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DESIGN AND TESTING OF CHEMICAL/BIOLOGICAL PROTECTIVE GARMENT SYSTEM—GENERATION 4

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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 4 garments. Assessments were conducted at LEHP, and at 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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DESIGN AND TESTING OF CHEMICAL/BIOLOGICAL PROTECTIVE GARMENT SYSTEM—GENERATION 4

1. Introduction

The Garment Team (GT) of the Philadelphia University Laboratory for Engineered Human Protection (LEHP) develops prototype chemically protective ensembles designed to protect Warfighters against battlefield toxic chemical agents. This report describes the iterative design process and materials used by the GT, summarizes the construction and test methods and the test results for 11 ensemble components, and presents conclusions drawn from the results. The work described was performed between January 2008 and August 2009 under Department of Defense University Research Initiative Grants (numbers W911QY-04-1-0001 and W911QY-09-1-0001) administered by the U.S. Army Natick Soldier Research Development and Engineering Center (NSRDEC), in support of the Warrior Systems Technologies Program.

The overall objectives of this effort included:

- Develop modular (adaptive) design garments to address a variety of missions and challenges from a common design platform.
- Develop coverall and two-piece style garments using the spiral development methodology.
- Optimize garment design for fit, functionality, ease-of-movement, performance, and cost.
- Improve ease of donning and doffing of both uncontaminated and contaminated garments.
- Investigate the performance of various activated carbon undergarment and liner configurations with outer shell components.
- Investigate various supplier-developed fabrics to include breathable and selectively permeable material (SPM) fabric systems.
- Take advantage of testing facilities' expertise outside of the University.
- 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.

The audience for this report is NSRDEC, Navy Clothing and Textile Research Facility (NCTRF), and Joint Project Manager-Individual Protection (JPM-IP), and other Department of Defense units they might designate.

This report, along with the garment patterns that will be supplied to NSRDEC in the future, provides sufficient information for a knowledgeable reader to duplicate the methods and garments created by means of the GT's spiral design process at LEHP.

2. Garment Design and Materials

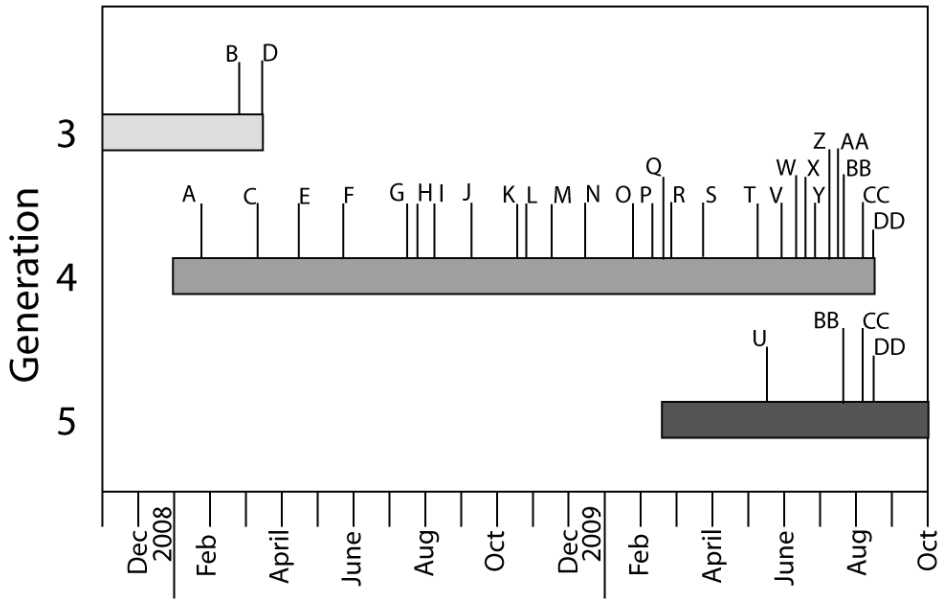
2.1 Generation 4 Prototype

Initially, the GT reviewed the existing two-piece Joint Service Lightweight Integrated Suit Technology (JSLIST) garment, as well as other military-issued chemically protective ensembles, and participated in discussions with scientists at the 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.

Design of the Generation 4 prototype garment was a culmination of lessons learned from the three prior prototypes designed and evaluated by the GT, and communicated in Technical Report PHILA-LEHP-GT-TR-08-02, *Design and Testing of Chemical/Biological Protective Coverall System, Generations 1–3.* New features of the Generation 4 prototype include: interior waist belt, shoulder retention strap, and knee-pad straps. The entire hood/mask area, including the wire brim and canister loops corresponding to the Joint Service General Purpose Mask (JSGPM), was significantly reworked from the Generation 3 garment.

Figure 1 shows the timeline for Generation 4 and for events that influenced its development, as well as overlapping events from Generations 3 and 5[1]. Figures 2 and 3 show the Generation 4 design.

[1] During development of the Generation 4 fixed-hood coverall prototype, the GT investigated design and construction of a two-piece fixed-hood Generation 5 ensemble. The Generation 5 two-piece fixed-hood ensemble will be described in a later report.



A-Outdoor Retailer Winter Market - January 22-25, 2008
B- Meeting with JSGPM at Edgewood - February 22, 2008
C- Meeting with NSRDEC consultant - March 11, 2008
D- Human Factors at PhilaU on Generation 3- March 12, 2008
E- Design Meeting with NSRDEC at PhilaU - April 10-11, 2008
F- JPEO-CBD (Joint Program Executive Office- Chem Bio Defense) meeting in Washington DC - May 20, 2008
G- Meeting with Chemical/Biological Incident Response Force at Indian Head, Maryland - July 17, 2008
H- Design Meeting with JPM-IP and NSRDEC- July 24, 2008
I- Outdoor Retailer Summer Market- August 7-8, 2008
J- Chemical/Biological Protective Clothing Forum - September 9, 2008
K- Human Factors at PhilaU on Generation 4 - October 15, 2008
L- Human Factors at PhilaU on Generation 4 - October 27, 2008
M- Human Factors at NSRDEC- November 2008
N- Design Review Meetings at NSRDEC - December 12, 2008
O- Outdoor Retailer Winter Market - January 23-24, 2009
P- Visit to JPM-IP at Stafford, VA - February 5, 2009
Q- Human Factors at PhilaU on Generation 4 - February 11, 2009
R- Human Factors at PhilaU on Generation 4 - February 23, 2009
S- Human Factors at PhilaU on Generation 4 - March 25, 2009
T- JPEO-Chemical and Biological Defense Advanced Planning Briefing - May 7, 2009
U- Design Review with NSRDEC at PhilaU - May 15, 2009
V- Human Factors at PhilaU on Generation 4 - May 27, 2009
W- Human Factors at PhilaU on Generation 4 - June 3, 2009
X- Human Factors at PhilaU on Generation 4 - June 11, 2009
Y- Joint CBRN (Chemical/Biological Radiological and Nuclear) Conference at Ft. Leonard Wood - June 23-25, 2009
Z- Human Factors at PhilaU on Generation 4 - July 8, 2009
AA- Human Factors at PhilaU on Generation 4 - July 16, 2009
BB- FAST at Research Triangle Institute - July 21-22, 2009
CC- Contaminated Doffing at Hazmat Sciences - August 4-5, 2009
DD- NSRDEC Annual Review at PhilaU - August 12-23, 2009

Figure 1. Timeline for Generations 4 through 5 of GT-Designed Protective Garments.

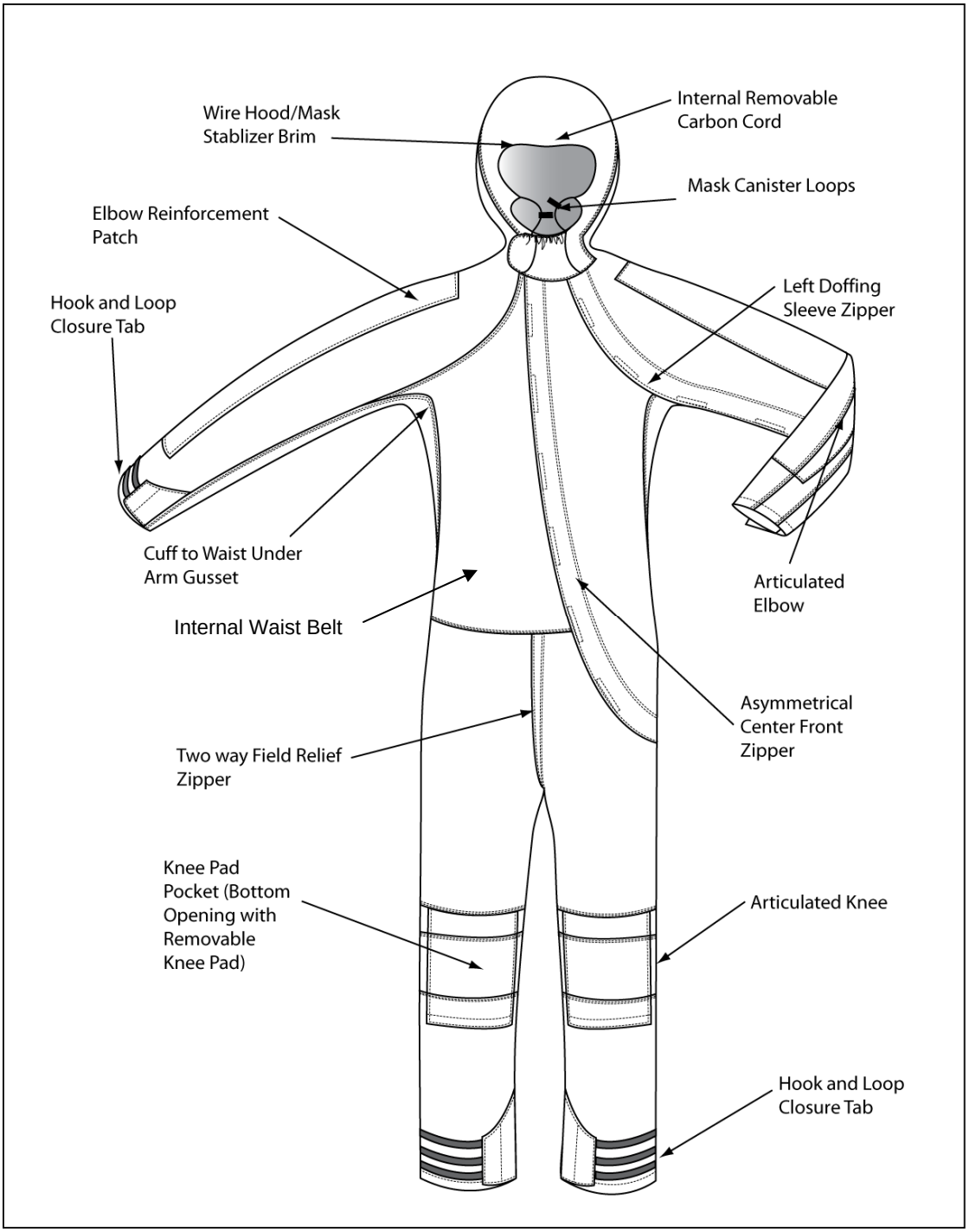


Figure 2. Generation 4 Flat Sketch—Front.[2]

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

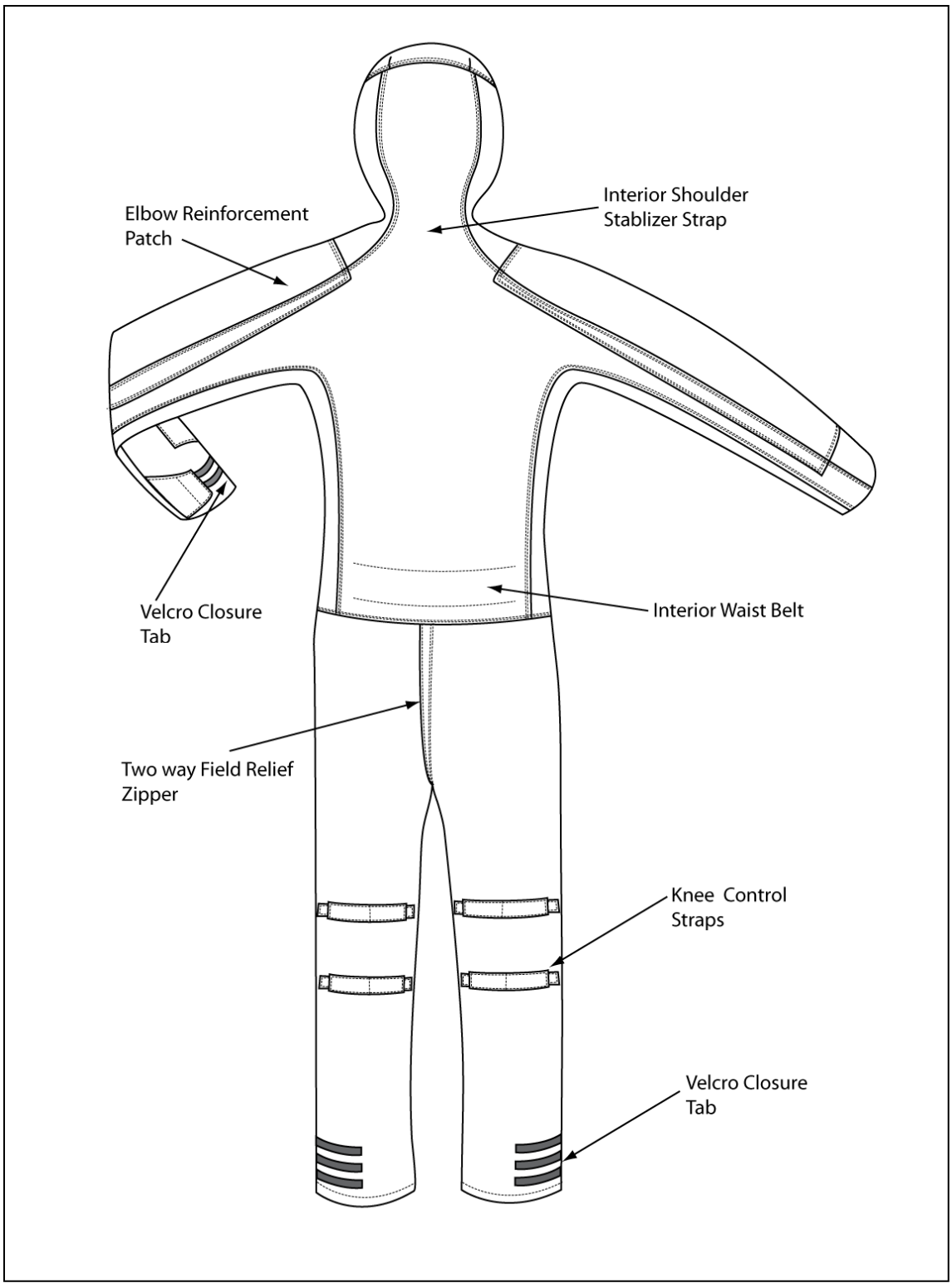


Figure 3. Generation 4 Flat Sketch—Back.

2.2 Design Process

The GT is challenged with evaluating through research procedures how component parts are integrated within the garment system design. The GT researches, in conjunction with the Materials Evaluation Laboratory (MEL), then selects and evaluates various shell, carbon, and membrane materials; closures, including zippers, ties, cording, and VELCRO® brand hook-and-loop fastener tape; and other components that might be used in the construction of the garment. This process, therefore, includes the use of manufacturing techniques and innovative ergonomically correct garment design.[3] The process is ongoing, iterative, and spiral in development as the garment design progresses.

When the LEHP project began, the military was issuing the JSLIST ensemble. The JSLIST is a permeable, two-piece garment system that relies on a permanent carbon layer sewn together with a durable outer shell fabric. In response to the University Research Initiative grant the GT, in collaboration with NSRDEC and NCTRF, has created four prototype garment styles. For information on Generations 1 through 3, see PHILA-LEHP-GT-TR-08-02, *Design and Testing of Chemical/Biological Protective Coverall System, Generations 1–3.*

The Generation 4 coverall was designed to be donned either over the duty uniform including combat boots or to be worn directly over undergarments (without a duty uniform). The garment was designed taking into consideration interfaces at the hood/mask, wrists, and ankles. The design maintained the need for field relief 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.

Major considerations initially were maximizing life expectancy of the garment, the possibility of reducing garment cost, and reducing the burden of disposing of spent garments. For example, the JSLIST has a life expectancy of 45 days once it has been removed from the protective vacuum-sealed packaging and exposed to the air. The design of the LEHP one-piece coverall uses separate carbon undergarments so that they could be discarded at the end of their life cycle and replaced while the existing one-piece coverall shell could be kept and reused.

[3] 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

Generation 4 garment systems were evaluated with fluorescent aerosol screening testing (FAST), and with LEHP and NSRDEC human factors studies. Generation 4 was evaluated at the Hazmat Sciences' Contaminated Doffing facility as well.

Obtaining testing data is very important to the spiral development process of the LEHP garments. Various in-house and off-location facilities provide invaluable feedback on the comfort and protection of the garments. The Generation 4 ensemble was evaluated as summarized below.

- Human Factors (external)—This test was completed at NSRDEC by Dr. Karla Allan. It included donning the garment in various MOPP levels, while performing a preselected motion routine. Participants may wear ancillary equipment such as: helmets, backpacks, body armor or tactical vests. This evaluation is important to the GT because it provides an outside evaluation of the garment using soldiers who have been trained to use the JSLIST and can provide appropriate feedback and comparisons. Selected results are presented in the body of this report. The complete test report is in Appendix A.

- Human Factors (internal)—This series of tests was performed at Philadelphia University in conjunction with the Biophysics Team. The motion routine used was based on that done at NSRDEC. Once the selected number of trials had been completed the Biophysics team analyzed the data for scientific validity. Results from one generation can then be compared to another generation prototype. Selected results are presented in the body of this report. More information about the Human Factors evaluations conducted at LEHP is in Appendix B.

- Fluorescent Aerosol Screening Test (FAST)—This test was performed at Research Triangle Institute (RTI) in Research Triangle Park, NC. In MOPP 4 the test participant entered a large chamber where he then performed a series of motions totaling 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 valuable data about where contaminate can penetrate the garments and reach the body through breaches at the interfaces. Selected results are presented in the body of this report. See Appendix C for LEHP testing notes for FAST and Appendix D for FAST results.

- Contaminated Doffing (CD)—This test took place at Hazmat Sciences in Santa Fe, NM. Hazmat Sciences is now a part of Northern New Mexico College. This test assessed the ease of doffing a contaminated garment without contaminating the wearer. During this evaluation the test participant was covered in a fluorescent fingerprint powder and then taken through a decontamination line. Once the garment was 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. Testing notes are in Appendix F, and the doffing script is in Appendix G.

This chapter discusses the construction and evaluation methods, and the results of the evaluations for the 10 components of the Generation 4 protective garments, plus the issue of costing. The garment components described are listed below.

(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) Waist Belt and Torso

(7) Asymmetric Front Zipper and Left-Sleeve Doffing Zipper

(8) Field-Relief Zipper

(9) Closures

(10) Shoulder Stabilizer Strap and Hood Retention Flap

3.1 Fabric

The GT strives to improve Warfighter comfort when situations require use of chemical protective garments in the various Mission Oriented Protective Posture (MOPP) levels. A common issue with protective clothing is that it is often stiff, bulky, and uncomfortable. Fabrics have generally had low breathability in an attempt provide the most protection. Throughout the generations an effort was made by the GT to optimize comfort and protection. In Generation 4 a permeable system was used, instead of the SPM system of the Generation 3 garment. This use of a permeable system allowed the GT to return to traditional sewing without seam sealing because the permeable outer shell is reinforced with a full carbon under suit. Fabric 53H was used in all Generation 2 and Generation 3 prototypes.[4] While working well for certain applications, some test participants considered this fabric to be hot. The process of finding new materials began again for the Generation 4 garment.

Fabric for Generation 4 was sourced from Tex-Shield, Stedfast USA (formerly Donaldson Membranes), Purification Products, and Calgon Carbon.

[4] Fabric 53H is a tri-laminate composed of a microporous ePTFE membrane layered between a 100% polyester woven shell fabric and a tricot knit liner made from polyester and carbon fibers.

Tex-Shield
2300 M St. N.W.
Suite 800
Washington, DC 20037
Telephone 202-973-3858

Stedfast USA (formerly Donaldson Membranes)
85 Railroad Dr.
Ivyland, PA 18974
Telephone 215-364-2900

Purification Products
Reliance Works
Saltaire Road,
Shipley
West Yorkshire BD18 3HL, England
Telephone +44 (0) 1274 530155

Calgon Carbon Corporation
P.O. Box 717
Pittsburgh, PA 15230
Telephone: 412-787-6700

Three different types of shell fabrics were procured from two of the suppliers:

- a non-laminated nylon/cotton and a non-laminated Nomex™ from Tex-Shield
- two versions of a Cordura laminated with an aerosol membrane by Stedfast USA

Five different carbon-containing fabrics were supplied by Tex-Shield, Purification Products, and Calgon (Zorflex®).

Table 1 lists fabrics that were considered by the GT for Generation 4. The weight of each fabric was determined by the LEHP Materials Evaluation Team (MET). All other data were obtained from the fabric manufacturers.

Table 1. Fabrics Considered by the GT for Generation 4.

LEHP Code	Supplier	Cloth Characteristics - Shell						
		Manu-facturer Style Number	**Fabric Structure**	**Structure Type**	**Fiber Blend**	**Coloration Method**	**Functional Treatment**	**Weight (oz/sq. yard)**
85M	Stedfast USA		laminate	330d Cordura shell with microporous ePTFE membrane	100% nylon 6,6 330 denier (Cordura)	jet dyed green	microporous ePTFE, durable water repellent finish	5.00
78C	Stedfast USA	Job# 253	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
31B	Tex-Shield	Article 00003	woven	non-FR	multiple fibers	universal camouflage print	durable water- and oil-repellent	5.20
61U	Tex-Shield	Article 00001	woven	n/a	flame-resistant	dyed green	durable water- and oil-repellent	5.30

Table 1. Fabrics Considered by the GT for Generation 4 (continued).

LEHP Code	Supplier	Cloth Characteristics- Liner						
		Manu-facturer Style Number	**Fabric Structure**	**Structure Type**	**Fiber Blend**	**Coloration Method**	**Functional Treatment**	**Weight (oz/sq. yard)**
13B	Calgon Carbon (Zorflex)	FM50K/ D201	knit	activated carbon knit laminated both sides w/ nylon knit	100% nylon knit activated carbon	nylon dyed black	N/A	5.20
63A	Purifica-tion 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
40C	Tex-Shield	Article 00005	laminate	spherical carbon with multiple fabrics	fiber combination with carbon	dyed green	N/A	5.84
54M	Tex-Shield	Article 00002	laminate	spherical carbon	multiple fibers with carbon	dyed black	N/A	6.74
96X	Tex-Shield	Article 00004	trilaminate	spherical carbon with multiple fabrics	fiber combination with carbon	dyed gray	N/A	11.42

3.1.1 Methods

All fabrics chosen for possible use in the Generation 4 garment (see Table 1) were tested by the LEHP MET for seam strength using the JSLIST seam strength as a baseline. All fabrics met or surpassed the seam strength in the corresponding shell or carbon layer except 13B, which was subsequently removed from the running for this reason. A variety of seam structures were used for this evaluation. For all fabrics the GT found that a flat felled seam provided the most strength. For more information see Technical Report PHILA-LEHP-FR-09-02 *Philadelphia University—Laboratory for Engineered Human Protection Final Report—Volume 2 of 8: Materials Evaluation Team.*

In an attempt to cut down on the thermal burden on wearers posed by multiple layers of fabric laminated together, two versions of Cordura were acquired from Stedfast USA to test the viability of using an unprotected membrane system. One version (85M) featured a Cordura shell with the microporous ePTFE membrane, unprotected, and the second version (78C) featured the same structure with a tricot backer laminated onto the microporous ePTFE membrane to protect its fragile structure. Plans were made to test fabric 85M in internal Human Factors evaluations to assess how the 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.

Also in an effort to reduce the thermal burden, Purification Products supplied a fabric (63A) with unprotected carbon powder adhered to a stretch knit.

Tex-Shield 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, are non-stretch and were used in the Generation 4 loose undergarment. The third carbon bead laminated fabric from Tex-Shield, 96X, is a stretch fabric and was used in the Generation 3 and 4 fitted bodysuit undergarment.

Because of limitations on fabric pairings another carbon fabric was sourced from Calgon Carbon (13B) to be paired with shell fabric from Stedfast USA. Unfortunately this fabric did not meet the MET's seam strength standards and was removed from consideration due to durability concerns.

Table 2. Pairings of Shell and Carbon Materials Considered by the GT for Generation 4.

Pair	Shell	Carbon	PhilaU HF	NSRDEC HF	FAST	Contaminated Doffing
1	31B	96X	X	X		
2	31B	40C	X	X		
3	31B	54M		X		
4	61U	54M	X	X		
5	85M	63A	X	X		
6	78C	63A	X	X	X	X

Fabrics were paired according to use limitations. The first four pairings are Tex-Shield fabrics. Because Tex-Shield guarantees their shell fabrics only when paired with Tex-Shield carbon fabrics, their carbon and shell fabrics must be used together. Fabric 61U is an FR fabric and, thus, could not be paired with any carbon fabric that would melt or drip, so 54M was the only available alternative. As a nylon/cotton fabric 31B had no such restrictions but could be paired only with corresponding Tex-Shield carbons. The 85M and 78C shells had no restrictions at all, and thus were paired with 63A.

3.1.2 Results

After multiple Human Factors trials and various model fittings 85M was evaluated and deemed unusable for LEHP's Generation 4 garment. After having been worn for two human factors evaluations and vetted by limited fittings for design presentations, garments constructed of 85M showed significant membrane wear at key stress points such as the knees, elbows and center-front chest area, along with many other areas on the body (see Figures 4, 5, and 6). Degradation of the 85M membrane was also observed during production of the garment when sewing only two layers of fabric together.

Test participants in the internal and NSRDEC Human Factors trials perceived no significant difference while trying on garments constructed from 85M and 78C.

Figure 4. Fabric 85M—Significant Wear at Center Front of Coverall.

Figure 5. Fabric 85M—Wear at Elbows on Coverall.

Figure 6. Fabric 85M—Wear at Knees on Coverall.

It was also observed after multiple Human Factors trials that the carbon liner fabric 63A showed some degradation of the integrity of the attached carbon powder. Visible wear on the knees and some seams caused concern, although it is unknown how this wear affects the performance of this vital layer (see Figures 7, 8, 9, and 10). A possible solution might be as easy as reinforcing key areas like the knees and elbows with another layer of the same fabric. This reinforcement was not tested because it was unknown how the wear on the carbon actually affected the protection. This fabric was judged by the soldiers in the NSRDEC Human Factors trial in November 2008 (report issued March 30, 2009; see Appendix A) to be the more comfortable carbon layer. "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."

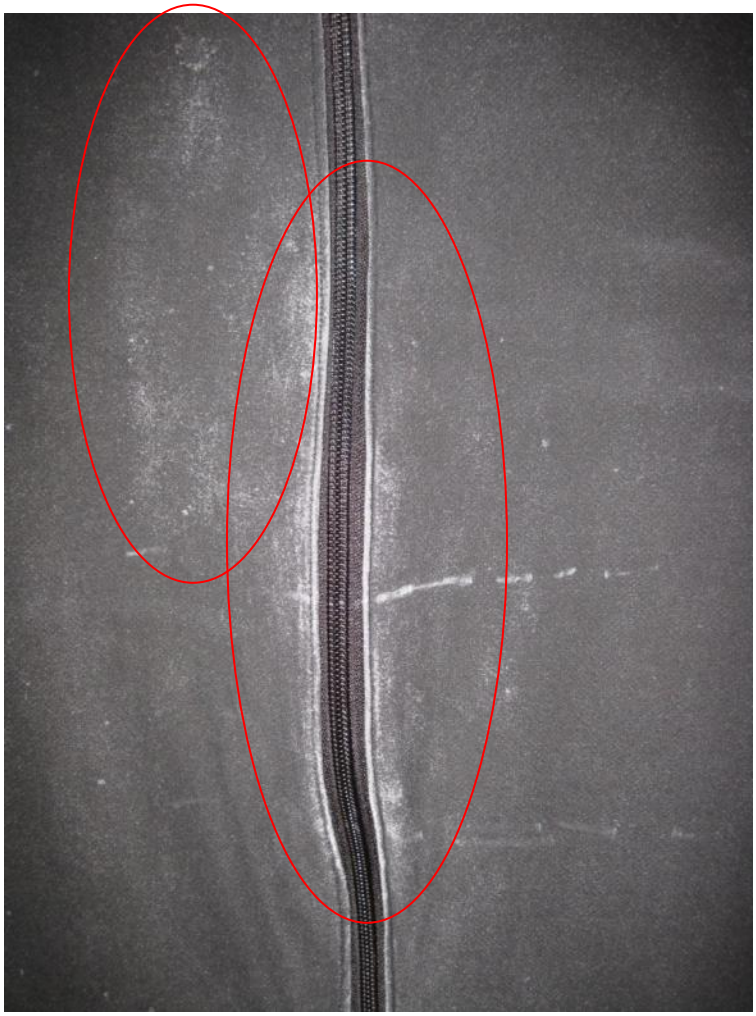


Figure 7. Fabric 63A—Wear at Mid-Chest.

Figure 8. Fabric 63A—Wear at Elbow.

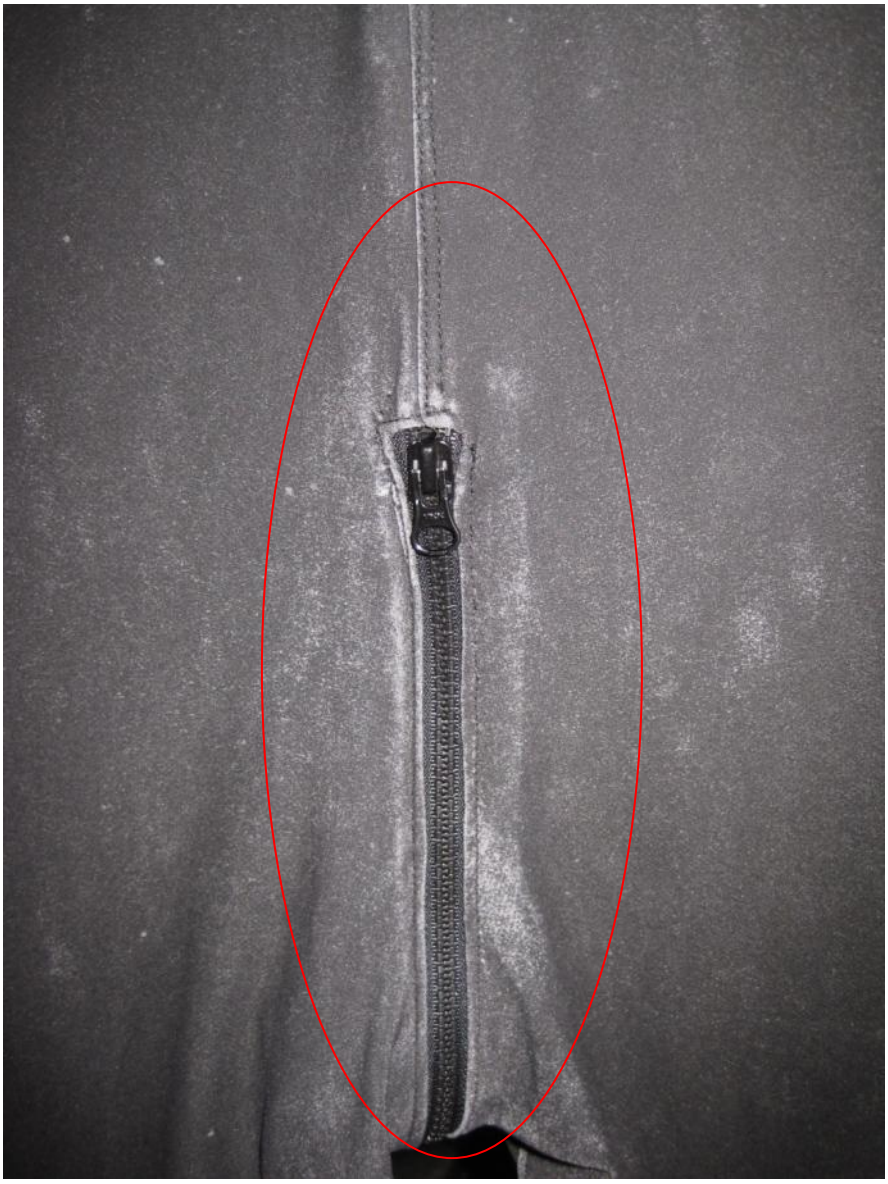


Figure 9. Fabric 63A—Wear at Back in Area of Seat/Field-Relief Zipper.

Figure 10. Fabric 63A—Wear at Knees.

Because the GT was not authorized to carry out penetration testing on the individual fabric pairs, the GT was unclear regarding the level of protection that each fabric provided. The principal purpose of the LEHP undertaking is to improve comfort. Therefore, when evaluating the data that were collected on fabrics that were made available to LEHP, the GT focused on fabrics that provided the most comfort.

Despite visible wear on 63A the GT chose to continue moving forward with this fabric because its thermal resistance (Rct) and water vapor resistance (Ret) were much lower than most of the

other carbon fabrics[5]. This fabric was also more breathable and received a very favorable response during Human Factors trials, and the fabric was generally well regarded by the GT researchers because of its light weight and perceived comfort. Further support for 63A came from the regression analysis developed and analyzed by LEHP members Les Sztandera and Niny Rao, respectively. The regression analysis is used to predict CALM scores for tactile comfort.[6] 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 Contaminated Doffing evaluations. Because of fabric combination use restrictions, 78C was chosen to be paired with 63A for all future FAST, Contaminated Doffing, and Human Factors evaluations of the Generation 4 garment.

3.2 Dual-Layer System

It was decided that the garment system in this prototype would be comprised of two parts: an outer shell that could ultimately be worn as an alternate duty uniform, and a separate disposable inner carbon liner. One issue with integrated carbon suits used by the military today is the carbon's shelf life. Once the carbon's life expires, disposal of the entire suit is necessary, resulting in much 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 the lifetime of the entire ensemble.

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

3.2.1 Methods

The Generation 4 prototype's design allows the shell to be worn with two different liner styles. A Warfighter does not always know the situation to be faced, so the GT provided two carbon suit options to accommodate varying scenarios. Both carbon suit styles are compatible with the Generation 4 shell.

One style, the fitted bodysuit (shown in Figure 11), is made from a knitted stretch carbon fabric. This fitted bodysuit is a very comfortable option for situations in which the Warfighter knows he will be entering a chemically contaminated environment, and he has the time to remove his duty uniform before donning the carbon bodysuit and protective coverall shell. In this case, the wearer is more comfortable for a longer period, because he is cooler without the additional insulation provided by a duty uniform.

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

[6] 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.

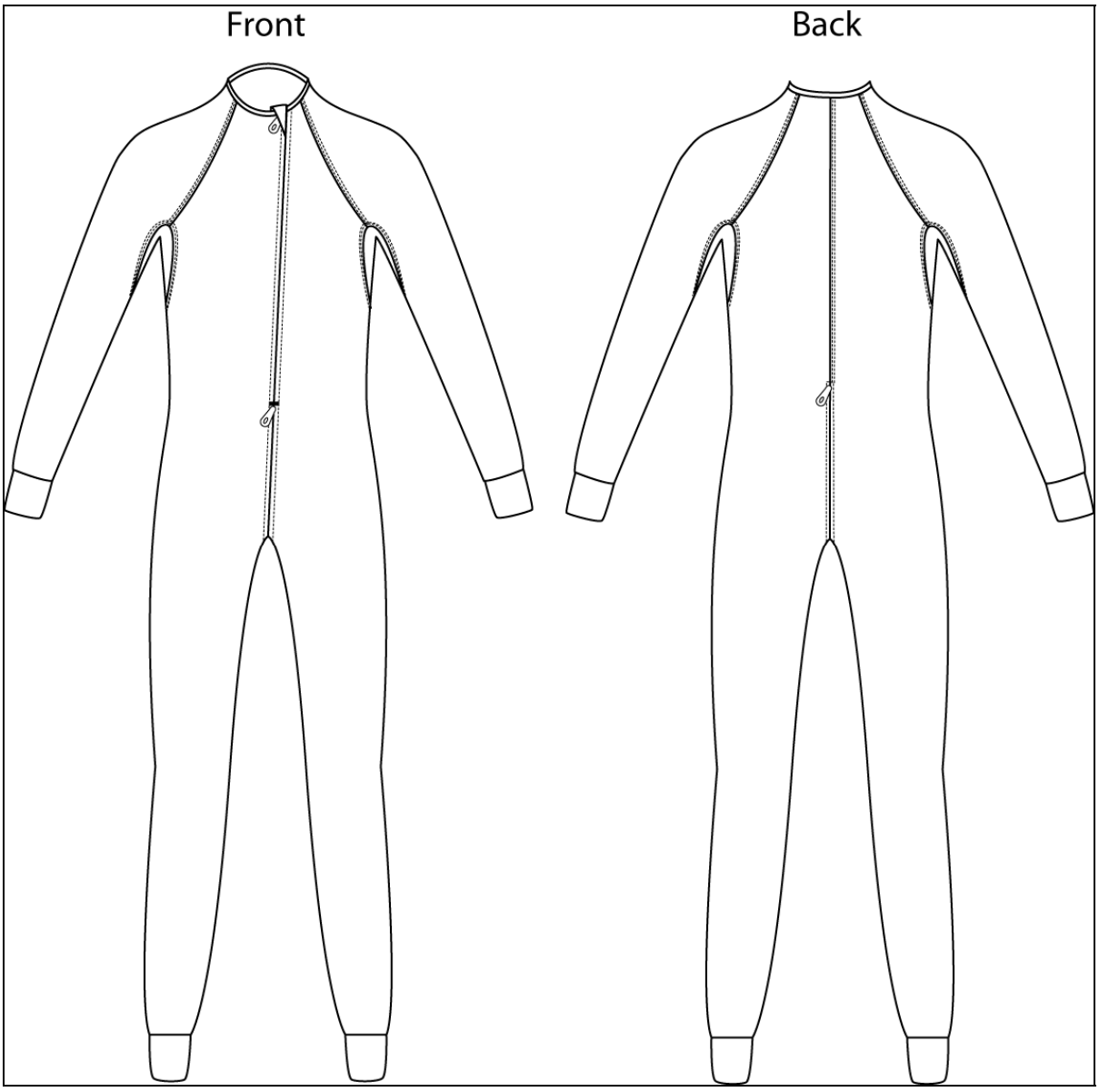

Figure 11. Generation 4 Fitted Carbon Bodysuit.

The fitted carbon bodysuit features a raglan sleeve with a small underarm gusset for increased flexibility and range of motion. The bodysuit contains a slightly asymmetric front zipper, and a zipper stop shield to minimize abrasion and discomfort at the neck caused by the zipper tab. To avoid "stacking" of the zipper tabs, the zipper on the fitted carbon bodysuit is positioned to terminate at the left side of the neck, which is opposite to the zipper termination on the outer shell. The fitted bodysuit also includes a two-way field-relief zipper; its placement corresponds with the placement of the field-relief zipper in the outer shell.

In instances where the soldier has to quickly don protection during a chemical attack, a loose carbon suit (shown in Figure 12) can be donned over the duty uniform and boots, and then

covered by the shell, much like the JSLIST. This loosely fitting carbon suit is made from a laminated non-stretch fabric that contains carbon beads. The loose carbon undergarment and the shell worn over a duty uniform are expected to be less comfortable than the carbon bodysuit and shell worn without a duty uniform because of the additional layers that could trap body heat.

The fabrics selected for the carbon suits were appropriate for the styles. A stretch fabric was used for the fitted bodysuit; a non-stretch material was used for the loose bodysuit.

The stretch fabrics used were 63A and 96X. The non-stretch fabrics used were 54M and 40C.

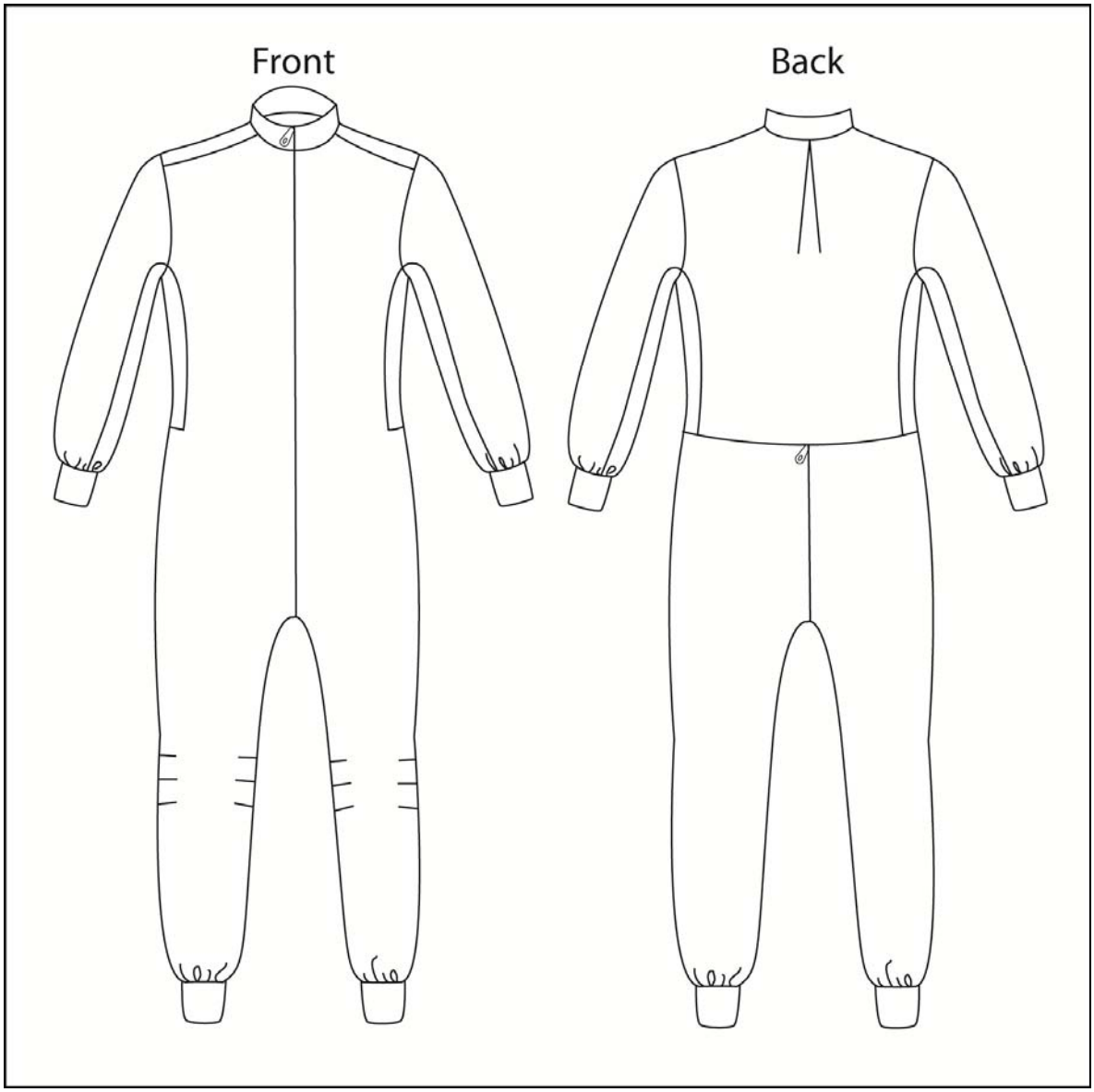

Figure 12. Generation 4 Loose Carbon Undergarment.

3.2.2 Human Factors Results

During the NSRDEC Human Factors Evaluation it was noted that the loose carbon undergarment fit the test participants well, both when it was worn over the Army Combat Uniform (ACU) and when worn with only underwear. The only discomfort noted was a participant's reporting that once the Improved Outer Tactical Vest (IOTV) was donned, his neck felt more crowded by the loose carbon suit than when he wore the tight bodysuit. This discomfort likely results because three layers (ACU, loose carbon suit, and shell) are worn with this configuration, but only two (carbon bodysuit and shell) with the other. Participants did not notice any difference in comfort between the two fabrics used for the loose carbon suit: 54M and 40C.

The test participants rated the tight bodysuit as "especially comfortable" and preferred 63A over 96X because they thought 63A felt lighter, and, therefore, would be cooler in the long run. For more details of this NSRDEC Human Factors evaluation, see Appendix A.

A total of 19 Human Factors trials were undertaken at Philadelphia University from October 2008 to July 2009 using the methodology described in Appendix B. In the early trials it was noticed that the loose undergarment (worn with a t-shirt and shorts) was very tight across the back and shoulders while the wearer extended his arms forward. This situation was remedied by revising the back of the loose undergarment to include a pleat at the neck, much like a dress shirt. Test participants also noted slight discomfort in the neck collar area on both the tight and loose carbon bodysuits. The neck area was minimally redesigned on the carbon undergarments to improve comfort. The loose carbon undergarment was revised very early in the Human Factors trials, and the rest of the trials were performed using the revised version.

3.2.3 FAST Results

The fitted carbon bodysuit style constructed of fabric 63A was used for all three FASTs performed at RTI. (See Appendix C for LEHP planning notes for FAST and Appendix D for FAST results.) No significant difference in protection was found, regardless of whether the carbon bodysuit leg cuffs were tucked into the combat boot or worn outside of the boot.

3.2.4 Contaminated Doffing Results

Undergarment fabric 63A was used for all three Contaminated Doffing trials. The test participants preferred that the leg cuffs on the carbon layer be tucked into the combat boot. Participants believed that tucking the carbon layer into the boot made doffing easier; the carbon suit did not get stuck on the combat boot. As a result, clean doffing was more likely. For details of the Contaminated Doffing trials, see Appendix E.

3.3 Hood/Mask Interface

The interface between the hood and the mask is a critical area for maintaining the protective seal; this interface is also one of the most difficult areas in which to prevent penetration of contaminants. Because of the concave shape of the JSGPM at the temple areas, the GT attempted to seal the area with filled pouches, a wire 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. The GT had to provide optimal comfort while the wearers bent their necks, and also provide full protection at this vital interface.

At this intersection, the shell 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 seal is needed. Bellowing is also a concern at this area; this vacuum effect can bring air and contaminants inside the garment. Secondarily, at this interface the hood/neck area of the protective garment wraps around and closes under the chin, covering the front zipper.

3.3.1 Methods

The hood neck flaps were significantly scaled down in the Generation 4 prototype to increase comfort and flexibility. The large neck flaps and stiff fabric featured in the Generation 3 garment created a "neck brace" effect that limited the wearer's range of motion as he tried to move his head. Because his head's range of motion was limited, his field of vision was reduced. The Generation 4 hood/mask interface is illustrated in Figure 13. The contrast between the Generation 3 and Generation 4 neck flaps is shown in Figures 14 and 15.

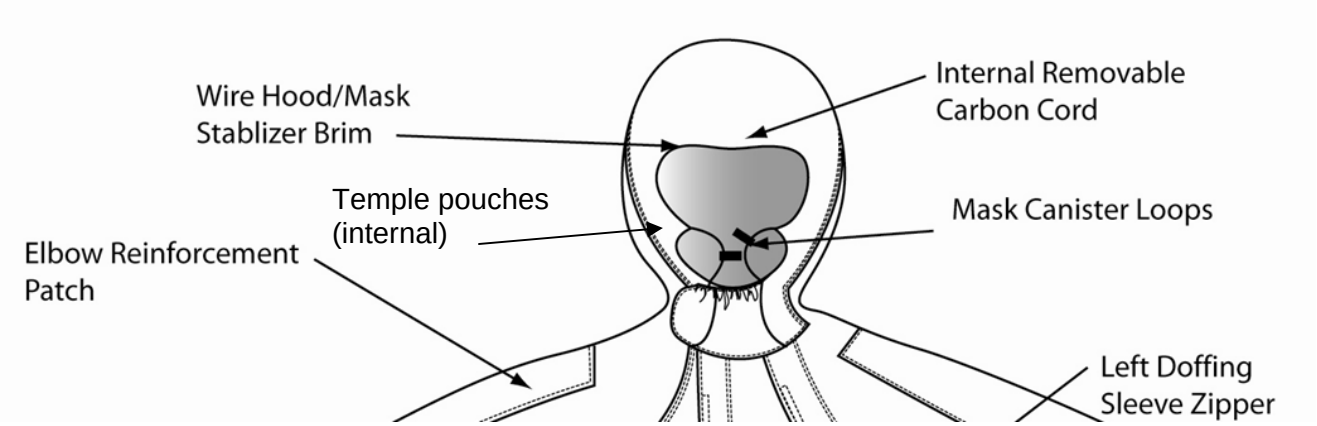

Figure 13. Generation 4 Hood/Mask Interface.

Figure 14. Generation 3 Hood with Mask

Figure 15. Generation 4 Hood with Mask.

In Generation 4 much of the design effort was focused under the chin area to lessen bulk while improving flexibility and fit. The neck of the suit was narrowed; the front neck/chin height was raised and curved, the flaps were reshaped, and hook-and-loop fastener tape was narrowed and positioned horizontally to provide more comfort for head movements and better field of vision (see Figure 16).

Figure 16. Generation 4 Interface under JSGPM.

The temple pouches were extended to provide protection while accommodating a greater range of mask contours between the lens and canister area. The brim shape was extended to expand protective coverage at the filter area. A removable carbon brim rope cord was added to the center-front brim at the forehead area above the mask lens to create an additional layer of carbon barrier protection and to prevent liquid contamination of the wearer during the decontamination process. (Liquid contamination was experienced during the Generation 3 Contaminated Doffing tests.)

The hood was designed with a construction seam over the crown (see Figure 17). In Generation 4 this seam was repositioned slightly in an effort to optimize fit and comfort. This seam runs from the neck area up over the crown of the head to the neck area on the other side. This modular feature allows additional options for mission-specific hood/mask interface manufacturing. This seam provides unlimited opportunity for modularity in design development and application of mask frames to address mission-specific requirements. The overall garment style can remain consistent, and a variety of mask styles could be accommodated with minimal disruption in uniform availability. A full uniform could be manufactured without the mask-frame front panel, and orders could then be placed for suits with specific mask compatibility. The manufacturer would benefit economically by producing large numbers of the uniforms without the mask panel; sewing only one seam would fit the basic uniform to different masks. Once the mask-frame panel is attached is it not easily removed and will not be compatible with masks other than the one for which it was designed. This option has the potential for translation

into cost savings because limited retooling for manufacturing would be required, and management of equipment storage and procurement efficiency would be improved.

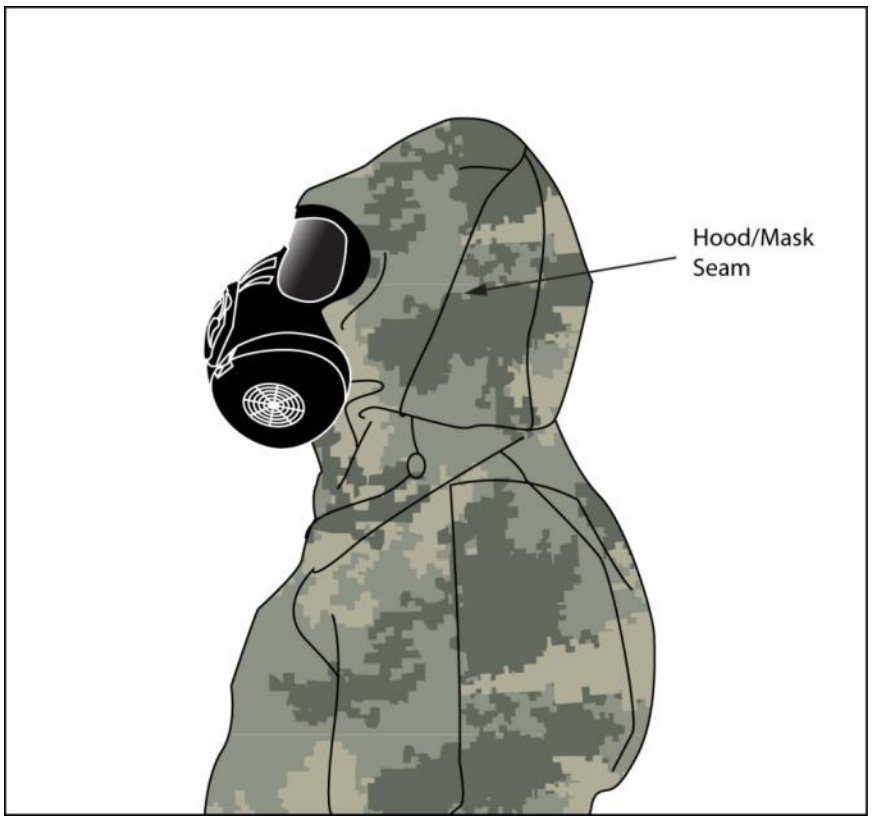

Figure 17. Generation 4 Hood/Mask Seam.

The shell garment is intended to be worn with a separate carbon hood to protect the wearer's face and head from contamination in areas not protected by the mask. An initial design was used during Human Factors evaluation and the first two tests at FAST (see Figure 18). Knitted inserts were used for the third test at FAST to try to cut down on simulant penetration at the temple area. During Contaminated Doffing three different inserts were used; knit, neoprene (see Figure 19) and filled pouches with an additional carbon cord around the opening (not pictured).

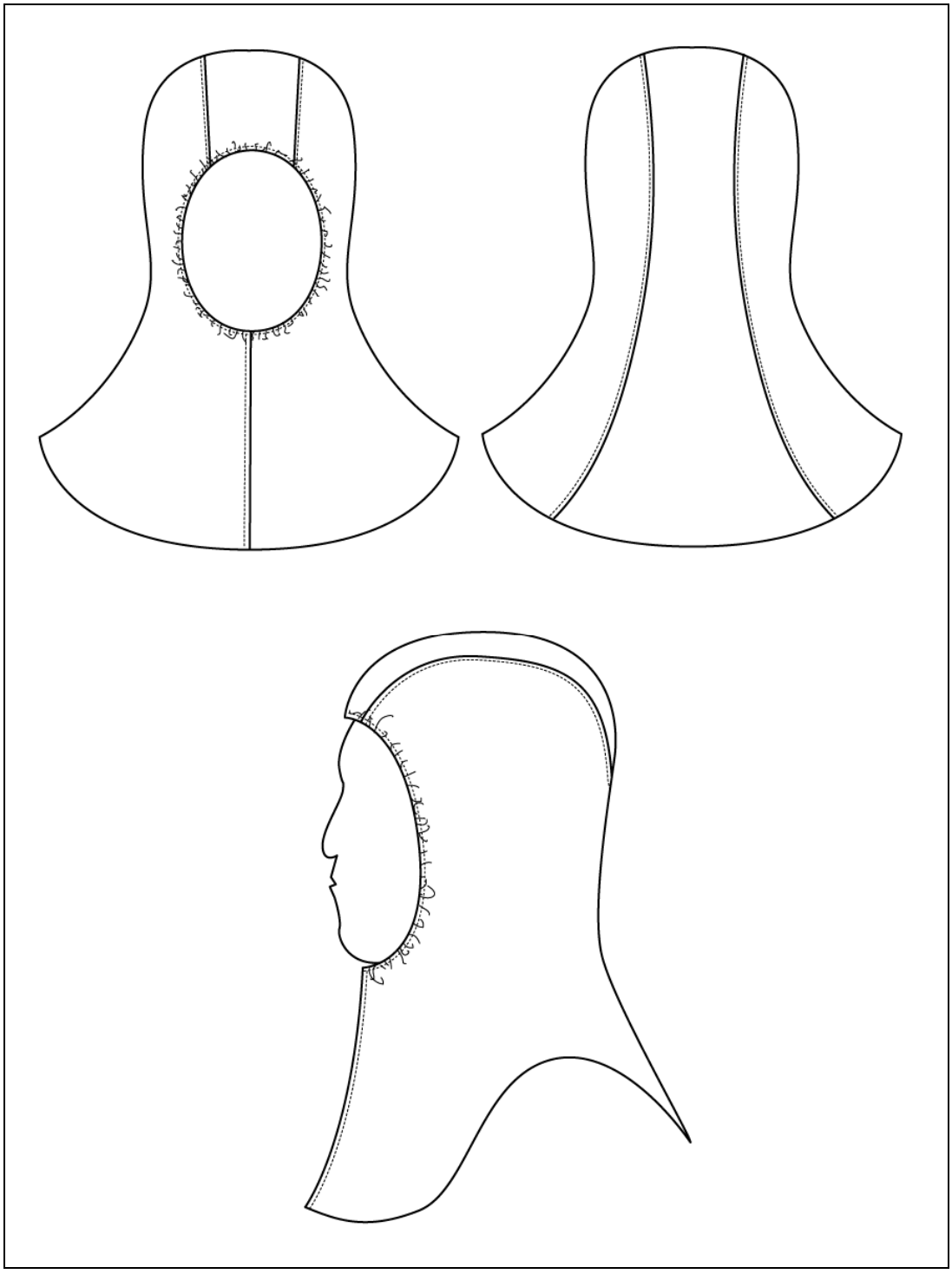

Figure 18. Generation 4 Carbon Hood Flat Sketch.

Photo A Photo B Photo C

Figure 19. Carbon Hood without Modifications (Photo A), with Knitted Insert Modification (Photo B), and with Neoprene Modification (Photo C).

3.3.2 Human Factors Results

During Human Factors Evaluations at NSRDEC, the neck interface breach point that was apparent in the Generation 3 garment under the neck flaps (beneath the chin) was rectified in the Generation 4 garment by extending the center front neck length to reach right under the mask. The addition of elastic on this edge under the chin and new placement of hook-and-loop tape provided an interface in the Generation 4 garment without any place where the researcher at NSRDEC could find a breach like that of the Generation 3 garment. With Generation 4 the test participant still had difficulty closing the hood/mask interface without help of the researcher. Making the closures simpler and more user-friendly was recommended. The researcher found it difficult to achieve and maintain a smooth interface at the neck flaps. GT members have not found achieving a smooth interface difficult—perhaps due to familiarity with the garment. Participants in LEHP 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.)

A snag hazard was brought to the attention of the GT during the NSRDEC Human Factors evaluations; the canister loops protruded while the test subject was not wearing the hood (see Figure 20).

Figure 20. Canister Loop Protruding from Hood.

There was also concern that the wire brim would poke into the wearer's neck when the hood was not donned (see Figure 21). This seemed to pose more of a problem while the test participant was wearing the IOTV, which compressed the neck area.

Figure 21. Wire Brim Poking Neck of Participant Wearing IOTV.

During Human Factors evaluations at Philadelphia University participants' evaluation of the comfort and range of motion of the hood were generally positive. The mean rating for hood comfort was on the comfortable end of the rating scale. However, it was often noted that there was minor restriction in the neck and head area due to the garment's shell. Participants experienced slight restriction while attempting to turn the head side to side. Audible hook-and-loop noise was also noticed while lifting the head up and down.

A few participants at Philadelphia University noted discomfort due to the wire brim's poking into their necks or ears while the hood was stowed. However, a direct correlation cannot be made to the study done by NSRDEC because Philadelphia University does not have access to the IOTV, which seemed to create the most discomfort for this area.

3.3.3 FAST Results

The July 2009 RTI FAST was very enlightening for the GT. Excerpts from the RTI report on this testing are below. For more information about the report results, see Appendix D. The photographs in this subsection are from that report.

The JSGPM was used in all the July 2009 FAST tests. The Test 1[7] hood and mask configuration are shown in Figure 22.

Figure 22. Generation 4 Test 1 Hood/Mask Interface.

Test 1: "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" [Figure 23].

This minor blow-through at the hood/mask interface was similar to that seen with the Generation 3 garment.

[7] In the RTI report, this test is identified as Test 1812.

Figure 23. Generation 4 Hood/Mask Interface FAST Test 1 Results—Clean Head and Neck Except for Deposits on Temple.

Test 2:[8] “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” [Figure 24].

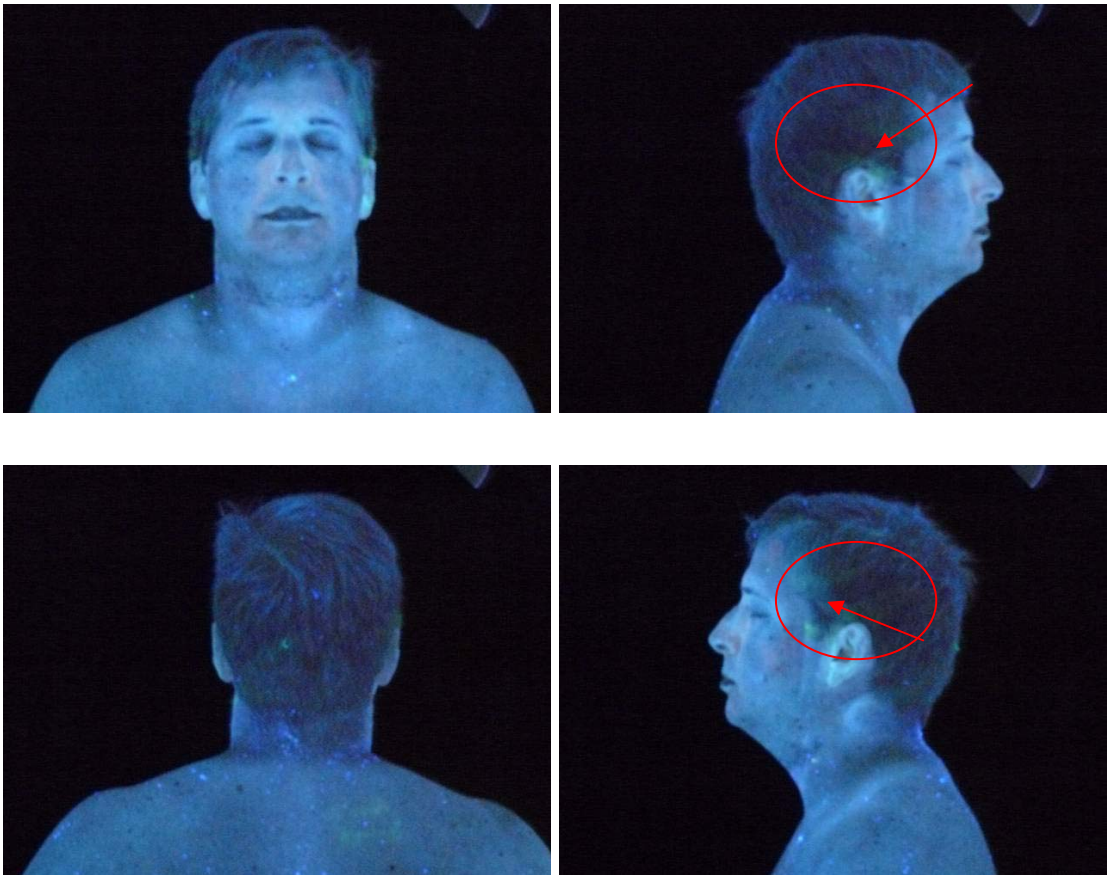

Figure 24. Generation 4 Hood/Mask Interface FAST Test 2 Results—Light Deposits on Sides of Face and Ears.

[8] In the RTI report, this test is identified as Test 1813.

Identical carbon hoods were used in the first two FAST tests. Before the third test small semicircles of rib knit fabric were added at the temples of the carbon hood (see Figure 25) in an attempt to eliminate the contaminant penetrating at the temple area. This addition seemed to help limit the amount of contaminant present on the head, but haze was still present around the ear area (see Figure 26).

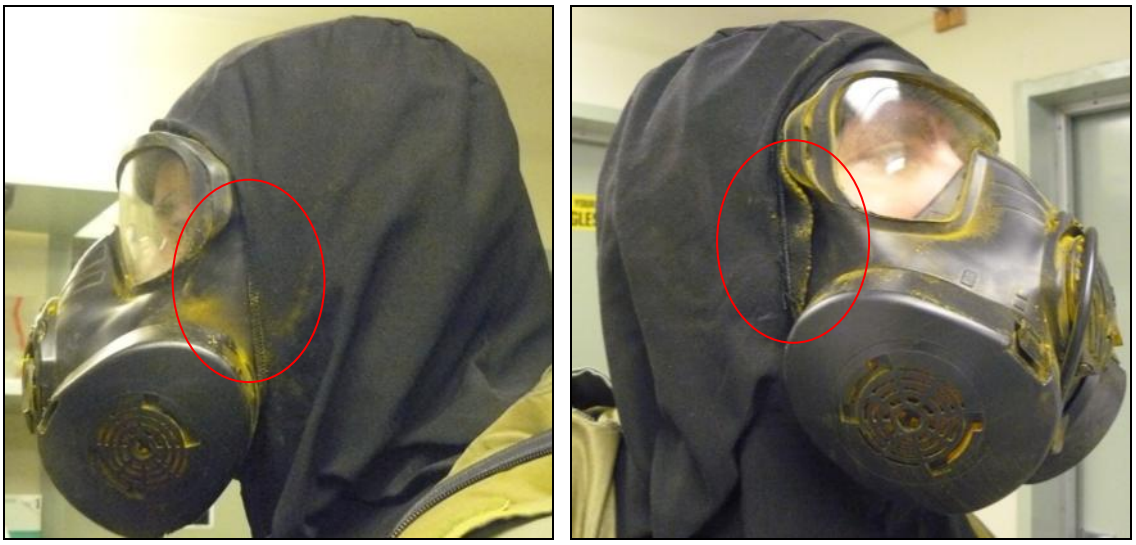

Photo A Photo B

Figure 25. Carbon Hood without Modifications—Tests 1 and 2 (Photo A) and with Knitted Insert Added for Test 3 (Photo B).

Test 3: [9]"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" [Figure 26].

[9] In the RTI report, this test is identified as Test 1814.

Figure 26. Generation 4 Hood/Mask Interface FAST Test 3 Results—Only Light Haze around Ears.

3.3.4 Contaminated Doffing Results

Small amounts of contaminant were found on the head area after going through the doffing procedure. Most of the contaminant showed up on the head as blue smudges from the decon water. In contrast to FAST, during Contaminated Doffing tests the participant is not subjected to exposure of the contaminant for a great length of time, and does not make as many movements while in the chamber, so the bellows effect is lessened. Therefore, significant contamination onto the body was not expected. As can be seen in the report prepared by Hazmat Science Applications (Appendix E), these expectations were justified. The blue decon solution present on the forehead came from one of the assistants bumping his hand against the test participant's head during the doffing procedure. (See Appendix F for LEHP planning notes for Contaminated Doffing evaluation and Appendix G for the procedure used during the evaluation.)

3.4 Articulated Knee and the Knee-Pad Pocket

To provide freedom of movement and offer a better ergonomic design, articulated knees are part of the design of the coverall (see Figure 27). The knee-pad pocket (attached to the outside of the garment so that an extra layer of protection is provided by a removable neoprene knee pad; see Figures 27 and 28) was modified from earlier designs. This integrated pocket reduces the gear burden imposed on the soldier; carrying separate knee pads is not required.

3.4.1 Methods

The knee area was slightly redesigned for the Generation 4 garment to provide more articulation in this area and to expand the range of motion. The knee-pad pocket was lengthened to accommodate wearers of a wider range of heights, and the trouser was narrowed to reduce noise from fabric rubbing while walking.

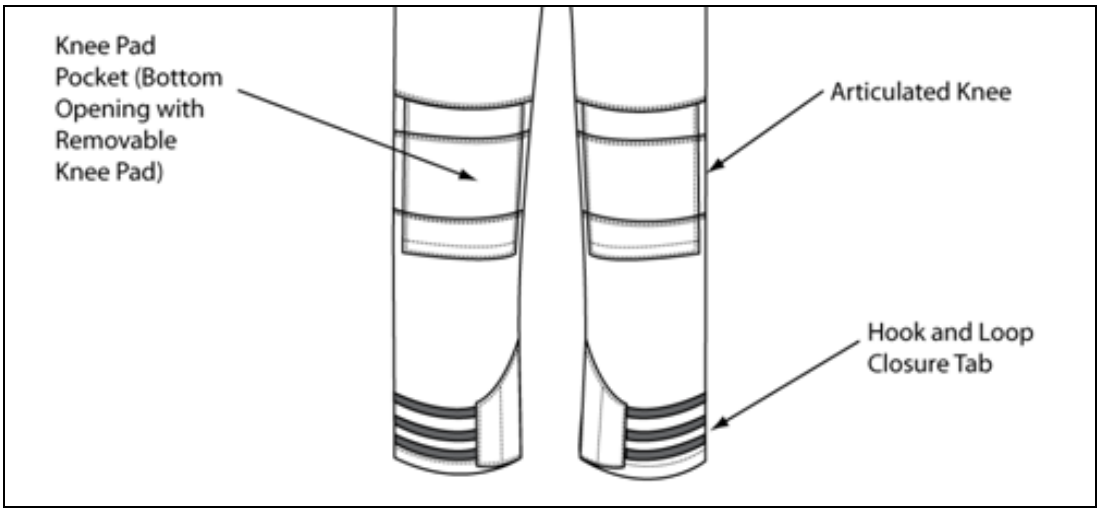

Figure 27. Generation 4 Articulated Knees.

Figure 28. Generation 4 Knee and Knee-Pad Pocket.

Knee-pad straps were added to help control placement of the knee pad to provide additional comfort and protection, as well as to help minimize the noise of fabric rubbing while the wearer walks or runs. These straps also assist with positioning of the knee pad to assure maximum range of motion in leg-lifting movements. The first knee-pad strap design is shown in Figure 29.

Figure 29. Generation 4 First Knee-Pad Strap.

After the first knee-pad strap was attached and evaluated during internal Human Factors, a new system was devised to help cinch the back of the knee more evenly so fabric did not bunch in any one area. The straps were also placed within inside channels to remove the snag hazard the straps posed while exposed.

Figure 30. Generation 4 Final Knee-Pad Strap.

3.4.2 Human Factors Results

Redesign of the knee and knee-pad pocket from Generation 3 to Generation 4 was well received during Human Factors at NSRDEC, but there was some concern that the knee pad was shifting toward the inner knee when the test participant was not wearing an ACU underneath. This feedback and the desire to cut down on any noise from rubbing fabric spawned the idea to add built-in knee-pad straps. The garment was not sent back to NSRDEC for new evaluation of this addition but was tested numerous times at Philadelphia University. The conclusion was that the knee-pad straps helped to control the knee pad's placement and reduced the bulk at the knees, which minimized noise while walking or running.

Photo A

Photo B

Figure 31. Generation 4 Before (Photo A) and After (Photo B) Addition of Knee-Pad Straps.

3.5 Articulated Sleeve and Elbow Reinforcement

3.5.1 Methods

To enhance comfort while bending at the elbow, the GT reshaped the elbow, creating a more ergonomic design. In Generation 4 the elbow area reinforcement (introduced in Generation 2) was extended to the shoulder for roll-over protection.

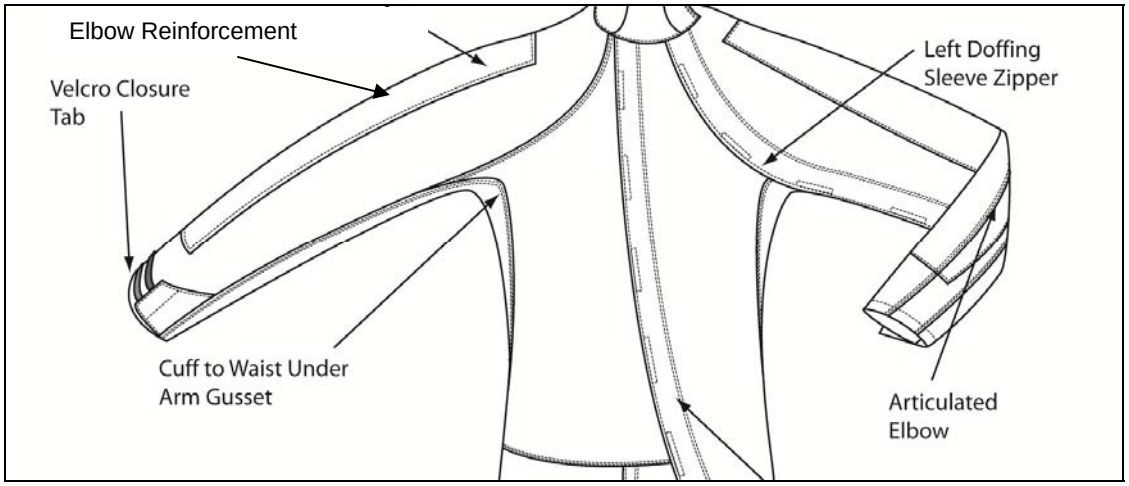

Figure 32. Generation 4 Articulated Sleeve and Reinforcement of Elbow.

3.5.2 Human Factors Results

During NSRDEC Human Factors testing the elbow reinforcement patch was again found to be satisfactory. While the subject is in the prone position, low crawl, or high crawl, the elbow

reinforcement patch is positioned correctly on the body. This elbow reinforcement patch was positioned well in Generation 3, so no changes were made in Generation 4.

3.6 Waist Belt and Torso

To accommodate a range of sizes and to prevent the crotch and knee of this roomy garment from hanging too low, a rear waist cinch (made of shock cord) was used in Generations 2 and 3. The cinch was positioned internally to reduce visible detection and eliminate snag risk.

However, the waist belt in these generations did not provide an adequate, comfortable method for drawing in the waist. Between Generation 3 FAST tests, a wide elastic belt was inserted in place of the shock cord.

3.6.1 Methods

Because of the favorable response to the wide elastic belt added during the third FAST evaluation on the Generation 3 garment, the elastic belt system was basically unchanged for the Generation 4 garment. The only enhancement was adding corresponding VELCRO patches on the inside of the garment so the belt can be worn in a relaxed position.

The elastic adjustable (hook-and-loop) internal belt (see Figure 33) not only provides waist-position control, but it also supports the garment in a partially doffed position that could be used to reduce heat during lower threat/downtime.

Figure 33. Generation 4 Waist Belt.

As a result of Philadelphia University Human Factors observations of Generation 3, in Generation 4 the garment's torso length was reduced by two inches to improve the wearer's walking, bending, and kneeling mobility. During all Human Factors evaluations, no discomfort was reported from this shortening of the torso.

3.6.2 Human Factors Results

During March 2009 Human Factors evaluation at NSRDEC it was noted that, "Unlike prior HFE evaluations of coverall style garments, no TP reported a baggy crotch, despite differences in [TP] torso and leg lengths. Furthermore, the waist adjustment was easy to use and comfortable to wear" (see Appendix A).

The waist belt helps to accommodate a wider range of sizes in the garment because the belt allows the wearer to secure the garment at the appropriate place on his body, thus preventing a low-hanging crotch and restriction of movement while bending the knees. (This problem had been experienced in prior generations before the addition of a waist belt.)

Test participants during Philadelphia University Human Factors trials noted that although the waist belt helped to keep the crotch and waist in the correct place, the belt was often pulled up too high on the torso due to lifting the arms over the head. Readjusting the belt was necessary after completing a task that required this motion. Because protective vests were not available to Philadelphia University at this time, it is unknown if a vest worn over the garment would prevent the belt from shifting upward during arm movement.

3.6.3 Contaminated Doffing Results

Test assistants suggested offsetting the hook-and-loop belt opening to the left to correspond better with the asymmetric front zipper opening. The belt was shifted in the garment, and the belt proved to be easier to open when it was closer to the front zipper opening.

3.7 Asymmetric Front Zipper and Left-Sleeve Doffing Zipper

The zipper opening in a protective garment plays a vital role in how successfully the wearer is able to doff the garment when it is contaminated. Therefore, the GT tried to design an innovative "peel off" system that would simplify the doffing procedure.

3.7.1 Methods

As with earlier generations, in Generation 4 an asymmetric front zipper was placed into the garment; the zipper begins to the right of center front at the neck and ends at the left mid-thigh (see Figure 2). The zipper is a water-resistant YKK coil zipper (YKK URETEK Part# CT40L-86-DABL E 5/8) that is covered by an outer flap of the shell material with hook-and-loop fastener tape closures.[10]

[10] The GT investigated waterproof and other water-resistant zippers from YKK and Riri, but concluded that the water-resistant YKK zipper used for earlier generations was appropriate for this generation, which is a permeable system and does not require a waterproof zipper. The zipper used in earlier generations proved to be satisfactory in HF and other evaluations.

A left-sleeve doffing zipper was used again; it begins at the left neck seam and continues down the left sleeve, ending between the elbow and the wrist. Like the front zipper, this sleeve zipper is also covered with a shell material flap and with hook-and-loop closures.

3.7.2 Human Factors Results

During NSRDEC Human Factors evaluation (see Appendix A) researchers noted that test participants almost always forgot to use the left-sleeve doffing zipper when removing the garment. The evaluators mentioned that the sleeve zipper might not be necessary. The GT notes that the sleeve-doffing zipper has been reported to be very useful while doffing the garment when contaminated; opening the zipper is not necessary when the garment is not contaminated.

No discomfort caused by these doffing zippers was reported during any Human Factors testing or outside testing at FAST or Contaminated Doffing.

3.7.3 Contaminated Doffing Results

Test participants liked the style of the zippers, and especially the way the sleeve zipper allowed the user to peel the garment off. Participants expressed their belief that the sleeve zipper helped them avoid brushing the contaminated side of the garment against their bodies and against the carbon suit. No penetration of contaminant simulants onto the body was noted along the zipper lines.

3.8 Field-Relief Zipper

In a coverall style garment a field-relief zipper is essential to the wearer's comfort as it eliminates the need to take off all gear and the entire ensemble to relieve oneself.

3.8.1 Methods

A two-way water-resistant zipper was implemented in the very first prototype and has remained virtually unchanged throughout the design process. The zipper begins at waist level at center front and ends at waist level at center back (see Figure 34). A flap of shell fabric protects the zipper from the outside. A corresponding zipper was placed on the carbon bodysuit as well to facilitate field relief.

The field-relief zipper in the coverall is YKK URETEK Part# CT40L-86-DABL E 5/8. The field-relief zipper in the carbon bodysuit is YKK continuous coil zipper size #5.

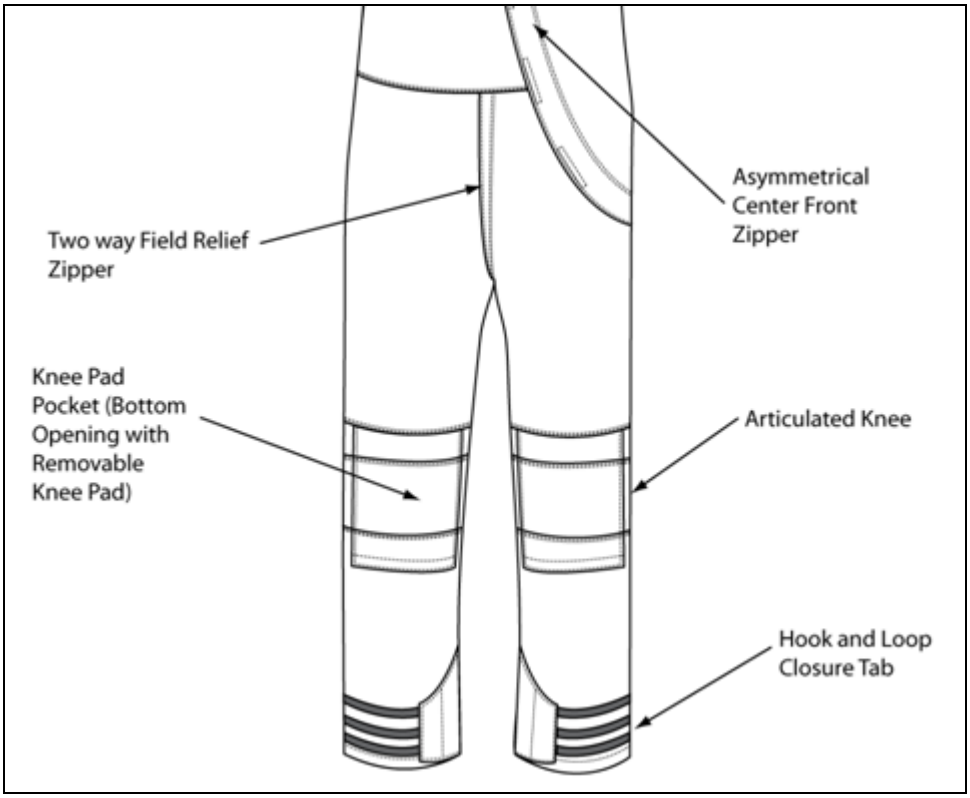

Figure 34. Field-Relief Zipper.

3.8.2 Human Factors Results

During NSRDEC Human Factors evaluation the researcher found that the carbon undergarment and the shell garment zippers correspond well with each other but if an ACU or even just personal underwear were worn with the garments, using the opening created for solid waste relief would be very difficult (see Appendix A). No discomfort was reported from this zipper.

3.9 Closures

3.9.1 Methods

Closures, in particular zippers, must address a number of challenges. Where closures marry at least two fabrics and where these openings must be backed by carbon interfaces, the GT had to consider a number of issues: performance against chemical agents, flexibility, price point, ease of use (opening and closing), availability (in stock or special order), closure placement (center front vs. off to the side, pit-zip venting, etc.), and applications in manufacturing (welded, stitched, flap over), and integrity of seal. The latter issue was of particular concern in the RTI FAST testing. During the development of the Generations 1 through 3 garments many zipper closure systems were investigated, and the GT found that a YKK water-resistant zipper worked best for its needs and thus continued to use the same type of zipper for the Generation 4 garment.

To facilitate the use of the zipper while wearing gloves, as is commonly necessary with this type of garment, the GT placed a zipper grab tab at the termination of the zipper on the left front thigh to give the wearer an anchor point to hold onto while pulling the zipper to the neck.

Figure 35. Zipper Grab Tab.

3.9.2 FAST Results

During FAST orange simulant was noticed in the zipper teeth on the front and sleeve zippers. It did not appear that any of the simulant penetrated through the zipper onto the carbon undergarment.

3.10 Shoulder Stabilizer Strap and Hood Retention Flap

3.10.1 Methods

During a September 2007 visit to Cherry Point Marine base the Generation 3 garment was shown to a group of Marine fliers. During a gear-donning demonstration and discussion, uniform shoulder displacement of the current Marine-issued flight suit was seen to result from gear straps. The GT designed an internal shoulder mesh / elastic stabilizer strap for Generation 4 (see Figure 36). This feature was intended to control the garment's position on the shoulder, resisting shoulder slide-off caused by gear straps, and preventing the resulting restriction of head movement. Incorporating elastic into this addition helped to prevent any movement restriction.

A hood retention flap was also added in Generation 4 to keep the hood out of the wearer's way when it is not required.

Figure 36. Generation 4 Shoulder Stabilizer and Hood Retention Flap.

3.10.2 Human Factors Results

At NSRDEC Human Factors it was noted that the shoulder stabilizer strap was self-adjusting, which is a plus, and the test participants did not notice any discomfort due to this addition.

The hood retention flap added in Generation 4 proved to be useful in restraining and stowing the hood while the test participant wore the garment without the hood donned.

3.11 Costing

3.11.1 Methods

To produce an estimated cost, the GT capitalized on the multiple garments production for FAST, Contaminated Doffing, and MET testing on the articulated manikin. During the small-scale production for the Generation 4 prototype shell, each sewing operation was timed at the local company that manufactured Generation 4 garments for LEHP.

3.11.2 Results

Having added the total minutes for the sewing operations, the GT estimates that two hours and fifty minutes are required to complete the Generation 4 coverall shell. At $15 per hour the price for labor costs would be $42.50. However, fabric is often the most expensive part of this type of garment.

The following fabric utilizations were found by making a paper marker by hand. (The patterns were not yet digitized into the Gerber system.)

- The Generation 4 shell requires 4.5 yards of 60-inch-wide fabric.
- The tight carbon bodysuit requires 3 yards of 50-inch-wide fabric.
- The loose carbon bodysuit needs 3.33 yards of 50-inch-wide fabric.

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

Producing the Generation 4 shell would cost a total of: $191 (excluding fastener and thread costs).

$42.50 + (4.5 x $33) = $191

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

$7.50 + (3 x $10.39) = $38.67

An estimated total cost for the Generation 4 garment shell and carbon ensemble would be about: $229.67 (excluding fastener and thread costs, manufacturer's overhead and markup, etc.). Costs in a large-scale production environment are estimated to be lower than that found in this limited production run.

4. Conclusions

4.1 Fabric

Fabric 63A was preferred for the undergarment fabric by test participants; this finding was confirmed by internal testing and the regression analysis of comfort factors.

4.2 Dual-Layer System

The dual-layer system was key to the great success experienced at Contaminated Doffing. Of the two styles of undergarments presented, test participants preferred the tight carbon bodysuit rather than the loose carbon bodysuit.

4.3 Hood/Mask Interface

The hood/mask interface was significantly improved over time; continuing spiral development of this interface led to many novel design ideas and improvements in protection. Increased protection at this vital interface was documented through FAST and Human Factors evaluations. Though this interface has seen many improvements, it continues to be an area of focus for maximum protection, comfort, performance, and achievement of a snug fit, especially at the contours such as the temple and forehead areas.

4.4 Articulated Knee and Knee-Pad Pocket

The newly reshaped articulated knee was well-liked by test participants. Addition of the knee control straps helped to control the knee pad position on the wearer, and reduced fabric rubbing and friction noise from movement.

4.5 Articulated Sleeve and Elbow Reinforcement

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

4.6 Waist Belt and Torso

The newly designed elastic waist belt proved to be successful in holding the shell's knees and crotch in the appropriate places on the body and for positioning the waist on various wearers' torsos. The elastic waist belt also helped to eliminate any restriction of movement that would result from the garment's crotch hanging low while the wearer tried to lift his knees or climb.

4.7 Asymmetrical Front Zipper and Left-Sleeve Zipper

Design of the asymmetric front zipper and the left-sleeve zipper continued to be well received during Human Factors trials and during Contaminated Doffing. Zipper placement remained mostly unchanged during the prototype generations because of the favorable earlier design that carried through.

4.8 Field Relief Zipper

The double-ended field relief zipper has been a successful design feature throughout the entire project. It has generated positive responses during Human Factors evaluations and remains largely unchanged through the multiple generations of garments.

4.9 Closures

For purposes of the LEHP garment a YKK water-resistant coil zipper was found to be satisfactory for all the zippers located at the front, the left sleeve, and the crotch (for field relief).

4.10 Shoulder Stabilizer Strap and Hood Retention Flap

The shoulder stabilizer was found to be self-adjusting and, thus, easy to use. The hood retention flap was able to restrain the hood in instances when hood was in the stowed position.

5. Recommendations

Following are recommendations of the GT based on comprehensive testing of the Generation 4 garments, together with the design and scheduled testing of Generation 5 and subsequent LEHP generations.

1. Create a two-piece ensemble exploring both fixed and removable hood systems.

2. Conduct the following tests on garments:

    a. FAST at RTI to provide information on aerosol blowthrough penetration at interfaces such as wrists, ankles, hood/mask, and zippers while motion routines are performed in a controlled environment.

    b. Contaminated Doffing at Hazmat Sciences to provide information on contaminant transferred onto the body during the doffing of the contaminated garment. This is an important test as it validates the design of the garment system and ensures a clean removal of the garment after exposure to contaminants.

    c. Protection Factor testing at Edgewood Chemical and Biological Center to provide data feedback on the impact of the garment system hood/mask interface on the integrity of the seal of the mask.

    d. 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 the wearers to perform discrete and mission-relevant movements. This evaluation also provides for observation of ease of donning and doffing.

3. Produce multiple garments for field testing using multiple human participants to provide feedback on all areas of concern noted throughout the report. Field testing would be conducted with NSRDEC's concurrence and involvement if funding (whether from LEHP and/or NSRDEC) permits.

4. Continue to investigate developmental and commercial fabrics available in the industry (including those developed jointly with LEHP), as well as their acceptability in future garment designs.

This document reports research undertaken at the U.S. Army Combat Capabilities Development Command Soldier Center, Natick, MA, and has been assigned No. Natick/TR-22/009 in a series of reports approved for publication

6. References

Brady, Janet. *Consolidated Data on Fabric Construction*. Technical Report PHILA-LEHP-ME-TR-08-02. Philadelphia, PA: Philadelphia University Laboratory for Engineered Human Protection, 2008.

Brady, Janet L. and Stephen S. Hirsch. *Philadelphia University—Laboratory for Engineered Human Protection Final Report—Volume 2 of 8: Materials Evaluations Team.* Technical Report PHILA-LEHP-FR-09-02. Philadelphia, PA. Philadelphia University Laboratory for Engineered Human Protection, 2009.

Frumkin, Steven, Kristen Hultzapple, John Venafro, Celia Frank, Stephen Hirsch, Carole Winterhalter and Scena Proodian. *Use of Innovative Technologies in Protective Clothing Design.* Technical Report PHILA-LEHP-GT-TR-08-01. Philadelphia, PA: Philadelphia University Laboratory for Engineered Human Protection, 2008.

Frumkin, Steven, Kristen Hultzapple, John Venafro, Celia Frank, Stephen Hirsch, Carole Winterhalter, and Scena Proodian. *Design and Testing of Chemical/Biological Protective Coverall System, Generations 1–3*. Technical Report PHILA-LEHP-GT-TR-08-02. Philadelphia, PA: Philadelphia University Laboratory for Engineered Human Protection, 2010.

Garment Requirements Document (GRD) for the Joint Protective Air Crew Ensemble (JPACE), Chemical Protective Coverall (CPC) with Lining. N00421-02-D-31401. March 2005.

Sztandera, Les. M. "Identification of the Most Significant Properties Influencing Tactile Fabric Comfort Using Regression Analysis." February 2009. *WSEAS Transactions on Computers*. Issue 2, Volume 8. 302–311.

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Appendix A

Reprint of *Final Test Report: Limited Human Factors Evaluation of the LEHP Chemical Biological Protective Garment—Generation 4 Prototype—March 30, 2009*

Reprint starts on next page.

FINAL TEST REPORT:
LIMITED HUMAN FACTORS EVALUATION OF THE
LEHP CHEMICAL BIOLOGICAL PROTECTIVE GARMENT --
GENERATION 4 PROTOTYPE

Submitted to:
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March 30, 2009

UNCLASSIFIED

EXECUTIVE SUMMARY

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 the Natick Soldier Research, Development and Engineering Center (NSRDEC), Materials and Defense Sciences Division. LEHP has worked iteratively, creating, assessing, and refining prototypes based upon human factors assessment, thermal properties assessment, FAST testing and contaminated doffing evaluation. The most current design, referred to as the Generation 4 prototype concepts, features an outer shell design constructed identically in six fabrics; plus four carbon-based undergarments, two constructed according to one design and two constructed according to another, to address different usage concepts. The objective of the current evaluation was to perform human factors assessment on a designated *subset* of six shell-undergarment combinations. The evaluation was performed by a member of NSRDEC's Ergonomics Team during November, 2008.

Methodology

Two active duty Soldier-Subjects wore each ensemble in the Human Systems Integration (HSI) Laboratory at NSRDEC while donning to Mission Oriented Protective Posture (MOPP) levels 2 and 4. At each level, they performed activities to simulate ground Soldier tactical movements and tasks. Approximately 1.25 hours was spent in each ensemble by each Subject over the course of 2 back-to-back days, per Subject. Through a combination of tester observations of performance, spontaneous Subject comments, and self-report surveys, each ensemble was assessed according to (1) thermal comfort (based on limited wear times and non-rigorous activities), (2) fabric comfort, (3) physical comfort and fit, (4) range of motion, (5) ease of use to include donning and doffing, (6) protective interface with CB footwear, hand wear, and head gear, (7) compatibility with standard ground Soldier military gear, (8) safety, and (9) Soldier acceptability and preferences. On December 11th, 2008, a preliminary summary of the HFE results was presented in briefing format to LEHP garment designers and other project stakeholders. One Soldier who had participated in the evaluation and a second Soldier recruited for this briefing were present to model the garments, perform movements as requested, and answer the designers' questions. This report expands upon that briefing in text format.

Findings

1. Changes made to the shell design since the ensemble was last evaluated at NSRDEC made a positive difference from the human factors perspective. For reference, the prior evaluation was reported July, 2007, in Primary Findings from the Human Factors Laboratory Evaluation of LEHP *Upgraded* 2nd Generation Prototype, (Karla Allan). Changes to the design since then, are:
    - Redesign of neck interface has eliminated a breach point
    - Redesigned waist adjustment band is effective at holding the trousers at a comfortable and appropriate level of choice per wearer. As a result, no baggy crotches or restriction in lower body or torso movements were observed.

- The redesigned shoulder stabilization mechanism was effective at holding the ensemble in place while Subjects donned and doffed heavy military gear at the shoulders.
- Lengthening the articulated knees and knee pad coverage provided value added, though further attention to this feature may be warranted. When the duty uniform and blousy style undergarments were worn beneath the garment shell, the knee pads cushioned the knees in every position examined. When the shells were worn over a long underwear style garment and no ACU, the trousers hung differently and the knee pads turned noticeably inward towards the groin. For some activities, though not the most critical ones, this resulted in the Subjects' knees being partially on and partially off the kneepads or their outer knee cap aligning precisely with the outer edge of the kneepad.

2. Findings for each assessment area are summarized, below.
   (1) Thermal Comfort: The temperature in the laboratory was between 60 and 70 degrees Fahrenheit at all times. At this range, Subjects reported feeling "Slightly Uncomfortable" with respect to heat, though some systematic differences were observed. Subjects rated more discomfort at MOPP4 than at MOPP2, more discomfort in MOPP4 with military gear than without it, and more thermal discomfort in the blousy undergarment style configuration (includes the duty uniform) compared to the long underwear undergarment configuration (duty uniform not worn). Similarly, more sweating was reported in MOPP4 than in MOPP2 and while wearing the blousy undergarment configuration compared to the long underwear configuration.
   (2) Fabric Comfort: Based on ratings and comments, fabric comfort was positive. At the conclusion of wear, per configuration, Subjects rated fabric comfort on a scale with 1= Extremely Uncomfortable and 5= Especially Comfortable. For both Subjects, all undergarments and shells received a rating of 4 "No Discomfort" with the exception that one Subject rated the fabric of Undergarment 96X as being Especially Comfortable.
   (3) Physical Comfort and Fit: Fit was excellent and comfortable for both Subjects with one exception: one of the Subjects, who had an especially large neck base circumference (greater than 99th percentile for Army Soldiers) reported tightness and discomfort at the neck in every ensemble.
   (4) Range of motion: There were no restrictions attributable to the LEHP ensemble over a variety of movements and tasks involving the head and neck, torso and shoulders, and lower body.
   (5) Ease of Use/Donning and doffing: Donning was easy and achieved quickly but Subjects did not like having to remove and then re-don their duty boots to dress to MOPP4 in an emergency scenario. Doffing each component of the ensemble was easy. The garment hood rollback mechanism – intended to store hood and neck panels out of the way when in MOPP level 2 -- was easy to use and effectively held the *hood* in place, but was less effective and efficient for use with the neck panels.
   (6) Protective interfaces: It was difficult for wearers to achieve smooth interface at neck and the non-smooth interfaces achieved by Subjects were frequently breached during movements. Even with help from the Tester, it was difficult to achieve a smooth interface, especially for the Subject with the slender neck (45th percentile). Protective

interface was easy to accomplish and well-maintained at wrists. At the ankles, it was challenging to achieve the appropriate degree of snugness at the closure, often resulting in a trouser leg on the outer garment that rose during movement and did not fall back down again.

(7) Compatibility with military gear: An incompatibility currently exists between the fielded duty helmet and the fielded CB protective ensemble for MOPP4: the helmet sits too high and does not seat securely on the head due to the upper edge of the CB mask; and because the helmet sits too high, the stabilizing chin straps cannot be fastened. This same phenomenon was observed when the LEHP garment was worn in MOPP4, but the problem is presumed due to the mask, not the garment itself. The LEHP prototype was fully compatible with all other duty (non-CB) items that were featured in the evaluation: duty boots, duty uniform, body armor, rucksack, assault pack, and weapon.

(8) Safety: There is potential snag hazard during MOPP2 from the circular canister cords which are exposed even when the hood is rolled back and fastened at the base of the neck. In addition, all shell garments were noisy, which could contribute to detectability. Based on Subjects' memory, however, the LEHP ensembles are *less* noisy than the current CB protective uniform.

(9) Subjects' acceptability and preferences: Both Subjects would accept and recommend the LEHP Prototype Generation 4 concepts as their CB protective ensemble. They had no strong preference among the shells (which differed only by fabric, NOT by design or fit). Of the two carbon undergarment styles, they clearly preferred the long underwear style. Between the two long underwear garments featured in this evaluation (63A and 96X), they both preferred 63A which they perceived as lighter weight and therefore cooler. Neither of the Subjects had a specific preference for one configuration (shell plus undergarment) over another.

3. The human factors concerns which may require further attention are noted, below:
   - Interface at Neck: Difficult to achieve solo or with assistance from the Tester. If wearer achieves sub-optimal interface, it degrades further during movements.
   - Interface at Ankles: Difficult to determine optimal level of snugness. If wearer fastens closure too tightly, trousers rise up during certain movements and do not fall back into place again. If fastened too loosely, chemical protection may be compromised.
   - Donning: Subjects forgot to cover the very top of the central zipper with its zipper flap nearly *all* the time.
   - Doffing: Subjects usually forget to use the arm zipper when doffing. They both felt that the arm zipper was not necessary for their body type but might be necessary for someone with larger chest or shoulders.
   - Knee pad: It may be necessary to widen the kneepads along all or part of their outer edges.

Recommendations for Further Ensemble Development

1. Continue to enhance neck interface to improve achievability.
2. Eliminate need for wearer to manipulate upper central zipper flap because they cannot remember to do this when donning to MOPP4 level.

3. Further investigate knee pad location when no ACU is worn beneath shell to ensure accommodation for critical infantry tasks and seek accommodation for any tasks where knees are pressed to the ground.
4. Consider garment stowage approach that will protect hood shape.
5. Redesign mechanism for holding neck panels out of the way during MOPP level 2:
6. Since the outer shell has the capacity to be donned over the duty boot, and the blousy undergarment is intended to be attached to the outer shell, redesign undergarment trouser so that it, too, may be donned over the duty boot.
7. Re-evaluate selected human factors issues after the blousy undergarment is attached to shell. Donning and doffing concepts and movements will be different because the Soldier dons one garment to achieve CB protection instead of two.

TABLE OF CONTENTS

TEST REPORT:
LIMITED HUMAN FACTORS EVALUATION OF THE
LEHP CHEMICAL BIOLOGICAL PROTECTIVE GARMENT,
GENERATION 4 PROTOTYPE

1. INTRODUCTION

1.1 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. LEHP has worked iteratively, creating, assessing, and refining prototypes based upon human factors assessment, thermal properties assessment, FAST testing and contaminated doffing evaluation. The most current design, referred to as the Generation 4 prototype, features an outer shell replicated in multiple fabrics (four shells of different fabrics were featured in this evaluation); it also features two styles of carbon-based undergarment, with each style produced in two fabrics for a total of four undergarments featured in this evaluation. Out of a total of 16 shell-undergarment possible combinations, six were selected by the garment designers to undergo human factors assessment. To emphasize this point, every shell was NOT combined with every undergarment, per the wishes of the garment designers. Instead, they carefully selected six combinations that would provide the information they sought.

1.2 Objective

Conduct an initial human factors assessment of six prototype CB protective garment configurations developed by LEHP

1.3 Scope of Assessment

A major objective of LEHP is to enhance wearers' physical and thermal comfort. These human factors dimensions were assessed within the constraints of a short wear-time laboratory evaluation that did not include rigorous physical activity or controlled temperature conditions. Another important focus of assessment was compatibility of the Generation 4 prototype with ground Soldier military gear which is available at NSRDEC but not to the garment designers. Other standard human factors dimensions were assessed as well for a total of nine dimensions, as follows:

(1) Thermal comfort
(2) Fabric comfort
(3) Physical comfort and fit
(4) Range of motion
(5) Ease of use/donning and doffing
(6) Protective interface with CB footwear, hand wear, and head gear
(7) Compatibility with standard ground Soldier military gear
(8) Safety
(9) Soldier acceptability and preferences

In the process of assessing the ensemble from these perspectives, the tester kept a special eye on the effectiveness, from an HF perspective, of recent design changes made to the prototype.

2. METHODOLOGY

2.1 Test Items: LEHP Shells and Undergarments

As indicated above, the Generation 4 concepts involve a CB protective carbon-based undergarment worn beneath a shell overgarment. The shell is a one piece, jumpsuit style. It incorporates a hood designed to fit precisely against the temples and cheek areas of the Joint Service General Purpose Mass (JSGPM). Neck closure panels on the jumpsuit provide protective coverage on the front and sides of the neck and overlap the edges of the mask at the lower jaw and chin areas providing coverage at this critical interface between garment and mask. The shell includes hook and loop closures at the ankles and wrists as well as large knee pads placed within leg pockets.

The primary changes to the shell since it was last evaluated at NSRDEC are the following:

1. Redesign of interface at neck with mask
2. Replacing a waist adjustment at the back of the shell with a fully encircling waist belt
3. Redesign of shoulder stability mechanism inside the upper back of the shell
4. The articulated knees have been lengthened and narrowed.

Four shells of identical design but constructed from different fabrics were assessed during this evaluation. The fabric treatment of each shell is depicted in Table 2-1, below.

Table 2-1. Fabric Treatment of Garment Shells Evaluated

Shell ID	Aerosol Membrane	Durable Water Resistant	Other/ Notes
61U	-	Yes	Nomex (flame resistant); Oil and water resistant finish
85M	Yes	Yes	Membrane is laminated onto the back
31B	-	Yes	Nyco unlaminated fabric
78C	Yes	Yes	Includes tricot backer to protect membrane

Information describing the complete cloth characteristics of the garment shells and undergarments has been provided by LEHP and is presented in the first table of the Appendix.

LEHP Prototype 4 is actually a family of ensembles that includes two styles of undergarment, each with a different wear concept, as explained in the next two paragraphs.

One undergarment style fits snugly against the body, like long underwear, and is meant to be worn over personal underwear only, in place of a duty uniform. This style has been referred to as the "Carbon Union Suit" by the LEHP, but it is referred to in this report as the "Long Underwear" style in order to capture its defining characteristic. The long underwear garment is

paired with the shell, alone; this system would be employed when CB protective gear is donned in advance of an immediate threat. Two long underwear garments composed of identical design but different fabric are featured in this evaluation.

The other undergarment design is looser and blousier because it is meant to be worn over the Soldier's duty uniform, in situations where time constraints do not permit removing the duty uniform before donning a CB protective system. This style has been referred to by LEHP as the "Loose Carbon Suit", but is referred to in this report as the "blousy undergarment." LEHP future plans call for the blousy undergarment to be tacked to the shell, so that the undergarment and shell will, in effect, comprise a 1-piece system. At the time of this evaluation, however, the blousy undergarment was still separate from the shell, and needed to be donned first and separately from the shell.

A third component of the LEHP Generation 4 prototype is a hood liner which matches, in fabric, the undergarment with which it is worn. The hood liner hugs the scalp and the contours of the JSGPM, forming an extra layer of protection between the mask and the hood of the shell garment. To be clear, the hood liner is not attached to the undergarment.

The LEHP team selected six undergarment-shell combinations to be evaluated at this time. These combinations, referred to herein as configurations, are depicted in Table 2-2, below.

Table 2-2. Configurations Evaluated

Configuration Number	Carbon Undergarment	Undergarment Style	Shell Overgarment
1.	54M	Blousy undergarment	61U *
2.	54M	Blousy undergarment	31B
3.	40C	Blousy undergarment	31B
4.	63A	Long underwear	85M
5.	63A	Long underwear	78C
6.	96X	Long underwear	31B

* This shell is flame resistant (FR). Only FR gloves may be worn with it.

As indicated earlier, information describing the complete cloth characteristics of the garment shells and undergarments has been provided by LEHP and is presented in the first table of the Appendix. The information is grouped by the configuration numbers employed for the evaluation.

Example photos depicting the two undergarment styles, the shell, and the hood liner are seen below.

Blousy Undergarment (54M)

Long Underwear Undergarment (96X)

Shell outer garment (61U)

Hood Liner (40C)

The size of all shells provided for the evaluation was identical, as was the size of all undergarments. The size of the shell resembles the size of the JPACE, size 40, regular length and the undergarment size has been designed to fit the same sized person who wears this shell size. Size prediction charts for JPACE are based on the two body dimensions of height and weight. Specifically, JPACE size 40 is expected to fit an individual of height range 68-72 inches and weight range 185-200. This Tester has past experience with 7 Soldier subjects who wore earlier LEHP prototypes produced in the same size as the garments in the present evaluation. Her records of their "goodness of fit" suggest that individuals of height 69-72 inches and with weights from 163 to 197 have all been well accommodated. Compared to the JPACE size 40 prediction range, the Tester's prediction range for the LEHP is slightly truncated in heights accommodated but encompasses a much larger range of weights accommodated. Due to a small Soldier test pool, the Tester sought individuals for the present evaluation whose body dimensions placed them within this latter, modified range of prediction for the LEHP, since a much larger weight range could be considered.

2.2 Subjects, Location and Schedule

Two Subjects of differing body shapes, but still within range, were sought. Five Active Duty Soldiers from NSRDEC's Human Research Volunteer (HRV) Platoon who met the modified size prediction criteria were screened for fit on the two LEHP ensemble styles (with long underwear undergarment worn beneath shell; with blousy undergarment and ACUs worn beneath shell). From among these five, three individuals found a good fit according to both wearer and Tester; based further upon their availability to participate in the evaluation, two of these individuals were selected to be Test Participants (TPs). Height and weight for the selected individuals is

listed in Table 2-3, below. Body dimensions and goodness of fit for all 5 individuals who were fit-screened are tabulated in the Appendix.

Table 2-3. Height and Weight of Participating TPs

TP ID	Height (inches)	Weight (lbs.)
TP1	71.10	186
TP2	70.39	160*

* TP2 was on record as weighing 166 lbs (in range) when selected for this evaluation, but during the week of evaluation he weighed only 160 lbs (slightly below range).

Both TPs held the Military Occupational Specialty of 11B (Infantry). To avoid the opinions of one TP biasing the opinions of another, evaluation with each TP was conducted separately.

2.3 Duration and Location

Each HRV was scheduled for two, 4-hour blocks of testing on back-to-back days, to facilitate wearing all six prototype garments with as little intervening activity as possible, so that the TPs could remember and make meaningful comparisons between configurations worn. The disadvantage of this approach is that thermal discomfort may be cumulative so that the 3rd configuration worn on one day could, for example, feel hotter than the 1st configuration, when there is no true difference in thermal burden. (The Thermal Comfort paragraph in the Results Section addresses this issue). The alternative of wearing a different configuration every day for six days straight was not an option from a scheduling standpoint. The evaluation took place during November 2008 in NSRDEC's Human Systems Integration Laboratory.

2.4 Assessment Methodology

Sequence of wear for the shell-by-undergarment combinations

To facilitate comparison within undergarment styles, TP1 wore all three blousy undergarment configurations first (Configurations 1, 2, and 3), followed by the three long underwear Configurations (4, 5, and 6). After wearing the first three configurations, the TP was asked to compare them on a number of human factors dimensions. After wearing the second three configurations, the TP was asked to compare among them on the same human factors dimensions. Once all six configurations were worn and comparisons within the second set were made, the TP was asked about his preferences among configuration type (i.e., long underwear versus blousy) and among all shells and all configurations. TP2 followed the same pattern, except that he wore all three long underwear configurations first (4, 5, and 6), followed by the blousy undergarment configurations (1, 2, and 3).

Preliminary instructions and familiarization

Before donning the garment, the TPs received familiarization training with the design features from the Tester who also instructed them on donning and doffing procedures and sequences. Based on a small pilot test already conducted at NSRDEC with one of the Generation 4

configurations, instructional emphasis was placed on achieving proper closure of the neck panels and on remembering to utilize the waist belt.

Sequence of Wear with regard to MOPP levels

Mission Oriented Protective Posture (MOPP) levels 0 through 4, with respect to CB threat are specified by Army doctrine. At MOPP level 0, CB gear is not worn but it is carried.

MOPP level 2 refers to a protective posture of partial enrobement in CB gear and readiness to move to total encapsulation. At MOPP level 2, Soldiers wear their CB overboots and their CB garment, but they are permitted to leave the CB garment open on the chest or at the collar area. They carry their mask/respirator on a sling strap or attached to their duty uniform or garment.

MOPP level 4 refers to the totally protective posture of complete encapsulation. At MOPP level 4, Soldiers wear CB footwear, CB garment, CB mask, CB mask-garment interface (if this is a separate item, such as a hood), and CB gloves.

CB garments are worn most frequently in either MOPP level 2 or MOPP level 4. In this evaluation, LEHP prototype configurations will receive human factors assessment at both levels, and donning and doffing transitions between levels 0, 2, and 4 will be observed.

Each TP performed six basic steps during which human factors information was collected. These steps were:

1. Don from MOPP0 to MOPP2 (and don military gear)
2. Perform movements and tasks in MOPP2
3. Don/transition from MOPP2 to MOPP4 (and re-don military gear)
4. Repeat movements and tasks performed in MOPP2
5. Doff to MOPP0
6. Don from MOPP0 to MOPP4, without military gear.

CB Protective Accessories

The CB protective accessories donned and worn in addition to the LEHP ensemble are listed in Table 2-4, below. Please note that each listed item is fielded and worn currently with the Joint Service Lightweight Integrated Suit Technology (JSLIST) – Type II. (Type II signifies an attached hood).

Table 2-4. CB Protective Accessories Worn during the Evaluation

Category & Item	Full Name or Details	When was it Worn?
Mask Carrier	Contains mask	Worn in MOPP0 through MOPP4. Worn around the leg, with a stabilizing belt at the waist or hip
Boots -AFS	Alternate Footwear Solution	MOPP2 through MOPP4
-BVOs	Black Vinyl Overboots	MOPP2 through MOPP4
Mask/Respirator	Joint Service General Purpose Mask (JSGPM) A.K.A. XM50	MOPP4 only
Handwear -JB1GU FR	JSLIST Block 1 Glove Upgrade, Flame Resistant*	MOPP4 only
-JB2GU non-FR	JSLIST Block 2 Glove Upgrade, Non-Flame Resistant**	MOPP4 only. Only with flame resistant CB garments.

* Flame resistant glove consists of a crinkly, CB protective liner and an outer glove for flame resistance.
** Non flame resistant glove consists of a cotton sweat liner and a butyl CB protective glove.

Military gear utilized during evaluation

An important aspect of the human factors evaluation was to assess compatibility of the LEHP prototype with military gear commonly used by a ground Soldier. Table 2-5, below, lists the military gear worn or carried and utilized during the evaluation activities. All items are applicable in MOPP2 and MOPP4 and were, therefore, worn or carried and utilized during activities at both MOPP levels.

Table 2-5. Military Gear Used for Compatibility Assessment

Category & Item	Full Name/Details
Body Armor	Improved Outer Tactical Vest (IOTV). This is the most recently fielded body armor system for ground Soldiers (see photos, below).
Rucksack	Large back pack – contents are meant to sustain a Soldier for multiple days in the field (change of clothing, sleeping roll, etc). Balanced and weighted to about 40 lbs. for this evaluation and used by TP1. (See photo, below).
Assault Pack	Smaller pack containing tactical items needed to accomplish a mission (balanced and weighted to about 40 lbs. for this evaluation and used by TP2)
Helmet	Advance Combat Helmet (ACH)
Canteen	One 2-quart canteen, carried in outer pocket on rucksack or assault pack
Weapon	M4 rifle (mock)
Ammunition and Grenade Pouches	Pouches (about size of deck of card) that attach to webbing on IOTV to hold ammo (rectangular shape pouch) or grenades (round shape). 2 ammo pouches and 1 grenade were worn on TP2's IOTV.

Front view of IOTV. This photo include the groin protector which was not worn during the evaluation so that leg movements could be more easily observed.

Close-up view of IOTV collar, which is the primary point of interface with the LEHP garment. IOTV is typically pulled on over the head; it can be donned from the side by opening the left shoulder strap mechanism, but this requires more time and more manual dexterity than donning over the head.

Rucksack side view, shows canteen, sleeping roll, and back straps. A frame attached around the waist is sometimes used, but was not available for this evaluation. The Assault pack is similar in shape but shorter in height, and does not include the sleeping roll. The Assault pack has a horizontal strap across the chest to anchor it which was worn during this evaluation.

Range of motion and maneuverability

While wearing MOPP2 plus military gear and while wearing MOPP4 plus military gear the TP performed actions selected to assess range of motion (e.g., bend to touch toes) and ability to execute military-relevant movements (e.g., assume weapons-firing positions). These actions are listed in Table 2-6, below.

Table 2-6. Actions Performed in MOPP2 and MOPP4

Head, Neck, and Bending	Knees and Prone Positions	Upright Actions
1. Head & neck rotations 2. Look left/look right/look back 3. Twist at waist 4. Bend from waist to "adjust" boots 5. Doff back pack, withdraw canteen. Simulate drinking in MOPP4 (via CB adapter cap in canteen and drinking tube in mask).	1. Kneel on both knees 2. Crawl on both knees 3. Kneel-to-fire 4. Perform low crawl with weapon 5. Fire from prone position 6. Access & toss grenade (using prone and kneeling positions)	1. Perform high knee raises 2. Perform climb & reach motion 3. Walk at road march pace 4. Jog across the room and back (about 25 feet each way) 5. Access & toss grenade in upright position

During donning of the configuration and CB and military gear, and during performance of activities, the HF analyst logged her own observations and consistently asked TPs to report in real-time any discomfort, difficulty, or interface breach.

After doffing each configuration for the last time, TPs completed a short questionnaire to assess their perceptions of:

- Comfort with regard to heat, fabric, and sweating
- Snag hazard, perceived safety, and perceived vulnerability/detectability
- Perceptions of fit at distinct body locations and overall
- Ability to perform tasks effectively
- Overall acceptability to the Soldier for performing his mission while wearing the garment in a CB threat environment

After a TP had worn *all* three prototypes of one style (e.g., blousy undergarment or long underwear design) he discussed his preferences with the Tester who noted his response. After a TP had worn all six configurations, he indicated his preference among undergarment styles and shells.

2.5 Results Format

Results have been prepared in two formats: (1) briefing/demonstration conducted on December 11, 2008 and (2) this Test Report. Copies of the slides presented at the briefing are available upon request to Ms. Carole Winterhalter, NSRDEC, who funded this evaluation.

3. RESULTS

The HF findings are grouped into three categories:

(1) Findings particular to the undergarment components of the prototype.
(2) Effectiveness of the recent design changes to the shell component
(3) Human factors findings grouped by human factors dimensions such as thermal comfort, range of motion, safety, etc. These findings apply to all six configurations evaluated.

3.1. Undergarment Components

As a reminder, the two undergarment styles correspond to two concepts of wear. The Blousy Underwear style is meant to support emergency donning *over the ACU*. The undergarment is meant to be attached to the shell as a liner, so that a single garment would be donned in an emergency/urgent situation when there is no time to remove the ACUs. The undergarments were not yet attached, however, at the time of the evaluation, so they were donned and doffed separately. The style is blousy to fit over the ACU and to track with the fit of the outer shell which is worn over it.

The Long Underwear style is meant to be worn *in place of the ACU*, and donned in non-urgent conditions. The shell is worn over it.

Blousy Undergarment Style

Two blousy undergarments were featured in this evaluation, known as 54M and 40C. 54M was worn in Configurations 1 and 2 and 40C was worn in Configuration 3. These garments were identical in size, shape, and design, differing only by fabric. No differences were observed between the two undergarments or between the three configurations with which they were worn. Shell 31B was worn with each of these undergarments plus one of the long underwear style undergarments (96X). It is worth noting that the shell fit both TPs well whether it was worn over the blousy undergarments plus ACU or was worn only over the long underwear garment. The only difference in that case is that the neck area, which felt crowded in all configurations for TP1 once he donned the IOTV, felt more crowded when he was wearing the blousy undergarment style compared to the long underwear style.

54M

40C

Long Underwear Style

Two long underwear style undergarments were featured in this evaluation, and were known as 63A and 96X. They were identical in size, shape, and design features but were constructed of different fabrics. Both undergarments were physically comfortable with regard to fit and fabric, and TP1 found the fabric of 96 X to be "especially comfortable," and said he felt as comfortable as if he were "wearing pajamas." Nonetheless, after wearing the garments for the evaluation activities, both TPs said they would prefer undergarment 63A to 96X because they felt it was lighter weight and expected that it would be cooler, over the long run. The undergarment actual weights were not determined, but to the Tester, the 63A fabric felt clearly thinner than the 96X fabric.

63A

96X

3.2 Recent Design Changes

Four design changes have been made to the shell component of the LEHP prototype since the NSRDEC Ergonomics team last evaluated it in July 2007. The results of each design change, from a human factors perspective, are indicated below.

(1) Neck: Redesigned garment-mask interface

In the prior design, with the protective neck flaps closed, the Tester could insert her finger about 1.5 inch at the left side of the neck and touch the bare skin of the wearer. (See photo at right, of former prototype.) This breach point has been eliminated, while keeping a similar neck closure design requiring overlapping neck panels drawn snugly from each side of the neck and attached by hook and loop at the right side of the neck.

Breach point in PRIOR prototype
(Has been eliminated)

The photos below show the LEHP Prototype 4 neck interface, in a fastened position. It was difficult for TPs to achieve a smooth layering of the panels and a secure fastening of the hook and loop. Even for the Tester, it was difficult to achieve a smooth interface on the more narrow neck of TP2. The photos below show fastened neck interfaces for TP1 (left photo) and TP2 (middle photo). Both interfaces look secure from the front view, but the right most photo of TP2 shows that his outer flap had a large overhang for which there was no attachment hook appropriately located. For reference, neck base circumference for TP1 was 19.21 inches, greater than 99th percentile of U.S. Army Soldiers. Neck base circumference for TP2 was 15.98 inches, equivalent to the 45th percentile for U.S. Army Soldiers. (All measurements were performed by members of NSRDEC's anthropometrics team and the percentiles are based upon the U.S. Army ANSUR data base, Gordon et. al., 1988).

TP1, large neck, > 99th pctile
(Config 6: 96X +31B)

TP2, small neck, 45th pctile
(Config 4: 63A + 85M)

(2) Waist: Replaced waist adjustment at back of shell with fully encircling waist belt

The new waist belt is an effective enhancement to overall fit. It allows the wearer to determine the length of his trousers and where to make the division between the torso of the garment and the lower half of body. Unlike prior HFE evaluations of coverall style garments, no TP reported a baggy crotch, despite differences in torso and leg lengths. Furthermore, the waist adjustment

was easy to use and comfortable to wear. For the first 3 to 4 donnings the TPs needed reminding to use waist belt, but after that they remembered on their own.

(3)Upper back: Added a shoulder stabilization mechanism
An elastic band was placed inside the shell at the upper back to keep the ensemble in place when donning or doffing equipment to/from the shoulders. This is referred to as the shoulder stabilization mechanism and results show that the CB ensemble consistently remained in place when TPs donned and doffed the IOTV (15 lbs.), and the rucksack or assault pack (each 40 lbs.) Over 12 donnings per TP of the IOTV and 12 donnings of either the rucksack or the assault pack, per TP, the CB garment moved substantially out of place and required readjustment only one time. This occurred when TP1 donned the IOTV over Configuration 6 while in MOPP2. The shoulder stabilization mechanism is user-friendly in that the adjustment occurs automatically during wear, with no pre-donning preparation required. The Tester would call this a positive "Sleeper" item: Warfighters are unaware of its existence, but it is working for them.

(4) Knees: Lengthened and narrowed
TPs performed four activities designed to determine – among other things – whether the lengthened and articulated knee area provided knee protection and comfort. These activities (listed in the Methods Section) are (1) kneel on both knees, (2) crawl on both knees, (3) kneel and fire, and (4) perform low crawl with weapon. For all of these activities, knee pad length was sufficient and ample. Some concern arose over kneepad width or lateral positioning when TPs kneeled and crawled in Configurations 4, 5, and 6 for which no ACU is worn beneath the outer shell. TP1 wore the other three configurations for his first day of evaluation, and the knee pad location was "spot on." As soon as he donned Configuration 4, however, he and the Tester both noticed that the knee pads, without the extra bulk from the blousy undergarment and ACU, were now oriented inwards toward the inner thighs.

In all three cases of kneeling on both knees and crawling on hands and knees for Configurations 4, 5, and 6, one or both of TP1's kneecaps were partially on and partially off the kneepads at the outer edges. TP2's experience was milder: his outer kneecaps aligned exactly with the outer edges of the kneepads when kneeling on both knees and crawling on hands and knees for Configuration 5, only. His kneepads appeared turned inward, however, on Configurations 4, 5, and 6.

Configuration 6, TP2, MOPP 4

Configuration 5, TP2, MOPP2

For both TPs, however, their knees <u>were sufficiently covered when they performed the low crawl and when they assumed the position of kneel-to-fire</u>. During the low crawl, the knees are dragged more than they are pressed to the ground, and, if anything, it is the inside, not the outside of the knee that makes the contact with the ground, so the "turned inward" kneepads presents no problem. For the correct kneel and fire position, all pressure should be applied to the center of the kneecap, which may explain why kneepad coverage was observed to be adequate for this position even when the kneepads turned inward. (See photo, at right: TP2 is wearing Configuration 6).

The Tester has learned that low crawl and kneel-to-fire are more commonly performed and critical infantry tasks than kneeling on both knees or crawling on hands and knees. The issue of insufficient kneepad width for the tasks of lesser importance is, therefore, of only mild concern. Of more interest, perhaps, is that the trousers of the LEHP shell clearly hang differently depending on which wear concept (long underwear style versus ACU plus blousy undergarment)

is employed. In the current evaluation, however, the differential hanging had no impact upon leg raises, jogging, or other actions that engaged the trousers.

3.3 Findings Grouped by Human Factors Dimensions

The remaining findings are grouped by the human factors dimensions assessed during this evaluation.

(1) Thermal Comfort: The temperature in the laboratory was between 60 and 70 degrees Fahrenheit at all times. Given this range, Subjects seldom reported feeling hot. Body temperature was rated on a scale of 1 to 5 with 1 = Extremely Uncomfortable and 5 = Especially Comfortable. Table 3-1, below, records TP ratings of comfort with respect to "Body Temperature" for differing MOPP level and gear combinations. The first three rows represent the ratings of TP1 and the lower three rows represent the ratings of TP2.

Even though the extreme ratings of 1 and 5 were never employed, systematic differences were observed between MOPP conditions, gear conditions, and the two configuration types (employing long underwear or blousy undergarment style). Ratings from TP1 are found in the first three rows of Table 3-1, below. Except for his anomalous rating for C6 (see Comment column, in table above), TP1 was slightly uncomfortable from heat in all configurations for both MOPP2 with gear and MOPP4 without gear. He was warmer (Moderately Uncomfortable) when wearing MOPP4 with gear, but only in the Blousy Undergarment Configurations (1, 2, and 3). For the Configurations employing the long underwear style his heat discomfort rating remained at "Slightly Uncomfortable" for all MOPP and gear conditions.

For TP2 (ratings found in the lower three rows of Table 3-1, below), he felt no thermal discomfort when wearing MOPP2 with IOTV and military gear. He felt slight thermal discomfort when wearing MOPP4 with or without the IOTV and gear.

Sweat was not rated, but at the conclusion of each configuration TPs reported if and where they sweated in MOPP4. TP1 did not sweat during the first configuration on both days of the evaluation, but thereafter he did sweat, equally, for the remaining two configurations each day. This suggests at least a partial, cumulative effect of sweating that occurred by the 2nd configuration each day and then remained constant. TP1 was not clear about where he sweated the most but the Tester could see that his face sweating while encapsulated in MOPP4 gear, and could see the sweat marks on his upper chest.

Rating scale for comfort:

Extremely Uncomfortable	Moderately Uncomfortable	Slightly Uncomfortable	No Discomfort	Especially Comfortable
1	2	3	4	5

Table 3-1. Thermal Comfort Ratings for TPs 1 and 2

TP ID	Condition	Blousy Undergarment Configurations			Long Underwear Configurations			TP Comments or Tester Observations
		C1	C2	C3	C4	C5	C6	
TP1	MOPP2 with Gear	3	3	3	3	3	4*	*Data contradiction: TP1 rated Config. 6 as more thermally comfortable than the other five configurations. This contradicts his recorded comments that he prefers the undergarment worn with C4 and C5 better than the one worn with C6 because is it lighter weight and cooler.
	MOPP4 without gear	3	3	3	3	3	3	Without IOTV and other military gear, TP1 rated MOPP4 as equally thermally comfortable to MOPP2 worn with gear. All configurations received the same rating.
	MOPP4 with gear	2	2	2	3	3	3	MOPP4 worn with IOTV and military gear received the lowest comfort ratings in the evaluation, from TP1, who rated all three Blousy Undergarment Configurations as Moderately Uncomfortable with respect to Body Temperature.
TP2	MOPP2 with Gear	4	4	4	4	4	4	TP2 felt no thermal discomfort in all 6 configurations when worn in MOPP 2 with IOTV and military gear.
	MOPP4 without gear	3	3	3	3	3	3	TP2 found all configurations in MOPP4 without IOTV and gear, to be "Slightly Uncomfortable" with respect to thermal comfort.
	MOPP4 with gear	3	3	3	3	3	3	TP2 found all configurations in MOPP4 with IOTV and gear, to be "Slightly Uncomfortable" with respect to thermal comfort (same rating as without gear).

Amount of sweat may also have been confounded by ambient temperature. On the day he wore the long underwear style configurations, TP2 reported sweating in the upper chest, upper back, and armpits for the first configuration (Configuration 4), but he did not sweat while wearing the other two configurations that morning (#s 5 and 6). A substantial drop in room temperature (from 69° to 65 ° Fahrenheit may account for this drop-off in sweating.

On the day he wore the blousy undergarments, TP2 again reported sweating in the upper chest, upper back, and armpits for the first configuration (Configuration 1), but he continued to sweat even more for the next two configurations (C2 and C3). For those two configurations, he reported sweating on his whole chest, whole upper back, armpits, and legs

(a new area). This added sweat occurred in spite of a drop, once again, in room temperature from 69° to 66 ° Fahrenheit.

With both order effects and room temperature effects having some impact on sweating, no clear conclusions can be drawn about amount of sweating between Configurations 1 through 6. A gross level conclusion can be drawn that – with the exception of TP2 sweating while wearing C4 – both TPs sweated more while wearing the blousy undergarment configurations 1, 2, and 3, compared with the long underwear configurations 4, 5, and 6.

(2) Fabric Comfort: Fabric comfort was rated on the comfort scale of 1 to 5 from Extremely Uncomfortable to Especially Comfortable. Table 3-2, below, records TP ratings of comfort with respect to the fabric of the undergarment and the fabric of the hood liner. The first three rows represent the ratings of TP1 and the lower three rows represent the ratings of TP2.

Table 3-2. Fabric Comfort Ratings

TP ID	Garment Component	Blousy Undergarment Configurations			Long Underwear Configurations			TP Comments or Tester Observations
		C1	C2	C3	C4	C5	C6	
1	Undergarment	-	-	-	4	4	5	Blousy undergarment did not touch TP1's skin so he could not rate fabric comfort
	Hood liner	4	4	4	4	4	4	
2	Undergarment	4	4	3	4	4	4	Blousy undergarments touched TP2's skin above wrist. He commented on slight discomfort of the C3 undergarment fabric (40C) where it touched his wrist area (the fabric, not the knit cuff).
	Hood liner	4	4	4	4	4	4	

(3) Physical Comfort and Fit: There were no physical comfort issues such as pressure points or rubbing or poking, so TP impressions of physical comfort (as something separate from thermal or fabric comfort) devolved from their views of fit. Both TPs felt that fit was roomy (but not over-large) and comfortable at all points of the body (e.g., sleeve length, trouser length, chest circumference, etc.). The one exception is that TP1 verbally reported tightness and discomfort at the neck for every configuration, but felt this most strongly for Configurations 1, 2 and 3 which employed the blousy undergarment and included wearing the ACU. For those configurations, he stated that it was "more crowded" at his neck. As reported earlier, TP1 had an especially large neck.

(4) Range of motion: Table 3-3, below, indicates the actions TPs performed while wearing each configuration at MOPP2 and MOPP4 levels. (The same table appeared earlier in the Methodology Section). No restrictions were ever encountered for any of the actions listed for Knees and Prone Positions and for Upright Actions. For items in the Head, Neck, and Bending Column, no restriction was observed or reported for any action except for the first two items: head & neck rotations and look left, right, and back over the shoulders. Sidebar

mini-experiments indicated, however, that the source of the restriction was the IOTV and not the LEHP ensemble. There was no restriction in these actions when the LEHP ensemble was worn without the IOTV in MOPP Level 2, and there was restriction when the IOTV was worn alone over the ACUs. This convinced the Tester that it was the IOTV and not the garment that constrained head and neck rotations and swiveling one's neck to look around. Additionally, TP2 had felt some neck-turning restriction because the sides of his face hit the LEHP hood which poked up from the IOTV collar; however, once it was discovered that the hood could be rolled back out of the way and secured during MOPP2 wear, this source of restriction disappeared.

Table 3-3. Actions Performed in MOPP2 and MOPP4

Head, Neck, and Bending	Knees and Prone Positions	Upright Actions
1. Head & neck rotations 2. Look left/look right/look back 3. Twist at waist 4. Bend from waist to "adjust" boots 5. Doff back pack, withdraw canteen. Drink (in MOPP4, only).	1. Kneel on both knees 2. Crawl on both knees 3. Kneel and fire 4. Perform low crawl with weapon 5. Fire from prone position 6. Access & toss grenade (using prone and kneeling positions)	1. Perform high knee raises 2. Perform climb & reach motion 3. Walk at road march pace 4. Jog across the room and back 5. Access & toss grenade in upright position

In MOPP4, some restriction in head turning remained (compared to MOPP2 or ACU only), due to the encapsulation effect of the hood and mask combination. This was true with or without the IOTV.

(5) Ease of Use/Donning and doffing:

Donning. Donning both the undergarment and the shell was easy and achieved quickly but HRVs did not like the fact that the undergarment intended for donning in an emergency, required first removal and then re-donning of their duty boots. When donning to MOPP4 and zipping their central zipper all the way to the top, the zipper flap did not automatically close over the top 2-3 inches of the zipper (though it did close over the rest of the zipper). If the zipper flap is not closed all the way to the top, it interferes with achieving a smooth closure of the two neck panels, yet TPs seldom remembered to close this flap. After repeated reminders from the Tester, TP2 usually remembered to do this during the 2nd half of the evaluation. TP1 did not remember to close the central zipper flap on his own until his 12th and last donning of the evaluation.

Time to Don. As an unplanned, sidebar exploration, time donning was conducted three times, total, during the entire evaluation, to get a sense of whether the ensemble could be donned to MOPP Level 4 within the doctrinally required 8-minute time limit. TP2 was timed twice, donning from MOPP0 to MOPP4 in emergency mode, thereby following a doctrinally correct sequence for donning the protective components.

TP2 was first timed while donning Configuration 1 (blousy undergarment 54M + shell 61U + hood liner). Because this was his 4th configuration worn, he had three prior, non-timed practices donning from MOPP0 to MOPP4. His additional CB gear donned included the JSGPM mask, JB1GU FR glove system (since shell 61U is flame resistant) and the BVO protective boots. Total time to achieve MOPP4 was 5 minutes and 4 seconds, but time to remove his duty boots prior to beginning was not captured; this is estimated to require at least 15 seconds.

TP2 was also timed while donning Configuration 3 (blousy undergarment 40C + shell 31B + hood liner). This was his 6th configuration worn. His additional CB gear donned included the JSGPM mask, JB2GU non-FR glove system and the AFS protective boots. Total time from MOPP0 (ACUs and duty boots) to achieve MOPP4 was 5 minutes and 7 seconds, with this time including initial removal of boots, followed by all other steps. Both layers of the non-FR glove system were tucked beneath the knit cuff of his undergarment, against his skin.

The two donning times for TP2 were near-identical, though the 2nd time includes 15 seconds that were needed to remove duty boots and 31 seconds required to re-don them, for a total of 46 seconds. So the 2nd time (3 seconds longer) actually reflects quicker donning by at least 43 seconds.

TP1 was also timed while donning Configuration 3, which was his third configuration of the evaluation. His CB gear donned included the JSGPM mask, JB2GU non-FR glove system and the AFS protective boots. His time to don is approximate because a wristwatch was used in place of a stop watch. Also, TP1 was not requested to don in accordance with an emergency sequence, and so he donned his garment and overboots before his mask, instead of donning the mask first. His total time to achieve MOPP4 was 6.5 minutes, but time to first remove his duty boots was not captured within that total. For the record, he donned the butyl layer of his glove system between the cuff of the undergarment and the sleeve of the outer garment.

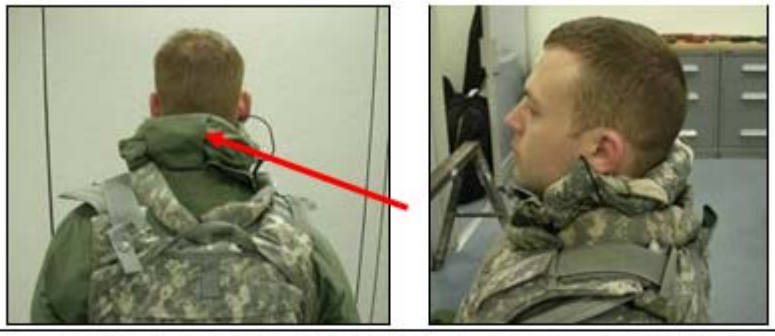
The total times to achieve MOPP4 for TP1 and TP2, across two garment configurations, two types of CB boots, and two types of CB gloves consistently suggest that the LEHP ensemble, Prototype 4, can be donned well within the 8-minute requirement. A breakdown of split times for TP2 donning steps can be found in the Appendix.

As a final note about donning, TP1 donned the 96X hood liner inside out because he could not distinguish between the near identical gray color on the inside and outside of the hood

Doffing. Every aspect of doffing was accomplished easily. Both TPs appreciated the added advantage of the arm zipper in doffing – it was quicker and kept them from having to wriggle out of the shoulders. At the same time, however, they did not consider the zipper to be crucial for donning and as a result they seldom remembered to use the arm zipper for doffing.

Hood and Neck Panel Storage during MOPP2 Wear. The garment hood rollback mechanism – intended to store hood and neck panels out of the way when in MOPP level 2 -- was easy to

use and effectively held the *hood* in place, but was less effective and efficient for use with the neck panels.



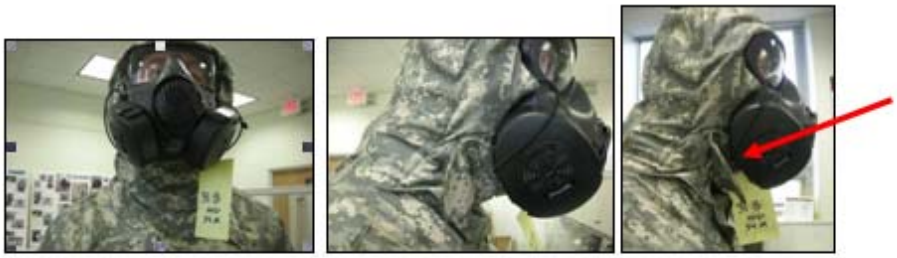
Views of hood rolled and stored under garment flap before and after positioning IOTV.

Hood Shape Retention during Storage of Ensemble. The semi-rigid front edge on the hood of the LEHP shell is contoured to mate with the JSGPM mask and does so successfully. There is concern, however, that this frame could lose its shape when the shell is stuffed into a Soldier's rucksack or assault pack.

Waste elimination. TP2 was asked to simulate solid waste elimination by opening the front to back/back to front zipper and squatting in an "as-if" position. He reported and the tester observed that the zipper was well placed and the garment opened sufficiently to accomplish waste elimination, but he said he could not imagine actually taking advantage of this feature – felt he would "hold it" if he had to. TP and tester also noted that clothing worn beneath the LEHP ensemble would hamper use of this feature. During the evaluation, the simulation occurred when the TP was wearing a long underwear garment, with his own personal undergarment beneath it. He tried reaching back to lower his personal undergarment but found it awkward both to lower and to retrieve his personal underwear and both TP and Tester concluded that this would be infeasible. If he had been wearing the blousy undergarment, he would have needed to reach through the waste relief zipper to lower and retrieve both his personal underwear and his ACU trousers. TP and Tester concluded that this would also be infeasible.

Assessment showed that liquid waste elimination would be easily accomplished due to the back to front/front to back zipper featured on the LEHP shell and undergarments. The zipper aligns well with fly openings on personal undergarments and the ACU trousers.

(6) Protective interfaces at neck, wrist, and ankles:
Interface at neck. It was difficult for wearers to achieve smooth interface at neck and the non-smooth interfaces achieved by Subjects were frequently degraded further or breached during movements. Even with help from the Tester, it was difficult to achieve a smooth interface, especially for the Subject with the slender neck (45th percentile).



(1) TP1 don lays smooth at front. (2) Same don, left view (3) After 6 minutes activity.
Config 2: 54M+31B

(1) (2)

(1) TP2's outer flap is cinched so far that panel extends beyond the hook fastener.
(2) Flap popped open when neck turned to left.
Config 5: 63A + 78C

Interface at Wrists. At the wrists, protective interface was easy to accomplish and well-maintained during movements.

FR glove. The JB1GU-FR glove system was worn with Configuration 1 because it featured a flame-resistant shell (61U). This glove system has 2 components, an inner CB protective layer and an outer FR glove layer. TPs had no difficulty inserting the inner glove beneath the cuff of the undergarment (for Configuration 1, this was the 54M undergarment). They were able to position the inner layer glove gauntlet to lie above the cuff against the bare arm. It was simple for the TPs to don the outer glove, positioning it between the inner garment cuff and the outer garment sleeve. Snugly fastening the hook and loop closure at the wrist posed no difficulties.

Non-FR glove. The JB2GU non-FR glove system consists of a cotton inner sweat liner and a butyl glove providing the chemical protection. It was simple for TPs to don the cotton sweat liner, tucking it beneath the cuff of the undergarment. With regard to appropriate layering of the butyl glove at the wrist area, the Tester consultant experts at the U.S. Army

Chemical School at Fort Leonardwood; but no concurrence was obtained on proper layering method; likely, this is because the Army has not yet fielded this glove system with a garment that has both an inner cuff and a sleeve. Therefore, layering of the butyl glove with the LEHP prototype was tried in two ways: (1) with the butyl glove tucked under the undergarment cuff along with the cotton liner, and (2) with the butyl glove positioned between the undergarment cuff and the sleeve of the shell outer garment. In each case, TPs were able to form an effective interface and then snugly fasten the hook and loop closure at the wrist.

The wrist interface was never breached or loosened during evaluation activities for either the FR or non-FR glove systems.

Interface at Ankles. At the ankles, it was challenging to achieve the appropriate degree of snugness, often resulting in trouser legs that rose during movement and did not fall back down again. Essentially, snug adjustments which "felt" right to the TPs led to trousers that would rise during certain activities and not fall back again. After two configurations, TP1 learned to secure his ankle hook and loop closure with less snugness so that the trousers would always fall back into place again. TP2 had narrower ankles and his natural tendency was to affix the loop flap to the hook patch at the furthest possible, snuggest possible position. The Tester trained him to affix the loop to the hook about ¾ inches looser than he naturally preferred, but even with this modification, if his trouser leg rose during an activity, it would not fall back down to its previous position.

Three evaluation activities caused the trouser legs to rise most of the time. These were: (1) low crawl. (2) high knee raises: when the right leg was raised, the left trouser would raise (and vice versa). (3) The reach and climb activity where the leg lifted and the foot placed upon a 30 inch-high metal barrier: when the TP lifted and bent his right leg, the left trouser would raise. After low crawl, and when TPs lowered their legs from these other activities, the opposite trouser leg would remain too high, i.e., often remaining above the middle fastener on the BVOs or AFSs, which is considered too high for adequate protection. As indicated, this problem persisted for TP2.

Photo at left was taken after low crawl, when both trousers rose above 2nd AFS fastener and did not fall back down again.

Tester refastened closures about 3/4 inch looser and repositioned them on AFS. During climb and reach activity, right trouser rose when left leg was lifted and did not fall back down again – it became bunched inside upper rim of AFS (photo at right).

Both photos are for TP2, wearing Configuration 4.

As another ankle interface issue, both TPs did not naturally achieve vertical alignment of the adjustment tab with the trouser leg (see photo at right) until the Tester trained them to do so. When donning MOPP4 in a hurry, they reverted to inadequate alignment.

(7) Compatibility with military gear: An incompatibility currently exists between the fielded duty helmet and the fielded CB protective ensemble for MOPP4: the helmet sits too high and does not seat securely on the head due to the upper edge of the CB mask. Because the helmet sits too high, the stabilizing chin straps cannot be fastened. This same phenomenon was observed when the LEHP garment was worn in MOPP4, but the problem is presumed due to the mask, not the garment itself.

The LEHP prototype was fully compatible with all other duty (non-CB) items that were featured in the evaluation: duty boots, duty uniform, body armor, rucksack, assault pack, and weapon. As an added exercise, ammunition pouches with mock ammunition and a grenade pouch containing a mock grenade were attached to the IOTV in military fashion. These did not impact on the LEHP prototype, and the TPs had no trouble accessing and tossing the grenade while wearing the LEHP garments.

Photos from the HF evaluation that illustrate CB garment compatibility with military equipment are presented below.

IOTV worn over ACUs

IOTV worn over LEHP garment (Config. 2)

Assault pack worn with IOTV and ammo & grenade pouches
(Config 6 on left., Config 2 on right)

TP hoist rucksack
(Config. 3)

TP wears rucksack. Holds weapon in military posture.
(Config. 3)

Assault Pack and Mask Carrier with MOPP 4
(Config 1)

IOTV with ammo pouches & grenade at MOPP 4
(Config. 4)

Simulated drinking from standard canteen in MOPP 4
(Config. 3)

(8) Safety: There is potential snag hazard during MOPP2 from the circular canister cords which are exposed even when the hood is rolled back and fastened at the base of the hood. In addition, all shell garments were noisy, which could contribute to detectability. TP1 noted that Configuration 1, the first one he tried on, went "Swish-swish-swish," and he felt that all subsequent configurations made the same sound. According to the memory of both TPs, however, the LEHP ensembles are less noisy than the JSLIST Type II worn currently in the field.

(9) Subjects' acceptability and preferences: Both Subjects would accept and recommend any of the LEHP Prototype Generation 4 configurations featured in this evaluation as their CB protective ensemble. They had no strong preference among the shells (which differed only by fabric, NOT by design or fit). Of the two carbon undergarment styles, they clearly preferred the long underwear style. They liked it because – without the ACU – it was clearly lighter weight and less bulky. They felt that they would not miss wearing the ACU in a chemical threat environment. TP2 also commented that both of the long underwear undergarments "just felt more natural... felt like clothing compared to the [blousy] style which felt rougher." Both TPs said that they would rather wear any of the three long underwear configurations than any of the blousy undergarments.

Between the two long underwear garments featured in this evaluation -- 63A and 96X-- they both preferred 63A which they perceived as lighter weight and therefore cooler. Actual weights of these two garments were not measured, but the Tester perceived with her fingers that the 63A fabric was thinner than the 96X fabric.

Neither of the Subjects had a specific preference for one configuration (shell plus undergarment) over another. When asked how to improve the LEHP Generation 4 prototype, in general, TP1 requested: (1) less bulkiness at the neck area and (2) a neck or other head gear interface that allows you to "see what you are attaching." Both TPs requested that for the emergency concept of wear – the blousy undergarment configurations – the ensemble should be able to be donned without first removing one's duty boots.

4. CONCLUSIONS

The following conclusions are based upon the findings presented above. It should be remembered that these results are based on a user evaluation of two users.

To avoid redundancy with text in the Results Section, the conclusions are presented in outline form.

Generation 4 Improvements

- Neck interface breach point has been eliminated
- Redesigned waist adjustment band is easy to use and effective for appropriately positioning trouser and upper body portions of garment on the body
- Shoulder stabilization mechanism prevented garment from moving out of place when body armor was donned or back packs were hoisted

Differences among Generation 4 Prototypes

- There were none to negligible human factors differences observed between:
  - The two long underwear undergarments (63A and 96X)
  - The two blousy undergarments (54M and 40C)
  - The four shell outer garments (61U, 31B, 85M and 78C)

- TPs preferred the long underwear style to the blousy undergarment style because the overall ensemble was lighter weight and less bulky

Comfort

- All comfort indices were positive for:
  - Thermal comfort (in temperate conditions)
  - Fabric comfort
  - Physical comfort & fit*
  - Overall comfort

* One TP with large neck experienced "slight discomfort" (uncomfortable pressure) in all ensembles at MOPP2 and MOPP4 levels
* Knee pads turn inward when ensemble is worn without the ACU; this could be a problem for some mission tasks.

Primarily positive findings for:

- Range of motion
- Ease of use, donning, and doffing*
- Protective interfaces**
- Compatibility with military gear
- Safety
- Soldier acceptability

*For protective interfaces, the wrist presented no problem; the ankle presented a slight problem with trousers raising and not falling back down again; and the neck presented a substantial problem, with TPs finding it difficult to achieve adequate protective interface.

** Donning presented no problem (outside of interface issues noted just above); also, TPs would prefer that all garments don and doff without necessitating removal of duty boots. Solid waste elimination may not be feasible due to underclothing that does not feature the same waste elimination zippers as the LEHP prototype.

Summary of Human Factors Concerns

1. Interface at Neck
   - Difficult to achieve solo or with assistance (in this case, from Tester)
   - Sub-optimal interface degrades further during movements
2. Interface at Ankles
   - Difficult to determine optimal level of snugness
4. Donning and Doffing
   - Easy to forget about arm zipper
   - TPs would prefer not to remove their duty boots
5. Location of knee pads may be sub-optimal when ensemble is worn without ACU
6. Solid waste elimination may not be feasible

5. RECOMMENDATIONS

Based upon the results and conclusions, noted above, the following recommendations with respect to human factors are proposed for further development of the LEHP Generation 4 Prototype:

1. Continue to enhance neck interface to improve achievability.

2. Eliminate need for wearer to manipulate upper central zipper flap because they cannot remember to do this when donning to MOPP4 level.

3. Further investigate knee pad location when no ACU is worn beneath shell to ensure accommodation for critical infantry tasks and seek accommodation for any tasks where knees are pressed to the ground.
    - Option: Extend all or part of width along outer edge by ½ to 1 inch.
    - Option: Determine if there is excess kneepad width at the inner leg when all configurations are worn. If so, shift knee pad assembly about ½ inch towards the outer leg.
4. Consider garment stowage approach that will protect hood shape.
5. Redesign mechanism for holding neck panels out of the way during MOPP level 2:
    - Option: Extend width of hood rollback patch to better accommodate neck panels.
    - Option: Provide separate, small Velcro patches at either side of neck base on shell for back-attaching the neck panels.
6. Since the outer shell has the capacity to be donned over the duty boot, and the blousy undergarment is intended to be attached to the outer shell, redesign undergarment trouser so that it, too, may be donned over the duty boot.
7. Re-evaluate selected human factors issues after the blousy undergarment is attached to shell. Donning and doffing concepts and movements will be different because the Soldier dons one garment to achieve CB protection instead of two.

APPENDIX:
REFERENCE TABLES

Cloth Characteristics of the Components of each Configuration

ID	LEHP Code		Fabric Structure	Structure Type	Fiber Blend	Coloration Method	Functional Treatment
Config 1	Shell	61U	Woven			Dyed green	
	Liner	54M	Laminate			Dyed black woven, undyed nonwoven	
Config 2	Shell	31B	Woven			Universal camo print	
	Liner	54M	Laminate			Dyed black woven, undyed nonwoven	
Config 3	Shell	31B	Woven			Universal camo print	
	Liner	40C	Laminate			100% Polyester, 100% Carbon, 100% Nylon	
Config 4	Shell	85M	Laminate			Jet Dyed green	
	Liner	63A	Knit			Dyed black knit	
Config 5	Shell	78C	Laminate			Jet Dyed green	
	Liner	63A	Knit			Dyed black knit	
Config 6	Shell	31B	Woven			Universal camo print	
Config 6	Liner	96X	Knit			Dyed grey both knit layers	

Temperature and Humidity during the Evaluation

Configuration Type	TP ID	Temperature (Fahrenheit)	Humidity
Blousy Undergarment (Configs. 1, 2, & 3)	TP1	66.5 - 69.7°	32%
	TP2	64.1- 69.1°	28-29%
Long Underwear (Configs. 4, 5, & 6)	TP1	67.5 - 68.4°	30 - 31%
	TP2	62.1 - 69.1°	26 - 27%

Selection of Evaluation Participants Based upon LEHP Prototype Fit

	Height (inches)	Weight (lbs.)	Chest circ (inches)	Inseam (inches)	Wearer: Fit Perception	Tester: Fit Perception	Candidate for Evaluation?
HRV-v*	71.10	186	40.87	31.62	Good fit except for snug at neck	Good fit; snug at neck	Acceptable
HRV-w*	70.39	160	37.09	31.66	Excellent	Ample fit,; a smaller size might fit, also	Acceptable
HRV-x**	71.97	195	41.38	33.12	Good to Excellent	Good to Excellent	Acceptable
HRV-y	71.73	168	39.41	33.35	Too small everywhere	Too small everywhere	Unacceptable
HRV-z	70.28	197	40.39	32.06	Good	Needed the width but legs too long & crotch very baggy.	Unacceptable

*HRVs "V" and "X" were selected to participate in the evaluation as TPs 1 and 2, respectively. TP2 was unavailable to participate in the briefing/demonstration on December 11, 2008.

**HRV "X" also had an acceptable fit and was selected to participate in the briefing/demonstration.

Body Dimensions of Evaluation Participants (Inches)*

Body Dimension	TP1/ Demo Participant	TP2**	Demo Participant Only
Height	71.10	70.39	71.97
Weight (lbs)	186	160	195
Chest circ.	40.87	37.09	41.38
Waist	33.70	31.80	34.84
Torso length	28.07	26.69	27.28
Inseam	31.62	31.66	33.12
Neck base circ.	19.21	15.98	17.50
Neck mid circ.	15.70	14.92	15.70
Neck length	3.82	4.29	____

* All measurements were taken by members of NSRDEC's Anthropometrics Team

** TP2 predicts into JPACE size 38, based upon his weight. The other participants predict into JPACE size 40.

Overall and Split Times to Don from MOPP 0 to MOPP 4 (seconds)

	Config 1 (54M + 61U) with BVOs, FR Gloves	Config 3 (40C + 31B) with AFS, Non-FR Gloves
Don mask	6	20
Remove duty boots	Not included	15
Don undergarment	55	39
Don duty boots and tuck undergarment cuffs into them	55	31
Don garment shell and affix hood and neck panels	81	74
Don overboots and affix ankle closures	55	104*
Don gloves and affix wrist closures	52	24
TOTAL TIME TO ACHIEVE MOPP4	304= 5 min, 4 secs.	307= 5 min, 7 secs.

*Boot strap popped off and had to be reattached to complete donning the boot.

Available Photos for CB Gear

JSGPM Mask	
Handwear **-JB1GU FR**	
-JB2GU non-FR	

Appendix B

Human Factors Evaluation at Philadelphia University

B.1 Introduction

The long-term goal of the LEHP project is to create a military garment prototype that provides an optimal combination of protection while retaining sufficient comfort to enable the users to wear the 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 garment. Human Factors testing was used to assess LEHP-designed and constructed garments before and after the completion of motion routines established to evaluate garment integrity and comfort of the Generation 4 garments. 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 identify pressure points and comfort/discomfort features.

The series of tests on Generation 4 garment systems was performed at Philadelphia University in conjunction with the LEHP Biophysics team. The motion routine is 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 can then be compared to another Generation prototype.

B.2 Methods

B.2.1 Participants

Participants were nineteen median-size males 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.2.2 Materials

Four shell components (85M, 31B, 61V, and 78C) and four carbon components (63A, 40C, 96X, and 54M) were paired to construct five different overall garment configurations. These configurations were as follows: 85M/63A (one trial), 31B/40C (two trials), 31B/96X (seven trials), 31B/54M (five trials), and 78C/63A (four trials).

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 garment. 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 concerning *fabric characteristics* (thermal comfort, scratchiness, stiffness);
- five questions concerning *garment characteristics* (comfort of the seams, comfort of the closure at the front next edge, comfort of the garment attachment to the gloves, comfort of the garment attachment to the boots, comfort of the weight of the garment);
- three questions concerning *range of motion* (in the legs, in the arms, and overall range of motion);
- one qualitative question concerning areas of potential *tightness or binding*;
- two questions concerning *the hood* (comfort of the hood, and range of motion of the hood area);
- one question concerning the ease of *donning* the garment;
- two questions concerning the *heat factor* associated with wearing the suit (with and without the mask).

B.2.4 Questionnaire

The Human Factors Evaluation questionnaire follows.

>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>><<<<<<<<<<<<<<<<<<<<<<<<

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

17. Please rate the heat factor while wearing the full suit without mask and hood donned.

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

>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>><<<<<<<<<<<<<<<<<<<<<<<<<<<<<<

B. 2.5 Procedure

Participants were recruited from the Philadelphia University community. Upon arrival at the Human Factors Evaluation (HFE) Lab, each participant was briefed on the purpose and general procedures of the study. After signing the informed consent form, 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. LEHP staff provided the appropriately-sized Generation 4 garment and assisted the participant in the donning of the garment. Donning was completed according to the prescribed donning procedure written by the LEHP staff. Participants then completed the seventeen-question Human Factors Evaluation Questionnaire (see B.2.4).

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

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

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, 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)

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

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, 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 they become uncomfortable or fatigued, participants 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 extreme 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 questionnaire again.

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.

B.3 Results

B.3.1 Introduction

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

Fabric Characteristics—Summary variable reflecting the three individual questions concerning thermal comfort, stiffness, and scratchiness.

Garment Characteristics—Summary variable reflecting the five individual questions concerning comfort of the seams, neck closure, gloves attachment, boot attachment and overall garment weight.

Hood—Summary variable reflecting the two individual questions concerning comfort of the hood, and range of motion with the hood.

Range of Motion—Summary variable reflecting the three individual questions concerning range of motion of the arms and legs as well as ratings of overall motion.

Heat Factor—Summary variable reflecting the two individual questions concerning the heat factor associated with wearing the garment (with and without the mask).

Donning Ease—Summary variable reflecting the single question concerning the ease of donning and doffing the garment.

Analysis of variance was conducted to assess differences between the various garment configurations for each of these summary variables.

B.3.2 Fabric Characteristics

Mean ratings of questions pertaining to fabric characteristics (thermal comfort, stiffness, and scratchiness) indicated strong acceptance of these characteristics of the fabrics evaluated. Thermal comfort across all garments was rated in a range indicating neutral heat loading (M = 4.58 [0.96] on a 7-point scale where 7 indicated very comfortable), Ratings of Stiffness (M = 2.84 [0.96]) and Scratchiness (M = 2.89 [0.88]) were in the range indicating perceptions of relative softness and smoothness, respectively. Analysis of variance did not indicate any significant difference among the different garment configurations with respect to the fabric characteristics ($F(4, 14) = 1.71$, $p < 0.20$)

B.3.3 Garment Characteristics

Garment characteristics (seam comfort, neck closure, glove attachment, boot attachment, and overall weight) were generally well rated for the various configurations (see Table B-1; higher scores indicate greater perception of comfort). Each individual characteristic was rated on the comfortable end of the rating scale. Analysis of variance did not indicate any significant difference among the different garment configurations with respect to the garment characteristics ($F(4, 14) = 0.75$, $p < 0.58$).

Table B-1. Mean Ratings for each of Five Garment Characteristics for Generation 4 Garment Configurations.

Characteristic	Mean	Standard Deviation
Seam Comfort	4.74	1.05
Neck Closure	3.63	1.38
Glove Attachment	5.16	1.21
Boot Attachment	5.16	1.12
Overall Weight	3.11	1.05
Overall Garment Characteristics	21.79	3.29

B.3.4 Hood

Evaluation of the comfort and range of motion of the hood were generally positive. The mean rating for hood comfort was on the comfortable end of the rating scale (M = 4.16 [1.26]), whereas the range of motion in the hood area was viewed as modestly restricted (M = 4.32 [1.11]). Participants in LEHP HF evaluations rated the closure at the front neck edge to be relatively comfortable (M = 3.63 [sd = 1.38]). Analysis of variance did not indicate any significant difference among the different garment configurations with respect to the hood ($F(4, 14) = 0.40$, $p < 0.81$).

B.3.5 Range of Motion

Participant ratings did not indicate noticeable restrictions in the range of motion for each assessed area of the garment: arm motion (M = 3.16 [1.176]), leg motion (M = 2.47 [0.97]), and overall motion (M = 3.11 [0.81]). Rather, each area was judged to have minimal restriction in the range of motion. Analysis of variance did not indicate any significant difference among the different garment configurations with respect to the range of motion ($F(4, 14) = 0.34$, $p < 0.85$).

B.3.6 Heat Factor

Each garment configuration was judged to be relatively thermal neutral for both the full suit with mask and hood (M = 4.89 [1.05]), and without hood and mask (M = 3.37 [1.12]). Analysis of variance did not indicate any significant difference among the different garment configurations with respect to the range of motion ($F(4, 14) = 0.26$, $p < 0.90$), nor was the heat factor with mask and hood on judged to be significantly different from suit without hood and mask ($t(18) = 0.42$, $p < 0.68$).

B.3.7 Donning Ease

Participants rated each garment configuration to be relatively easy to don (M = 4.05 [1.51]). Analysis of variance did not indicate any significant difference among the different garment configurations with respect to donning ease ($F(4, 14) = 0.79$, $p < 0.55$).

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Appendix C

Reprint of *Philadelphia University LEHP FAST Testing Notes—July21–22, 2009*

Reprint starts on next page.

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

Attendees:
LEHP: K. Hultzapple, J. Venafro
NCTRF: S. Proodian
RTI Test Team: James Hanley, Jason Hill and Clint Clayton.

Test participants (TPs):

TP-#9

- TP approved for testing based on availability: Weight 147 is outside JPACE Size 40 weight range (185-200). Height 67-1/2 which is ½-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 ½-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

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
GVD	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

PHILADELPHIA UNIVERSITY - LEHP FAST — Testing Notes
JULY 21-22, 2009

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

- Add 2-inch thongs (fabric pulls) to zipper sliders

- Undergarment
  - Add 2-inch thongs (fabric pulls) to zipper sliders
  - Eliminate rib knit cuff on leg bottom. And replace with body material cuff 13 inch circ and same height as current cuff
  - Add stops for zipper (center front waist and crotch zipper)
  - Sleeve cuffs are OK
- Balaclava
  - 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
  - Leg cuff worn inside combat boots. GVOs worn over
  - Appeared to fit OK and length was OK
- Undergarment shirt
  - 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
  - Need to ensure that protective fly is in correct position during doffing. Should be flat under the zipper
  - Circumference of shirt OK
  - Sleeve length OK
- Uniform Trousers
  - 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
  - Velcro at waist skirt opened when TP sat to don boots
  - Length too short (after donning GVOs, closing leg tabs and moving around – leg bottoms shifted to just below top of GVOs
  - Knee width appeared to be OK so knee pad straps were **NOT** engaged
- Uniform Coat
  - Snug on this TP – again he is outside JPACE 40R dimensions
  - Upper Coat (shoulders) OK (bi-swing was closed) on this TP but from under arm to hem a bit snug
  - Chest circ was snug
  - 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
  - Lower back conforms well to body
  - Sleeve length – OK After closing sleeve tab

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

Doffing:

- Uniform
  - 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
  - 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.
  - Longer tape on filter straps and duct tape color provided easier doffing of straps
  - Hood doffing worked good – yellow simulant at R temple and less at L
  - 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
  - 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
  - Sleeves were very comfortable – no restriction when reaching high
  - Some discomfort when lying on stomach from all layers
  - 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
    - 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

- 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
    - Body hair on legs (knees) is pulled by undergarment material when TP moves. Painful at times
    - Overall this ensemble is more comfortable with increased range of motion of body and arms over coverall ensemble
    - 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.

PHILADELPHIA UNIVERSITY - LEHP FAST **Testing Notes**
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Recommendations for next run:

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

Overall recommendations for Gen5 system:

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

Appendix D

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

Reprint starts on next page.

Philadelphia University

Fluorescent Aerosol Screening Tests (FAST)

Test Report

Purchase Order Number: B0001250
RTI Project Number: 0210914.042

Prepared by:
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July 31st, 2009

RTI INTERNATIONAL | *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 = ~ 5,000 mg m^{-3} min
- "JSLIST" motion routine

Exposure Chamber
(photo from prior testing)

25' x 50'

10 mph

~ 70° F

~ 50% RH

~ 170 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

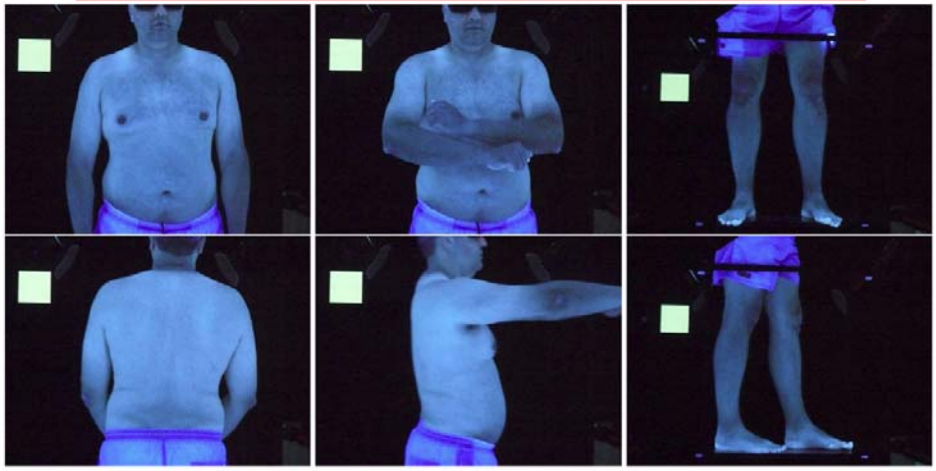
Test Matrix

Date &Time	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
RTI Test #	1812	1813	1814	1815	1816	1817
Test Participant	3	4	9	3	4	9
Configuration / Garment	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
Mask	JSGPM	JSGPM	JSGPM	JSGPM	JSGPM	JSGPM
Boots	Combat & GVO	Combat & GVO	Combat & GVO	Combat & GVO	Combat & GVO	Combat & GVO
Gloves	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

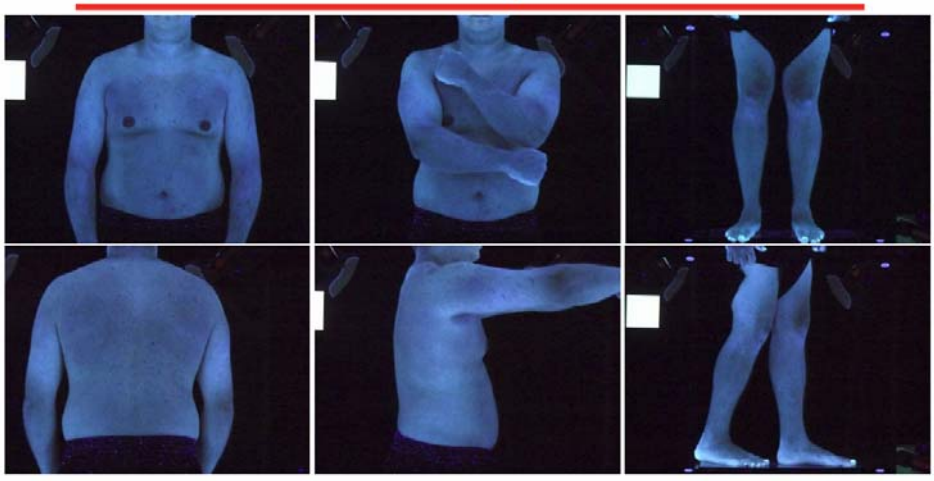


Pre-test photos. The test participant's forearms have a darker appearance than his upper arms under UV light.

Background UV Photos
Test Participant #4

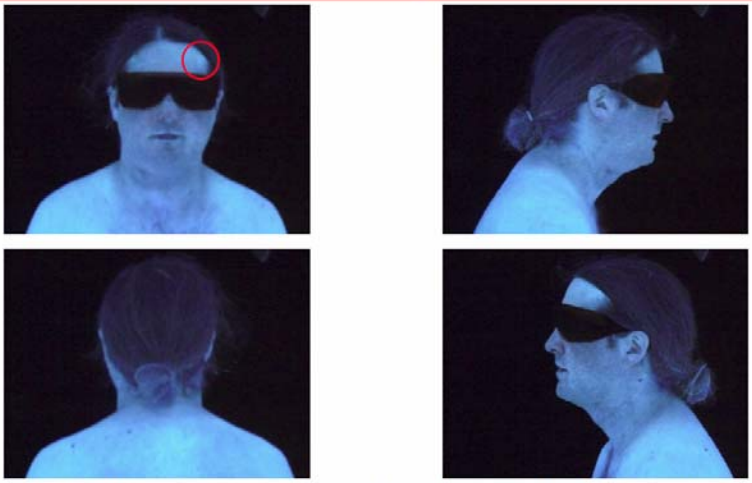
Pre-test photos. The back of this participant's neck has a fairly dark appearance under UV light due to the presence of a suntan.

Background UV Photos
Test Participant #4



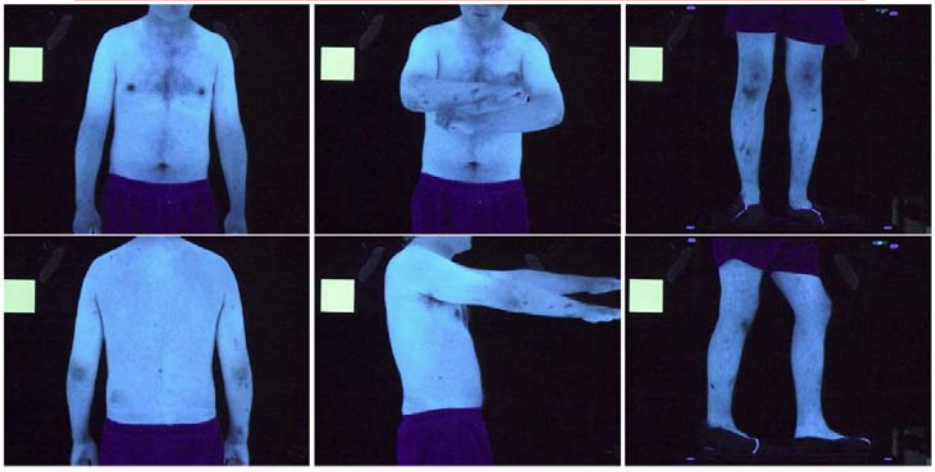
Pre-test photos. The forearms and noticeably darker in appearance than the upper arms and torso, again, due to suntan. Also, the thighs are somewhat brighter than the lower legs.

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.

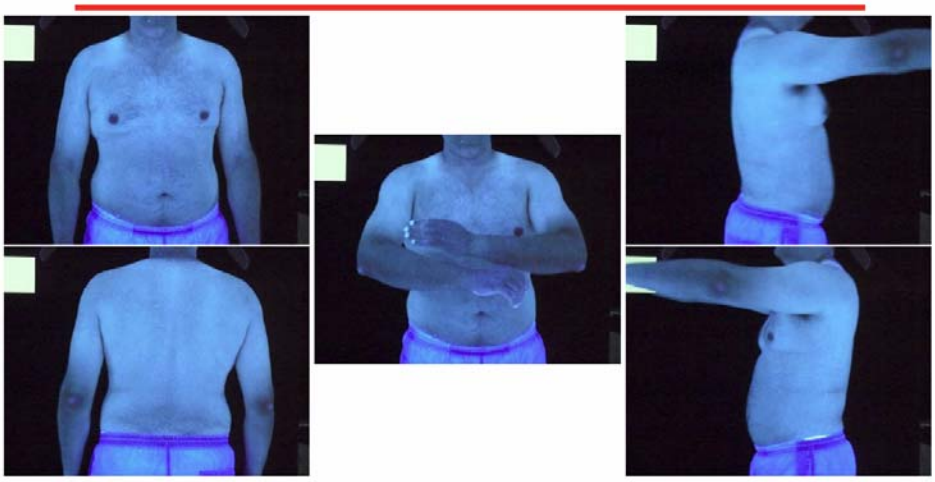
Test #1812, Coverall
Pre-Test Photos

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

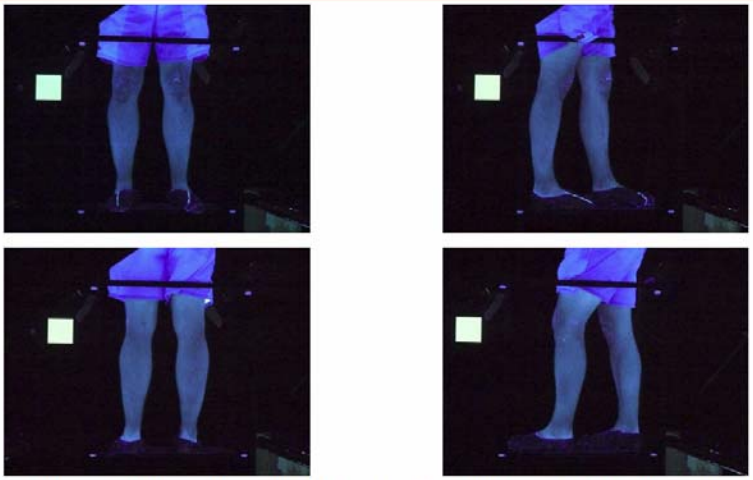
There was a distinct, bright line of deposited aerosol near the right temple, possibly indicating a localized breach of the hood-mask interface. The head and neck otherwise appeared clean.

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



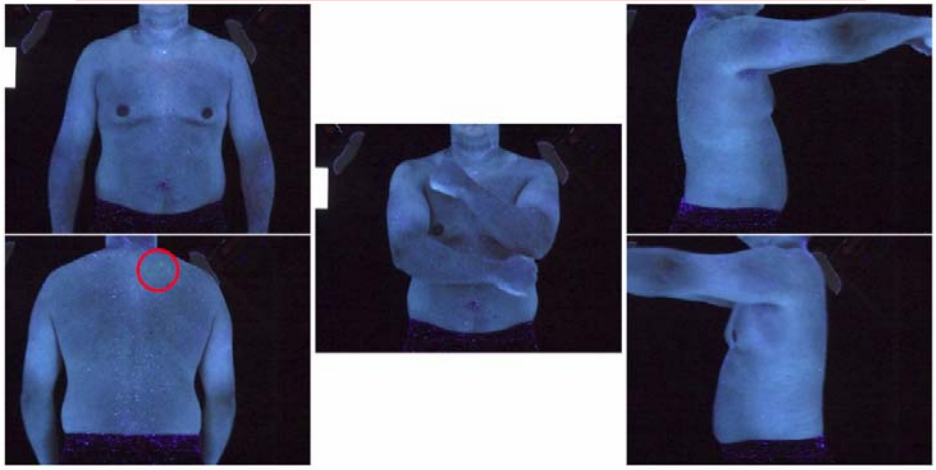

For this test, the ankles of the black inner suit were donned over the combat boots. During the test, the front neck flap closure flipped up.

Test #1813, Coverall
UV Photos: Head and Neck



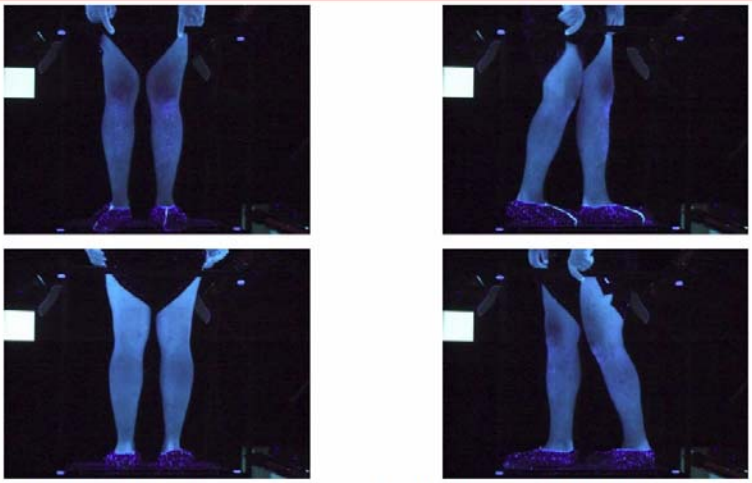

A small, yellow track mark was seen at both temples. The sides of the face and the ears had a light blue haze of deposited aerosol. The "clean" areas under the mask harness straps were clearly visible and are indicated here by the red arrows.

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.

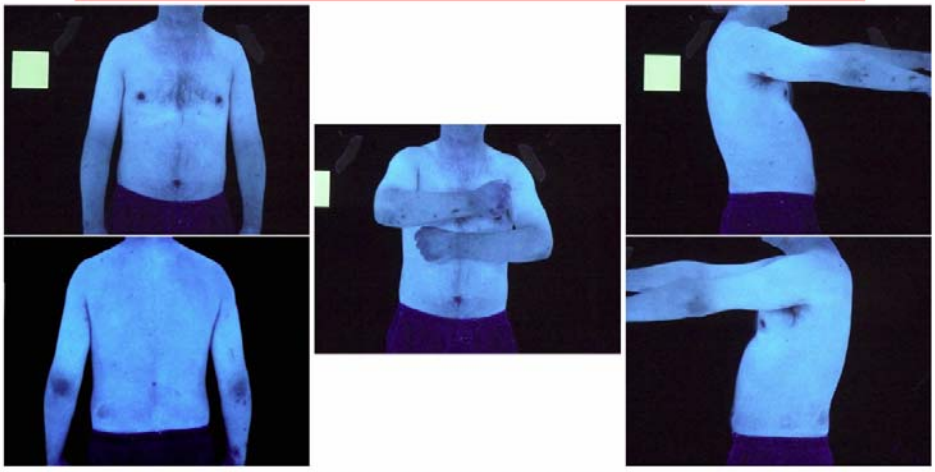
Test #1814, Coverall
Pre-Test Photos

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

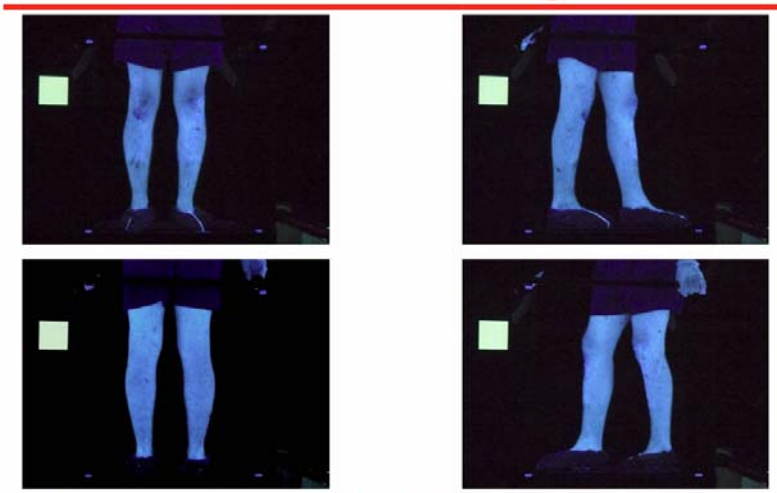
There was a light blue haze around the ears. The bright spot on the upper left forehead due to the natural fluorescence of the test participant's skin, as seen in the background photos.

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



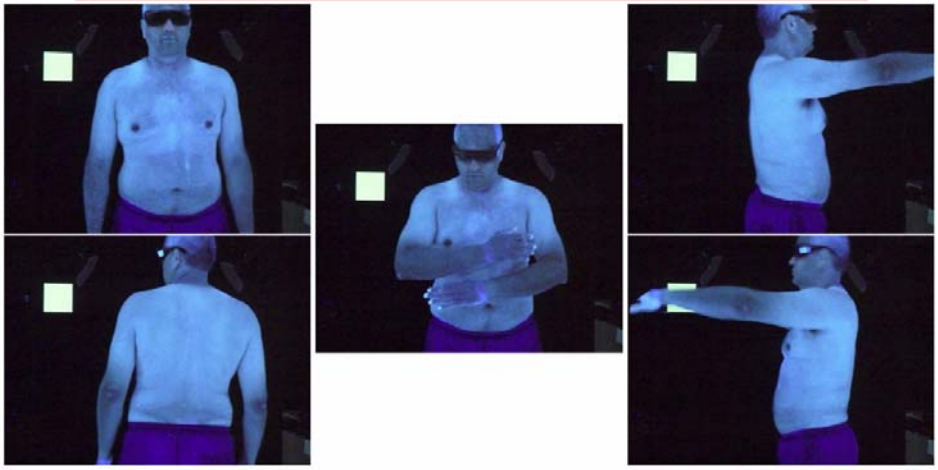

The black inner garment shirt was worn tucked into the inner garment pants. During the test, the ankles of the outer garment rode up above the top loop of the GVOs.

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



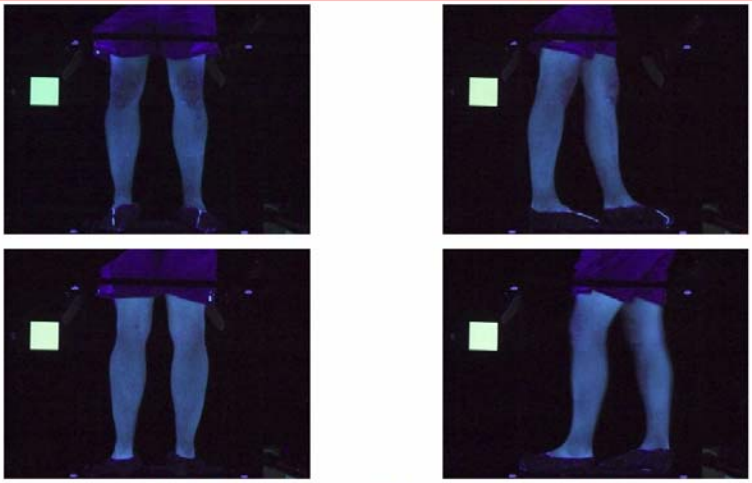

A light level of aerosol deposition was visible on the right cheek and in the hair just above the middle mask strap.

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

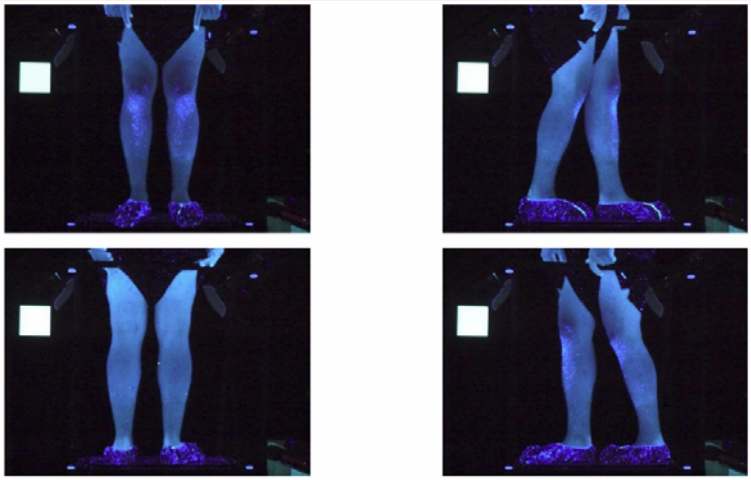



There was a blue haze on the cheeks and around the ears. Additionally, there was a small yellow hotspot on both sides of the face. The cause of the hotspots was not immediately apparent. The lower mask straps are visible below the hotspots.

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.

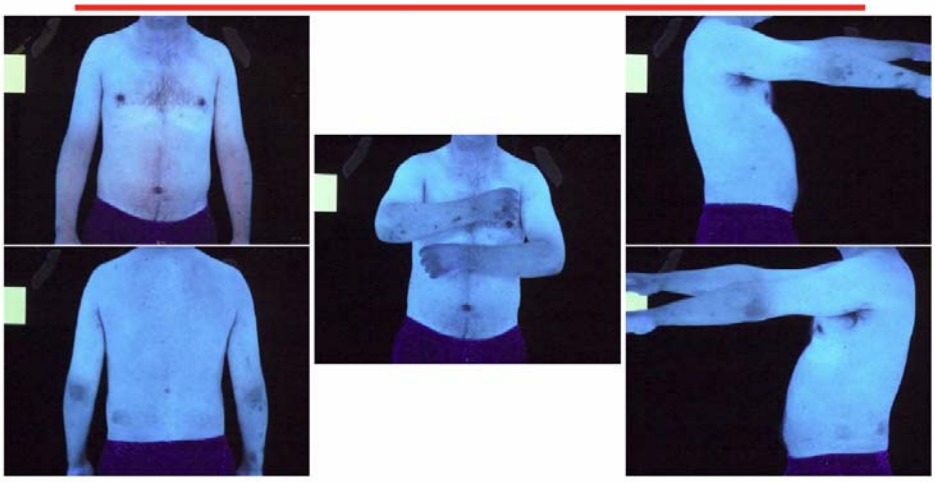
Test #1817, Two-Piece
Pre-Test Photos

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

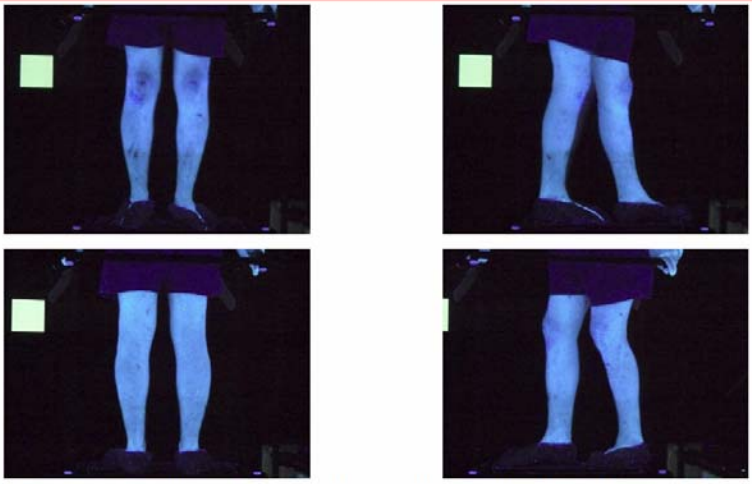
Light to moderate levels of aerosol deposition were visible on the cheeks and under the chin, including a line of moderate deposition on the left cheek.

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.

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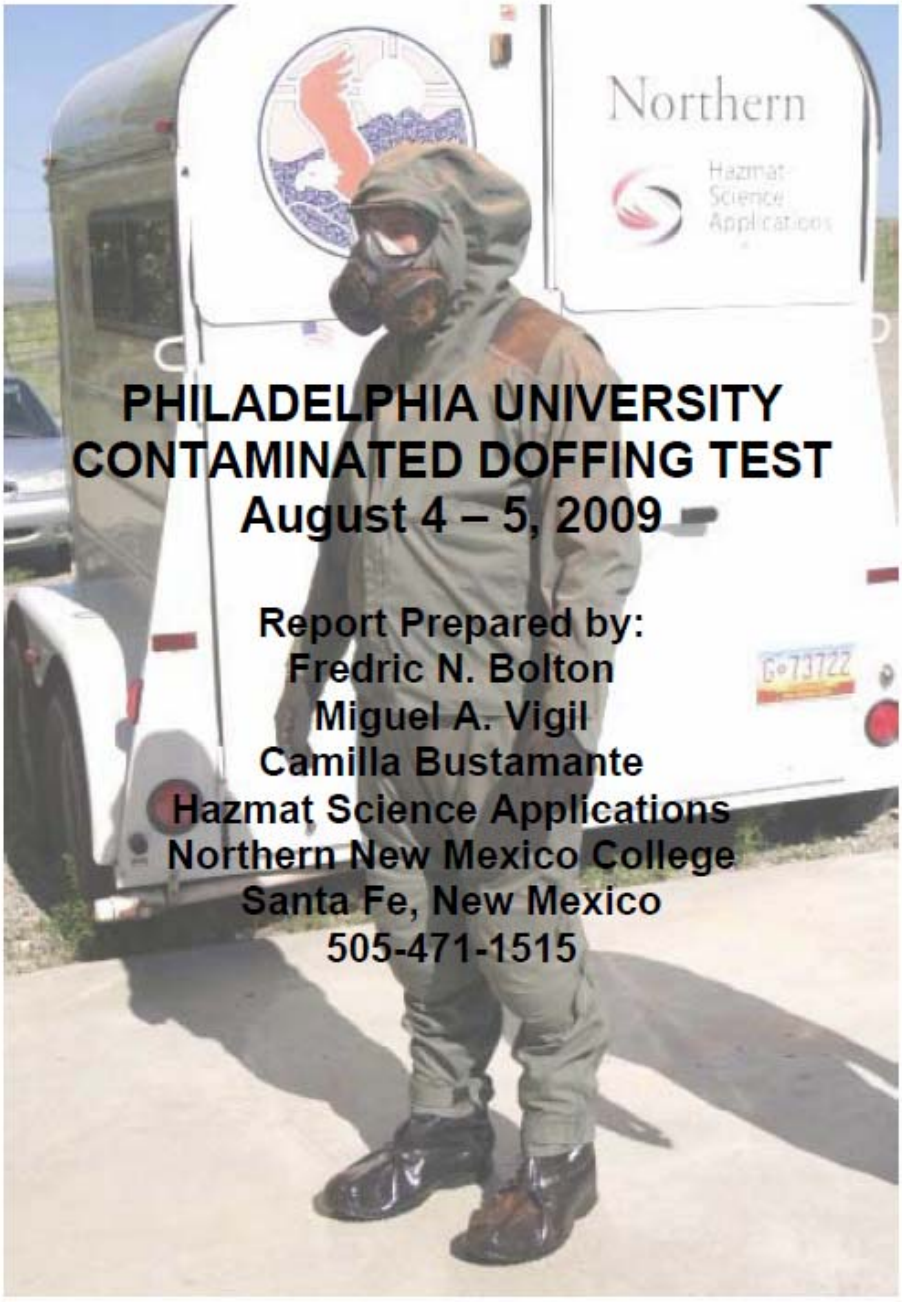
Appendix E

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

Reprint starts on next page.



PHILADELPHIA UNIVERSITY CONTAMINATED DOFFING TEST August 4 – 5, 2009

Report Prepared by:
Fredric N. Bolton
Miguel A. Vigil
Camilla Bustamante
Hazmat Science Applications
Northern New Mexico College
Santa Fe, New Mexico
505-471-1515

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

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.

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

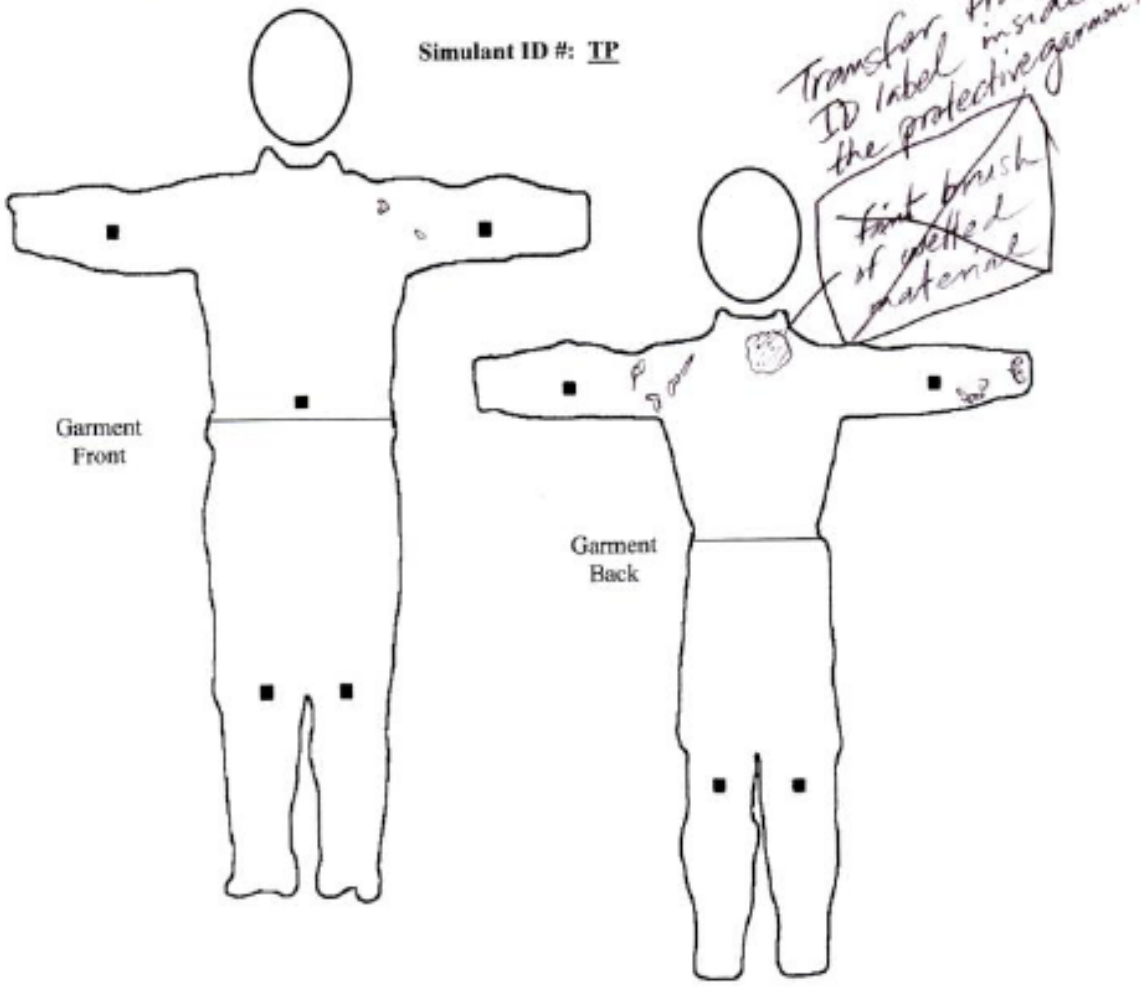
PhilaU Raw Data Sheets

Hazmat Science Applications

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

DeconPro® POST-TEST SIMULANT LOCATION MAP

Simulant ID #: TP



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

Head, neck, & face — clean. 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.

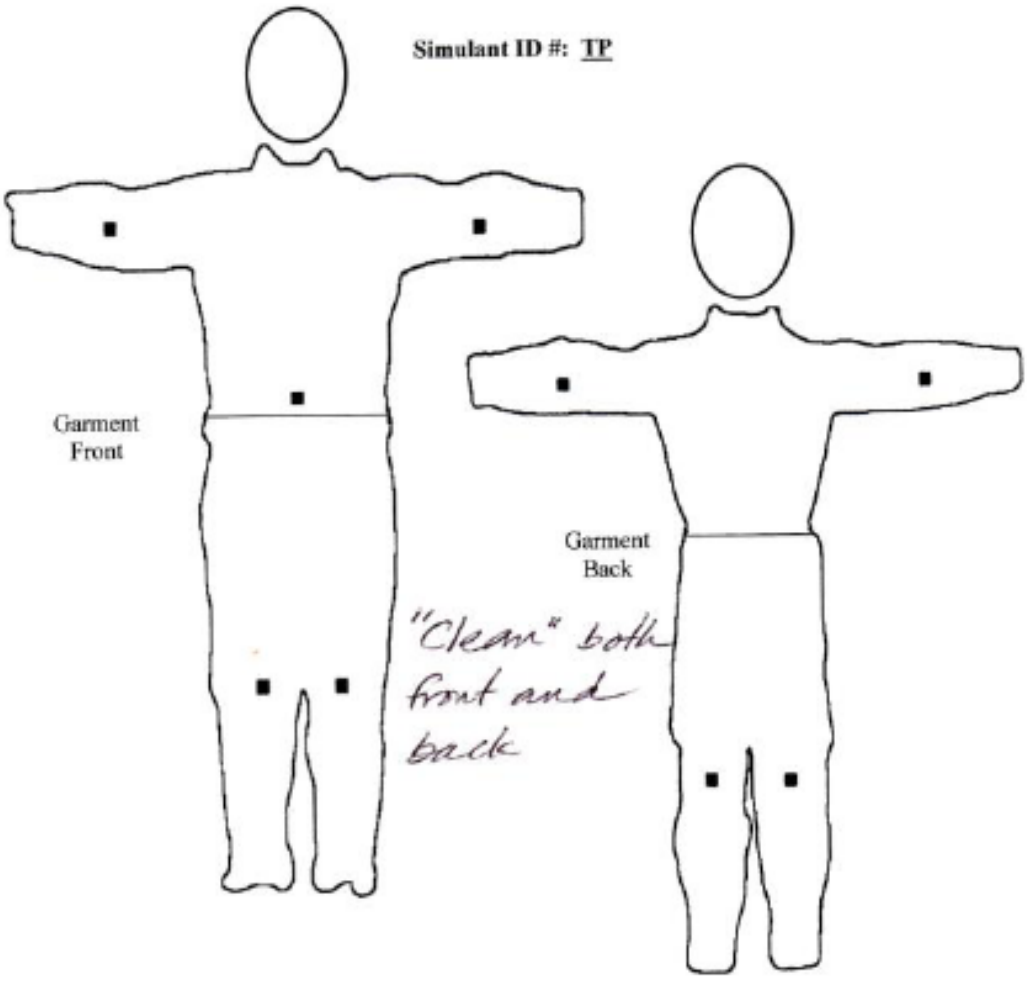
Checklist actions completed by (initials): Date: 04 Aug 09

Hazmat Science Applications

Department/Agency: PhilaU LEHP Date: 04 Aug 09 Run # 2

DeconPro® POST-TEST SIMULANT LOCATION MAP

Simulant ID #: TP



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

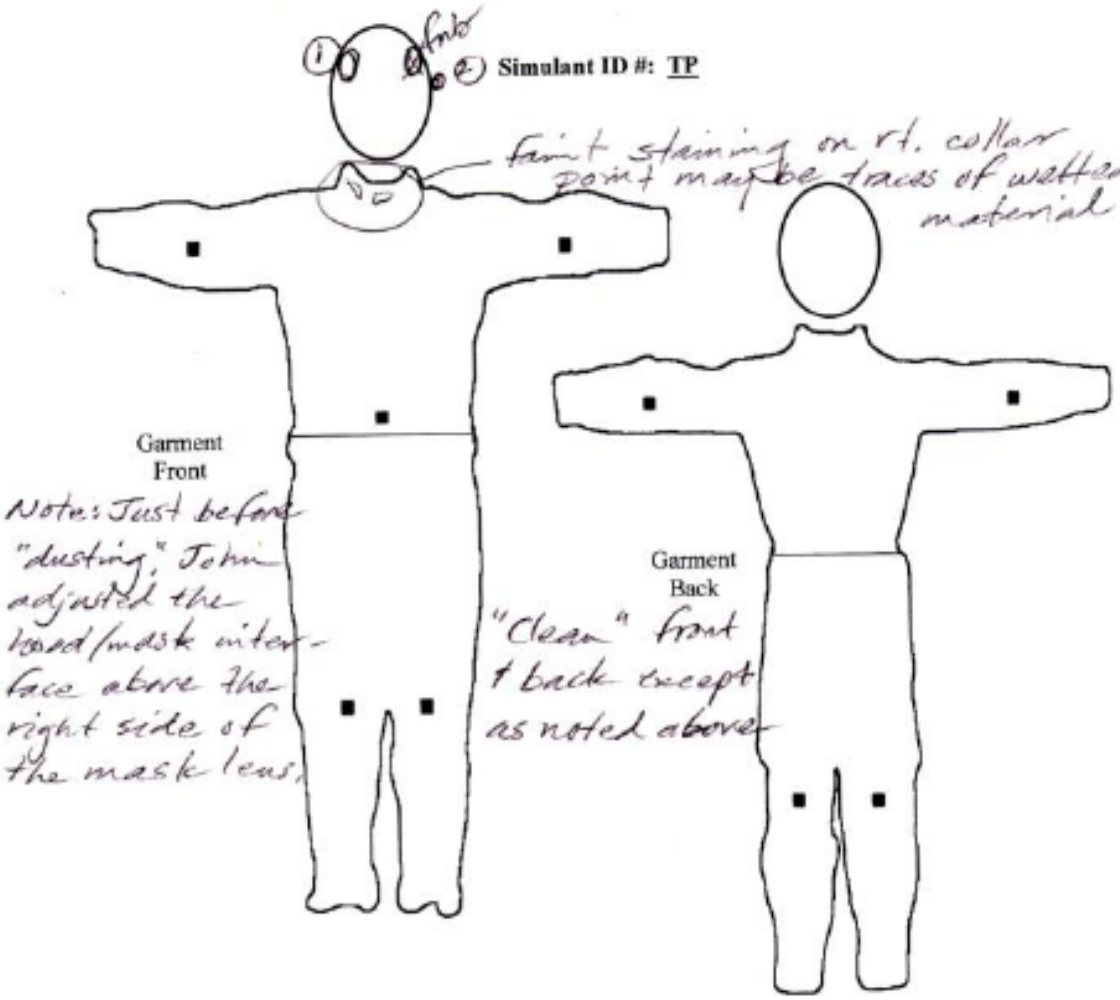
Head, neck & face - clean. The test undergarment appears to be free of any clear evidence of simulant transfer from protective ensemble exterior surfaces.

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

Hazmat Science Applications

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.

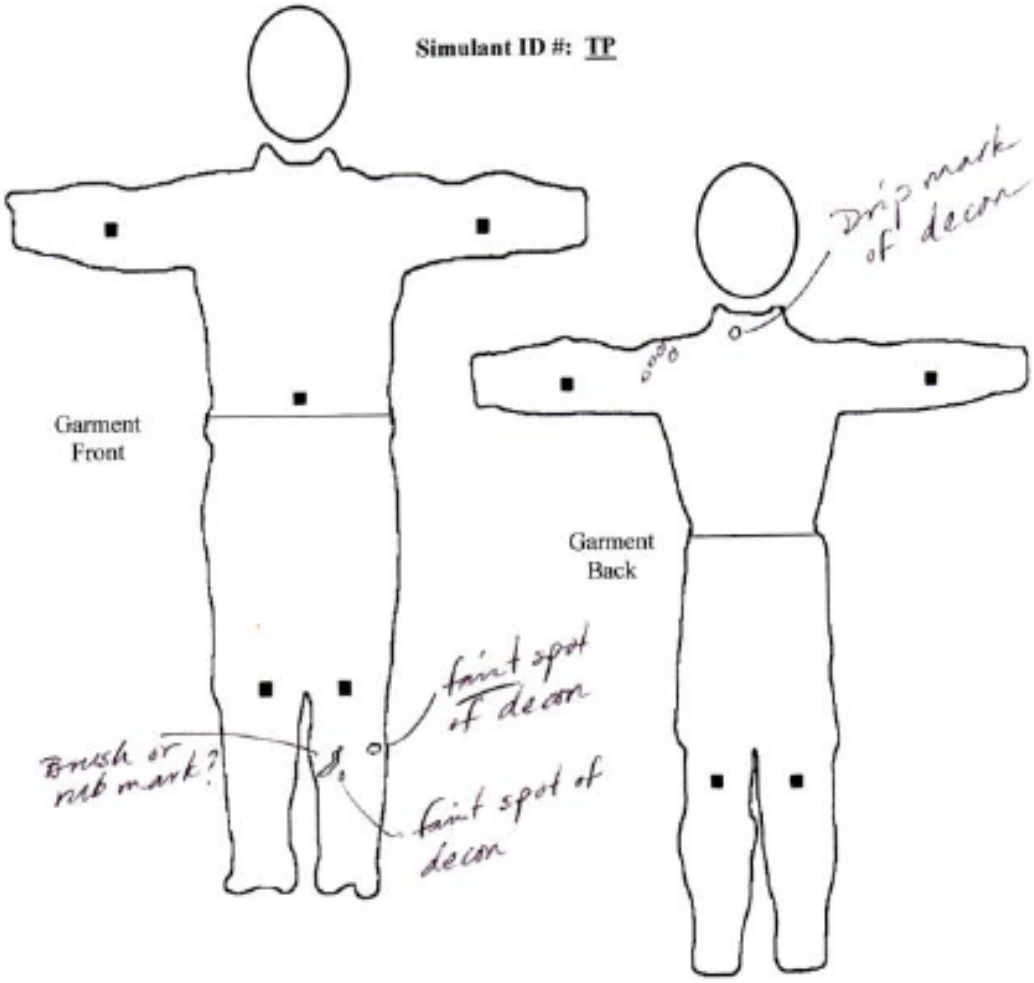
Checklist actions completed by (initials): [illegible] Date: 04 Aug 09

Hazmat Science Applications

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

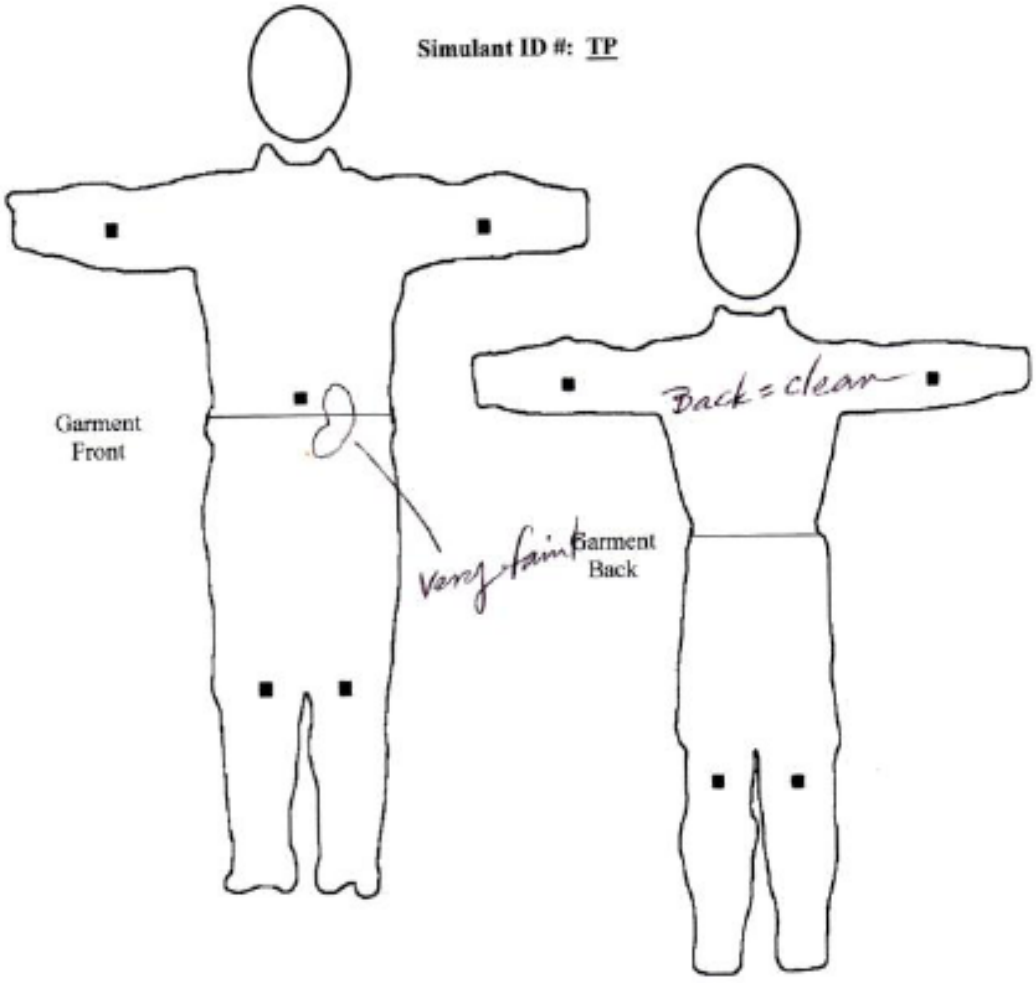
Checklist actions completed by (initials): _____ Date: 8/5/09

Hazmat Science Applications

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

DeconPro® POST-TEST SIMULANT LOCATION MAP

Simulant ID #: TP



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

Very faint hazing on left front abdomen to left of navel

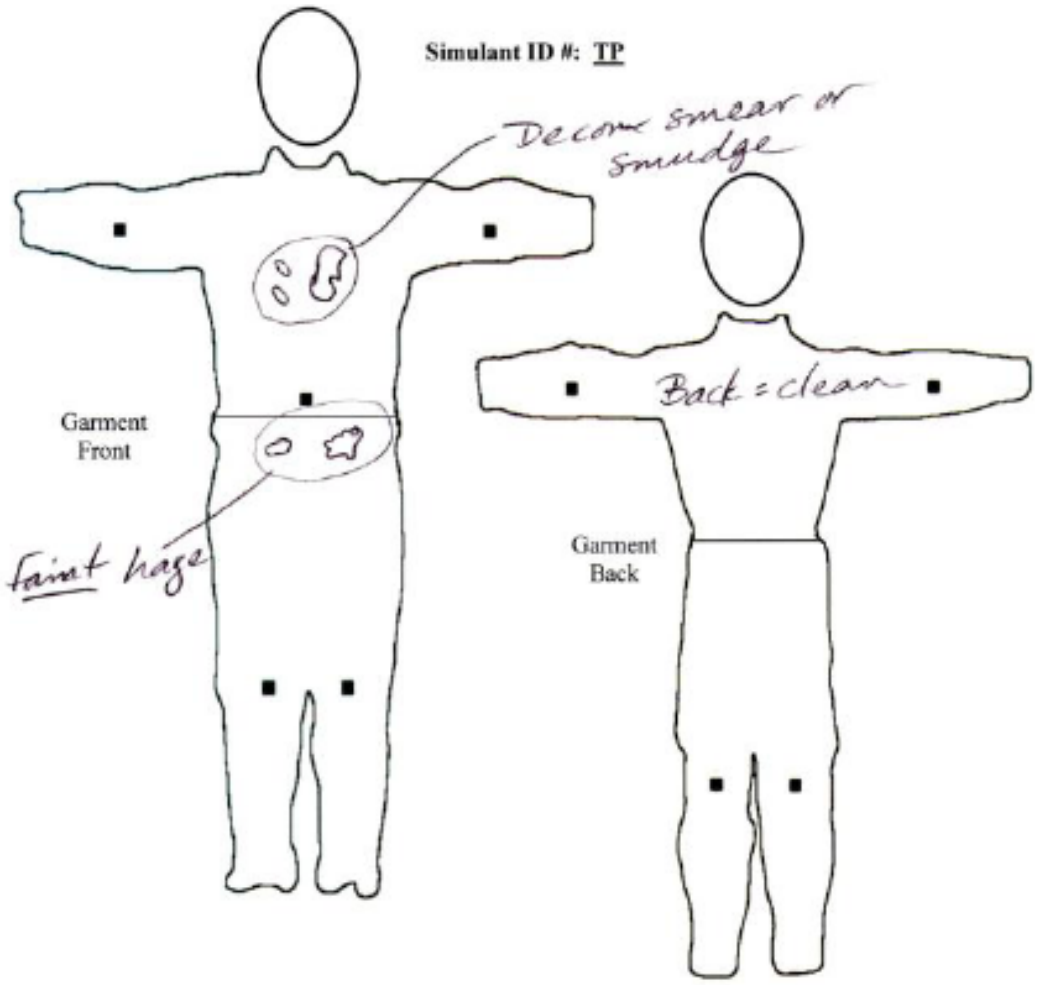
Checklist actions completed by (initials): [signature] Date: 8/5/09

Hazmat Science Applications

Department/Agency: PhilaU LEHP Date: 05 Aug 09 Run # 3

DeconPro® POST-TEST SIMULANT LOCATION MAP

Simulant ID #: TP



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

All patterns noted were extremely faint.

Checklist actions completed by (initials): Date: 8/5/09

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

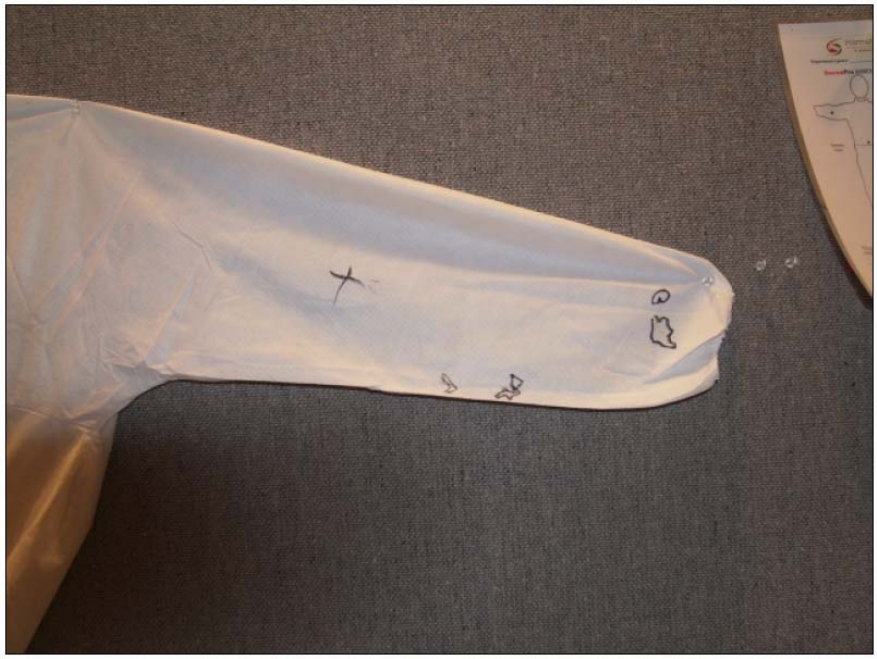
The following images document the test undergarment condition following inspection under ultraviolet light. Discernible patterns of residual contamination simulant were marked with an indelible pen so that photographs could be taken under white light conditions.

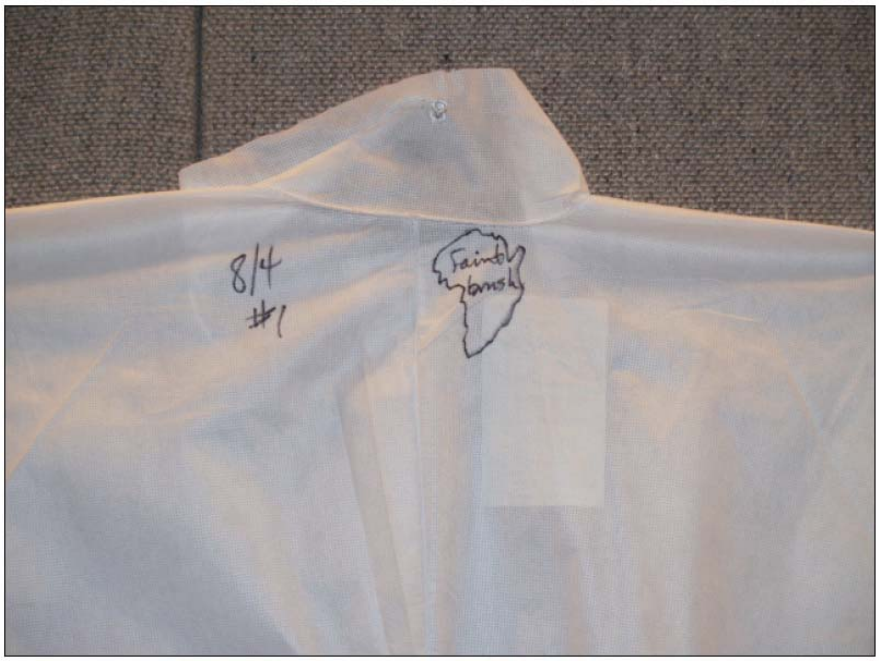
PhilaU Post-Doffing Images

August 4, 2009

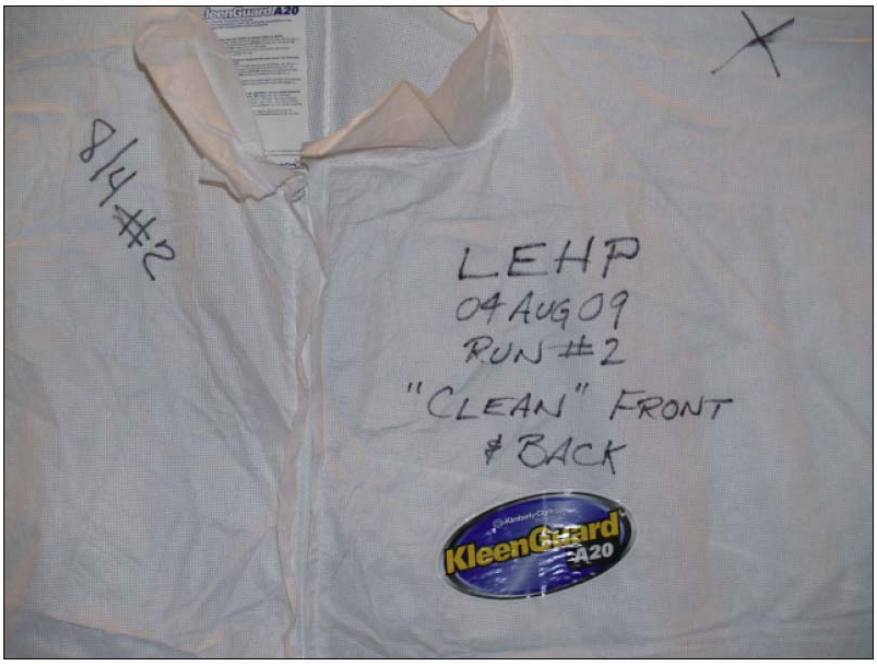

8/4
#1
LEHP
KleenGuard
A20

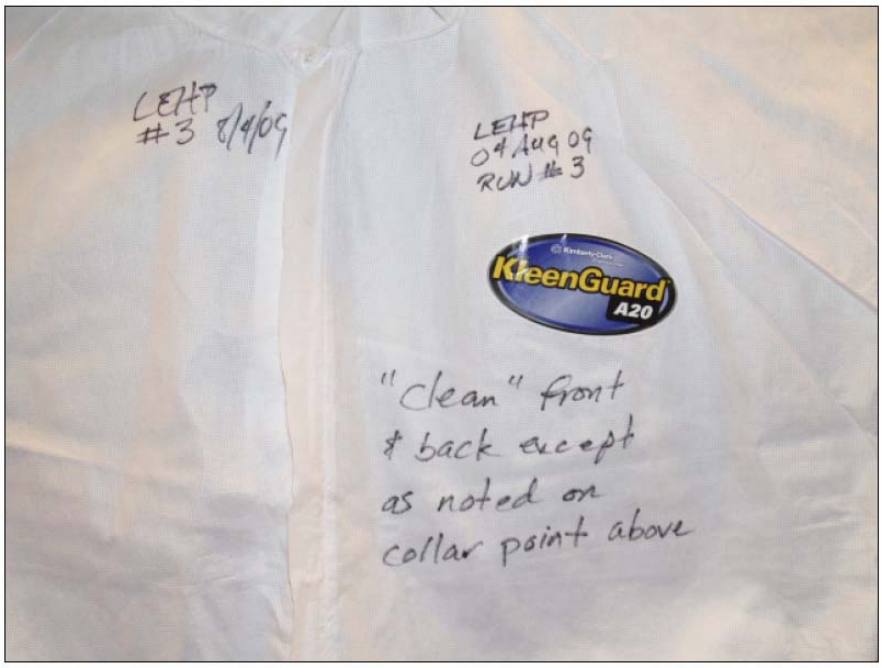

8/4
#1
LEHP
KleenGuard
A20

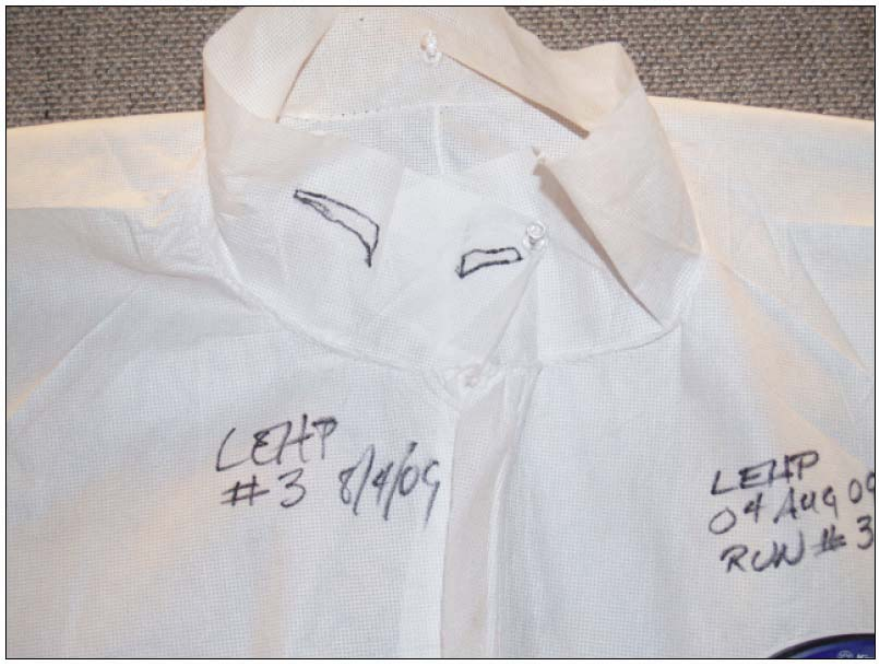



8/4
#1


8/4
#1


8/4 #2
LEHP
04 AUG 09
RUN #2
"CLEAN" FRONT
& BACK
KleenGuard
A20

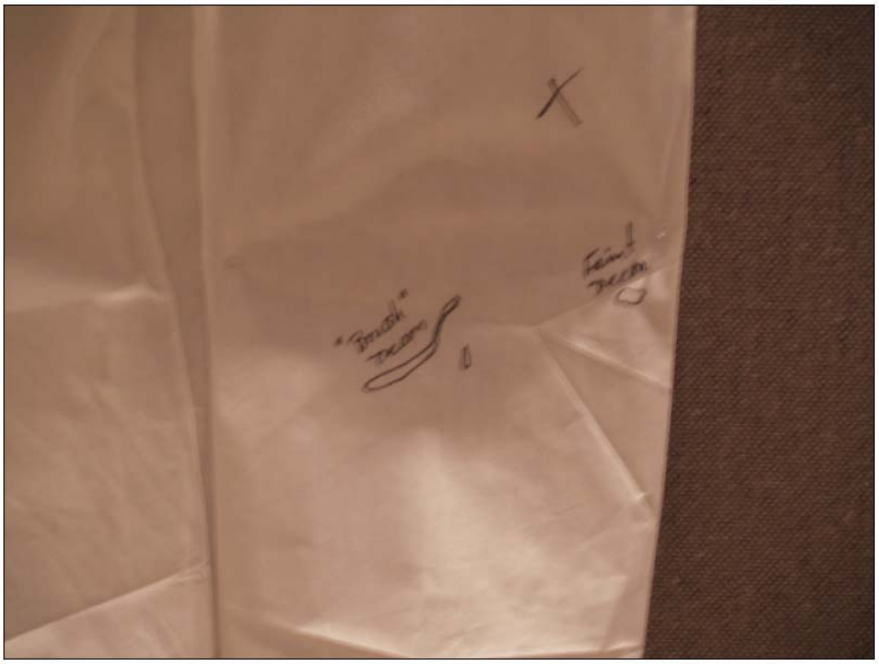

LEHP
#3 8/4/09
LEHP
04 Aug 09
RCW #3
KleenGuard
A20
"clean" front
& back except
as noted on
collar point above


LEHP
#3 8/4/09
LEHP
04 Aug 09
RCW #3

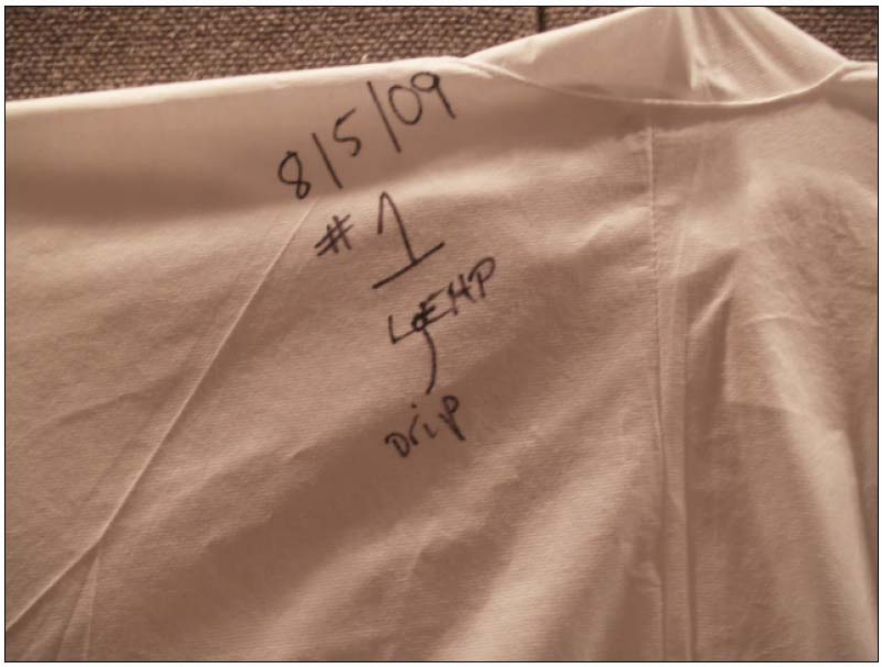
PhilaU Post-Doffing Images

August 5, 2009

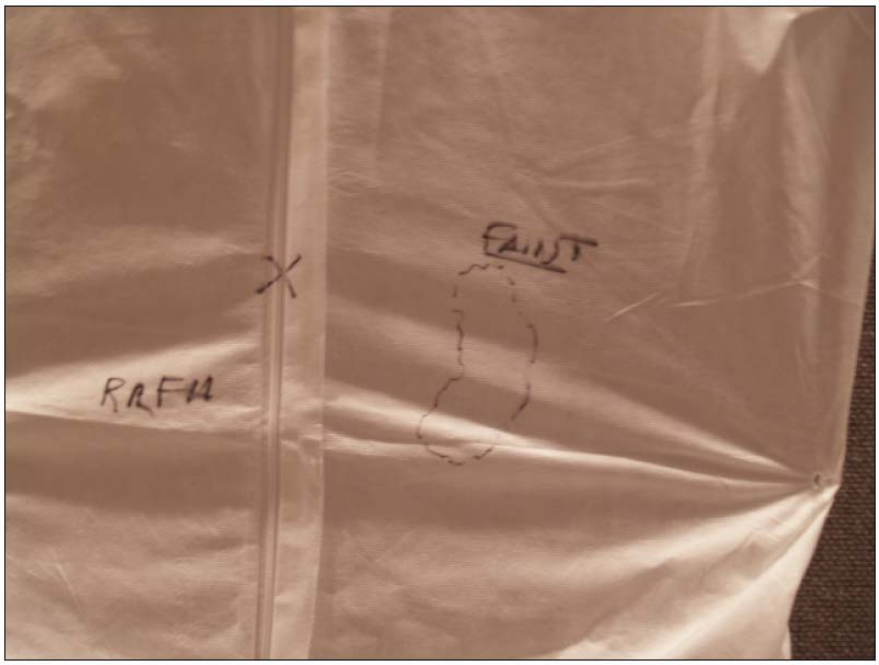

LEHP
05AUG09
RW #1
KleenGuard



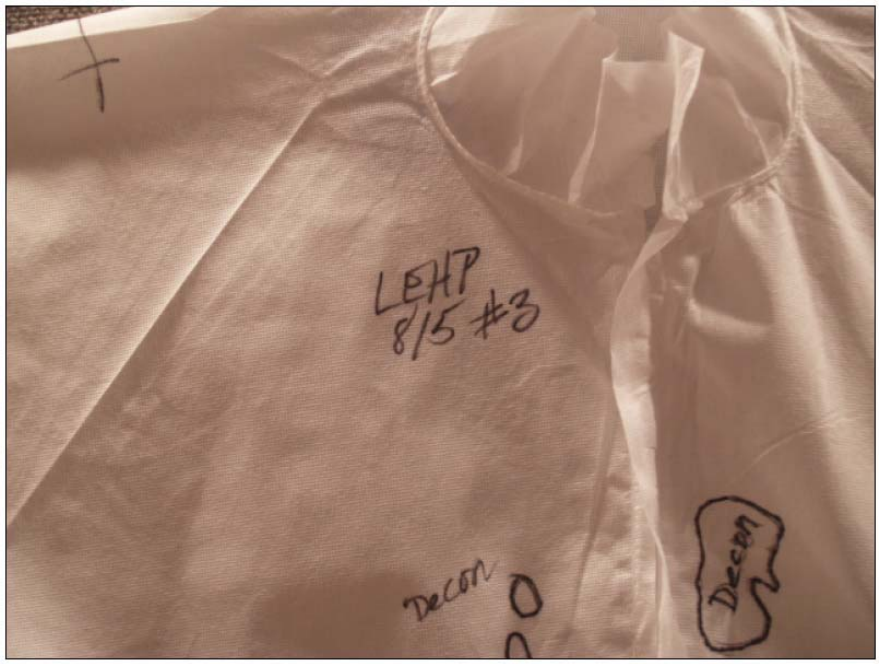

Deconned fingers?

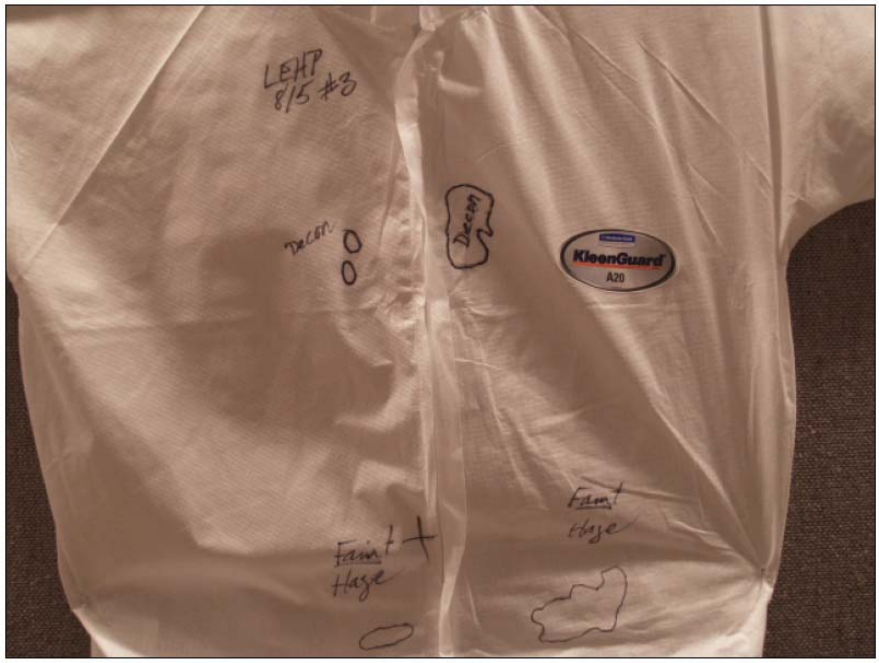

8/5/09
#1
LEHP
DRIP

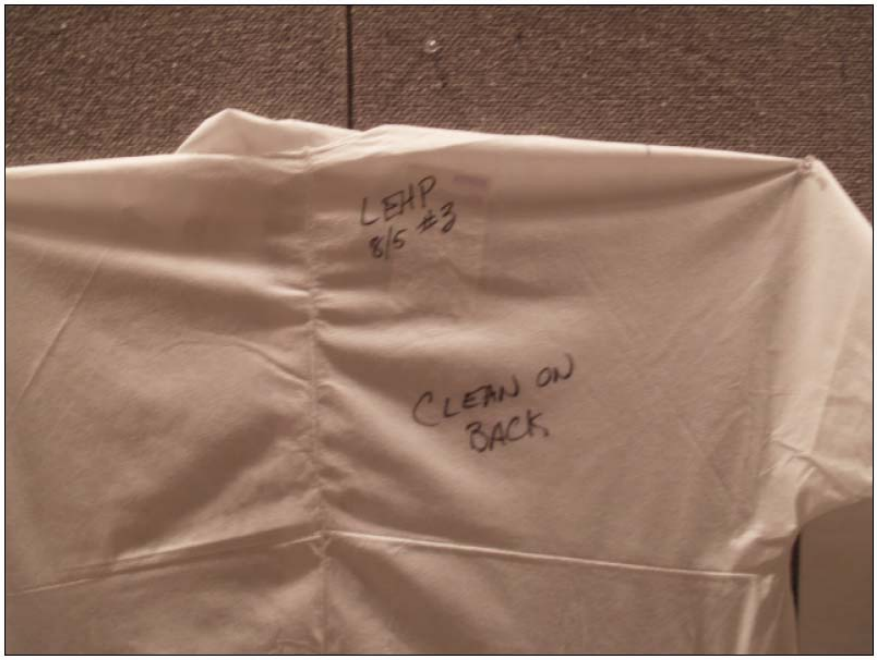

X
LEHP
KleenGuard
A20


X
RRFM


LEHP
8/5
#2
BACK= CLEAN


LEHP
8/15 #3
Decon
Decon


LEHP
8/15 #3
Decon
Decon
KleenGuard
A20
Faint
Haze
Faint
Haze


LEHP
8/5 #3
CLEAN ON
BACK

Appendix F

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

Reprint starts on next page.

PHILADELPHIA UNIVERSITY - LEHP **Testing Notes**
CONTAMINATED DOFFING **AUGUST 4-5, 2009**

Attendees:
LEHP: K. Hultzapple, 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 ½
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 ½
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

- 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 Sleeve Length	35
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 Sleeve Length	33
Raglan Sleeve Length	30
Cross Shoulder	21
Back Length	23 1/2
Inseam	32
Outseam	40

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)

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

- 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 to 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

<u>Recommendations for next run:</u>

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

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

- Doffing-
  - Release all Velcro as early as possible in the doffing procedure to reduce amount of contaminate reaerosolized in a cleaner environment
  - 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.
  - 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

- 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 ½ 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

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

- 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
  - The draw cord at the waist may be unnecessary, subjects don't seem to want it pulled around their waist
  - Make the zipper flap at center front ⅝ inch bigger so it is easier to grip and remove the jacket for decon
  - 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
  - Revise waist interface with the pant and skirt, needs to provide more protection and prevent blow through without becoming too complicated
  - Add ½ inch width to knee pad strap casing to allow easier retraction of straps into casing
  - Add ½ inch width to ankle strap casing to allow easier retraction of straps
- Undergarment – Shirt
  - Velcro at neck is uncomfortable, it needs to be repositioned or slimmed down so it doesn't poke into the neck
  - Switch the fabric neck collar on the shirt so that the rough side is not against the skin
- Undergarment - Drawers- none
- Balaclava- none

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.

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Appendix G

Reprint of *LEHP Contaminated Doffing—Final Script, Generation 4—August 4, 2009*

Reprint starts on next page.

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

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