PPE Design Retrofit Approaches
Ebola Grand Challenge: Mission #1: PPE Design Retrofit

Building on initial PPE Design Retrofit Concepts work to make same field gear more user-simple, we offer new approaches for manufacturers to consider.

Intended for testing different design approaches to current PPE to make donning and doffing simpler, in accordance with current manufacturing best practices and feedback from frontline healthcare providers in the field.

Today:

The goal is to understand what modifications can be made to existing PPE to meet current field requirements, healthcare standards and regulatory certifications to fast-track upgraded gear improvements to workers that need them now – to stop infection at point of removal.

Tomorrow:

Future considerations for improved PPE highlight the need for a systems approach to outer garments, inner garments, and possible cooling mechanisms to reduce core body temperature, heat and humidity discomfort, as well as to increase visibility, hearing and overall freedom of movement.

Basic Design Concepts Refined:

Rear Entry Design

- Use a rear entry design approach for one or two piece suits, with or without integrated hood, to facilitate a clean front without apron or obstruction to increase freedom of movement, improve decontamination or washdown, and quickly but safely remove or doff outer garments. Incorporate sealable rear zip concepts using purposely placed “Grab Tabs” to support self-removal.

“Grab Tabs”

- Create contrasting colored assists logically placed inside or outside garments to quickly grab, shed and doff hazardous PPE, using looped PPE material pulls tabs, flap tabs with current adhesives, big zipper rings or finger tugs, corded zipper pulls, and sealable (hide-able) hanging grab-able threads.

Wearable “Flash Sensors”

- Create an alert mechanism for PPE users to avoid maximum levels of heat exposure.

- Consider low-cost chemical or electro-mechanical sensors that are pocketable, externally visible, or work in concert with outer garments or other wearable cooling systems.

See original document: PPE Design Retrofit Concepts
Expanded Design Principles (see Appendix for detailed overview):

Outer Gear

- Explore single and two-piece PPE suit options for both existing and newer materials – to make the process of entry (donning), cleaning, and exit (doffing) easier, safer and universally standard – creating splash, tear and puncture proof gear for field, hospital or homecare providers.

- Explore the adoption of simple support mechanisms and low-cost design changes to facilitate proper PPE use and training – using integrated sleeve, leg and body tapes, finger zipper pulls, fabric and elastic loops and tabs, plastic eyelets and hooks, foams, and sealable PPE material flanges with the same chemical resistive tape for major openings or closings.

  Note: Follow standard healthcare product development practices for cleaning and disinfection – no unnecessary grooves, textures or recesses to prevent sterilization in nooks or crannies.

- Explore fully viewable covered hood options for single or two-piece suit options to facilitate breathability, person-to-person communication, comfort, freedom of movement, and hearing, as well as the ability to use mobile electronic communications earpieces or other support technologies without exposure or contamination.

- Explore phase change material (PCM) for incorporation into outergarments – to absorb or reflect heat, specifically near the head, neck and back areas. Preliminary research shows the availability of phase change (temperature control) fabrics used in making clothing.

  For example, Temptrol® heat reflecting fabric insulation:  
  [http://www.radiantbarrier.com/temptrol.htm](http://www.radiantbarrier.com/temptrol.htm)

- Explore existing industry data (extended field trials and customer feedback) on future surface designs of low-cost disposable face respiration masks that decrease humidity and heat under PPE suits. Existing PPE masks such as the surgical N95 respirator are known to have wearable design flaws in relation to other PPE equipment like outer garments. Industry experts having studied improved cooling effects with different design constructions that increase breathability around the face, nose and mouth, that result in overall body comfort.

  For example, industry experts suggest working backwards and leveraging lessons learned from existing top-level field gear:  

- Explore existing footwear technologies for next-generation boot and sock materials for breathability and comfort.

  For example, simple footwear and sock innovations:  
Undergarments

- Explore problems with existing undergarment materials – to move away from loose-fitting and bunching cotton scrubs to more appropriate body contoured and wicking reusable (washable) materials, reducing dehydration, delirium, and heat exhaustion from combined use with PPE outerwear.

For example, research modified scrub designs and materials:
http://www.crazyscrubs.com/brands.html
http://www.scrubs123.com/brands/performax.html

- Explore passive phase change materials (PCM) in common undergarment materials such as headbands, skullcaps, neck wraps and vests (at a minimum) – to increase outer garment comfort and reduce body temperature, sweating, and dehydration. PCMs are reusable and washable, and can be easily tested for field applicability.

For example, modification of the following products and ingredient technologies:
http://www.polarproducts.com/polarshop/pc/home.asp
http://watersorb.com/index.html
http://www.frogtoggs.com/cooling/the-chilly-pad.html
http://www.therapearl.com/our-products/
http://www.blackicecooling.com/compare_personal_cooling.html

Sensors and Alerts

- Explore the application of traditional phase change materials or body agents (such as temperature tapes or monitors) that are recognizable by others to provide personal alerts or buddy-system warnings.

- Explore a field-proven worker-productivity and self-monitoring system using a body-worn data collection sensing system wirelessly connected to healthcare-ready and enterprise-class rugged mobile computers – to bring back data over the cloud for more advanced analytics and research discovery.

For example, see Ebola Grand Challenge: Mission #3: Virus Dashboard: Using Mobile Data Capture to Contain the Spread of Ebola

For example, see ZephyrLIFE™ and BioPatch™ patient monitoring solutions:
http://zephyranywhere.com/training-systems/defense-solutions/
http://zephyranywhere.com/healthcare/zephyrlife-home/
http://zephyranywhere.com/products/biopatch/
• Explore other emerging low-cost body sensing technologies to facilitate simple biometric feedback on mobile handheld devices.

For example, prototype system from Stony Brook University for emerging economies:

A low cost adhesive body sensor with built-in temperature probe of roughly 2-inches in diameter is placed under the right lower quadrant over the liver to provide accurate reading of core temperature.

Data is sent wirelessly via Bluetooth to a mobile device and easily displayed using a simple user interface. Recommended data to be displayed includes: time in suit, and time with or left with patient. If temperature exceeds a predetermined threshold, the number turns red and an alert is sent or alarm sounds.

The current prototype has an initial bill of materials of about 6 dollars. A separate lab prototype measures respiratory rate and body position (originally developed as a SIDS monitor).
Cooling Systems

- Explore enterprise cost reduction strategies and value engineering methods for existing phase change materials and cooling system components. The combination of off-the-shelf parts with a low-cost manufacturer of softgoods can significantly reduce the cost of existing cooling vests, even when purchasing lower volumes or quantities.

For example, trusted global suppliers of enterprise-class softgoods:
http://www.agoraleather.com/
http://www.forwardindustries.com/index.htm

- Explore existing industry data (extended field trials and customer feedback) on future configurations of powered air purifying respirators (PAPR) that decrease humidity and heat under PPE suits. Next-generation PPE PAPR devices may require less cubic feet per minute (CFM) of air flow to achieve the same desired comfort levels – at about a third of current industry standards (50-60 vs. 180 liters per minute). Industry experts having studied improved cooling effects with different PAPR design configurations that decrease PPE humidity that result in overall body comfort.

- Explore how current passive and active air, water, fabric or other chemical cooling systems can be improved in terms of enterprise cost reduction strategies and value engineering – to better move
and distribute air between outer and inner garments – to both cool and monitor body temperature (possibly working or integrating with other sensor systems).

- Explore future generation water cooling filtration suits using different body placements and configurations leveraging gravity and common physical or mechanical motions to create a self-contained or low maintenance system for newer PPE gear.

- Explore targeted methods to cool body pulse points on the wrists, neck and forehead (see example PCM links in the Undergarments section).

Training and Use:

Universal PPE Instructions

- Issue a standard PPE gear pack for the right environments – in field, in hospital, or in homes (for caregivers).

- Create a simpler set of common and universal instructions for donning and doffing new standard PPE – all-in-one suit, suit with hood, or other.

To simplify the following: [http://www.cdc.gov/vhf/ebola/hcp/procedures-for-ppe.html](http://www.cdc.gov/vhf/ebola/hcp/procedures-for-ppe.html)

- Create a standard communications protocol or PPE process for the right environments – in field, in hospital, or in homes (for caregivers).

- Use a printed visual guide and simple 1-2-3 iconographic (more visual, less text) instructions on PPE plastic suit or hood packaging.

To simplify the following: [http://biologicalsubstancepackaging.com/ppe-poster.pdf](http://biologicalsubstancepackaging.com/ppe-poster.pdf)

- Deploy redesigned or retrofitted PPE using a common design language to make training easy to follow and remember.

- Use simple video to express proper procedures and protocols so that the PPE experience becomes learned and second nature.

- Use social media to drive attention to the new standards posted online – easily shared, easily reached.

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Appendix:

*By Intelligent Product Solutions, with contributions from Motorola Solutions Enterprise (Symbol Technologies) and Stony Brook University*

• PPE Outergarment, Undergarment & Sensor/Cooling Brainstorm
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Intelligent Product Solutions

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Executive Summary

The undergarments worn under Personal Protective Equipment (PPE) of those fighting the Ebola virus present several major issues. These undergarments are meant to provide an extra layer of protection as well as provide comfort while healthcare professionals are caring for Ebola patients. As shown in the image below, the undergarments are too baggy causing excess and unnecessary heat they get damp and heavy from perspiration, and have no cooling capabilities. These undergarments are worn in 100+ degree weather causing serious health issues (e.g. dehydration, delirium, heat exhaustion) for the workers, potentially causing infection from the virus.

The results of the brainstorm that follow in this report reveal several opportunities to solve the issues described above. Ideas that were discussed relate to moving and distributing air between the outer and inner garments offering heat relief, providing a means to actively and passively cool the body, and lastly, monitoring body temperature to warn the healthcare professional of any danger.

The solution may be a combination of using existing technology (e.g. sweat wicking athletic gear) and creating simple but sophisticated solutions (e.g. a vest that snakes cold water through attached tubes), thus providing the ultimate undergarment for the healthcare professional. The goal of the brainstorm was to keep the solution simple, feasible, and as low cost as possible. With the right combination of existing technologies and engineered solutions, the undergarment can be vastly improved.
Inner Garment Problems

• Too baggy
• Too hot - Causes “loopiness” and mistakes made when disrobing
• Gets damp from sweat
• No cooling capabilities
• Weight becomes an issue when garments get damp

Can we move air between the outer and inner garments?

• How to keep air clean, if coming from outside?
• Recycle air within the suit?
• Combining U/V light to an air filter that the virus cannot get through?
• Can tubes be connected to a wearable reservoir?
• Can the tube connections be accessible externally to swap reservoirs when the water gets hot? (i.e. reference liquid cooled micro’s in desktop computers... inexpensive, low energy).
• Reservoir can have off-the-shelf ice packs. Use an in line, battery powered pump.
• Can monitor coolant temp and either modulate pump speed or cycle pump on/off -- save energy and avoid coolant getting uncomfortably cold in tubes.

Active concepts

• Snaking tubes across the body that transports cool water.
  o If cold water is accessible, you can flush and refill your tubes with new cold water as needed via hose
  o Water in the tubes would contain chlorine solution to kill any remnants of the virus
• Solar panel piezoelectric crystals with heat sink connected to outer garment
  o Used in robotics. Requires small power
• Desiccants – closed cycle cooling effect (http://www.solarmirror.com/fom/fom-serve/cache/35.html)
Active Concepts (cont’d.)

Desiccants -
Could be passive. Packets inserted into soft goods

Water cooling filtration
Replace coolant with lower temp coolant. Ice bath in cooler?

Passive Cooling Concepts

• Clothing material needs to be:
  - Breathable (e.g. Gore-Tex, polyester, spandex)
  - Cooling technology (Major athletic companies have solved this problem already; e.g. Nike, Under Armour, etc.)
  - Tight on the body
  - Thin material, sweat wicking fabric
  - Gets moisture away from skin but will accumulate in gloves and boots. Does this help? Can readily be tested.
  - See images below

• A battery operated neck cooler
  - The part that touches your neck is made from anodized aluminum, has a small fan, and holds small amount of water (2 oz) to create a cooling sensation
  - Powered by AA batteries that lasts between 2-4 hours

• Cooling gel packs sewn into under garments or pockets
  - Could be velcro’d into pockets in garment and replaced

• Sodium polyacrylate crystals (Material used in the FRIO® insulin wallets)
  - Cooled via water and stays cool for up to 48 hours
  - Also known as “artificial snow”
  - https://www.youtube.com/watch?v=_Gq-rJ7n_t8
Passive Cooling Concepts (cont’d.)

- https://www.youtube.com/watch?v=_Gq-rJ7n_t8
- You can buy off the shelf "phase change" chem packs which will not have to be frozen. Still cooler, but higher temp than refrigerated or frozen. Reusable.

Athletic cooling technology

Battery operated neck cooler

Breathable material, maybe Gore-Tex?

Sewn in/pockets for gel packets

Coolant contact, gel packs or phase change material packs should be strategically located on body to the most effective locations only.
Ways to monitor body temperature

- High frequency beeper connected to sensor that’s reading skin temp and alerts wearer at a particular threshold. Audible alerts do not require anyone to read a visual indicator. Visual alerts can be missed.
- Something similar to a fish tank thermometer
  o http://www.petsmart.com/fish/heaters-thermometers/grreat-choice-strip-thermometer-zid36-5203382/cat-36-catid-300016;pgid=wVGvEzj3LsISRPaXxJ1M_Jd0000N2
- Measure ambient temp inside goggles/mask and determine how long a person may last.
  o May be

Parking Lot

- Is evaporation the problem?
- Are people aware when they’re about to pass out, can we sense it instead? Is temp the indicator?
- Do they need undergarments that are so big? (Pants, sleeves, etc)
- Do we solve the problem of detecting temperature?
Executive Summary

The outergarments of Personal Protective Equipment (PPE’s) worn by those providing health care to victims of the Ebola outbreak present several major problems. The garments are intended to protect workers from infection while enabling them to provide patient care. They are complicated, costly, and do not always prevent the workers’ skin from being exposed. Because they are difficult to doff safely, removing them has been known to cause fatigued workers (who have been working in conditions of 100+ degrees F) to become infected with the virus. Methods used to ‘hose down’ workers before doffing the garments can result in the splashing that has been known to cause some worker infections.

The results of the brainstorm which follow in this report reveal a number of approaches to solving some of the issues described above. Ideas that were discussed involve simplicity in packaging, cost containment, ease of donning and doffing, safe and expedited doffing, enhanced worker protection and providing for the patients’ better visibility of the workers’ facial expressions. Also addressed are methods for ‘customizing’ a one-size-fits-all outergarment for better fit and alternatives approaches to suit cleaning prior to disrobing.

With the right combination of materials and design, PPE outergarments can be improved for greater worker safety and improved patient care. The goal of the brainstorm was to devise solutions with all stakeholders in mind: those providing/paying for PPE’s, the health of the care providers wearing them and the well-being of the patients receiving care.
Realized Technologies

1

**Single use is our advantage**
- These suits are envisioned to be single use. This allows the suit to more effectively cover the user and protect from material ingress. Entering the suit is enabled through a zipped opening. Exiting the suit is accomplished by tearing open larger single use seals to allow the suit to be removed.

2

**One-Size-fits-all**
- Dexterity and mobility is difficult in current lower cost suits due to their large size and bulk. Ideally a single size suite could fit many human sizes. The excess material can be controlled by implementing a strap system at the cuffs. The long cuff straps wrap around the body to both gather extra material and create a seal. An adhesive tab at the end of the cuff strap secures the strap in place. Removal is accomplished by tear open this single use tab. The straps not only contain the extra material of the suit but also create a seal at the ankles and wrists.
Safety from all directions

- Major issues brought to our attention were; uncomfortable headgear, impaired hearing, proximity of hands to face while disrobing. This reverse bib concept addresses the above mentioned issues. Additionally the suit can be flat packed. The concept works by having the hood connected to the front half of the suit with a flap and string attached to it. The hood is donned by holding onto the strings and flipping it backward over the head. Once on the head, ties around the waist keep it in place. The reverse allows the hood to be removed.
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4 Goggles for all

- Another issue noted issue is that currently used goggles are uncomfortable, fog up easily, and are especially troublesome for people with glasses, and can create openings in your seals against the Ebola virus. A concept combining the hood, elastic band, foam and a flexible / transparent sheet enables a lens to be incorporated into a hood that can be packed flat.

5 Dry alternative to wet spray down

- After a doctor gets out of a high risk zone, they are showered with a dose of a chlorine solution. A potential alternative could be to use a powered solution instead of the current liquid solution.
Watch your feet

- One of the most troublesome parts of doffing is the removal of the boots. Balance and effort are required to remove the boot. A three step system for removal can potentially improve this. The system has three layers of protection; standard boot, bootie integral to the suit, and a very thin neoprene sock. To begin a boot jack is used to remove the outer boot. The user then steps into a tray of solution, cleanses the suit and then removes the lower portion of the suit. The user steps out of the tray in neoprene booties, enters a second tray and then into a pair of open footwear. At each stage the user is moving into zones of decreasing risk level.
Concept B

- Flat to pack
- Hood with open face
- Smock covers front and back, sides open
- ID pouch
- Rear entry zipper
- Cuff flap with adhesive
- Pull tab to tear
- Integrated inner glove
- Engagement hook for glove removal

Front Back (smock) Back (body suit)
Concept C

- Integrated Face Shield
- Two Layer bonded suit
- ID pouch
- Rear entry, unzips to feet
- Gore-Tex top
- Sleeves pull
- Integrated glove
- Suit falls away back and front
- Gathers around boots
- Tear flap

Front

Back

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PPE Outergarment Brainstorm

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Concept D
System Design

1

The “Grate” Concept

- A puddle of chlorine is produced during the wash-down process. This puddle can be muddy and slippery and potentially hazardous. Puddles accumulate and create potentially unsanitary conditions. The person being washed stays in one area while disrobing. We propose an environment where the user stands on a grate over pan to control puddles. The area is divided into sections starting at the high risk entry zone and ending with the lower risk exit. It is envisioned that each grate corresponds to a step or small series of steps. The concept below focuses on having the user move forward after each article of clothing is removed and located over a grate and pan system that removes the solution from their location.