Next Generation Structural Fire Fighting PPE with CBRN Protection for MSA SCBA

Contract No. W91CRB-09-C-0098

Final Report
Contract Line Item No. 001 (Data Items A004)

Prepared for:

Technical Support Working Group
Attn: Christina Baxter
P.O. Box 16224
Arlington VA 22215

Prepared by:

International Association of Fire Fighters
Occupational Health, Safety, and Medicine
1750 New York Avenue, N.W.
Washington, DC 20006

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Overview

This report is provided by the International Association of Fire Fighters (IAFF) and its project team members to fulfill the contract requirements for delivering a draft final report that provides all findings to date and the overall design achieved by this project (Data item A004). It has been prepared in accordance with DI-MISC-80508.

This final report provides specific details for the execution and completion of this project, which include:

1. Background on the design of the Project HEROES structural fire fighting protective ensemble with CBRN option with descriptions of current interfaces.

2. The project technical approach in terms of proposed solutions for making changes in both the hood interface and the SCBA facepiece for integrating the MSA CBRN SCBA.

3. Detailed descriptions of each task and subtask including their interrelationships.

4. Diagram and other information showing the redesign of the ensemble and interface piece for the MSA CBRN SCBA facepiece.

5. Target performance criteria used for evaluating prototype ensembles and the modified SCBA facepiece.

6. A description of the evaluation approaches used for the conduct of testing in terms of integrity testing and total inward leakage testing.

7. Project findings and results of testing used to demonstrate development of the design for providing wearer integrity.

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Next Generation Structural Fire Fighting PPE with CBRN Protection for MSA SCBA

Draft Final Report

International Association of Fire Fighters
Occupational Health, Safety, and Medicine
1750 New York Avenue, N.W.
Washington, DC 20006

1.0 Introduction

A project team consisting of the International Association of Fire Fighters (IAFF), International Personnel Protection, Inc (IPP), Honeywell First Responder Systems (HFRS), and Mine Safety Appliances (MSA) has worked to develop appropriate interfaces for the MSA CBRN SCBA to be integrated as part of the Project HEROES Protective Ensemble and qualified to the CBRN Option of NFPA 1971, *Standard for Protective Ensembles for Structural and Proximity Fire Fighting*. This report describes the approach and findings that have been used in this development of the modified ensemble.

2.0 Background

The International Association of Fire Fighters (IAFF), as part of their ***Project HEROES®*** (Homeland Emergency Response Operational and Equipment Systems) initiative, received a federal government contract from the Technical Support Working Group (TSWG) with initial funding from the Department of Homeland Security (DHS), and subsequent funding from the Department of Defense (DoD), the Defense Threat Reduction Agency (DTRA) and the Joint Science and Technology Office (JSTO). The project involved:

- Development, testing, and prototyping of structural fire fighting PPE (Personal Protective Equipment) with enhanced chemical, biological, radiological, and nuclear (CBRN) protective qualities to account for emerging emergency and terrorist threats.

- The creation of a certified protective ensemble that is as indistinguishable as possible from current structural fire fighting gear but still offers improved CBRN and overall hazardous substance protection together with enhanced thermal protection without sacrificing wearer comfort and functionality during routine structural fire fighting operations.

A CBRN option was added to the new 2007 edition of NFPA 1971, *Standard on Protective Ensemble for Structural and Proximity Fire Fighting*. This option establishes rigorous criteria to ensure that CBRN ensembles will meet the high demands for providing extensive chemical, biological agent, and radiological particulate protection over their intended service life. Specific requirements include:

- Ensemble composite materials must demonstrate resistance to permeation by chemical warfare agents and selected toxic industrial chemicals after the materials have been subjected to multiple washings and heat exposures, repeated flexing and severe abrasion.

- The overall ensemble (coat, pants, hood, gloves, and footwear together with a self-contained breathing apparatus) must prevent inward leakage of CBRN agents when tested using human subjects exercising in a closed chamber containing surrogate chemical warfare agent vapors (Man-in-Simulant Testing). The overall ensemble is also tested for liquid integrity in a "shower" test after multiple launderings.

- All ensemble elements must meet all other criteria applicable to that element. For example, garment composites must still meet the same total heat loss requirement for breathable performance to reduce the stress impact for wearing the ensemble.

- Manufacturers must specify complete ensembles, including SCBA.

Because of the strict requirements for testing, the IAFF Project Team evaluated a large number of composite materials including a variety of outer shell, moisture barrier (CBRN barrier layer), and thermal barrier materials and selected the optimum composite to provide the overall superior performance. This material system consists of the following materials:

- The traditional moisture barrier is replaced by a CBRN barrier layer in garments, the hood, and the footwear bootie. This layer is the GORE™ CHEMPAK® selectively permeable membrane, a robust material from W. L. Gore & Associates. This material has demonstrated permeation resistance against key chemical warfare agents and toxic industrial chemicals, while also achieving the NFPA 1971 total heat loss (THL) requirements in combination with the selected outer shell and thermal barrier.

- The industry proven Kombat 750 with Super Shelltite finish from Southern Mills is used as the selected outer shell, exhibiting a combination of outstanding durability, high strength and liquid repellency.

- The Southern Mills Quantum One-layer thermal barrier providing a balance of sufficient insulation and moisture management characteristics.

- Gloves use a different version of the GORE™ CHEMPAK® product technology for the CBRN barrier.

The IAFF Project Team has created a unique entire ensemble design with modifications to the coat, pants, hood, gloves, and footwear to ensure complete body protection when worn with a CBRN SCBA:

- Key interface components have been developed that function to provide passive CBRN protection when needed (the fire fighter does not have to do anything special to activate this protection).

- Initial overall ensemble testing showed average protection factors greater than 1000 and compliance for individual body areas. Some issues with these performance values were discovered after the conclusion of the project and are discussed in greater detail below.

- New features actually enhance structural fire fighting protection by providing additional insulation and preventing penetration of scalding liquids.

- Practical performance testing at several large metropolitan fire departments demonstrated end user acceptance of the overall ensemble design and served to identify further improvements through the evolution of the ensemble design leading to the accommodation of both Scott Health & Safety and MSA SCBA facepieces.

- Thermal protection requirements have been validated in live fire training where all participating fire fighters preferred Project HEROES ensemble over their current gear.

Prior to the start of this project, all design and development efforts have been with the Scott Health & Safety CBRN SCBA. A gasket provided in the attached hood provides a sealing interface with the SCBA facepiece. Yet, a key interface has been the insulating cooling system. This system captures and channels SCBA exhalation air to coat interior producing positive pressure to prevent inward leakage into the upper torso area of the ensemble. The feature also provides extra thermal insulation and upper torso cooling – gear is more comfortable and safer. However the specific attachment point with the SCBA is in the exhalation area of the facepiece. For the Scott Health & Safety SCBA, a collector cap was designed and mounted for easy attachment directly onto the exhalation valve. Nevertheless, the interface is only designed for the Scott Health & Safety SCBA. A unique interface must be custom-designed for each manufacturer's facepiece to ensure that the system operates correctly. Since the U.S. Military is transitioning to MSA SCBA, it is important the Project HEROES ensemble be built to accommodate and be certified with the MSA CBRN SCBA.

3.0 Technical Approach

3.1 Project Goal. The specific goal of this project was to design a specific interface that will permit the MSA CBRN SCBA to be integrated with the Project HEROES protective ensemble and that the resulting design can be certified under the CBRN Option of NFPA 1971. Figure 1 shows how a Scott Health & Safety CBRN SCBA is integrated to the protective ensemble through both a hood seal to the facepiece and a hose that connects the facepiece exhalation valve to the protective coat torso. The latter feature is known as the "cooling insulation system" or "air-flush system."

3.2 Proposed Solutions. The IAFF Project Team redesigned the Project HEROES® structural fire fighting protective ensemble to accommodate the MSA CBRN SCBA. This process included an examination of each interface area identified in Figure 1 and information that was obtained during the later stages of the ensemble's design process in the original contract.

1. The hood-to-respirator facepiece interface will be redesigned to universally accommodate most SCBA, including at least the Scott Health & Safety and MSA CBRN facpieces.

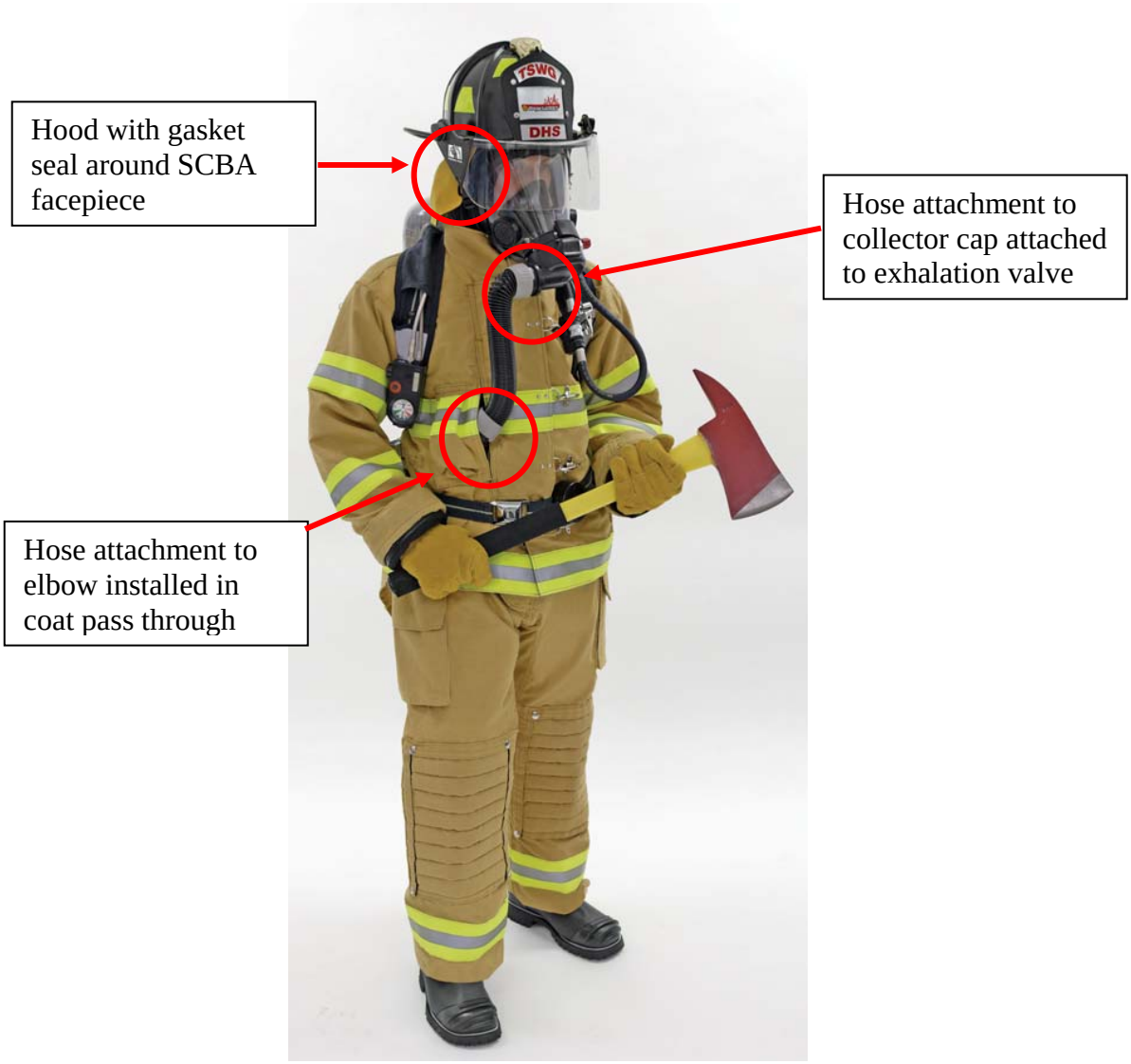


Figure 1 – Project HEROES SCBA Interface Configuration

2. A unique interface will be designed for attachment of the air flush hose onto the MSA facepiece.

3. No changes were identified for the hose attachment to the ensemble since this interface is independent of the SCBA.

It was found through Man-in-Simulant Tests (MIST) that the ensemble could qualify in providing acceptable protection factors without the cooling insulating system. While there was a reduction in the overall and individual body area protection factors, the results were still above the required minimum performance criteria. Consequently, as part of this development, the evaluation of the ensemble was performed both with and without the cooling insulation system.

The principal difference between these two ensembles was the existence of the facepiece and ensemble connections for the air flush hose. Work on both ensembles showed that a key part of the design was the improvement of the hood and gasket design for creating a seal around the SCBA facepiece.

3.2.1 ***Certification Philosophy*** – This effort was intended to provide the necessary design work and testing that would enable the certification of the Project HEROES ensemble to the CBRN option of NFPA 1971. However, this certification was only possible for the ensemble design without the cooling insulation system. This is because the full certification of an ensemble with the MSA CBRN SCBA in the configuration with the cooling insulation system in place also requires separate and complete recertification of the SCBA by MSA. MSA has stated that it was not prepared to undertake this certification until the project proves successful and market demand was sufficiently demonstrated to warrant their investment in this process.

3.2.2 ***Measurement of Project Success*** – The IAFF Project Team has established criteria up front to judge the completion and success of this work effort. Specific project objectives and evidence of their attainment are provided in Table 1.

Table 1 – Techniques for Measuring Project Progress and Success

No.	Objective	Status of Project Program and Success
1	Demonstrate adequate seal between ensemble hood and MSA CBRN facepiece	Some tests show passing performance in both MIST and overall liquid integrity evaluations; specific additional changes to the ensemble were identified where seal could be improved.
2	Develop modified facepiece design that accommodates connection of air-flush hose on MSA facepiece	Parts were designed that can be molded using conventional manufacturing methods and that provide a low profile of the air flush hose
3	Qualify Project HEROES ensemble using MSA CBRN SCBA and air-flush system	Near passing performance in MIST evaluations has been achieved. Overall liquid integrity evaluations show passing performance; acceptable ratings for prototype system were obtained with firefighters wearing new design.
4	Verify no adverse effects on MSA CBRN SCBA when integrated to Project HEROES ensemble with air flush system	A procedure was developed for the measurement of total inward leakage testing of complete ensemble. An engineering assessment showed that the resulting SCBA change would not interfere with NFPA 1981 compliance.

3.3 Task Structure and Deliverables. The work effort was divided into four tasks:

1. Design of interface and fabrication of prototypes
2. Testing of Interface for NFPA 1971 CBRN requirements
3. Evaluation of ensemble effect on SCBA respiratory protection requirements
4. Preparation of design documentation and final report.

3.3.1 ***Task 1 – Interface Design and Prototype Fabrication.*** This task encompassed the two design approaches described above in Section 3.1 where both the conformance of the hood and hood gasket were investigated for design modifications and a suitable method for attaching the exhalation hose to the MSA facepiece was identified. This task consisted of the following subtasks:

- Subtask 1.1 – Evaluation of current hood design for conformity with MSA facepiece
- Subtask 1.2 – Implementation of changes to hood/gasket for improved facepiece fit
- Subtask 1.3 – Redesign of hood and gasket as warranted by integrity testing
- Subtask 1.4 – Creation of initial prototype pieces for hose connection to facepiece
- Subtask 1.5 – Preparation of engineering diagrams for prototype facepiece parts
- Subtask 1.6 – Fabrication of prototype facepiece parts
- Subtask 1.7 – Redesign of facepiece attachment as warranted by integrity testing

As part of this task, design efforts were first undertaken to ensure that the Project HEROES hood properly accommodated the MSA CBRN SCBA facepice and that the connection point on the protective coat was appropriately located. This work encompassed informal user trials based assessment of hood conformity to the facepiece (Subtask 1.1). For example, Figure 2 shows these initial efforts that permitted making adjustments in the hood patterning and gasket layout for achieving a proper fit without hindrance to the wearer (Subtask 1.2). Further redesign of the hood-SCBA facepiece interface became necessary after initial results of the integrity testing showed some leakage in the hood area (Subtask 1.3). The results of this redesign effort are discussed in Section 4.

Figure 2 – Hood Interface with SCBA Facepiece

The modification of the MSA CBRN SCBA facepiece was undertaken by Honeywell First Responder Systems (HFRS) with the cooperation of Mine Safety Appliances (MSA) engineers. In their first step, Honeywell identified a preliminary configuration of the exhalation port that permitted the attachment of the initial prototype fixtures using a mock up of the facepiece (Subtask 1.4 – see Figure 3).

Figure 3 – Initial Concept for Retrofitting MSA CBRN SCBA by Replacing Exhalation Piece

MSA then provided the engineering drawings for the exhalation port area of their SCBA and HFRS redesigned the piece for the attachment of the hose connection by modifying these drawings (Subtask 1.5). Initial work was then performed using rapid prototyping methods where temporary parts were fabricated for wearer trials and certification testing (Subtask 1.6). Successive prototypes were evaluated by informal user trials at Honeywell First Responder Systems to ensure that the hose connection placement does not interfere with wearer tasks. After a suitable prototype design was identified, additional parts were made to support testing. Plans were then made to create a standardized mold for the finalized parts. Lastly, final changes were made to the parts to meet ensemble integrity requirements (Subtask 1.7). The deliverable for this task became the final design of the SCBA interface and prototype parts.

3.3.2 ***Task 2 – Testing of Interface to NFPA 1971 Requirements*****.** In the second task, two sets of integrity tests were performed. The first set of tests were performed on ensembles that had the modified hood to accommodate the MSA CBRN SCBA facepiece. The second set of tests was conducted on ensembles that also included the air-flush system with the modified MSA CBRN SCBA facepieces. This task was divided into the following subtasks:

- Subtask 2.1 – Preparation of the test plan
- Subtask 2.2 – Fabrication of ensembles for integrity testing
- Subtask 2.3 – Installation of parts into sample MSA CBRN SCBA
- Subtask 2.4 – Integrity testing to assess the hood-facepiece seal effectiveness
- Subtask 2.5 – Integrity testing to assess the complete ensemble with both hood interface and air-flush system

A testing plan was put together describing the testing to be performed (Subtask 2.1). Required testing entailed both overall liquid integrity and Man-in-Simulant Test (MIST) evaluations. To support this testing, sample ensembles were prepared (3 for liquid integrity testing and 4 for MIST) and then subjected to 10 cycles of laundering conditioning as specified in NFPA 1971 (Subtask 2.2). In parallel, a sufficient number of MSA CBRN SCBA facepieces were prepared with the fixture that allows the operation of the cooling insulation system (Subtask 2.3). Integrity testing was conducted for the non-air-flush system ensembles (Subtask 2.4) and ensembles where the air-flush system was integrated using the new SCBA interface (Subtask 2.5).

All tests were performed by Intertek Testing Services (ITS) though preconditioning of ensembles was initially conducted by the Honeywell First Responder Systems laboratory under the supervision of ITS and later at ITS once their new laundering equipment was installed. Two iterations of this testing were conducted to account for design changes that were made as part of the prototyping efforts in Task 1. This testing was undertaken to ensure that the ensemble could be certified to the CBRN option requirements in NFPA 1971. The deliverables for this task included the test plan and test results of all testing carried out as part of the task.

3.3.3 ***Task 3 – Qualification of Respiratory Protection and SCBA Certification.*** Additional testing was carried out as part of Task 3 to assess the impact of the facepiece change on the MSA CBRN SCBA when as part of the Project HEROES ensemble. The following subtasks were undertaken as part of this task:

- Subtask 3.1 – Preparation of test procedures to assess the ensemble impact on SCBA
- Subtask 3.2 – Selection of test methods to evaluate respirator facepieces per NFPA 1981
- Subtask 3.3 – Submission of a test plan for respirator protection and certification testing
- Subtask 3.4 – Respiratory protection testing

A total inward leakage test for the respirator was used for the assessment of the ensemble impact on the SCBA (Subtask 3.1). Additional tests were identified from NFPA 1981, *Standard on Open-Circuit, Self-Contained Breathing Apparatus for Fire and Emergency Services*, to determine if the redesign of the facepiece would also affect the certification of the SCBA (Subtask 3.2). Both of these testing approaches were defined in a comprehensive plan (Subtask 3.3) with testing carried out by ITS (Subtask 3.4). Test plans and test reports were provided as part of the output for this task.

3.3.4 ***Task 4 – Project Documentation.*** Task 4 involves the preparation of the interface design documentation and a final report on the contract that includes all design specifications, test results, and other findings as part of the proposed effort. Three different subtasks form part of this effort:

- Subtask 4.1 – Preparation of Monthly Status Reports
- Subtask 4.2 – Preparation of the Project Final Report
- Subtask 4.3 – Preparation of the Product Specifications

Figure 4 provides a diagram showing the interrelationship of all tasks and subtasks.

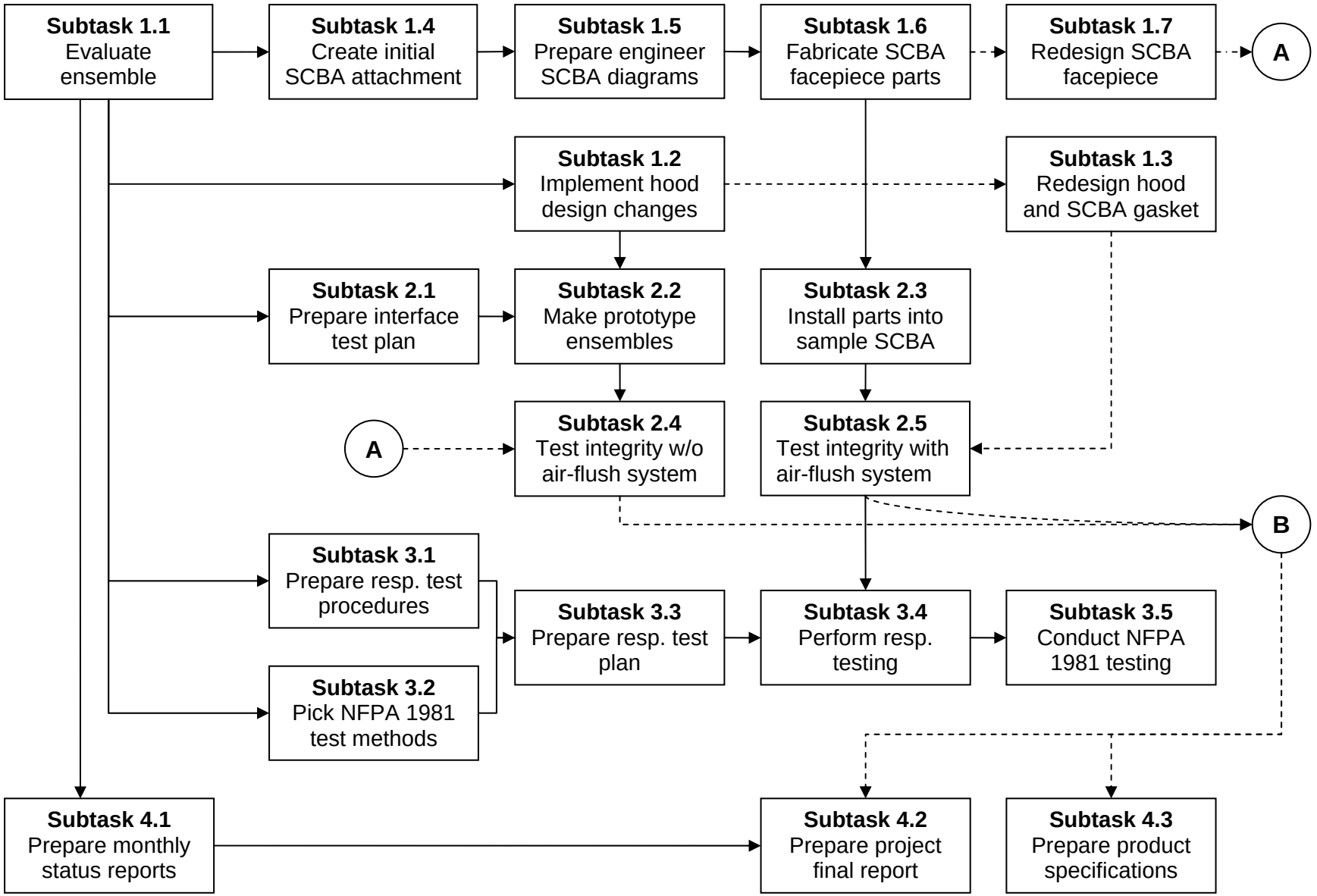


Figure 4 – Relationship of Project Tasks and Subtasks

4.0 Redesign of Hood-to-Facepiece Interface

A key attribute of the Project HEROES ensemble is its ability to integrate with the SCBA facepiece. The area of the head represents the most challenging of all interface areas because at this juncture, the garment hood, garment front closure, SCBA facepiece and helmet must all work together to create an effective interface that provides a barrier to both liquids and vapors in all modes of wearing. While the original development of the ensemble was patterned around the Scott Health & Safety NXG CBRN SCBA with AV3000 facepice, it became apparent that for each SCBA a new hood interface would be needed. To obviate this problem, Honeywell undertook changes to the gasket to permit its accommodation of most major industry SCBA facepieces. For this project, these efforts focused on the two leading SCBA facepieces – those from Scott Health & Safety and Mine Safety Appliances Company (MSA). These facepieces are pictured in Figure 5.

Figure 5 – Side View of Scott Health & Safety and MSA Facepieces

While the diameter of the facepiece seal sections for both SCBA facepieces are similar, there were some differences in geometry, particular as the method for which the exhalation valve is attached, which affected the sealing surface. These differences were closely studied to arrive at a “universal” fit gasket..

In their first design iteration, Honeywell made changes to the size, shape, and durometer (stiffness/elasticity) of the rubber gasket to accommodate each facepiece. They also had to make adjustments to the hood dimensions, taking into account information gained in field testing at the Houston Fire Department. The later information pointed to how the front closure completed the gasket seal onto the facepiece. The resulting gasket is pictured in Figure 6.

Figure 6 – Redesigned Hood Gasket

Only the leading edge of the gasket was exposed as part of the hood design with the remainder of the gasket internal to the hood with design portions intended to fit differences in the two facepieces. Adjustments to the hood were made to size correctly to the gasket, accommodate a range of head shapes and sizes, and to permit adequate movement of the hood without breaking the gasket seal. Particular attention was provided the design of the zipper closure as the closing of the zipper creates the tension on the gasket that keeps the gasket around the facepiece. It was therefore essential that the zipper pull lay flat when closed as this locks the zipper from moving. A flap across the zipper to ensure the pull remained flat was added later. Photographs showing results of these design changes are provided in Figure 7.

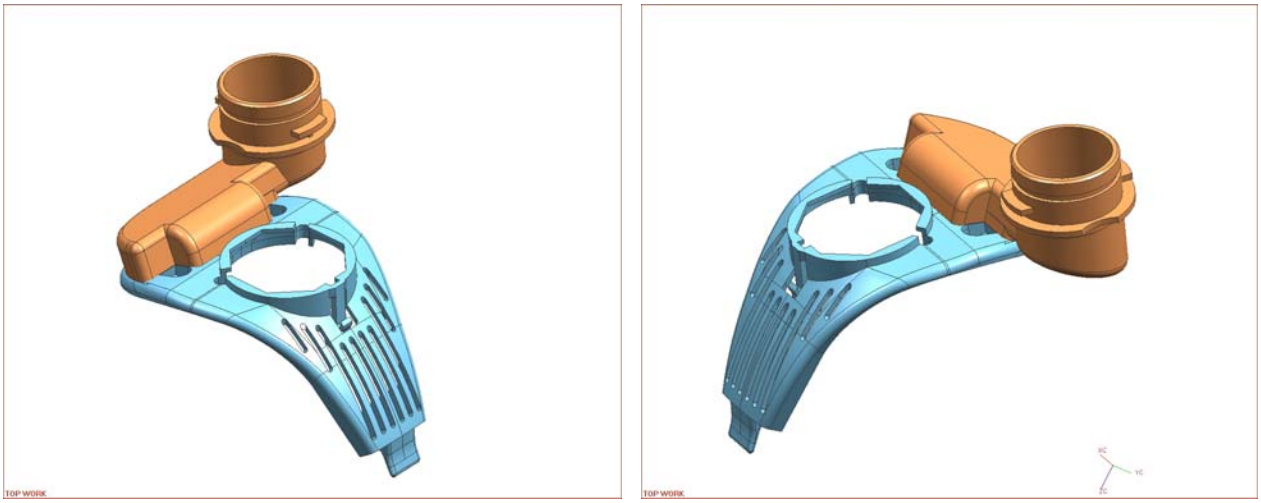
Figure 7 – Resigned Hood for Accommodating Both Scott and MSA Facepieces

At the time this report was prepared, additional hood changes were made but not photographs were available. Photographs of the final design will be provided with the corrected final report.

5.0 Modification of MSA Facepiece

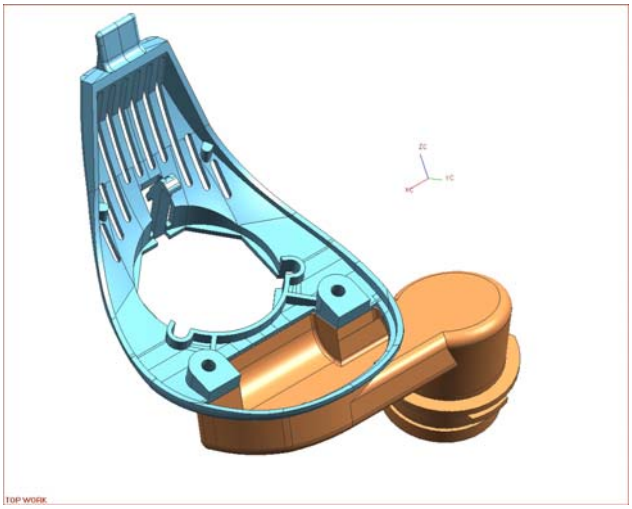
Honeywell worked with the MSA engineers to determine the best means for integrating a connection onto the MSA facepiece. As originally conceived, the most appropriate design approach was to remove the front exhalation grill and replace it with a new piece with a hose connection was attached. The grill piece is easily removed with a screwdriver.

Some variations of the design were made so that the pitch of the hose and the placement of the attachment created the least interference of the hose with the facepiece as determined by limited ergonomic testing. MSA provided engineering drawings and as a result of the design process, the attachment shifted the hose connection from being on top of the grill to the left side. Optimization steps took the form of the changing the pitch (or angle) of the hose connection, which in turn affects the how the hose was positioned on the facepiece and away from the end user. Diagrams of the revised parts are provided in Figure 8. Complete views of the assembled facepiece with the new part are shown in Figure 10.

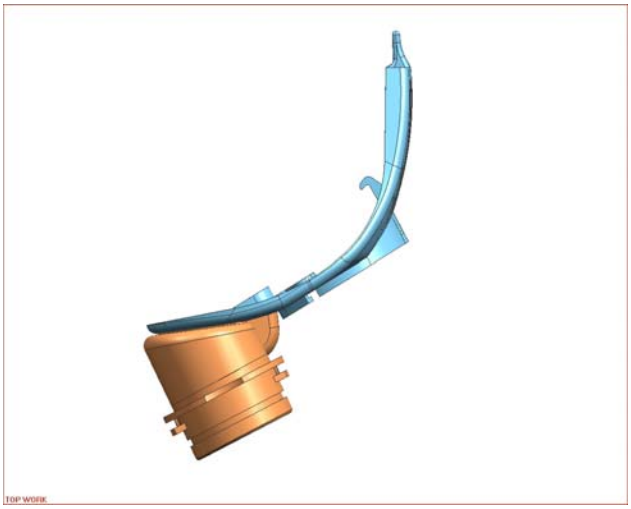


(a) Top/Front Left Side View **(b) Top/Front Right Side View**

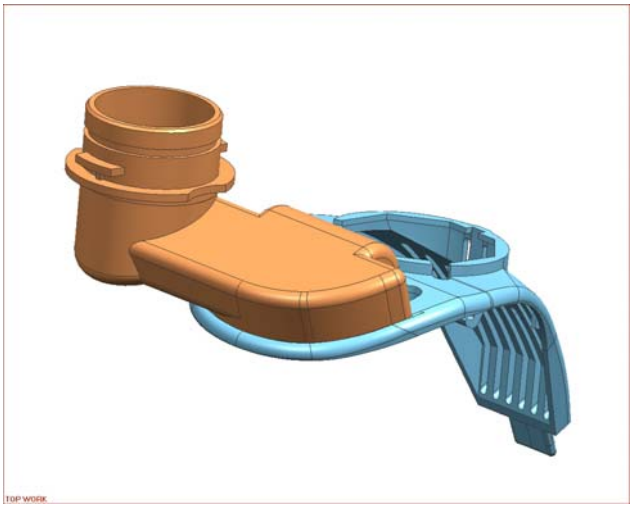
Figure 8 – Various Views of Prototype SCBA Interface Component



(c) Bottom View



(d) Side View



(e) Front View

Figure 8 – Various Views of Prototype SCBA Interface Component (continued)

(a) Front View with Regulator

(b) Close Up without Regulator

Figure 9 – Photographs of Installed Part on MSA Facepiece

6.0 Integrity Testing of Prototype Ensembles

The IAFF Project Team developed an approach to cover each of the phases of testing that will be employed during the project. Ensemble testing was conducted to determine particular overall integrity of the integrated ensemble (using MSA CBRN SCBA with and without the air flush system. These tests included:

1. Liquid integrity testing
2. Man-in-simulant test (MIST) evaluations

Criteria for these tests are provided in Table 2. A description of these tests follows.

Table 2 – Test Criteria Applied to Modified Ensemble

Property	Test Method*	Measurement(s)	Proposed Criteria
Vapor penetration resistance	ASTM F2588, modified	Protection factor for overall system and individual body locations	≥ 360 (system) ≥ 361 (local)
Overall liquid integrity (static)	ASTM F 1959, 20 minute exposure	Observation of liquid penetration inside garment (to liquid-absorptive inner garment)	No observed penetration

* Ensemble tests to be performed following before and 10 industrial laundering cycles

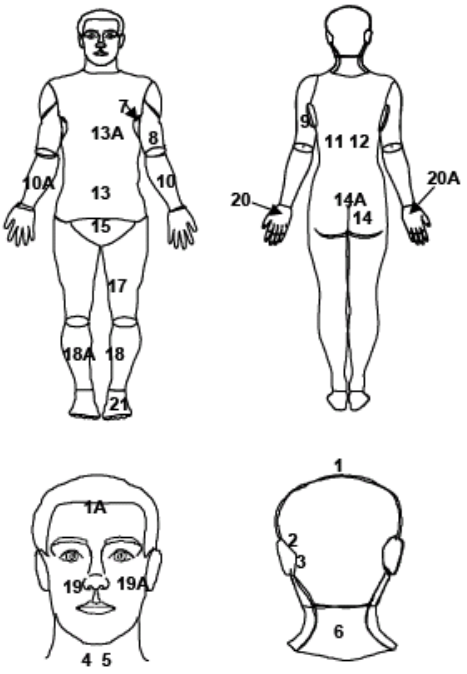
6.1 Liquid Integrity Testi Procedures. The overall liquid integrity test is commonly called the "shower" test. As this name implies, samples of protective ensemble are placed on a manikin dressed in a liquid-absorptive garment that is subjected to a liquid spray exposure to assess the overall liquid protection provided by the garments. The liquid absorptive garment is then inspected to determine if any liquid penetrated to the undergarment. This test has been found to be highly diagnostic for liquid penetration pathways for the ensemble in prior testing. Shower test photographs are shown in Figure 10.

(a) Overall Shower Test Set Up **(b) Water Mark on Right Shoulder**

Figure 10 – Photographs of Overall Liquid Integrity Test

6.2 MIST Evaluation Procedures. The Man-In-Simulant-Test (MIST) is a technique that was employed by the military for years for testing battlefield chemical warfare agent protective clothing. MIST involves the placement of special adsorbent pads on test subjects at several different locations (see Figure 11). The test subjects then wear the ensemble and perform a series of exercises replicating response activities inside a closed chamber where they are exposed to a surrogate chemical agent for mustard gas (methyl salicylate). Procedures for conducting MIST evaluations are provided in Section 8.66 of NFPA 1971, Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting, 2007 Edition. These procedures specify that garment and gloves undergo 10 cycles of laundering prior to testing. Footwear must be flexed 1 millions times on a machine designed to simulate use. Test results are reported for each local area and for the entire system using a Body Region Hazard Analysis (BRHA). The BHRA weighs the respective body area and the relative vulnerability of that body area in an overall equation to provide a systemic value.

Site number and location
1 scalp
1A forehead
2 left ear upper
3 left ear lower
4 neck right
5 neck left
6 nape
7 left armpit
8 left inner upper arm
9 left outer upper arm
10 left forearm
10A right forearm
11 middle back left
12 middle back right
13 abdomen
13A chest
14 right buttock
14A lower back
15 groin
16 left of crotch
16A right of crotch
17 left inner thigh
17A right inner thigh
18 left inner shin
18A right inner shin
19 right cheek
19A-left cheek
20 left hand
20A right hand
21 left foot



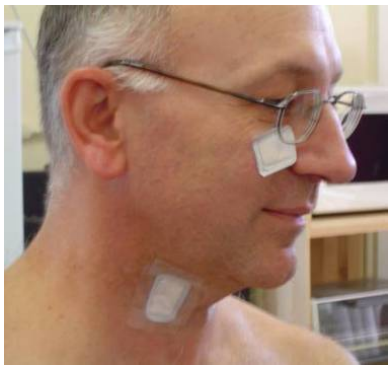


Figure 11 – Man-in-Simulant Test

After the 30-minute exposure, the adsorbent pads are removed from the test subjects and then analyzed to determine how much surrogate chemical penetrated the ensemble. The results are provided by individual body location based on the position of the adsorbent pad, providing information for where the leakage occurs and how much chemical would be absorbed onto the skin. The information from all of the pads is also used to provide an overall protection factor for the ensemble. The protection factor is the ratio of the outside agent concentration to the inside concentration of surrogate agent collected on the pads. For the CBRN option in NFPA 1971, a minimum overall protection factor of 360 is required while individual location-by-location protection factors must be at least 361.

6.3 MIST Evaluation Research. The project team has worked with Intertek Testing Services (ITS) to overcome some of the problems being experienced for ensemble testing during Man in Simulant Test (MIST) evaluations. This work is included a number of experiments to ascertain the sources of variability in the test and to provide a better means of failure mode analysis. An extensive test plan was developed to overcome these problems and is presented in both the Table 3 and Figure 12.

This process was carried out using different experiments designed for improving the repeatability of the test; these efforts were successful with the following findings:

6.3.1 ***PAD Construction Variability*****.** PAD variability was characterized by evaluating a number of PADs for variability. These results are provided in Table 4.

Table 3 – Experiments to Determine Inconsistencies with Ensemble MIST Results

A. Address PAD variability

1. Characterize 24 pads for differences in size, exposed surface area, weight of adsorbent, and uptake rate
2. Make similar requests to Royal Military College and North Carolina State University to produce data from three laboratories
3. Prepare letter to supplier and request improvement of quality of PADs in meeting current specifications.
4. Develop acceptance criteria for PADs prior to use in evaluations (consider use of templates to check acceptable size and weighing overall pad)

B. Complete characterization of PAD effectiveness under different conditions

1. Assemble existing data for vertical and horizontal PAD locations
2. Acquire and analyze data for agitated PADs, and pads exposed to different levels of relative humidity, moisture contact, and temperature
3. Conduct additional experiments as needed to evaluate these effects (include these experiments as part of overall best value evaluations)
4. Evaluate pad concentrations both at 15 and 30 minutes inside chamber
5. Determine optimal conditions for maximum pad uptake in chamber that account for pad location, in chamber conditions

C. Investigate potential contamination sources

1. Conduct experiments which evaluate MeS contamination to back and sides of PAD
2. Simulate contaminated handling of PADs and determine significance
3. Determine optimum procedures for minimizing contamination of pads during decontamination and removal

D. Institute changes in analytical procedures

1. Determine a reasonable minimum detection level of MeS to establish a default concentration for PADs where no MeS is detected
2. Establish boundaries and procedures for acceptance of test chamber conditions based on rapid analysis of PAD uptake rate of exterior exposed prior to conducting full testing
3. Identify locations where additional pads can be placed on the test subjects body's to check precision of analytical findings
4. Require a "test assistant" to ensure correct pad placement and do the same for removal to reduce potential for contamination or confusion of pads and ID's

E. Conduct a series of full MIST tests

1. Choose a single test subject from prior test series and specific ensemble; use the following:
   - Improved procedures for PAD selection, PAD location and analytical changes
   - Increased number of exterior PADs to validate prior experiments
   - Increased number of interior PADs to allow multiple analyses
2. Perform the following tests:
   - "Blank" or negative contol (without any MeS challenge)
   - With MES challenge to compare against previous test

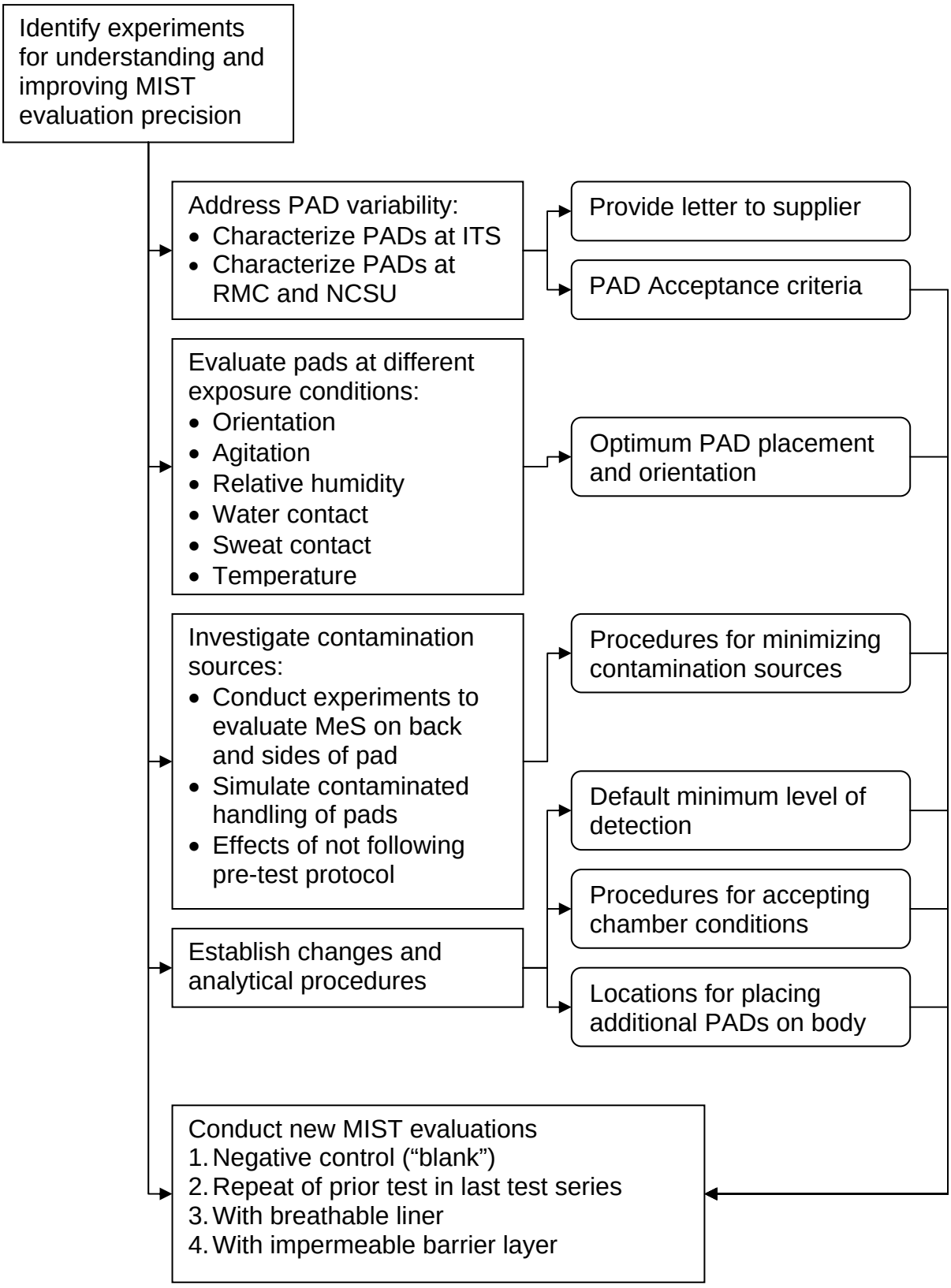


Figure 12 – Flowchart for MIST Experiments

Table 4 – Variance of Specific Measured Attributes for PADs Used in MIST Evaluations

PAD	Outer Length (mm)	Outer Width (mm)	Film Sampling Surface Length (mm)	Film Sampling Surface Width (mm)	Film Sampling Surface Area (mm^2)	Edge Dimension Width (Sides) (mm)	Edge Dimensions Length (Ends) (mm)	Weight of Tenex TA (mg)
1	33.87	23.59	24.65	12.75	314.29	5.42	4.61	20.7
2	34.86	24.9	23.42	13.53	316.87	5.69	5.72	21.3
3	33.98	23.03	27.15	17.96	487.61	2.54	3.42	22.7
4	32.41	23.43	26.75	18.83	503.70	2.30	2.83	22.9
5	32.37	23.01	26.41	18.89	498.88	2.06	2.98	23.9
6	32.03	24.94	23.97	18.15	435.06	3.40	4.03	23.3
7	34.23	25.22	27.2	18.96	515.71	3.13	3.52	24.4
8	33.35	24.01	27.48	17.45	479.53	3.28	2.94	22.7
9	35.06	25.67	27.14	17.66	479.29	4.01	3.96	24.4
10	34.32	23.4	25.9	13.54	350.69	4.93	4.21	24.7
11	33.5	24.95	22.02	13.97	307.62	5.49	5.74	24
12	34.87	23.77	26.67	18.33	488.86	2.72	4.10	24.2
13	31.89	21.62	26	16.19	420.94	2.72	2.95	24.2
14	35.32	23.16	25.37	12.31	312.30	5.43	4.98	20.3
15	34.54	23.59	27.33	18.16	496.31	2.72	3.61	26
16	33.21	24.17	25.61	17.24	441.52	3.47	3.80	22
17	35.22	24.18	27.11	16.03	434.57	4.08	4.06	23.7
18	33.91	22.66	26.35	17.56	462.71	2.55	3.78	23.1
19	34.94	25.69	25.57	14.91	381.25	5.39	4.69	23.2
20	32.89	24.32	26.03	18.15	472.44	3.09	3.43	22.7
Average	33.84	23.97	25.91	16.53	430.01	3.72	3.97	23.22
%RSD	3.23	4.39	5.57	13.40	16.91	33.19	21.35	6.00
Min	31.89	21.62	22.02	12.31	307.62	2.06	2.83	20.3
Max	35.32	25.69	27.48	18.96	515.71	5.685	5.74	26
Specification Limits:	35	25	25	18	438.75 - 461.25	0.68	0.19	36.0 - 44.0
% Error From Spec.	3.3	4.1	3.6	8.2	2.0	446.8	1987.4	35.5

PAD specifications compared with ASTM F2588; colored regions show variance from specifications

- The analysis of the PADs against the specification principally showed variance between the specifications for both the exposure surface area and the amount of adsorbent. Contact with North Carolina Status University confirmed this observation, but no specific additional data were provided.

- The PAD supplier was contacted and after explaining these issues agreed to reexamine their manufacturing process and make improvements. They reported that a dye would be used for creating the PADs to create a more uniform exposure area and agreed to obtain a more accurate balance.

- In the absence of new PADs, ITS developed acceptance criteria for each PAD that involved a physical examination before its use.

6.3.2 ***Evaluation of PADS under Different Exposure Conditions*****.** The different exposure conditions included:

- Level of moisture exposure
- PAD orientation and exposure to movement
- Different temperatures and relative humidity
- Length of time

Moisture concerns for PADs arise because PADs placed on the test subject can become exposed to sweat. Sweat may occlude the exposed surface area of the PAD and affect adsorption of MeS. Externally placed PADs can also be exposed to moisture is placed on the SCBA and if condensation occurs on the SCBA cylinder as it cools. In an experiment, where PADs were covered with simulated sweat, there was a 34.3% reduction in the MeS pick up of the PAD.

The MIST procedures require that three PADs be placed externally to determine chamber exposure concentration for calculation of the protection factors. No additional specifications are provided for locating these PADs. Often, PADs are placed on the test subject using the logic that this placement will best capture the exposure of the test subject. However, this placement also subjects the PAD to chaotic movement. A series of experiments were done with PAD placement on horizontal, vertical and moving surfaces. The measurements in these experiments are shown in Table 5. Photographs of the testing appear in Figures 13 and 14. These tests were also repeated under different environmental conditions of temperature and humidity that fell within the conditions specified in the test. Measurements for these experiments are also provided in Table 5. The results for this testing provided the following findings:

- There were small differences in the MeS concentrations whether PADs were oriented vertically or horizontally during testing.

- MeS concentration had the highest variation when in a vertical orientation.

- Movement provided the highest MeS measurements.

- Higher temperatures and relative humidity decreased MeS absorption into the PADs.

Table 5 – Evaluation of PADs under Different Exposure Conditions

	Test 1 Vertical	% Difference Vert vs Horiz. Test 1	Test 2 Vertical	% Difference Vert vs. Horiz Test 2
	131.409	6.3	79.6405	11.6
	140.698		71.505	
	136.16		80.5215	
	156.487		67.066	
	147.677		66.7155	
	115.8205		77.8285	
% RSD	10.1		8.5	

	Test 1 Horizontal	Test 1 Vertical Moving	Test 2 Horizontal	Test 2 Moving
	127.131	161.425	83.026	89.8645
	146.44	164.436	72.7685	93.5325
	158.437	147.505	81.457	88.365
	147.6225	163.853	91.952	101.32
	154.429	167.749	84.224	85.312
	148.1105	164.918	84.649	95.102
% RSD	7.3	4.2	7.5	10.9

	Test 3 Static (Horiz)	Test 3 Moving	Test 4 Static (Horiz)	Test 4 Moving
	112.4305	150.935	86.021	97.68
	125.222	161.117	96.649	93.42
	110.773	161.413	82.2055	101.0755
	114.938	168.871	77.354	100.2585
	117.524	146.346	84.279	85.972
	121.843	160.699	80.187	115.068
		153.813		87.636
				113.541
% RSD	4.8	4.8	7.9	10.8

Test Conditions:	Normal	Upper Limit of Standard	Elevated Temperature	Interior Suit Conditions
	Test 1 (75F 45% RH)	Test 2 (75F 85% RH)	Test 3 (100F 45% RH)	Test 4 (100F ~100% RH)
Average Vert.	138.0	73.9	-	-
Average Horiz.	147.0	83.0	117.1	84.4
Average Moving	160.5	94.2	157.6	99.3
	% Decrease. Test 1 vs Test 2	% Decrease. Test 3 vs Test 4	% Decrease. Test 1 vs Test 3	% Decrease. Test 1 vs Test 4
Vertical	46.5	-	-	-
Horizontal	43.5	27.9	20.3	42.6
Moving	41.3	37.0	1.8	38.1

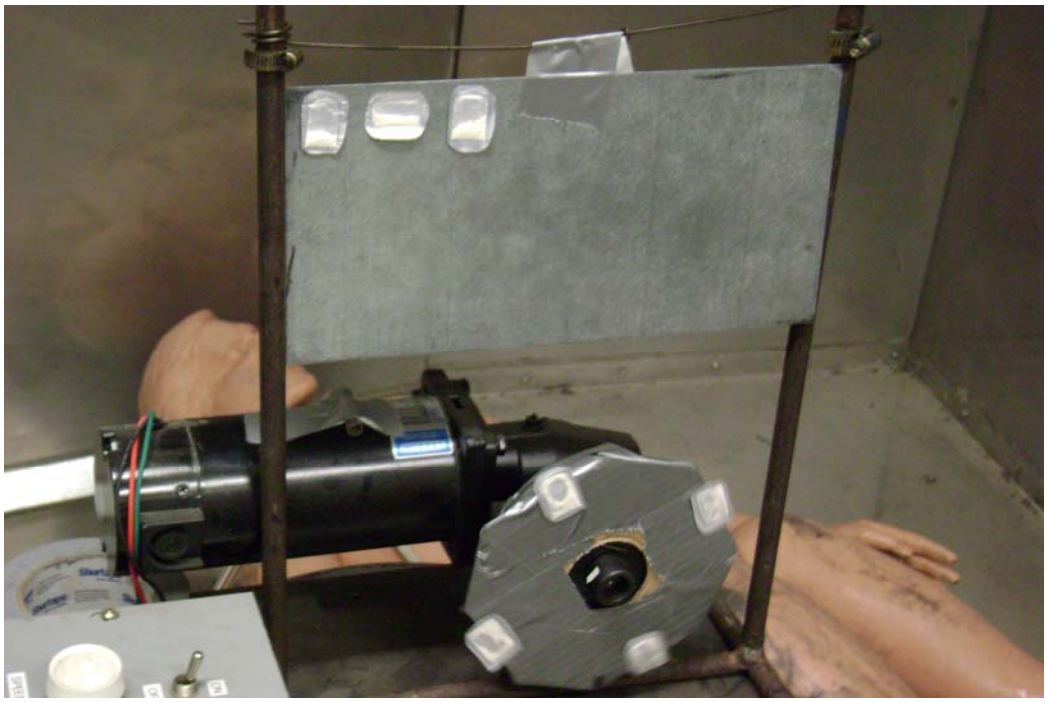


Figure 13 – Placement of PADs for Exposure Condition Experiments

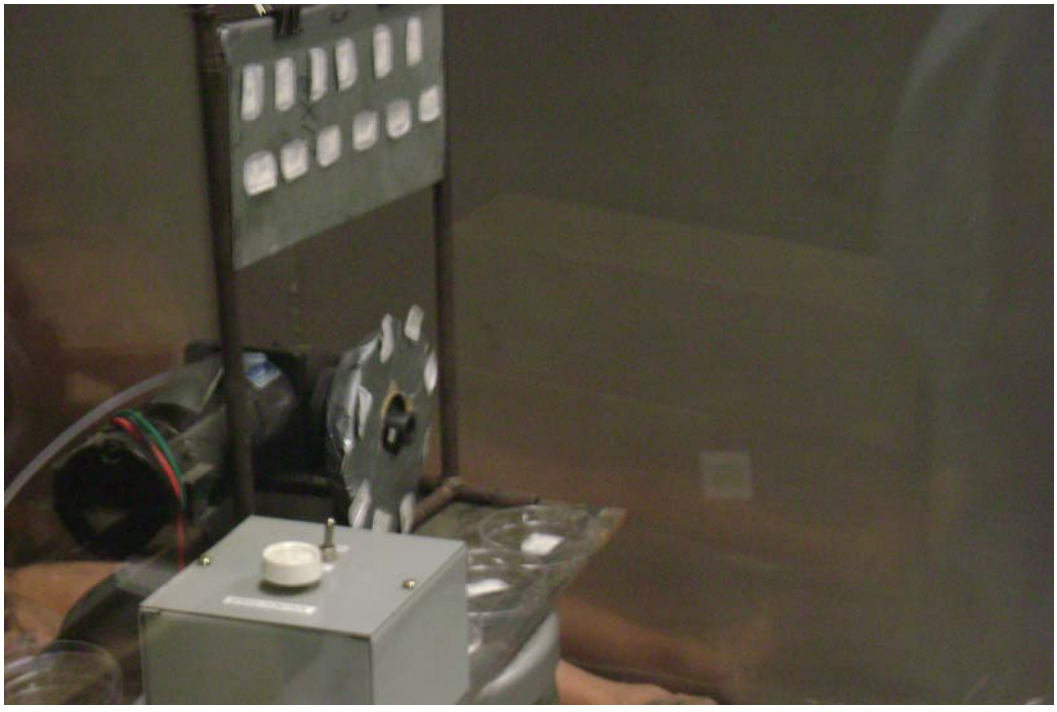


Figure 14 – Additional Placement of PADs for Exposure Condition Experiments

One part of the NFPA procedures state that the chamber PAD exposure period should be 15 minutes (8.66.4.11) while another part indicates the PADs should not be removed until after 30 minutes of exposure (8.66.6.3). However, the latter paragraph also requires setting the PAD exposure time so that the PAD dosage does not exceed the linear rate of absorption. Several PADs were place in the chamber and removed at 5 minute intervals ranging from 5 to 60 minutes. These resulting MeS concentrations are plotted in Figure 15. Though a linear correlation could be established, these results suggest that saturation of the PAD begins to occur between 45 and 60 minutes.

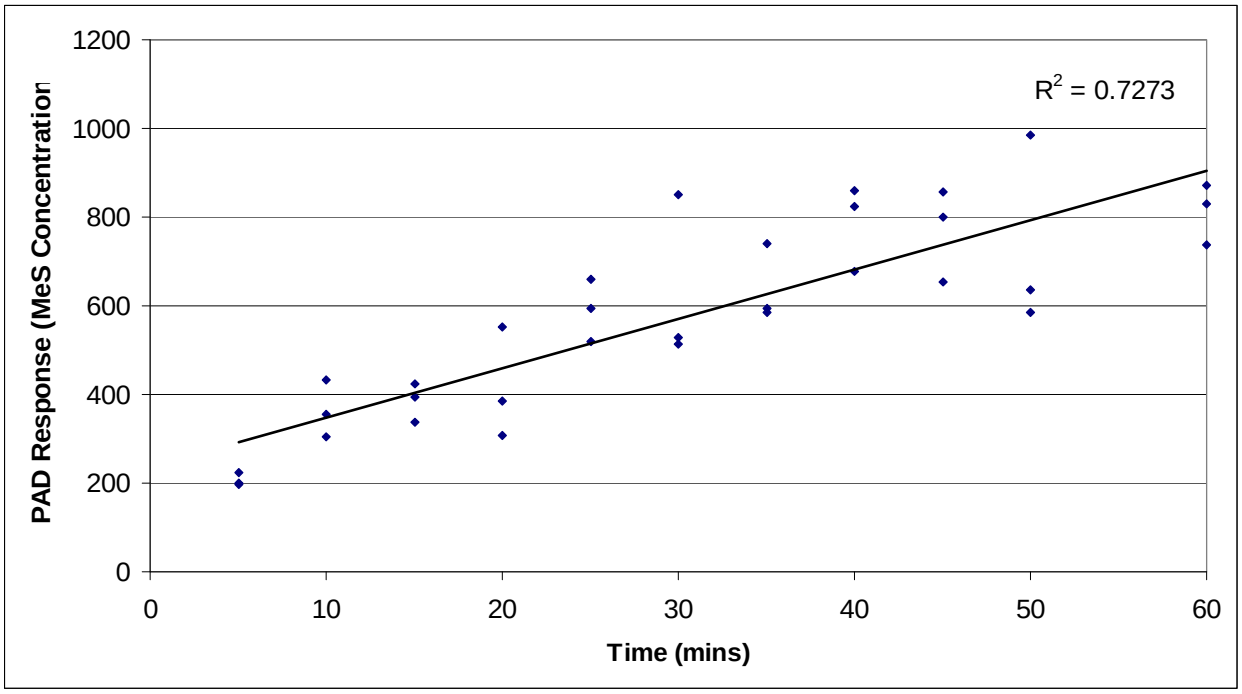


Figure 15 – PAD Response per Time of Exposure

6.3.3 ***Assessment of Contamination Effects*****.** Additional experiments confirmed that the PAD adhesive could become a source of contamination. The most likely causes of this contamination would occur if a PAD became loose during the evaluation exposure the back of the PAD or in the handling of the PAD during its removal, the PAD picked up surface contamination (i.e., an individual touching the PAD with contaminated gloves). Furthermore, new procedures were instituted to prevent contamination that might occur, particularly during the removal of the PADs. A separate individual that had not been near the exposure chamber was used to assist in the removal of the PADs.

6.3.4 ***Establishment of Analytical Procedures*****.** Intertek Testing Services (ITS) performed additional work to fine tune their procedures and lower their level of quantification (LOQ) for the methodology used to measure MeS concentration in PADs. A lower LOQ provides the basis for high potential protection factors since for null PADs (where no MeS is detected), the protection factor is dependent on the denominator where the LOQ is used.

6.4 MIST Evaluations of Overall Ensembles. Findings from the different experiments and other information were used to improve test precision. Changes were made in the standard operating procedures for this evaluation at ITS.

Based on earlier tests, a single individual was selected and the same ensemble previously was tested was subjected to both a blank and a standard MIST evaluation.

- The purpose of the blank was to assuring that no contamination was present in the test.

- The standard evaluation was used to assess the repeatability of the test when the same subject and ensemble were used.

Findings from the blank test did show some contamination. However, the analytical procedures used by ITS could not discern whether the contaminant was MeS or some other chemical that has similar absorption properties that acts as an interference for the test. An analysis of the determine levels showed that these contamination levels were small enough as to not affect the outcome of the test.

The first standard test was a repeat of an earlier test with the same test subject and ensemble. This test produced results, which after the corrections to the procedures, showed relatively good correlation of results between the two tests. These results are shown in Table 6 and showed that principal area of failure was in the hood to SCBA facepiece given the PAD locations where MeS was detected.

A redesign of the hood was made that involved the change in the pattern of the hood and neck circumference. These changes were made to permit better movement of the hood on the wearer without strain on the hood gasket to SCBA facepiece seal. Two additional tests were conducted using these changes, but overall system failures occurred. Nevertheless, the placement of additional PADs enables averaging of results in those areas where duplicate PADs were used. These results are also provided in Table 6.

At the time this report was prepared additional testing was in process. Successful results were expected for both MIST and liquid integrity evaluations.

7.0 Total Inward Leakage Testing

Respirator testing was planned for assessing the effect of the ensemble on the respiratory protection provided by the SCBA and also the performance of the modified respirator to selected requirements in NFPA 1981.

The government had previously advocated total inward leakage testing of the respirator when worn separately and with the ensemble, but had not proposed any specific guidelines for this testing. Further, Honeywell First Responder Systems as part of their efforts to evaluate the impact of the ensemble on the Scott Health & Safety SCBA submitted two ensembles to NIOSH in June 2009 for total inward leakage but this testing had not been conducted due to a lack of a decision on what test procedures should be used.

Table 6 – Summary of MIST Evaluation Results

PAD No	PAD Location	Test 1	Test 2	Test 3	Test 4	Test 3 Recalc.	Test 4 Recalc.
1	Scalp (SCA)	2093.47	14688.19	5363.85	5950.14	5363.85	5950.14
2	Forehead (F)	2093.47	14688.19	5363.85	5950.14	5363.85	5950.14
3	Behind Left Ear Upper (LED)	**55.30**	**18.15**	**125.01**	**310.54**	2630.50	3130.50
4	Behind Left Ear (LE)	**29.05**	**18.59**	**162.82**	**207.60**	798.00	3079.00
5	Neck Right (NED)	2093.47	**147.18**	2273.78	**142.08**	1141.50	**177.00**
6	Neck Left (NE)	**112.13**	**25.30**	**120.43**	673.59	467.00	3312.00
7	Nape (NA)	**236.97**	**125.39**	2817.12	1529.94	2273.50	1538.50
8	Left Armpit (LA)	1046.73	734.16	2681.93	2975.07	2681.93	2975.07
9	Left Inner Upper Arm (LIU)	**292.26**	524.48	2681.93	2975.07	2681.93	2975.07
10	Left Outer Upper Arm (LOU)	1046.73	617.81	2681.93	2975.07	2681.93	2975.07
11	Left Forearm (LFA)	**107.50**	1109.44	2681.93	2975.07	2681.93	2975.07
12	Right Forearm (RFA)	**190.97**	**235.77**	872.76	2811.88	1703.00	2893.35
13	Middle Back (MB)	2093.47	1685.21	5363.85	5950.14	5363.85	5950.14
14	Middle Back Dup. (MBD)	2093.47	1442.37	5363.85	5950.14	5363.85	5950.14
15	Abdomen (AB)	2093.47	14688.19	5363.85	5950.14	5363.85	5950.14
16	Chest (C)	**336.24**	963.36	5363.85	465.42	2999.00	540.00
17	Right Buttock (RB)	2093.47	3505.53	1342.71	5950.14	1342.71	5950.14
18	Lower Back (LB)	433.70	2041.89	5363.85	5950.14	5363.85	5950.14
19	Groin (GR)	2093.47	14688.19	5363.85	5950.14	5363.85	5950.14
20	Crotch (LCR)	523.37	1924.34	1340.96	1487.54	1340.96	1487.54
21	Crotch (RCR)	523.37	1988.76	1340.96	1487.54	1340.96	1487.54
22	Left Inner Thigh (LIT)	2093.47	6689.26	5363.85	5950.14	5363.85	5950.14
23	Right Inner Thigh (RIT)	2093.47	2511.55	5363.85	5950.14	5363.85	5950.14
24	Left Inner Shin (LIS)	2093.47	4727.62	5363.85	5950.14	5363.85	5950.14
25	Right Inner Shin (RIS)	2093.47	4012.57	5363.85	**230.62**	5363.85	**230.62**
26	Cheek (RM)	2093.47	14688.19	5363.85	5950.14	5363.85	5950.14
27	Cheek (LM)	2093.47	14688.19	5363.85	5950.14	5363.85	5950.14
28	Left Hand (G)	1046.73	532.87	2681.93	679.55	2681.93	679.55
29	Right Hand (GD)	1046.73	421.24	2681.93	1976.52	2681.93	1976.52
30	Foot (B)	2093.47	14688.19	5363.85	5950.14	5363.85	5950.14
	PPDFsystemic	**137.78**	**72.77**	**351.58**	**231.39**	**480.50**	**372.50**
	Maximum Protection Factor	439.72	3672.05	1340.96	1487.54	1340.96	1487.54

Tests 1, 2, and 3 were performed with the same test subject.
Tests 1 and 2 were performed with the same ensemble.
Tests 3 and 4 used the new ensemble design.

At a critical meeting of the NFPA Technical Correlating Committee in February 2010, alternative testing approaches and criteria were discussed. The IAFF made plans to have ITS conduct the total inward leakage testing and propose specific procedures and criteria for evaluating the effect of the ensemble on sample ensembles that integrate the MSA CBRN SCBA facepiece.

Initially, it was believed that sodium chloride or corn oil aerosol testing could be used for measuring protection factors for the SCBA by itself and in comparison with the full ensemble. However, early testing demonstrated that it was possible to use Methyl Sacilylate for this testing, using modified protocol for the MIST evaluation. This testing was still under development at the time this report was prepared and awaiting approval as a viable approach by the responsible committee.