeared to be relatively clean. The small, white specks of brightness near the knees were due to lint, not the fluorescent test aerosol.

Test #1813, Coverall Pre-Test Photos



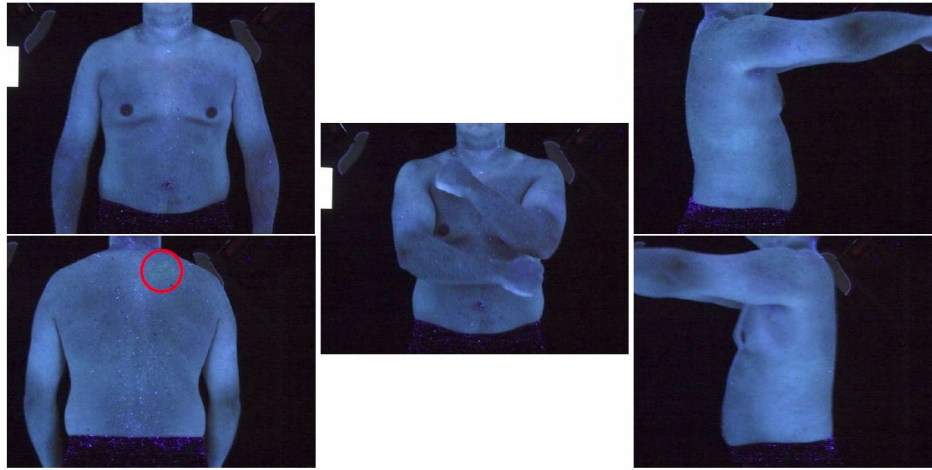
For this test, the ankles of the black inner suit were donned over the combat boots. During the test, the front neck flap closure flipped up.

Test #1813, Coverall UV Photos: Head and Neck



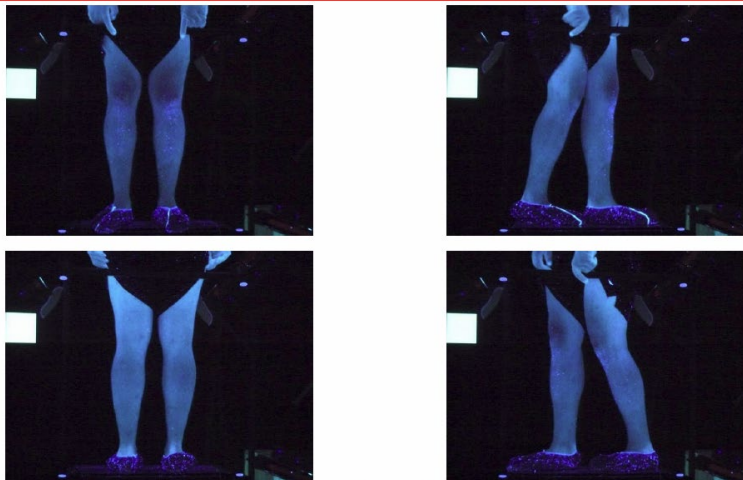
A small, yellow track mark was seen at both temples. The sides of the face and the ears had a light blue haze of deposited aerosol. The "clean" areas under the mask harness straps were clearly visible and are indicated here by the red arrows.

Test #1813, Coverall UV Photos: Torso and Arms



There was a considerable amount of lint on the arms and torso, but there wasn't much visible aerosol. The black light photographs indicate a faint patch of green on the back of the right shoulder, as highlighted by the red circle.

Test #1813, Coverall UV Photos: Legs



The legs appeared to be relatively clean. The small, white specks of brightness near the knees were due to lint, not the fluorescent test aerosol.

Test #1814, Coverall Pre-Test Photos



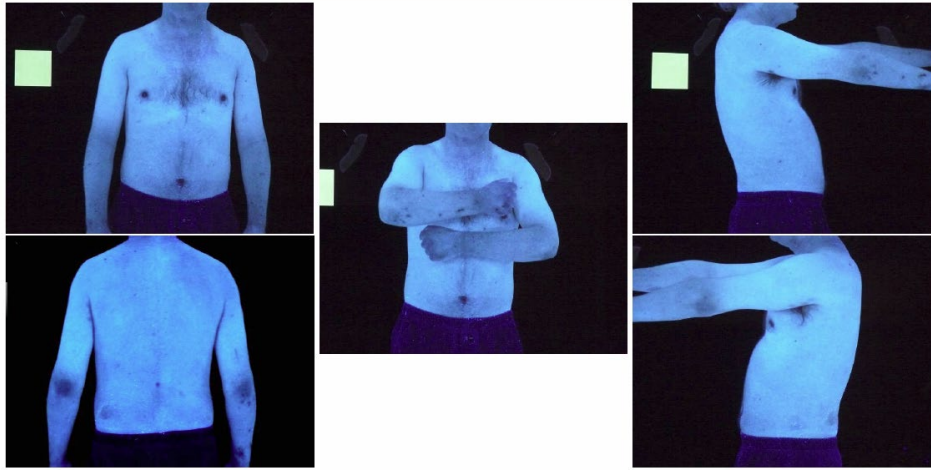
For test 1814, the ankles of the black inner garment were modified. The elastic on the right ankle was cut vertically and duct taped together to give a larger circumference. The left ankle elastic was removed completely. Both ankles were donned over the black combat boots.

Test #1814, Coverall UV Photos: Head and Neck



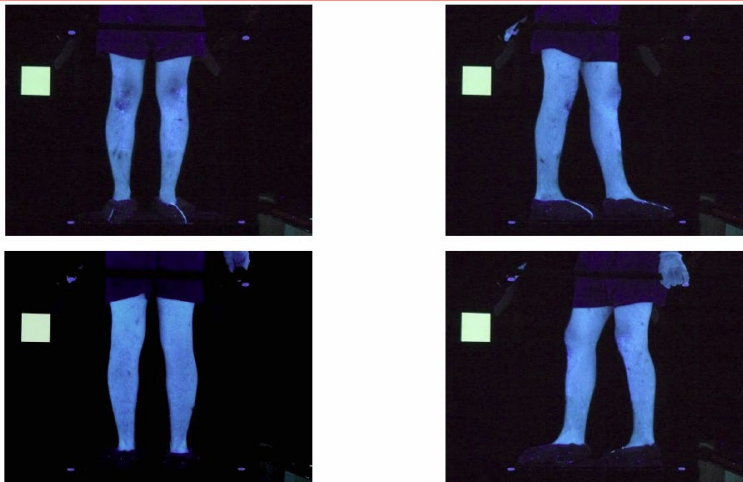
There was a light blue haze around the ears. The bright spot on the upper left forehead due to the natural fluorescence of the test participant's skin, as seen in the background photos.

Test #1814, Coverall UV Photos: Torso and Arms



The arms and torso appeared to be mostly clean. The only observed aerosol deposit was a faint blue patch between the shoulder blades.

Test #1814, Coverall UV Photos: Legs



The legs appeared to be relatively clean. The small, white specks of brightness near the knees were due to lint, not the fluorescent test aerosol.

Test #1815, Two-Piece Pre-Test Photos



The black inner garment shirt was worn tucked into the inner garment pants. During the test, the ankles of the outer garment rode up above the top loop of the GVOs.

Test #1815, Two-Piece UV Photos: Head and Neck



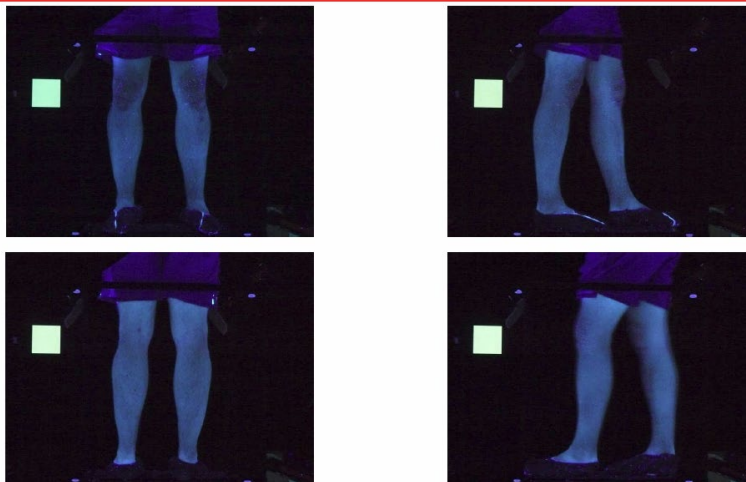
A light level of aerosol deposition was visible on the right cheek and in the hair just above the middle mask strap.

Test #1815, Two-Piece UV Photos: Torso and Arms



There was a light level of aerosol deposition on the central chest and downward along the centerline of the torso, generally in the area of the shirt zipper.

Test #1815, Two-Piece UV Photos: Legs



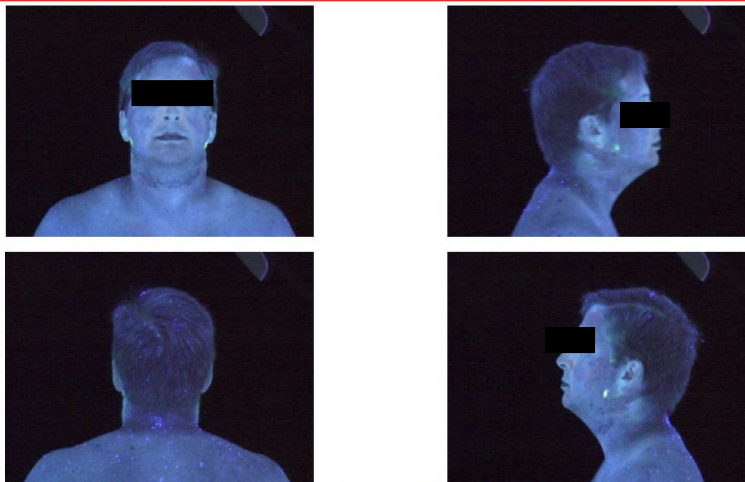
There was a very light blue haze on the shins above the top edge of the socks. This low level of aerosol deposition was almost imperceptible on the right shin.

Test #1816, Two-Piece Pre-Test Photos



The black inner shirt was donned over the black inner pants. The elastic around the ankles of the black pants was cut off, and the ankles were donned over the combat boots.

Test #1816, Two-Piece UV Photos: Head and Neck



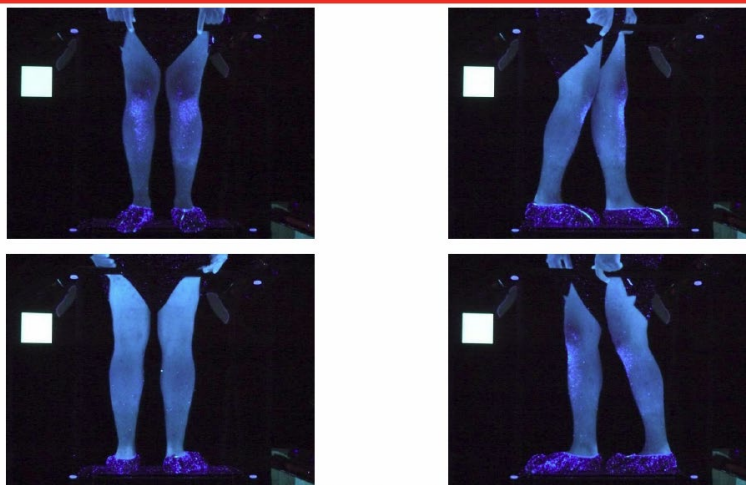
There was a blue haze on the cheeks and around the ears. Additionally, there was a small yellow hotspot on both sides of the face. The cause of the hotspots was not immediately apparent. The lower mask straps are visible below the hotspots.

Test #1816, Two-Piece UV Photos: Torso and Arms



There was a light blue haze on the central chest, indicating a low level of aerosol deposition.

Test #1816, Two-Piece UV Photos: Legs



There was a light blue haze on the left shin above the top edge of the sock. The small, white specks of brightness near the knees were due to lint, not the fluorescent test aerosol.

Test #1817, Two-Piece Pre-Test Photos



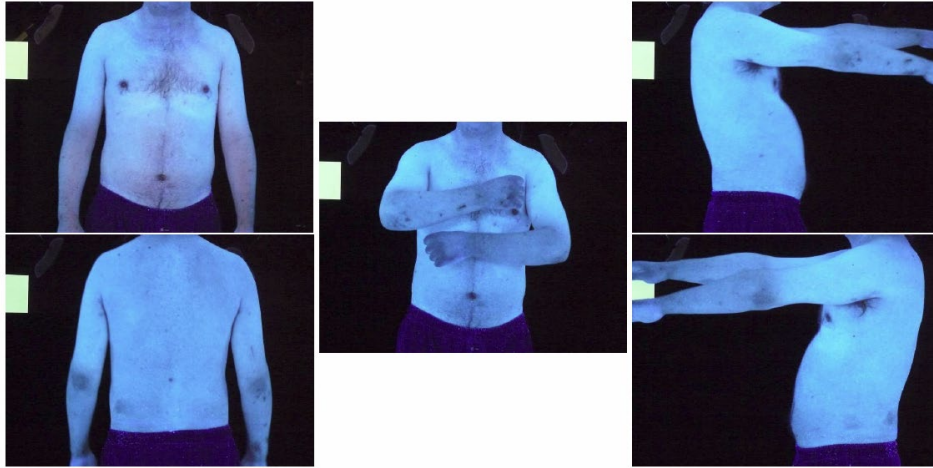
The waist closure of the outer garment was heavily duct taped to try to minimize aerosol infiltration at that interface. As in test 1816, the black inner shirt was donned over the black inner pants. The elastic around the ankles of the black pants was cut off, and the ankles were donned over the combat boots.

Test #1817, Two-Piece UV Photos: Head and Neck



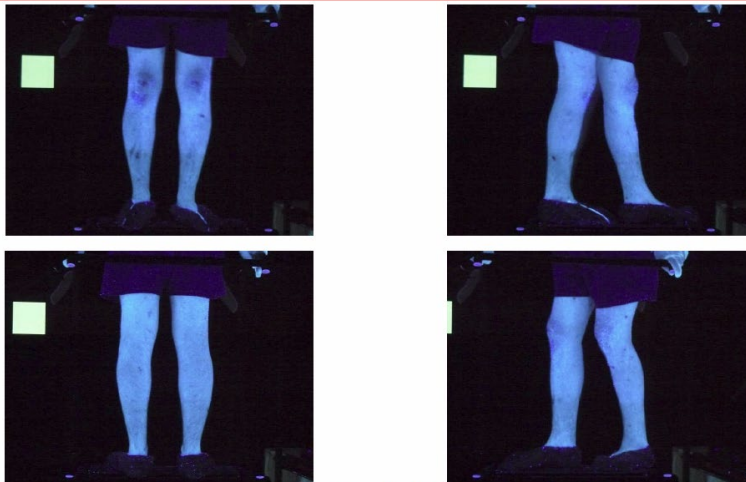
Light to moderate levels of aerosol deposition were visible on the cheeks and under the chin, including a line of moderate deposition on the left cheek.

Test #1817, Two-Piece UV Photos: Torso and Arms



The torso and arms appeared relatively clean.

Test #1817, Two-Piece UV Photos: Legs



A light blue haze was visible on the lower legs, indicating a low level of aerosol deposition.

Summary / Observations

- The Coverall ensemble:
 - Test results indicated little or no aerosol deposition on the arms, legs, or torso.
 - There appeared to be a small patch of light aerosol deposition near the shoulder blades for tests 1813 and 1814.
 - All three tests of this configuration exhibited aerosol deposition on the sides of the face and/or hair, probably as a result of infiltration through the mask/hood interface.
 - Modifications made to the ankles of the inner garment did not have a noticeable effect on the results.
- The Two-Piece ensemble:
 - This ensemble allowed somewhat more aerosol deposition on the body than the Coverall ensemble, though deposition levels were still relatively low.
 - For tests 1815 and 1816, there was light deposition on the central chest and downward along the centerline of the torso. For test 1817, in which the waist closure was sealed with duct tape, little or no deposition was observed in this area.
 - All three tests of this configuration exhibited light to moderate levels of aerosol deposition on the sides of the face and/or hair, probably as a result of infiltration through the mask/hood interface.
 - Modifications made to the ankles of the inner garment did not have a noticeable effect on the results.

Donning Procedures: Coverall (abbreviated)

1. Don the briefs, PT shorts, and socks.
2. Don the black inner layer coverall and zip up the front.
3. Don the outer layer coverall up to the waist.
4. Put on and lace the combat boots.
 - The position of the inner layer ankle relative to the combat boot varied by test.
5. Don GVO and secure the hook closures.
6. Position outer layer garment legs over the GVO and secure the hook and loop closures.
7. Don the rest of the coverall over the shoulders and position the inner strap around the waist.
8. Earplugs.
9. Don short cotton glove liners and butyl rubber gloves, positioning the rubber gloves between the inner and outer garments. Secure the hook and loop wrist closures.
10. Don the JSGPM mask and secure the harness straps.
11. Position the black inner layer balaclava over the head and shoulders, and tuck it into the outer layer coverall.
12. Position the hood over the head and secure all closures.

Donning Procedures: Two-Piece (abbreviated)

1. Don the briefs, PT shorts, and socks.
2. Don the black inner layer pants.
3. Don the black inner layer shirt and zip up the front.
 - The overlapping of the inner shirt and pants varied by test.
4. Don the outer layer pants.
5. Put on and lace the combat boots.
 - The position of the inner layer ankle relative to the combat boot varied by test.
6. Don GVO and secure the hook closures.
7. Position outer layer pants legs over the GVO and secure hook and loop closures.
8. Don the outer layer coat, secure the circumferential zipper, and secure the vertical zipper up to mid-chest.
9. Earplugs.
10. Don short cotton glove liners and butyl rubber gloves, positioning the rubber gloves between the inner and outer garments. Secure the hook and loop wrist closures.
11. Don the JSGPM mask and secure the harness straps.
12. Position the black inner layer balaclava over the head and shoulders, and tuck it into the outer layer coat.
13. Position the hood over the head and secure all closures.

Doffing Procedures: Coverall (abbreviated)

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. Unhook the loops securing the GVOs.
5. Starting with the right, the test subject steps out of the GVOs.
6. De-lace the combat boots.
7. Open hook and loop closures at the neck, and unhook the filter retention straps.
8. Open the hook and loop closures along the torso and arm zippers.
9. Unzip the arm and torso zippers, and fold down the flap.
10. Open the elastic waist belt.
11. With an outward roll, remove the hood over the head.
12. Pull the coverall off the shoulders and arms and down to the ankles.
13. Starting with the right, the test subject steps out of the coverall and combat boots.
14. Starting from the back, lift the balaclava over head to expose the edge of the mask.
15. Loosen the lower mask straps, and remove the mask over the head.
16. Remove the butyl gloves and cotton liners, and re-glove with disposable gloves.
17. Unzip the black inner layer coverall completely.
18. Pull the coverall off the shoulders and arms and down to the ankles.
19. Starting with the right, the test subject steps out of the coverall.

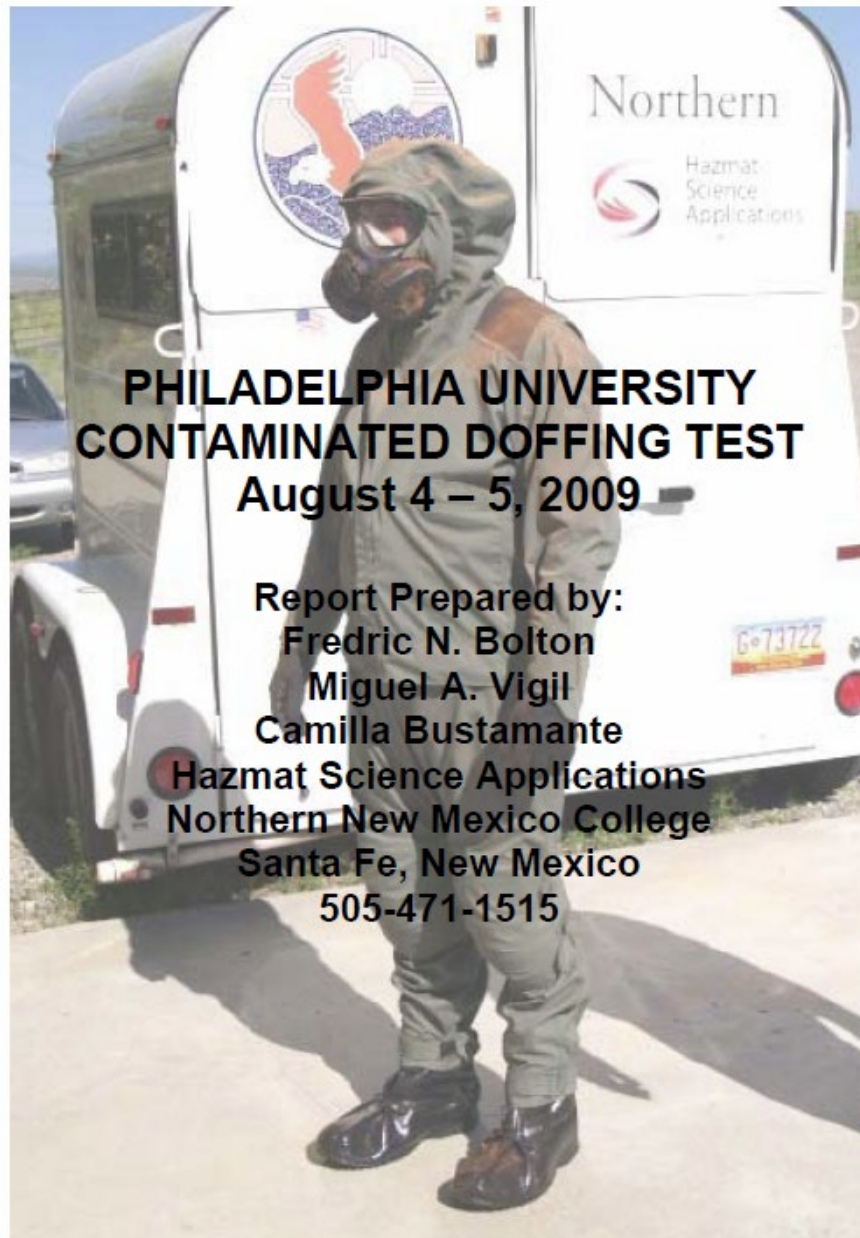
Doffing Procedures: Two-Piece (abbreviated)

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. Unhook the loops securing the GVOs.
5. Starting with the right, the test subject steps out of the GVOs.
6. De-lace the combat boots.
7. Open hook and loop closures at the neck, and unhook the filter retention straps.
8. Decon along the coat zipper flap.
9. Unzip the coat zipper completely.
10. With an outward roll, remove the hood over the head.
11. Doff the coat and trousers in one motion by pulling the coat off the shoulders and arms and down to the ankles.
12. Starting with the right, the test subject steps out of the trousers and combat boots.
13. Starting from the back, lift the balaclava over head to expose the edge of the mask.
14. Loosen the lower mask straps, and remove the mask over the head.
15. Remove the butyl gloves and cotton liners, and re-glove with disposable gloves.
16. Unzip the black inner layer shirt completely.
17. Pull the shirt off the shoulders and arms.
18. Pull the inner layer pants down to the ankles.
19. Starting with the right, the test subject steps out of the pants.

Appendix E

Philadelphia University Contaminated Doffing Test—August 4–5, 2009

(Reprint of original)



CONTAMINATED DOFFING EVALUATION FINAL REPORT: PHILADELPHIA UNIVERSITY PROTOTYPE GARMENTS

August 4 – 5, 2009

EXECUTIVE SUMMARY

Hazmat Science Applications (HSA), a division of Northern New Mexico College, performed Contaminated Doffing Evaluation of two PhilaU protective ensemble prototypes during the period August 4-5, 2009. The evaluation was performed at the HSA facility in Santa Fe, New Mexico; members of the New Mexico National Guard 64th WMD-CST served as the testing participants by providing both individuals to wear the tested ensembles as well as to perform the decontamination and doffing actions contained in the PhilaU-provided testing scripts. A full testing day was devoted to each of the two garments; the working schedule allowed sufficient time for familiarization of the CST members with ensemble construction details for doffing purposes. Each ensemble was subjected to three (3) contaminated doffing tests following garment familiarization review. Decontamination and doffing used a PhilaU-provided script and incorporated wet methods and state-of-the-art practices appropriate to the level of training for the 64th WMD-CST.

The results of these tests led HSA staff to conclude that the two prototype protective ensembles are capable of being doffed while minimizing the amount of contaminant transferred to unprotected skin and/or duty uniform beneath the protective ensemble barrier.

The PhilaU CDE report includes: 1) digital images relevant to the protective ensemble configuration; 2) digital images of the HSA test garments used for evaluation purposes; and 3) scanned images of the PhilaU CDE data sheets. Video records may be made available upon request.

CONTAMINATED DOFFING EVALUATION FINAL REPORT: PHILADELPHIA UNIVERSITY PROTOTYPE GARMENTS

August 4 – 5, 2009

INTRODUCTION

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

The purpose of CDE testing 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, a division of Northern New Mexico College.

TEST METHODOLOGY

Evaluation Methodology

The HSA evaluation methodology seeks to 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 from 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 CDE testing was performed during the period August 4-5, 2009.

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; documentation of this review was provided to the study sponsor prior to the start of testing.

CONTAMINATED DOFFING EVALUATION FINAL REPORT: PHILADELPHIA UNIVERSITY PROTOTYPE GARMENTS

August 4 – 5, 2009

Test Protocol

The HSA test protocol is summarized below:

1. The HSA co-Principal Investigator completed the Informed Consent process with ACCA participants.
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 (jacket, pants, boots, overboots, respirator, and gloves).
5. Digital images were collected of the dressed participant.
6. The participant was placed in an enclosure and the simulant material was applied to the protective ensemble as described in the HSA testing protocol.
7. The participant was escorted to the HSA processing line.
8. Decontamination processing was completed.
9. The participant and test garment were inspected and evaluated. Data records were collected and photographs taken of the evaluated undergarment.

Digital Photography and Video Recordings

A combination of still and moving images was collected, including:

1. Pre-test images of the participant to document the protective ensemble configuration.
2. Post-test images of the test undergarments as marked under black light illumination.
3. Video recordings of decontamination processing line activities.
4. Still images of decontamination processing line activities.

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. Images 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 simulant mixture. The color change associated with the water-soluble component makes it possible for certain conclusions to be drawn about the nature of residual contamination on the

CONTAMINATED DOFFING EVALUATION FINAL REPORT: PHILADELPHIA UNIVERSITY PROTOTYPE GARMENTS

August 4 – 5, 2009

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.

Discussion

Over the course of the two testing days, the total processing time (beginning with introduction into the doffing chamber and ending with removal of the JSGPM respirator) was reduced from approximately 37 minutes to about 22 minutes. The reduction in processing times reflects a combination of the proficiency of the 64th WMD-CST members (who are well-trained and familiar with the testing techniques employed by HSA) and an expressed desire on the part of the subjects to more accurately replicate "combat speed" during contaminated doffing.

In general terms, both prototype garments provided substantial reduction in the amount of simulant reaching unprotected skin or duty uniform:

1. One of the six test undergarments was judged to be "clean," i.e., free of any blacklight-visible evidence of simulant cross-contamination.
2. Hazing was *rarely* noted on any of the test undergarments.
3. Faint hazing was noted on the lower left abdomen during two of the "day two" undergarments, which was attributed to a last-minute garment modification.
4. Several tests noted some ingress of dry simulant along the edges of the jacket/mask interface with only very faint appearance on skin (temples near the upper front pinna) beneath the hood.
5. CST members suggested that "combat speeds" could be reached with similar results, but time was not available for the purpose of training.

CONCLUSIONS

1. Both prototype ensembles are capable of being effectively doffed while minimizing the amount of contaminant transferred from external surfaces to unprotected surfaces within the protective ensemble barrier.
2. From the perspective of processing times, the garments appear to be clearly capable of being doffed at "combat speeds" while retaining the ability to maintain continuity of protection.
3. The tests suggest that multiple layers (e.g., having a separate carbon suit as opposed to charcoal impregnation of suit components) may provide some benefit to maintaining cleanliness through the completion of the decontamination and doffing processes.
4. The ensemble interface between the jacket hood and JSGPM face-piece was found to vary *slightly* in its ability to effectively exclude contaminant ingress. The performance variation is attributed to design differences, i.e., a single-piece reinforcing structure within the hood front as opposed to a two-piece structure. No evidence of contamination ingress was found in the first case. Improvements are likely through a combination of design changes, doffing procedures, and field dress-out actions.

**CONTAMINATED DOFFING EVALUATION FINAL REPORT:
PHILADELPHIA UNIVERSITY PROTOTYPE GARMENTS**

August 4 – 5, 2009

SUGGESTIONS / RECOMMENDATIONS

None

ATTACHMENTS

1. Test Garment Data Sheets
2. Pre-Dust Images
3. Post-Doffing Images

OTHER DELIVERABLES

Digital images (to be provided as separate deliverable in CD or DVD form)

ATTACHMENT 1

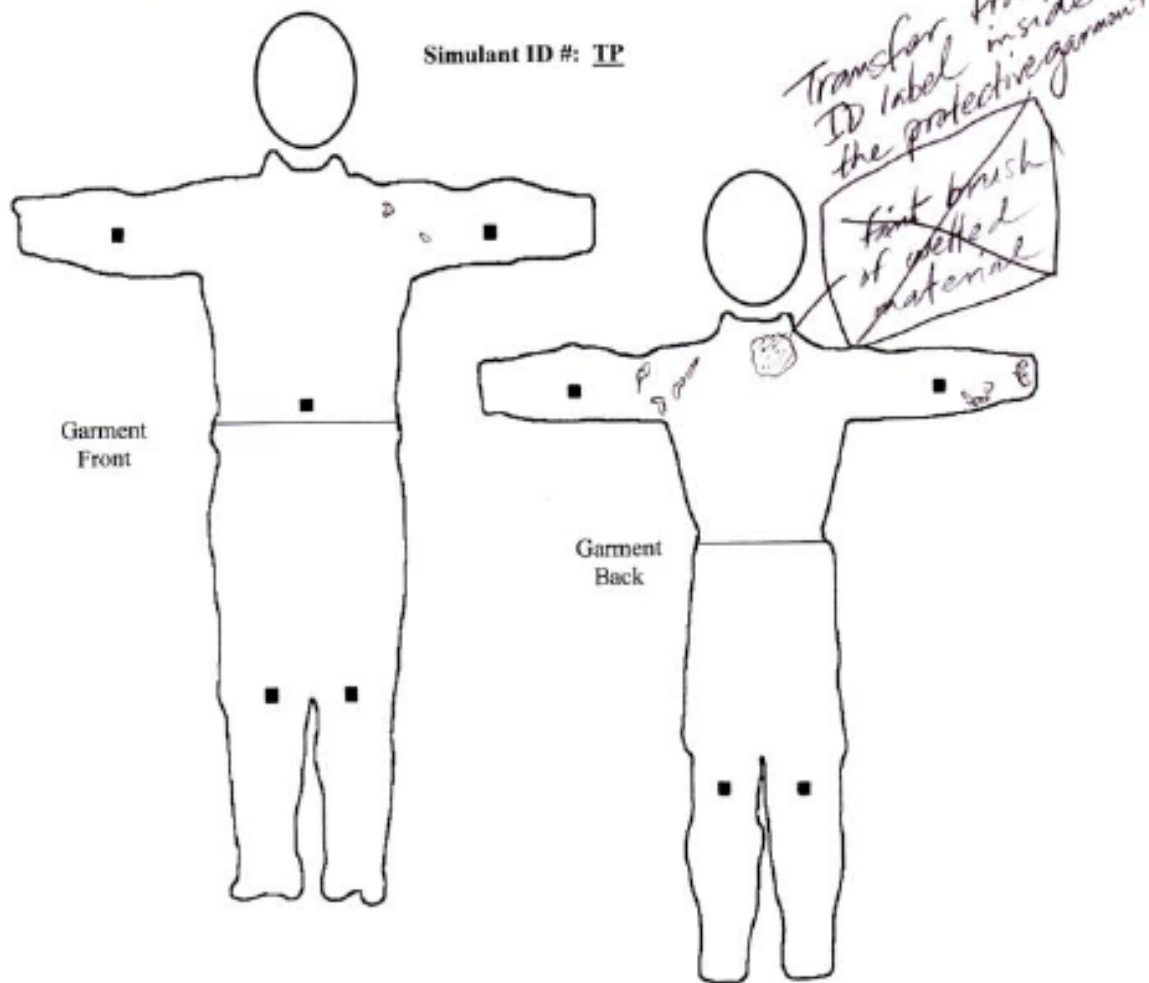
PhilaU Raw Data Sheets



Hazmat
Science
Applications

Department/Agency: PhilaU LEHP Date: 04 Aug 09 Run # 1

DeconPro® POST-TEST SIMULANT LOCATION MAP



Mark relative size and location of residual contaminants. Add other comments as needed:

Head, neck, & face — clear. In general, the
garment is free of "visible" (i.e., UV) haze, and
the small areas noted above appear to be a result
of incidental contact with wetted materials i.e., decon soln.

Checklist actions completed by (initials): JLB Date: 04 Aug 09

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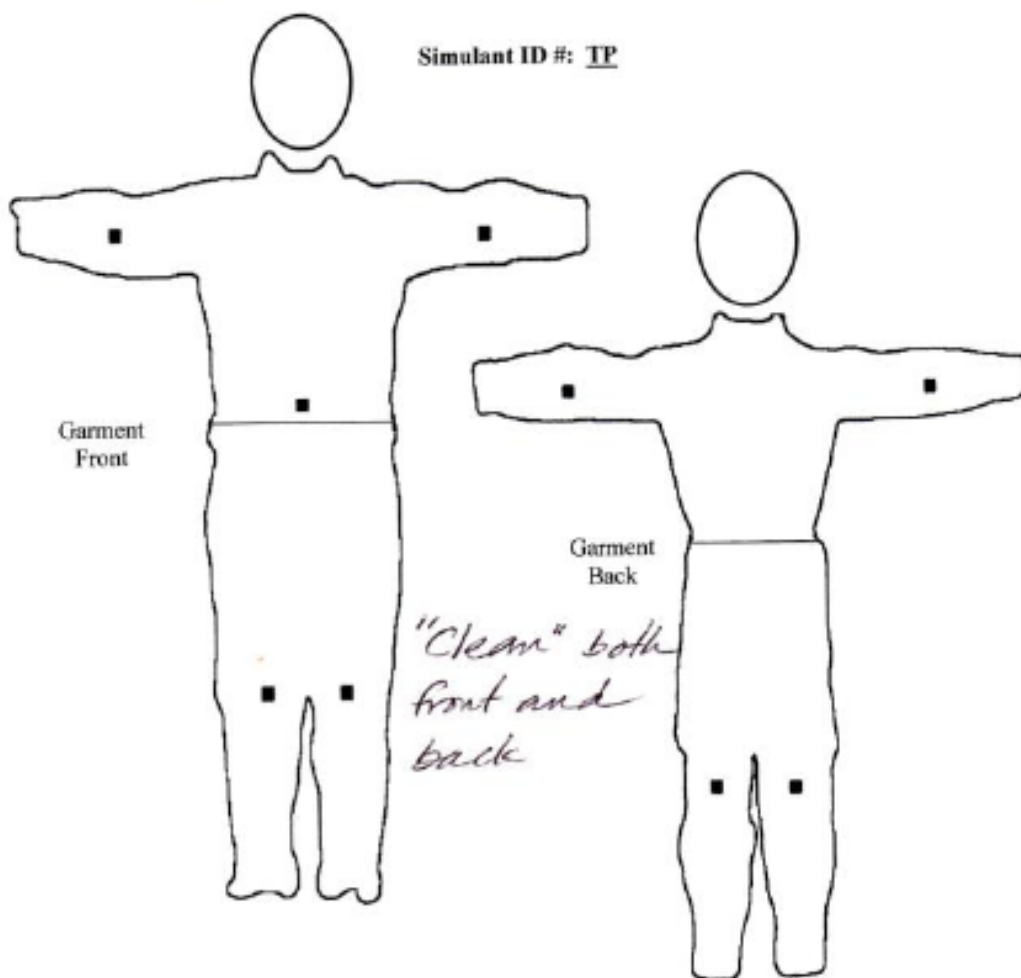


Hazmat
Science
Applications

Department/Agency: PhilaU LEHP

Date: 04 Aug 09 Run # 2

DeconPro® POST-TEST SIMULANT LOCATION MAP



Mark relative size and location of residual contaminants. Add other comments as needed:

Head, neck, & face - clean. The test undergarment appears to be free of any clear evidence of simulant transfer from protective ensemble exterior surfaces.

Checklist actions completed by (initials): SNB

Date: 04 Aug 09

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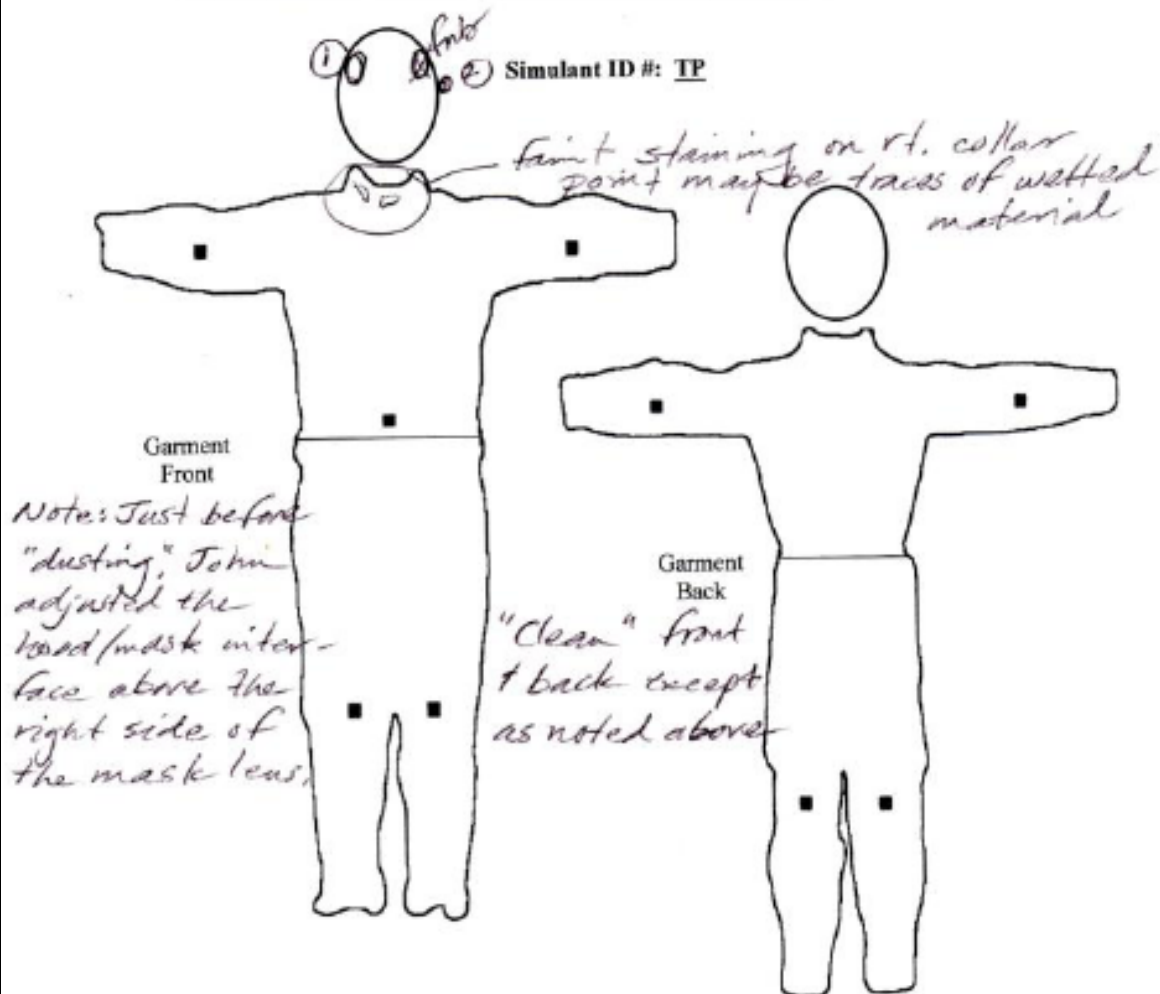


Hazmat
Science
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Department/Agency: PhilaU LEHP

Date: 04 Aug 09 Run # 3

DeconPro® POST-TEST SIMULANT LOCATION MAP



Mark relative size and location of residual contaminants. Add other comments as needed:

Head, neck & face — evidence of contamination transfer above & forward of rt. temple ① and top of left outer ear; none noted on face @ mouth & nose. Test garment was "clean" except as noted above.

Checklist actions completed by (initials): TLB

Date: 04 Aug 09

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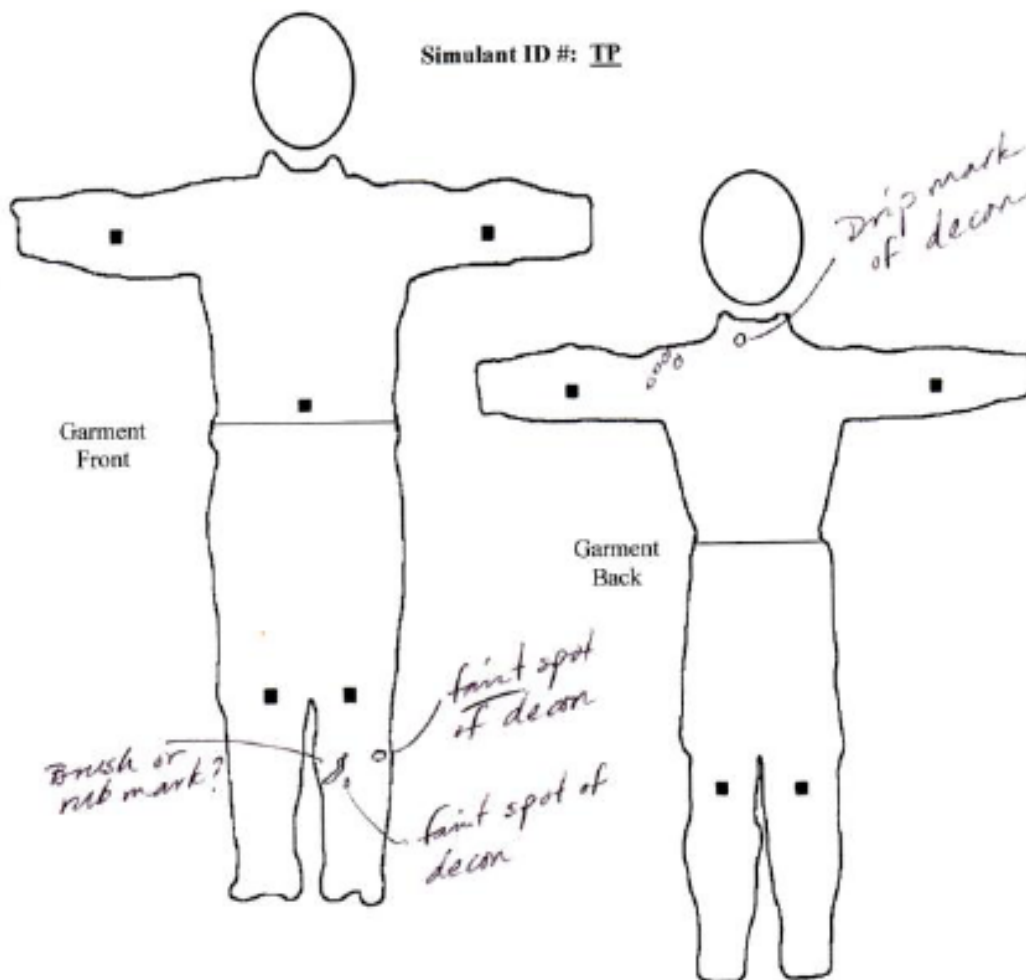
Department/Agency: PhilaU LEHP

Date: 05 Aug 09

Run # 1

DeconPro® POST-TEST SIMULANT LOCATION MAP

Simulant ID #: TP



Mark relative size and location of residual contaminants. Add other comments as needed:

Garment was clean except as noted

Checklist actions completed by (initials): [Signature]

Date: 8/5/09

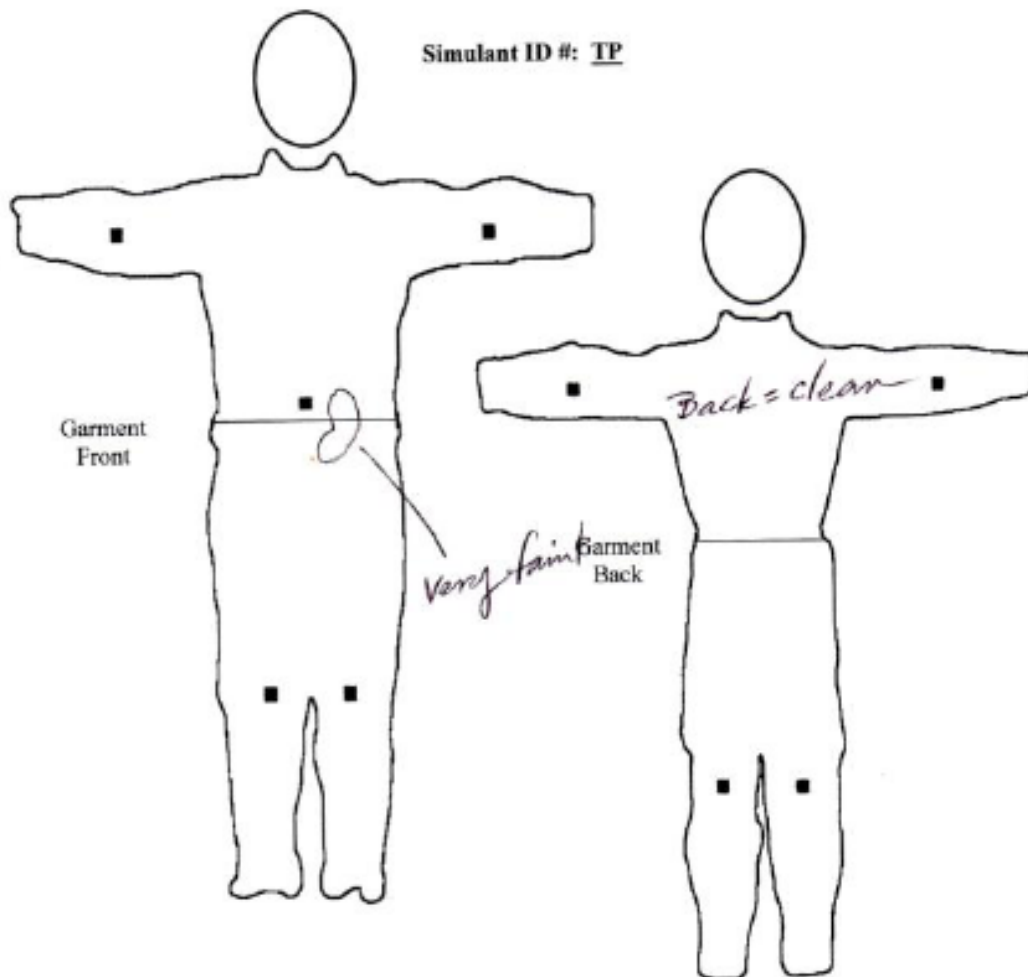
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Hazmat
Science
Applications

Department/Agency: PhilaU LEHP Date: 05 Aug 09 Run # 2

DeconPro® POST-TEST SIMULANT LOCATION MAP



Mark relative size and location of residual contaminants. Add other comments as needed:

Very faint hazing on left front abdomen to
left of navel.

Checklist actions completed by (initials):

Lat

Date:

8/5/09

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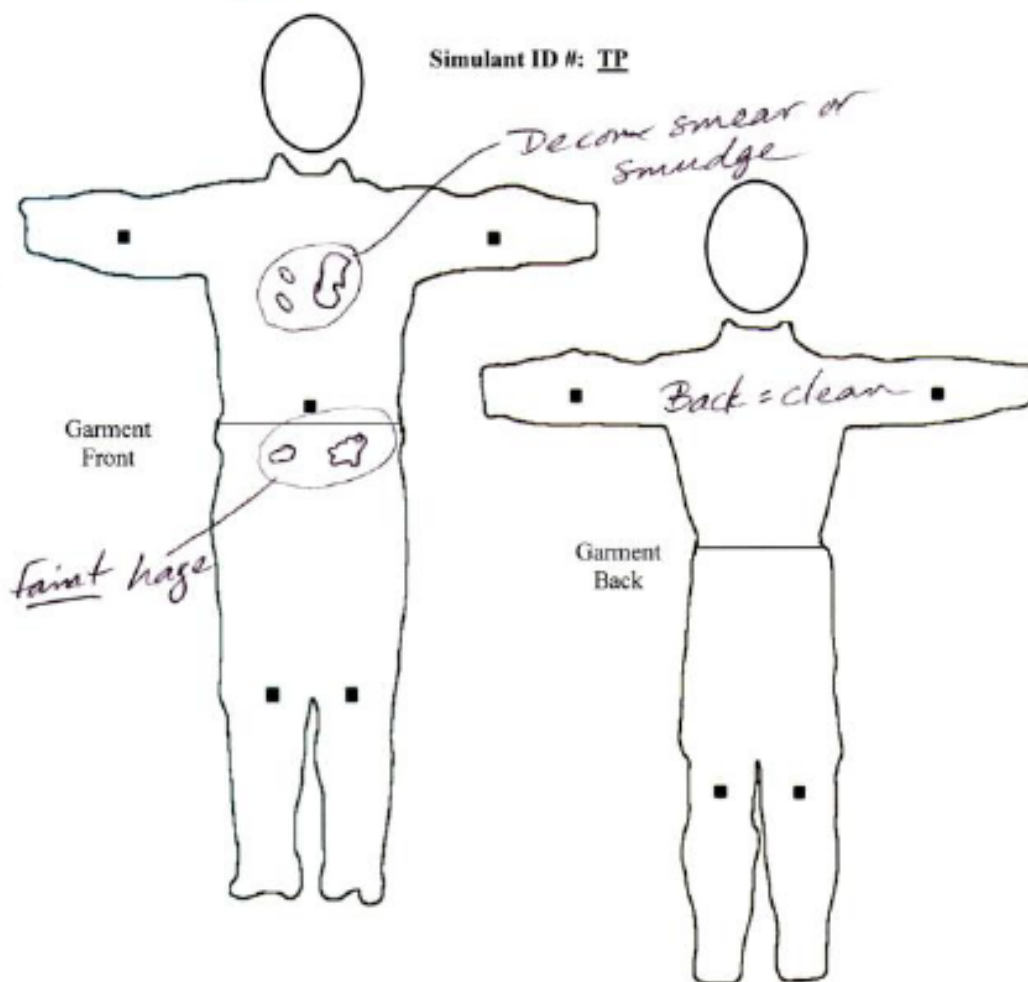


Hazmat
Science
Applications

Department/Agency: PhilaU LEHP

Date: 05 Aug 09 Run # 3

DeconPro® POST-TEST SIMULANT LOCATION MAP



Mark relative size and location of residual contaminants. Add other comments as needed:

All patterns noted were extremely faint.

Checklist actions completed by (initials):

LB

Date:

8/5/09

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ATTACHMENT 2

PhilaU Pre-Dust Images

The following images document the protective ensemble in its donned configuration just prior to applying the simulant used for contaminated doffing test and evaluation.

PhilaU Pre-Dust Images

08/04/09 Run #1







PhilaU Pre-Dust Images

080409 Run #2







PhilaU Pre-Dust Images

080409 Run #3







PhilaU Pre-Dust Images

080509 Run #1







PhilaU Pre-Dust Images

080509 Run #2







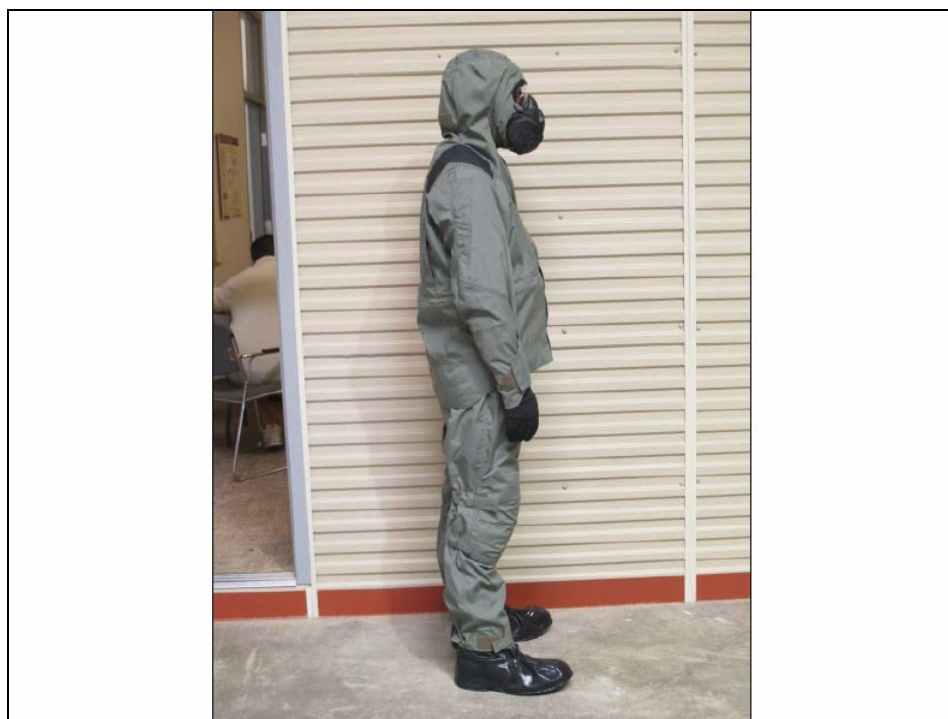


PhilaU Pre-Dust Images

080509 Run #3







ATTACHMENT 3

PhilaU Post-Doffing Images

The following images document the test undergarment condition following inspection under ultraviolet light. Discernible patterns of residual contamination simulant were marked with an indelible pen so that photographs could be taken under white light conditions.

PhilaU Post-Doffing Images

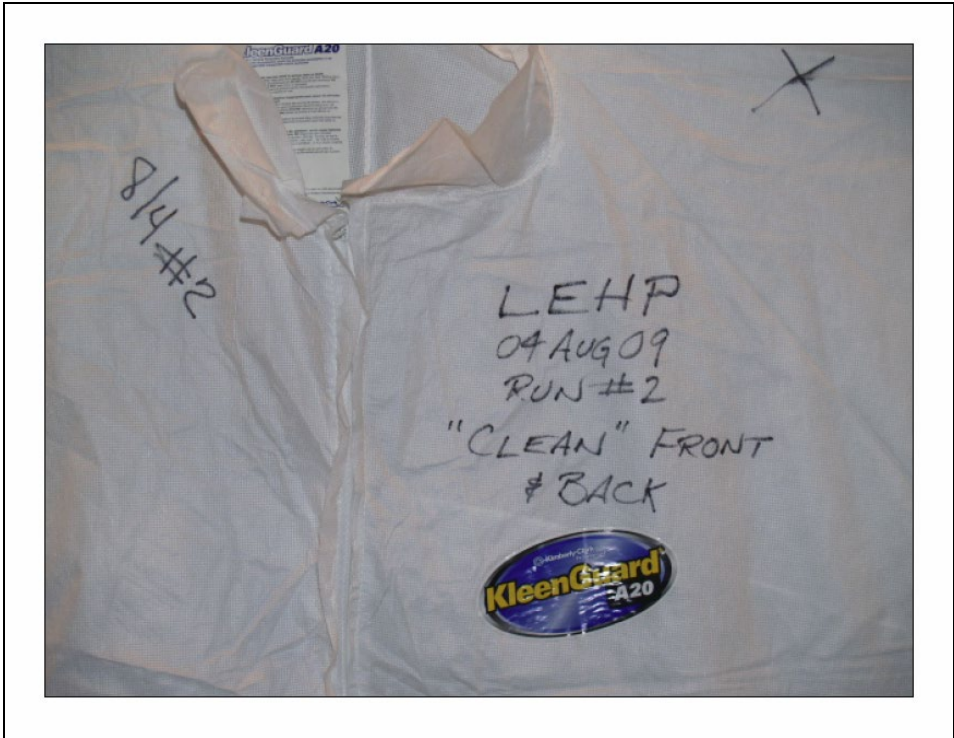
August 4, 2009

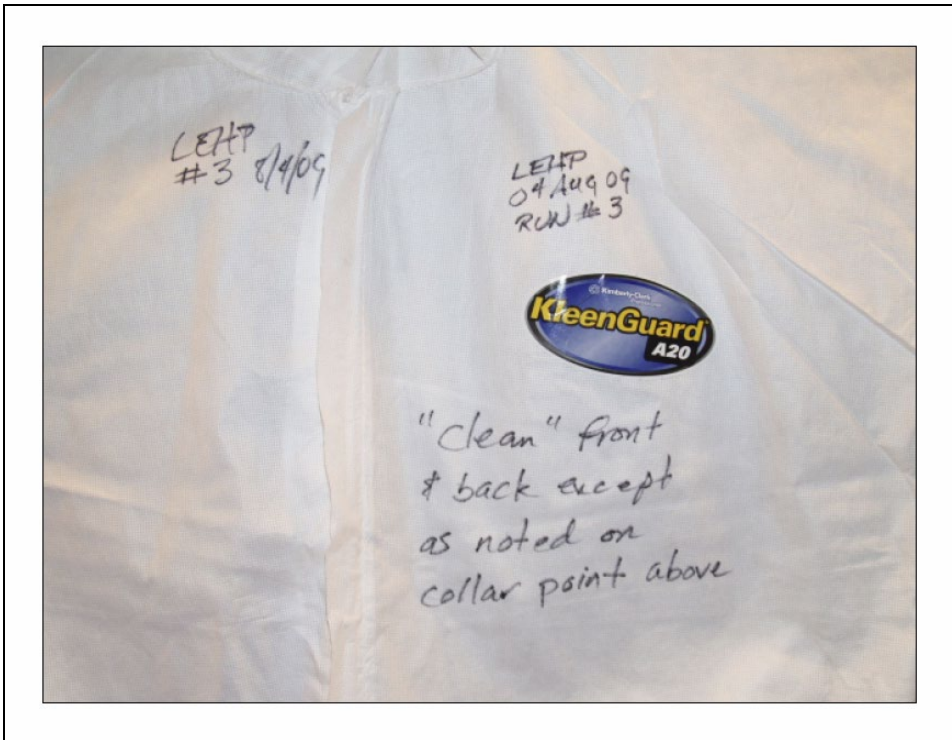


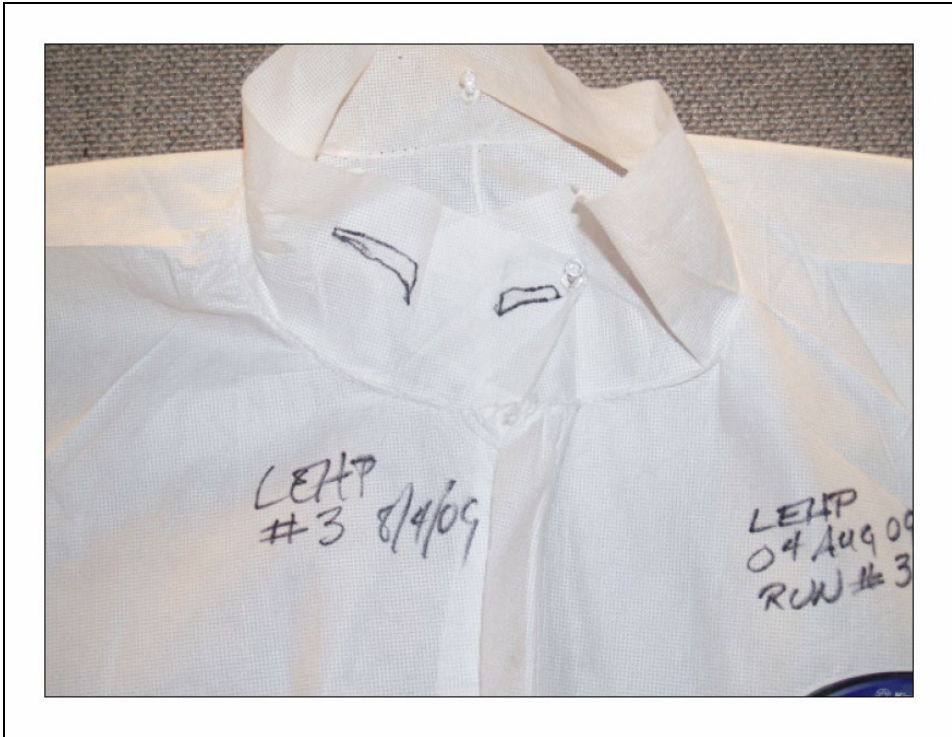








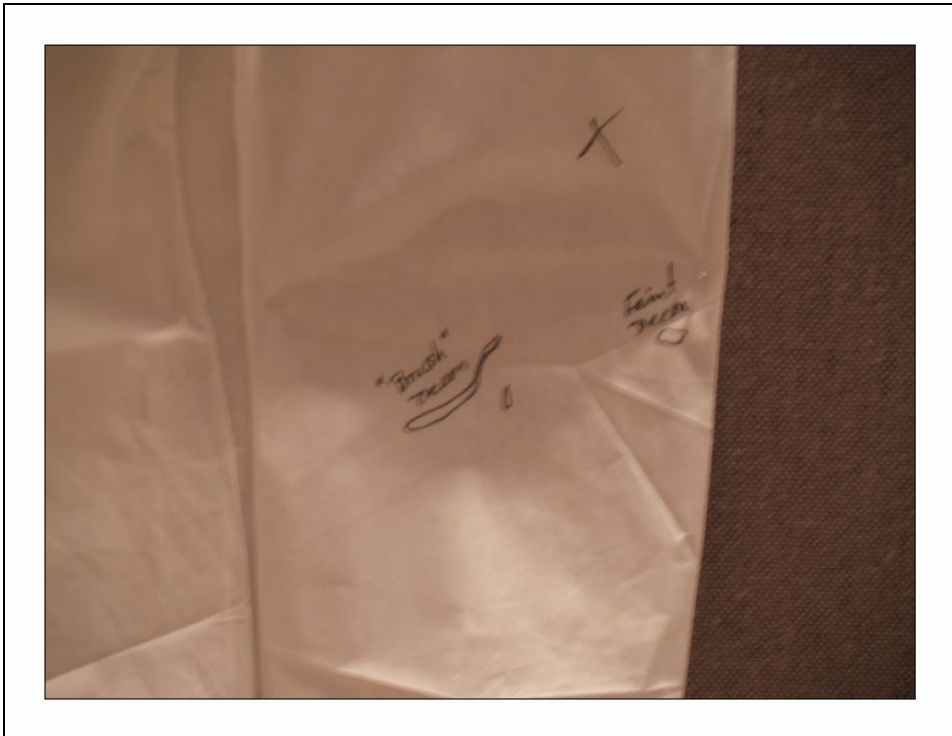




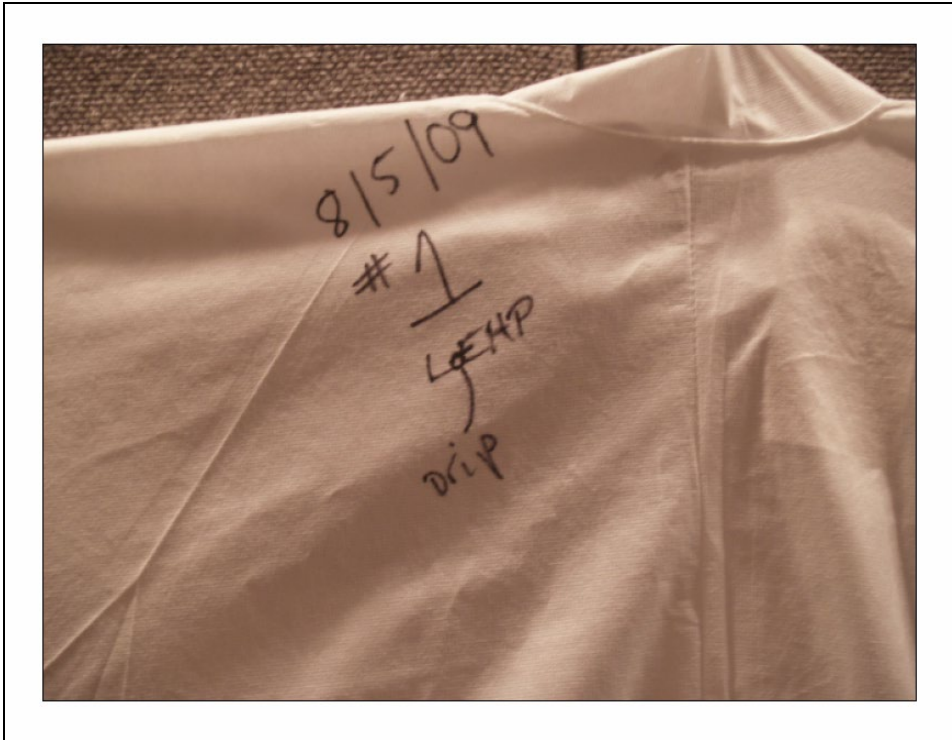
PhilaU Post-Doffing Images

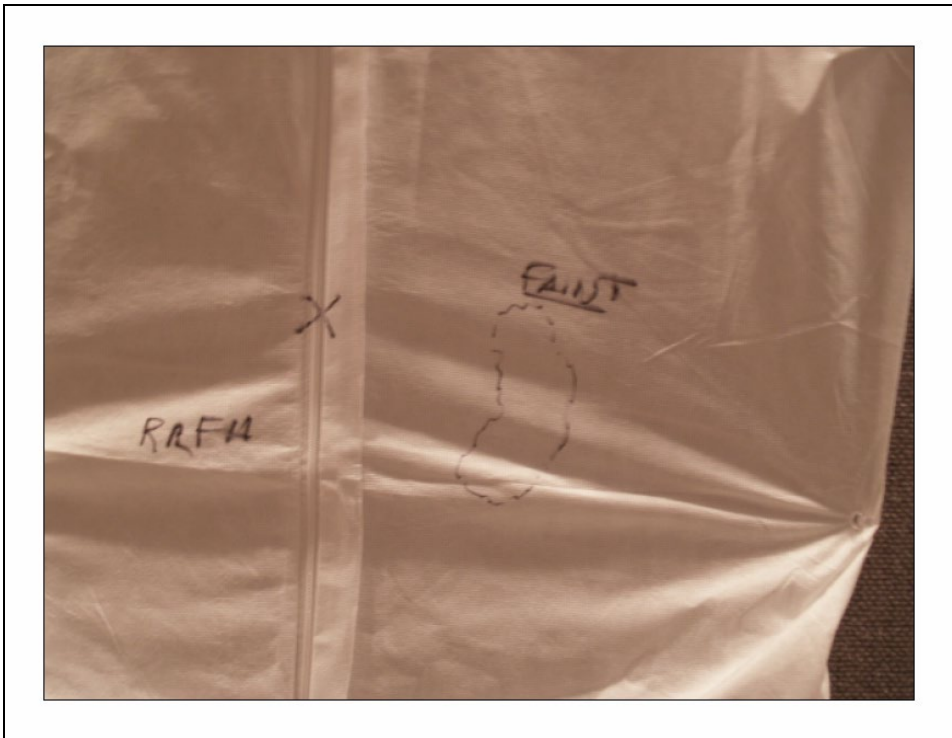
August 5, 2009



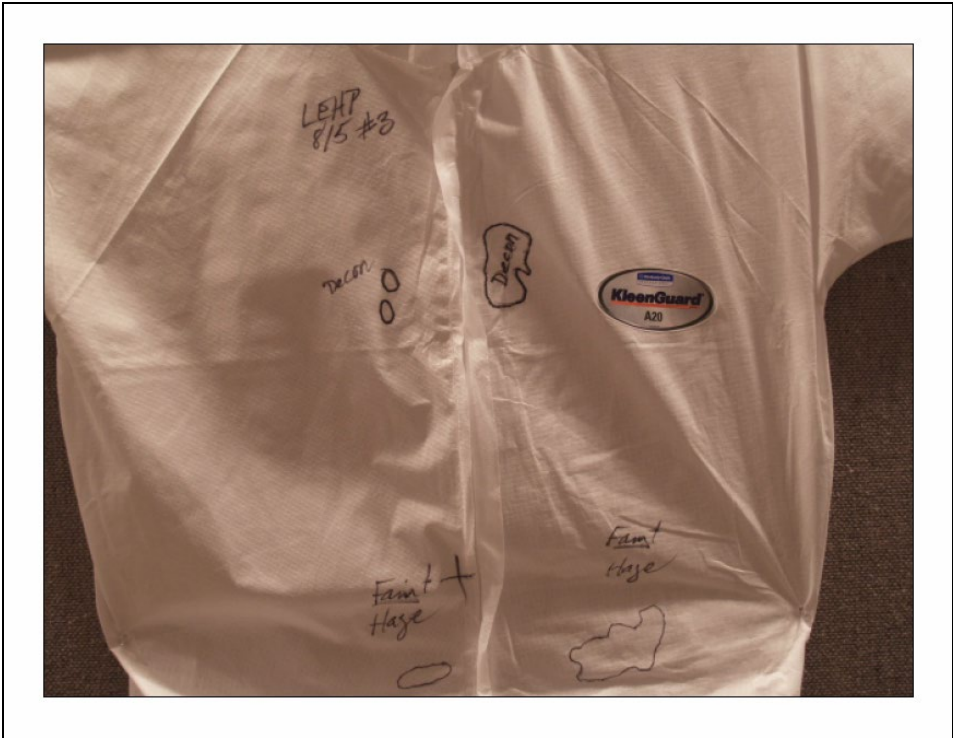
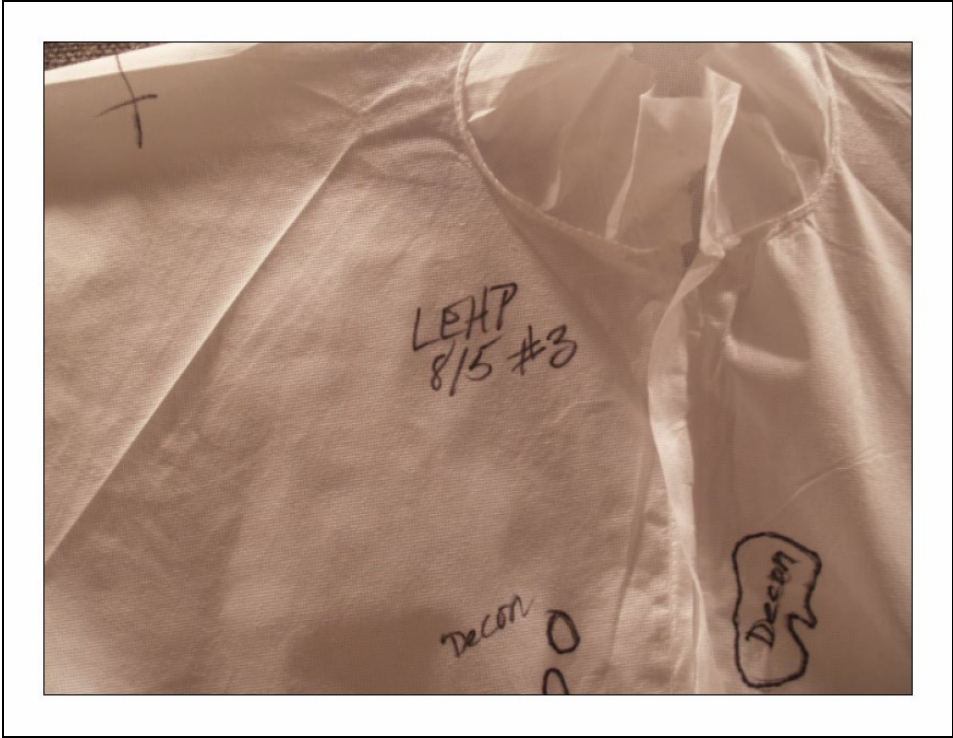


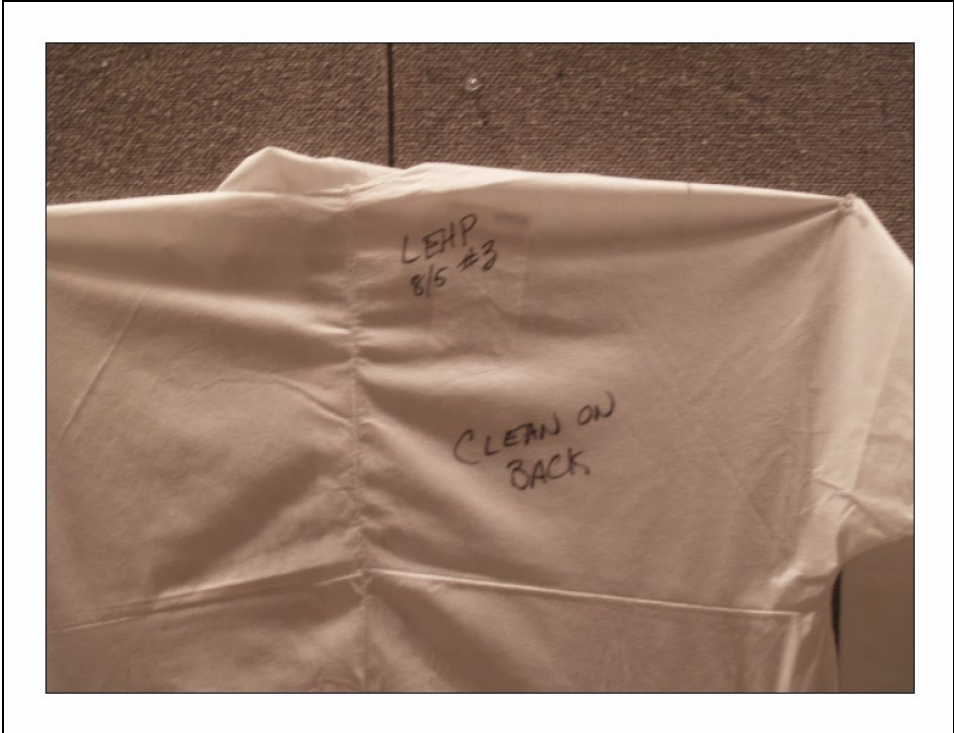












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Appendix F

Philadelphia University LEHP Contaminated Doffing Testing Notes—August 4–5, 2009
(Reprint of original)

PHILADELPHIA UNIVERSITY - LEHP CONTAMINATED DOFFING

Testing Notes
AUGUST 4-5, 2009

Attendees:

LEHP: K. Hultzapfel, J. Venafro
Hazmat Team: Fred Bolton, Miguel Vigil

Test participants (TPs):

- TP-#1
 - TP approved for testing based on availability: Weight: 155 lbs. Height: 68 inches.
 - Subject measurements:

Body Location	Measurement
Neck	15 1/2
Chest	37
High point to waist	22
Waist band	32 1/2
Waist - natural	32 1/2
Hip	39 1/2
Center back- Sleeve Length	33 1/2
Raglan Sleeve Length	27 1/2
Cross Shoulder	19
Back Length	20
Inseam	30
Outseam	38

- TP-#2
 - TP approved for testing based on availability: Weight: 155 lbs. Height: 71 inches.
 - Subject measurements:

Body Location	Measurement
Neck	15
Chest	36 1/2
High point to waist	23
Waist band	33 1/2
Waist - natural	31
Hip	36
Center back-Sleeve Length	34 1/2
Raglan Sleeve Length	30 1/2
Cross Shoulder	20 1/2
Back Length	23 1/2
Inseam	33 1/2
Outseam	41

**PHILADELPHIA UNIVERSITY - LEHP
CONTAMINATED DOFFING**

**Testing Notes
AUGUST 4-5, 2009**

- TP-#3
 - TP approved for testing based on availability. Weight: 175 lbs. Height: 71 inches
 - Subject measurements:

Body Location	Measurement
Neck	16
Chest	39 1/2
High point to waist	23
Waist band	34
Waist - natural	33 1/2
Hip	40
Center back	35
Sleeve Length	
Raglan Sleeve Length	31
Cross Shoulder	20 1/2
Back Length	21 1/2
Inseam	32 1/2
Outseam	41

- TP-#4
 - TP approved for testing based on availability. Weight: 195 lbs. Height 72 inches
 - Subject measurements:

Body Location	Measurement
Neck	15
Chest	40
High point to waist	25
Waist band	37
Waist - natural	36
Hip	42 1/2
Center back	33
Sleeve Length	
Raglan Sleeve Length	30
Cross Shoulder	21
Back Length	23 1/2
Inseam	32
Outseam	40

**PHILADELPHIA UNIVERSITY - LEHP
CONTAMINATED DOFFING**

**Testing Notes
AUGUST 4-5, 2009**

Test Schedule: Initial matrix was adjusted as testing proceeds.

	Tues	Tues	Tues	Wed	Wed	Wed
	1100	1345	1515	0930	1100	1315
Coverall (Gen4) with Undergarment	1	2	3			
Coat/Trousers (Gen5) with 2-pieced Undergarment				4	1	3
JSGPM mask and carbon hood	X	X	X	X	X	X
JB1GU outer glove and liner	X	X	X	X	X	X
AFS	X	X	X	X	X	X

Test Item Descriptions:

Undergarments

Shorts and T-shirt, with Kleen Guard over top and taped at the wrists and ankles. The Kleen Guard protects the subject's skin from the contaminant and helps to analyze the contamination when removed from the body. It is a blousy white disposable garment.

Gen4 Coverall

Design: One piece coverall with attached hood. Designed to fit the JSGPM. Features include canister straps, two front neck flaps, an asymmetrical center front zipper, a left sleeve doffing zipper, two way relief zipper, articulated elbows and knees, knee pad pocket with removable knee pad, elbow abrasion patches, interior waist belt, zipper pull tab, shoulder retention harness, and hood stowage system.

Materials: 78C

Gen4 Undergarment

Design: Fitted one piece body suit with knit ankle and leg cuffs with center front asymmetrical zipper and two way relief zipper.

Materials: 63A (stretch)

Gen4 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. Changes- three different types were tested. First was designed the same as the revisions made during FAST, carbon stretch knit was inserted in a semi circle shape at the temple area. Second, filler pouches at the temple and a carbon cord around the face opening was inserted. Third, a semi circle shaped piece of neoprene was sewn into the temple area.

Materials: 63A (stretch)

**PHILADELPHIA UNIVERSITY - LEHP
CONTAMINATED DOFFING**

**Testing Notes
AUGUST 4-5, 2009**

Gen5 Uniform (Coat & Trousers) (note: used Gen4 Balaclava for this testing)

Design: The coat features a bi-swing back with gripper patches at the shoulders to prevent gear slippage. The sleeve includes an articulated elbow with a reinforcement patch and shaped wrist cuffs. The pant sits high on the waist and includes a zip fly and side size adjustment straps. Redesigned articulated knees improve movement, but still include the knee pad pocket with removable knee pad. Ankle cuffs are elastic with a Velcro pull tab. The coat and trousers form an integrated unit when zipped together at the waist. An internal removable skirt is attached to the coat that zips to the pant; this system is adjustable for split sizing. Changes were made to the skirt to attempt to eliminate the blow through experienced in this area during FAST.

Materials: 78C

Gen5 Undergarment (Shirt & Drawers)

Design: Undergarment shirt includes an asymmetrical center front zipper, with backup flap for comfort and knit cuffs. The drawers feature a high waisted style along with knit cuffs and waist band. The shirt was lengthened, front zipper was off set to left side, and Velcro closure neck collar added.

Materials: 63A

Tuesday – August 4th

1100 TEST

Design: Configuration:

Gen4 Coverall with Gen4 One-pieced Undergarment & Gen4 Hood (TP #1)

2007 JSGPM

JB1GU outer glove and liner

AFS

Donning:

- Overall fit is good, legs and arms good length. No issue at waist.
- Leg bottom of UG drawers worn inside combat boot. Then AFS. Leg bottom of Coverall secured over AFS.
- Carbon shirt worn over carbon drawers
- Gen4 balaclava positioned on JSGPM before donning. Knit inserts at temple of balaclava (same as in FAST)
- Once mask is secured in place, balaclava is pulled over the head and then tucked inside coverall. Front zipper is closed to neck. Hook/loop of left and right flaps are secured and straps closed around filters.

Doffing:

- While Assistant 1 was deconing the subject the hose came off the larger bug sprayer, he switched to the smaller sprayer
- Subject covered filters to avoid getting them wet while Assistant 1 was using the bug sprayer
- Subject appeared to be thoroughly wet after decon, visible beading and rolling off of the water
- Extended Velcro behind head seems to work successfully
- Under liner gloves came off with undergarment

**PHILADELPHIA UNIVERSITY - LEHP
CONTAMINATED DOFFING**

**Testing Notes
AUGUST 4-5, 2009**

- Right sock came off while doffing legs of undergarment
- Doffing time: 37 minutes

Black lighting:

- Attendant 1 is covered in simulant around hands, chest, and legs. Back is mostly clean.
- Subject appears completely clean on pre-blacklighting
- Upon inspection when subject removes protective Kleen Guard "simulated skin" one spec of orange simulant on left shoulder near neck
- Back left shoulder near armpit, very small smudges from decon solution
- Very slight small bluish haze tint on back neck. NOTE: it was determined in test 2 that the white tag from the carbon undergarment was rubbing off onto the Kleen Guard suit and creating the haze
- Underside of right arm near wrist- 3 small smudges of blue, one thumb print size, other two are smaller
- Fred deemed it "very clean"

Subject Feedback:

- Coverall is tight on the neck when the zipper is all the way up. It creates restriction when bending the neck
- Plenty of range of motion in legs and arms
- Does change the shape of the mask, but subject feels that it pulls it closer to the face and wouldn't compromise the seal of the mask
- The one piece wire brim is appealing to the subject, feels snug around the mask when canister cords are in place
- Suit feels comfortable and isn't too hot
- Hazmat comments- the suit came out cleaner than (non LEHP) suits tested at the facility the week prior
- Use the "Wiseman" roll to remove carbon balaclava. Roll balaclava from back neck up to crown of head and roll up slightly in front so balaclava cups the canisters on the JSGPM

Recommendations for next run:

- Sleeves - none
- Legs- leg cuffs on undergarment put outside combat boot
- Head/Neck - none
- Body- slide waist belt opening from center front to left front for easier doffing

Tuesday - August 4th

1345 TEST

Design: Configuration:

Gen4 Coverall with Gen4 One-pieced Undergarment & Gen4 Hood (TP #2)
2004 JSGPM
JB1GU outer glove and liner
AFS

**PHILADELPHIA UNIVERSITY - LEHP
CONTAMINATED DOFFING**

**Testing Notes
AUGUST 4-5, 2009**

Donning:

- Carbon balaclava – updated version includes cord around circumference of hood opening and temple pouches
- Cuffs on carbon undergarment worn on outside of combat boot
- Carbon shirt worn over carbon drawers
- Fit: leg falls at second hook on AFS, sleeve length looks good, body I slightly loose but looks good

Doffing:

- Subject is covering filters while Assistant 1 uses bug sprayer
- Shuffle pit in station II was turned 45 Degrees to the left for viewing from camera
- It appears that when the knee pad straps are loosened they do not retract completely into the casing
- Subject holds mask while Assistant 1 removes canister straps
- Assistant 1 had difficulty opening the center front zipper
- Paused doffing at Station III and used blacklight right after hood is loosened – orange simulant appeared on top of eye lens of mask and visible wicking of decon water solution onto the carbon balaclava
- Assistant 1 had difficulty removing right combat boot and right sock came off with removal of combat boot
- Assistant 1 pulled back of balaclava up to top of head and rolled up to top of head and front of balaclava is rolled up prior to opening of center front zipper of undergarment
- Difficulty opening the center front zipper on the undergarment
- Subject was standing with arms back and head forward while removing undergarment from feet
- Doffing time: 30 minutes

Black lighting:

- In chamber the first large shuffle pit helps to keep the water from the bug sprayer that is rolling off coverall
- Pre-blacklight- no visible simulant on Kleen Guard suit
- Kleen Guard suit on wall- Small smudges on both inside wrists possibly from tape around wrists
- Small smudge on back neck- determined that it is from the tag sewn into the carbon undergarment

Subject feedback:

- No neck restriction
- Range of motion seemed good

Recommendations for next run:

- Sleeves – none
- Legs – wear carbon cuffs tucked into garment, makes it easier to doff
- Head/Neck – none

**PHILADELPHIA UNIVERSITY - LEHP
CONTAMINATED DOFFING**

**Testing Notes
AUGUST 4-5, 2009**

Tuesday – August 4th

1515 TEST

Design: Configuration:

Gen4 Coverall with Gen4 One-pieced Undergarment & Gen4 Hood (TP #3)

2004 JSGPM

JB1GU outer glove and liner

AFS

Donning:

- Carbon balaclava modified to include a neoprene insert at the temple area
- Subject wore his own tan combat boots
- Subject prefers the cuff on the carbon undergarment to be worn inside the combat boot, they all feel it is easier to doff this way

Doffing:

- Subject coved filters while being sprayed
- Subject continues to hold mask while the assistant wipes down the mask areas
- Doffing time: 24 minutes

Black lighting:

- Bright spot of blue on left ear top
- Dry orange simulant/ wet blue decon water on right forehead
- Front and back of Kleen Guard is completely clean
- Orange simulant on right side of mask temple
- On right temple haze of orange around eye lens area on carbon hood- simulant clearly getting past the shell and onto the carbon hood
- Orange simulant on interior of both shell temple pouches
- Is to much decon solution being used?

Subject feedback:

- Wear the carbon undergarment leg cuffs tucked into the combat boot

Overall recommendations for Gen4 system:

- Coverall-
 - o Adjust waist belt so that the opening is positioned to the left side of the body rather than to the center
 - o Neck may be a little small for subject with larger necks, look into increasing the circumference in this area.
 - o Widen knee pad strap control channels ½” to make easier for straps to retract into the channel
- Undergarment-
 - o Wear leg cuffs tucked into the boot, provides for easier doffing
- Balaclava- none

**PHILADELPHIA UNIVERSITY - LEHP
CONTAMINATED DOFFING**

**Testing Notes
AUGUST 4-5, 2009**

- DoFFing-
 - o Release all Velcro as early as possible in the doffing procedure to reduce amount of contaminate reaerosolized in a cleaner environment
 - o Wear undergarment tucked into boot, all soldiers will be used to this feeling and will not find it uncomfortable. It is easier to doffing the garment this way, without having to reach up under the carbon undergarment to unlace/cut boot laces, and prevents the cuff from getting caught on the boot while it's removed.
 - o Use the "Wiseman" roll to doff the balaclava and mask in one motion

Wednesday – August 5th

0930 TEST

Design: Configuration:

**Gen5 Uniform (Coat/Trouser) with Gen5 Undergarment (Shirt & Drawers)
& Gen4 Hood (TP # 4)
2004 JSGPM
JB1GU outer glove and liner
AFS**

Donning:

- Carbon pant tucked into combat boot
- Balaclava style with rib knit inserts at temples
- Carbon shirt worn over pant
- Carbon shirt and pant fit well
- Shell pant is a little snug at waist
- When subject bends down the knee pad hits right on the knee, it may be a little high for him
- Shell coat fits well- sleeves are the right length

Doffing:

- Assistant was having a little difficulty releasing the knee straps completely
- Visible water beading/ running off of subject during decon with bug sprayer
- Subject held mask while mask area being deconed
- Assistant wiped down the center front zipper and lifts jacket to wipe fly area
- Velcro release at skirt works well
- "Wiseman" roll works well
- Carbon shirt and glove liners are able to be doffed in one motion
- Doffing time: 21 minutes

Black lighting:

- Possible simulant at right top of ear- while donning the subject noted that he could feel a breeze on the right temple area
- Inspection under blacklight shows simulant getting under carbon hood onto mask edge- may be the reason simulant was present on ear

**PHILADELPHIA UNIVERSITY - LEHP
CONTAMINATED DOFFING**

**Testing Notes
AUGUST 4-5, 2009**

- NOTE: while blacklighting, decon water is clearly getting through the seams where there is stitching- no evidence of this transferring to the carbon undergarments or onto the body. This is not a surprise because 78C is not a waterproof membrane and thus the seams are not taped.
- Suit front appears completely clean, no haze on chest like FAST
- On left back bicep small smudges from decon water
- Water droplet on upper left back
- A couple of orange simulant particles on right side waist

Subject Feedback:

- Make the zipper flap at center front ¼ inch bigger so it is easier to grip and remove for decon
- Likes the idea of the shoulder reinforcement/ grips
- Likes Velcro closure at top of zipper, makes easier to open zipper while doffing, but edge of Velcro on carbon shirt is poking into the neck, needs to be reduced to make more comfortable.
- Tight on the neck when turning far right and left
- Shaped sleeve appealing for crawling
- Subject and Assistants prefer the one piece carbon undergarment to the two piece because they feel it's easier to doff

Recommendations for next run:

- Sleeves – none
- Legs – none
- Head/Neck – none

Wednesday – August 5th

1100 TEST

Design: Configuration:

**Gen5 Uniform (Coat/Trouser) with Gen5 Undergarment (Shirt & Drawers)
& Gen4 Hood (TP # 1)
2004 JSGPM
JB1GU outer glove and liner
AFS**

Donning:

- Waist fits better on this subject
- Knees in good position, while kneeling they hit the middle of the pad
- NOTE: subject has bright simulant droplet on forehead prior to test beginning from assisting in test
- Balaclava style: carbon cord with filler pouches
- Right side of canister strap area looks better than test #1, it is sitting better on the mask temple area

**PHILADELPHIA UNIVERSITY - LEHP
CONTAMINATED DOFFING**

**Testing Notes
AUGUST 4-5, 2009**

Doffing:

- Subject holds mask in place whenever assistant wipes mask area
- Stitching tore at the revision flap at the skirt area - Assistant #2 reached inside coat to remove Velcro
- No problems doffing sleeve with glove liners
- Assistant hung mask up for later blacklighting
- Doffing time: 21 minutes

Black lighting:

- Small bright spot about the sized of a pencil eraser, on right temple and slight haze at mask edge, edge clearly visible
- Very faint hazing of orange simulant on waist area and slightly darker on left stomach right below belly button
- Back clean

Subject Feedback:

- Subject notes that the mask feels better than in the coverall version, and the neck doesn't feel as tight
- The draw cord at the waist is unnecessary, subject likes the garment to have a looser fit

Recommendations for next run:

- Sleeves - none
- Legs - none
- Head/Neck - none

Wednesday – August 5th

1315 TEST

Design: Configuration:

**Gen5 Uniform (Coat/Trouser) with Gen5 Undergarment (Shirt & Drawers)
& Gen4 Hood (TP # 3)
2007 JSGPM
JB1GU outer glove and liner
AFS**

Donning:

- Pants fit well, legs come down past second hook on AFS
- Sleeve length good
- Tape up on skirt to prevent the blow through at the waist
- Balaclava style: neoprene inserts at temple area

Doffing:

- Subject holds mask while it is being wiped down
- When the center front jacket is opened the duct tape used in this area stuck to the draw cord on left side of jacket

**PHILADELPHIA UNIVERSITY - LEHP
CONTAMINATED DOFFING**

**Testing Notes
AUGUST 4-5, 2009**

- Assistant recommends loosening glove liners and removing right and left carbon shirt sleeves at same time to minimize contamination risk
- Doffing time: 20 minutes

Black lighting:

- Very small orange particles at right jaw bone
- Faint haze of orange at left temple
- Smudge at center chest- not sure what from- blue decon water
- Orange simulant at same place on left stomach area below belly button and faint haze on right waist
- Back clean
- Mask black light- orange simulant on left side at temple on mask right below mask hook, on right side neoprene stopped most of the simulant from penetrating but you can clearly see where it came in below the insert and deposited simulant on the jaw line of the subject

Subject Feedback:

- Good range of motion but very aware of the zipper and bulk at the waist
- Neck has no restriction
- Jacket has more range of motion in the arm area than the coverall
- Likes the shoulder grips to help keep backpacks on

Overall recommendations for Gen5 system:

- Duty Uniform – Coat
 - o The draw cord at the waist may be unnecessary, subjects don't seem to want it pulled around their waist
 - o Make the zipper flap at center front ½ inch bigger so it is easier to grip and remove the jacket for decon
 - o Neck is still providing some discomfort while turning to right and left for subjects with larger necks, increase circumference to accommodate them
- Duty Uniform – Trouser
 - o Revise waist interface with the pant and skirt, needs to provide more protection and prevent blow through without becoming too complicated
 - o Add ½ inch width to knee pad strap casing to allow easier retraction of straps into casing
 - o Add ½ inch width to ankle strap casing to allow easier retraction of straps
- Undergarment – Shirt
 - o Velcro at neck is uncomfortable, it needs to be repositioned or slimmed down so it doesn't poke into the neck
 - o Switch the fabric neck collar on the shirt so that the rough side is not against the skin
- Undergarment - Drawers- none
- Balaclava- none

**PHILADELPHIA UNIVERSITY - LEHP
CONTAMINATED DOFFING**

**Testing Notes
AUGUST 4-5, 2009**

Overall Notes for Gen 4 and 5:

- Subjects feel that they could easily remove both style garments themselves with little training.
- Subjects like that the Gen 5 two piece system can be doffed as a one piece. They feel that it makes the doffing easier.
- They prefer to doff the one piece carbon undergarment as opposed to the two piece.

Appendix G

LEHP Contaminated Doffing—Final Script, Generation 4—August 4, 2009

(Reprint of original)

LEHP Contaminated Doffing – FINAL

78C/63A Coverall Shell – One-piece tight Carbon Undergarment- JB1GU glove and liner

Generation 4

4 Aug 2009

Step	Executed By	Procedure	Comment
STATION I			
1	A-2	1. Escort Subject to Station I to shuffle pit 2. Instruct Subject to only respond to instructions from you and not from the prompter. Also remind SUBJECT to remain as still as possible throughout the procedure	
2	A-1	1. Release knee pad straps 2. Conduct a gross decon of the complete ensemble using sprayer starting at head and working to boots. 3. Check Mask/Canisters and decon using a damp sponge in crevices if needed	
3	A-2	Instruct SUBJECT to stand with arm out front	
4	A-1	1. Decon SUBJECT's gloves from wrist tab to fingertips using sponge 2. Open sleeve wrist tabs on coverall and reattach loosely 3. Remove outer glove and dispose of 4. Change your gloves	
5	A-2	Escort SUBJECT to STATION II and into shuffle pit	

ASSISTANT 1 = A-1 ASSISTANT 2 = A-2

Page 1 of 7

F: LEHP DoffingSCRIPT-FINAL- GEN4.4Aug091.doc

Step	Executed By	Procedure	Comment
STATION II			
1	A-2	Instruct SUBJECT to spread legs a shoulder width apart without touching sides of shuffle pit.	
2	A-1	1. Using long handled brush, decon the overboots and lower trouser legs. Use special care to clean the back of the overboots. 2. Decon your gloves.	
3	A-2	Instruct SUBJECT to step up and out of the shuffle pit and forward. Instruct SUBJECT that when overboots are removed he should step forward	
4	A-1	1. Open leg tab and reattach. Roll up bottom of each leg to mid- overboot 2. Open lacings of over boots 3. Step to line 4. Move to BACK of SUBJECT and hold heel of RIGHT overboot as SUBJECT loosens heel inside overboot and then steps forward and out in one motion. Place overboot in disposal container 5. Hold heel of LEFT overboot as SUBJECT loosens heel and then steps forward and out in one motion. Place overboot in disposal container	
5	A-2	Escort SUBJECT to STATION III to line	

ASSISTANT 1 = A-1 ASSISTANT 2 = A-2

Step	Executed By	Procedure	Comment
STATION III			
1	A-1	1. Move to FRONT of SUBJECT, untie or cut bootlaces. Loosen each boot so that the SUBJECT's foot can easily be removed. 2. Doff gloves and don new	
2	A-2	Instruct SUBJECT to stand erect with arms slightly back (approx. 30-45 degrees), lift chin and spread legs slightly	
3		WARNING to A-1: When performing the following steps do not put hands inside garment; ensure respirator does not touch SUBJECT after opening the coverall. If contamination is present or suspected, decontaminate front closure (outer flap and zipper) with sponge.	
4	A-1	1. Open outer and inner hood flaps below neck and decon area with wet sponge. 2. Instruct SUBJECT to place two fingers on mask to secure in place 3. Using tab carefully unhook the straps from around mask canisters. Decon area if needed 4. Roll neck flaps to back and attach behind head 5. Wipe down center front flap, fold back center front flap and decon under flap and zipper 6. Decon gloves	
5	A-2	Instruct SUBJECT to lift chin and extend LEFT arm to side until it is level with shoulder	

ASSISTANT 1 = A-1 ASSISTANT 2 = A-2

Step	Executed By	Procedure	Comment
STATION III			
6	A-1	1. Wipe down left sleeve zipper, open outer left sleeve flap and decon under flap and zipper 2. Decon your gloves	
7	A-1	1. Open left sleeve zipper to arm pit and peel back 2. Open center front zipper to mid-chest and peel down 3. Move to back of SUBJECT and with a slight outward roll, pull coverall hood off head	
8	A-1	1. Completely open the sleeve zipper 2. Completely open the center front zipper and fold garment down away from body while releasing the waist belt	
9	A-2	Instruct SUBJECT to rotate arms to rear keeping LEFT arm elevated and make a fist to ensure glove liner doesn't come off.	
10	A-1	1. Move to REAR of SUBJECT. Grasp the outside of the coverall near the shoulders. Pull the coverall up and off of the shoulders, rolling it onto itself. 2. Continue to the pull down until the SUBJECT's gloved hands are free of the sleeves and continue to work the coverall to the SUBJECT's waist and then the knees. 3. Instruct SUBJECT to push the inside of coverall legs down to expose boots 4. Decon your gloves.	

ASSISTANT 1 = A-1 ASSISTANT 2 = A-2

Step	Executed By	Procedure	Comment
STATION III			
11	A-2	1. Instruct SUBJECT to stand straight, keep arms away from body and relax hands. He may place a gloved hand on A-2s shoulder for stability 2. Instruct SUBJECT that the coverall and boot will be doffed in one motion and that once garment leg is removed, he will place that foot across the contamination control line 3. Change your gloves	
12	A-1	1. Hold the heel of the RIGHT boot and leg bottom of the coverall as the SUBJECT steps forward and out in one motion. Remove the garment leg and boot as a single integrated unit until the SUBJECT's foot is clear. Allow the SUBJECT to place this foot over the contamination line 2. Repeat with LEFT foot 3. Place garment and boots in disposal container 4. Doff your gloves and don new	

ASSISTANT 1 = A-1 ASSISTANT 2 = A-2

Step	Executed By	Procedure	Comment
STATION IV			
1	A-1	1. Grip neck on undergarment through the carbon balaclava and open the center front zipper to the stopper below the waist	
2	A-2	Instruct SUBJECT to lower arms, keeping hands away from body but keep chin up away from chest.	
3	A-1	1. Grasp shoulders of undergarment and roll off the body to the ankles	
4	A-1	1. Instruct SUBJECT to hold hands up and loosen the glove liners by pulling gently on the fingertips and remove the liners taking care not to contaminate the hands. 2. Once doffed- instruct SUBJECT to hand liners to A-1 for disposal	
5	A-1	1. Grasp leg cuffs and instruct SUBJECT to step over contamination control line	

ASSISTANT 1 = A-1 ASSISTANT 2 = A-2

STATION V			
1	A-1	1. Instruct SUBJECT to turn 180 degrees and face station IV 2. Pull hood up over head from back and encapsulate canisters	
2	A-1	1. Grasp the mask by the voicemitter cover	
3	A-2	1. Instruct SUBJECT to loosen the two lower mask straps. 2. Instruct SUBJECT, "When given command to Go", lean forward, hold your breath and close eyes as SUBJECT removes the mask over your head, then step to the door.	
4	A-1	1. Give command to "GO" and remove the mask over the head. 2. Place mask in disposal container.	
5	A-1	1. Open center front zipper to zipper stop below waist on carbon undergarment 2. Move to BACK of SUBJECT, grasp right sleeve cuff and right shoulder and pull off, repeat with LEFT side 3. Work carbon undergarment to feet. 4. Hold RIGHT leg cuff and instruct SUBJECT to step out of coverall 5. Hold LEFT leg cuff and instruct SUBJECT to step out of coverall and across contamination line.	

ASSISTANT 1 = A-1 ASSISTANT 2 = A-2