A series of models have been developed (Breakthrough, GasRemove, and MULTIVAPOR). Since Breakthrough 2004 was made available in software form and uploaded to OSHA’s web page as a compliance tool (along with a user-friendly video tutorial):

- It has been downloaded from the OSHA web page more than 4,500 times
- There have been more than 10,000 visits to the OSHA website to view the video or to ask questions about the model
- 1000 CDs containing the model and the training video have been requested from NIOSH

### Project Goal
Develop mathematical models to predict respirator cartridge service lifetime

### Background
- OSHA requires that service life determination for air-purifying cartridges be included as part of an employers respirator program.
- Employers are required to develop cartridge/canister change schedules
  - Manufacturer recommendations
  - Mathematical models
- Reliance on odor thresholds are not permitted as the primary basis for determining the service life
- Service life is affected by temperature, humidity, air flow through the filter, work rate, and presence of other chemicals

### Future Plans
- Publish manuscript describing multi-vapor model
- Develop web based version of MULTIVAPOR and make available to the public. MULTIVAPOR will replace Breakthrough on the OSHA website.
- Public release of GasRemove software (when data becomes available)

### Publications
**Project Goal**
Produce an intelligent respirator with ESLI to improve health of air-purifying respirator users and comply with OSHA regulations.

**Stakeholders**
- Respirator manufacturers
- Emergency responders
- Industrial workers

**Background**
OSHA requires a change out schedule or end-of-service life indication for air-purifying respirator cartridges

**Methods**
The goal of this project is to develop a sensor-based system to provide information to the user about the condition of their air-purifying respirator cartridge. A two-phase approach has been taken. A Near-term strategy is to utilize off-the-shelf chemiresistor sensor technology. A long-term research program also being conducted to develop a sensor backbone system that could be applied to various types of PPE to give an end-of-service life indication.

**Approach**

**Near-Term Technology**

**Cyrano Sciences**

Figure 2. Example of flexible sensor element strip

**Preliminary Results**
A reduced sensor set (2 sensors) of the standard Cyrano configuration (32 sensors) has been identified as having good response for a broad range of organic vapors. Minimum detection levels for this sensor set appears to be appropriate for the application.

**Long-Term Technology**

**Carnegie Mellon University**

**Future Research**
Polythiophene chemistry is being optimized. A prototype ESLI sensor system is being fabricated and will be tested against a suite of organic vapors and interferences (e.g., temperature, humidity). Partnerships with respirator manufacturers will be cultivated for the purpose of testing sensor systems in cartridges.
Respirator Filter Performance Against Bioaerosols under Heavy Workload Conditions
Samy Rengasamy

Project Goals
- Determine human respiratory parameters under heavy workload conditions
- Testing respirator filter efficiency against biological aerosol particles at high flow rates
- Evaluation of the significance of reaerosolization of particles from respirators

Stakeholders
- Respirator Users, manufacturers, healthcare facilities, industrial hygienists

Partnerships
- U.S. Army RDECOM
- Battelle

Background
- A breathing rate higher than 85 L/min is expected under heavy work conditions
- There is a lack of studies on respirator filter efficiency against aerosols at higher than 85 L/min flow rate

Methods
- Simulation of respiratory parameters for heavy workload conditions with a breathing machine
- Aerosol particle analysis - Scanning Mobility Particle Sizer (SMPS) and Aerodynamic Particle Sizer (APS)
- Bacillus globigii (BG) and MS2 (wet and dry particle preparations) penetration and reaerosolization

Results
- BG (Wet) Aerosol Penetration through Filters
- BG (Dry) Aerosol Penetration through Filters
- MS2 (Wet) Aerosol Penetration through Filters
- MS2 (Dry) Aerosol Penetration through Filters

Key Findings
- Particle (20-300 nm) penetration increased with increasing flow rates under constant and cyclic flow conditions
- N95 and P100 respirators efficiently captured BG and MS2 particles
- The most penetrating particle sizes were 100-200 nm for P100 cartridges and 50-100 nm for N95 cartridges and filtering facepieces
- Reaerosolization of particles under cough conditions increased with increasing levels of particle loading.
Development of Computer-Aided Face-Fit Evaluation Methods
Ziqing Zhuang, Ph.D., Dennis J. Viscusi, and Ronald E. Shaffer, Ph.D.

Project Goals
- Develop a new anthropometric database detailing the face-size distribution of today’s respirator users
- Evaluate the applicability of existing respirator fit test panels
- Investigate correlation between facial dimensions and respirator fit
- Develop new respirator fit test panels for incorporation into NIOSH and ISO standards

Stakeholders
- OSHA, ISO, MSHA
- Respirator wearers
- Respirator manufacturers

Methods
- Field anthropometric survey and laboratory investigation
- Traditional methods and 3-D scanning
- Stratified sampling plan:
  - 2 gender strata x 3 age groups x 4 race/ethnic groups
  - Nationwide respirator users: 8 states
  - Construction, manufacturing, healthcare, fire, and police departments
- A total of 3,397 subjects were measured and 1,039 scanned

Key Findings to Date
- The current LANL full-facepiece panel excluded > 15% of the current US workforce
- Subjects in the 2003 NIOSH survey had larger key facial dimensions
- The recent NIOSH survey is more representative of the current U.S. workforce
- Face length and face width are appropriate dimensions for the development of the respirator fit test panel

Current Research
- Develop new respirator fit test panels
- Use principal component analysis (PCA) to explore relationships among race, age, gender, body mass index on facial measurements
- Develop test headforms representative of U.S. workforce

Background
- Existing data on the head and face of U.S. workers is woefully inadequate and out-of-date
- Current fit test panels are based on 1960s’ military data which does not represent today’s diverse workforce
- Worker demographics have changed in the past 30 years

Publications

The findings and conclusions of this poster are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.
Polythiophene-Based Chemical Sensors for Detecting Respirator Cartridge End-of-Service Life

Jay Snyder

A sensor chip, packaged in a TO-5 housing, incorporates 3 matched sensor-pairs, each fabricated with a different polythiophene-based polymer. Each sensor pair includes one device that is exposed to the analytes, and one capped device to act as a reference in a bridge circuit to minimize sensitivity to temperature variations. An SU-8 layer facilitates capping, and also seals exposed gold traces against humidity.

The TO-5 sensor package is mounted on a PCB containing sensor conditioning circuitry and a humidity & temperature sensor module. Matched sensor pairs are configured in a half-bridge to cancel common-mode temperature variations. The bridge is driven by a 1 Hz square wave, and the bridge output is demodulated to reject baseline sensor drifts (measured as 0.9%/day for P3HT divider). The output of the demodulator, which is amplified and filtered, and the outputs of the temperature/humidity sensors are interfaced to a PC through a NI AD card. The data is captured and further processed by LabView.

A "demo box" system was developed for quick screening studies and as a portable system to demonstrate the sensing technology to industry, on site, or in the field. Air is bubbled through liquid analyte, and the resulting gas is mixed with air. The mixture is flowed through a carbon containing glass ampule, as a surrogate filter, and the outlet flow is channeled over the TO-5 sensor package. A NI USB AD converter interfaces the sensor board output to a laptop PC running LabView.

A cartridge simulator test-bed has been developed to systematically evaluate sensors embedded within carbon filter beds. Gas analyte concentrations can be measured at specific locations in the beds using an adjustable gas chromatograph sampling tube. Computational fluid models can predict flow patterns to help predict expected distributions of analytes throughout the carbon bed.

The findings and conclusions of this poster are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.
Footwear, footwear covers, work gloves, and cleaning gloves were added to the 2003 Edition of NFPA 1999 to supplement the existing categories of examination gloves, garments (single use and multiple use), and eye/face protective devices. The 2003 Edition does not include head protection design or performance requirements.

A number of products have been certified to this standard, but there have been no certifications of cleaning gloves or single use protective garments. In addition, there has been relatively little industry response to eye/face protection devices, work gloves, and footwear.

The lack of certifications is a result of several problems with the current standard:

1. Mutually exclusive criteria that actually make it impossible to comply with the standard.
2. Identical criteria for single use and multiple use garments that are not appropriate for either type of garment.
3. Criteria that result in clothing that does not reflect end user needs.

The findings and conclusions of this poster are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.
Decontamination Strategies and Reusability of Chemical Protective Clothing (CPC)

Pengfei Gao, Ph.D., CIH

Project Goals
- Develop evaluation methods for decontamination efficacy of CPC materials based on changes in permeation resistance and changes in tensile strength and ultimate elongation
- Develop suitable methods for CPC decontamination
- Develop guidelines for reusability of CPC
  – Decontamination, retirement, or disposal

Stakeholders
- CPC Users & Manufacturers
- OSHA
- AIHA
- Emergency responders
- ISEA
- ASTM
- CPC Users & Manufacturers
- OSHA
- AIHA
- Emergency responders
- ISEA
- ASTM

Partnerships
- ICS® Inc. Laboratories, Brunswick, OH
- University of California, Davis, CA

Background
- More than $800 million per year of protective gloves sold in the U.S.
- Cost of illness due to skin exposure was estimated to be $1 billion per year
- Nondisposable CPC is too expensive to discard
  – Level A Hazmat Suit is more than $3,500
  – Viton® Gloves are more than $100
- Repeated use of CPC without effective decontamination may result in secondary exposure and injury
- OSHA requires decontamination of CPC under two regulations: 29 CFR 1910.120 and 29 CFR 1910.132, but they do not specify how this decontamination should be done

Methods
- Tests: permeation (ASTM Method F 739-99a) and tensile strength/ultimate elongation (ASTM Method D 412-98a)
- CPC Materials: 7 commonly used materials for suits and gloves: natural rubber, nitrile, PVC, neoprene, Tychem®, butyl, and Viton®
- Chemicals: 12 of the 15 liquid chemicals listed in ASTM Method F 1001-99a

Decontamination Methods:
- **Heat Extraction**: 100°C for 16 hours
- **Water/Detergent**: Alcojet wash, automatic dishwasher rinse, followed by drying
- **Self-decontamination**: Incorporate halamine functional groups in clothing material

Typical Results
- Tests: permeation (ASTM Method F 739-99a) and tensile strength/ultimate elongation (ASTM Method D 412-98a)
- CPC Materials: 7 commonly used materials for suits and gloves: natural rubber, nitrile, PVC, neoprene, Tychem®, butyl, and Viton®
- Chemicals: 12 of the 15 liquid chemicals listed in ASTM Method F 1001-99a

Decontamination Methods:
- **Heat Extraction**: 100°C for 16 hours
- **Water/Detergent**: Alcojet wash, automatic dishwasher rinse, followed by drying
- **Self-decontamination**: Incorporate halamine functional groups in clothing material

Key Findings
- Some CPC materials can be reused multiple times after heat extraction
- Permeation and material degradation should be carefully investigated in evaluating CPC reusability

Publications

Preliminary – Not for Citation
Project Goals

- Development of new materials and ensemble design to allow the production of a firefighting ensemble that will meet the requirements of:
  1. NFPA 1971, *Standard on Protective Ensemble for Structural Firefighting*
  2. NFPA 1994, *Standard on Protective Ensemble for Chemical/Biological Terrorism Incidents, Class 2 (modified)*
- Establish test methods and protocols to ensure new technologies/designs can be tested appropriately
- Work closely with standards organizations to ensure that the current and future editions of standards will allow for inclusion of new technologies

Stakeholders

- Firefighters/emergency responders
- Standards organizations (NFPA, ASTM, ISO)
- Manufacturers of materials and ensembles

Background

- Firefighters and emergency responders are the first to respond to events involving fires, emergency medical operations, search and rescue tasks, hazardous materials incidents, and terrorist attacks. Typically, firefighters respond to events wearing turnout gear that was designed to fight structural fires.
- Current materials and ensemble designs do not provide the appropriate level of protection for all hazards, such as incidents involving chemical, biological, radiological, and nuclear (CBRN) terrorism.
- New materials and designs must not add additional stress to the wearer or significantly increase donning time, while providing a higher level of ensemble integrity
- Project HEROES® is funded externally by TSWG and is managed by IAFF

Project Milestones

<table>
<thead>
<tr>
<th>Activity</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project planning and criteria development</td>
<td>Apr 2004</td>
<td>Jul 2004</td>
</tr>
<tr>
<td>Materials identification, testing and selection</td>
<td>Jun 2004</td>
<td>May 2005</td>
</tr>
<tr>
<td>Ensemble laboratory testing</td>
<td>Feb 2006</td>
<td>Dec 2006</td>
</tr>
<tr>
<td>Field testing</td>
<td>Aug 2006</td>
<td>Feb 2007</td>
</tr>
<tr>
<td>Project final documentation</td>
<td>Feb 2007</td>
<td>Apr 2007</td>
</tr>
</tbody>
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NPPTL Role

- Develop physiological test protocol and conduct ergonomic and physiological testing to assess the performance of the HEROES ensemble.
- Support the development of test methods to ensure all ensembles and materials are tested appropriately.
- Supply language and support to standards organizations to remove design restrictions and allow advanced technologies to be investigated and possibly certified.
Respiratory Protection Research for Infection Control

Jon Szalajda, M.S., Samy Rengasamy, Ph.D., Raymond Roberge, M.D., M.P.H., Ronald Shaffer, Ph.D.,
Evanly Vo, Ph.D., Dennis Viscusi, and Ziqing Zhuang, Ph.D.

Program Goals

The specific aims of these projects are to conduct laboratory and field studies to:
- Understand the efficacy of decontamination and to assess the impact of decontamination on filtering facepiece respirator (FFR) performance
- Understand the risks associated with handling a respirator exposed to virus particles.
- Assess causative factors affecting temporal changes in respirator fit
- Quantify the benefit of annual fit testing

Stakeholders
- Healthcare Workers
- Healthcare Facility Administrators
- Pandemic/Infection Control Policy Makers
- General Public
- Respirator Manufacturers

Potential Partnerships
CDC, ISEA, FDA, EPA, ASTM, LLNL, OSHA

Background

- During a pandemic, healthcare workers and the general public will have increased reliance on disposable N95 FFR for infection control
- According to a report from the National Academies’ Institute of Medicine (IOM), during an influenza pandemic over 90 million N95 FFR will be needed to protect workers in the healthcare sector during a 42 day outbreak. Additional respirators would be needed by the general public.

Background (cont’d)

- Some of the recommendations in the IOM report indicate that research studies should be conducted:
  - to understand the efficacy of simple decontamination methods that could be used without negative effects on respirator integrity
  - to understand the risks associated with handling a respirator that has been used for protection against a viral threat (e.g., study the likelihood that the exterior surface of the respirator might harbor pathogenic microorganisms and thus serve as a fomite)
  - on issues related to compliance with respiratory protection guidelines, including the importance of proper fit
- The proposed research projects will attempt to address some of the recommendations from the IOM report

Proposed Studies

1. Reusability of Filtering Facepiece Respirators

- Develop standard test protocol to measure decontamination efficacy
- Conduct laboratory studies to test surrogate virus (MS2) viability on FFR
- Measure efficacy and changes in fit and filtration efficiency caused by decontamination of FFR
- Quantify test surrogate virus reaerosolization under various conditions (flow rates, loadings)

2. Quantify the Benefit of Annual Fit Testing

- Conduct a multi-year laboratory study to identify anthropometric changes (e.g., weight changes, facial shapes, etc.) that result in changes to respirator fit
- Conduct a large-scale field study to assess the benefit of annual fit testing of filtering facepiece respirators
  - Phase I – estimate the fraction of respirator-wearing workers who fail their annual fit test and, therefore, need to change to a different respirator model or size.
  - Phase II – workers who fail their fit test will be retested with a more accurate reference test

Proposed Studies (Cont’d.)

Expected Outcomes
- Improved guidelines and recommendations for respiratory protection against influenza and other infectious aerosols
- Improved test methods and performance requirements for respiratory protection used by national and international standards development organizations

Program Timelines

FY07: Complete peer-review, obtain HSRB approval
FY08: Experimental studies
FY09: Complete experimental studies
FY10: Produce final reports and guidance documents

The findings and conclusions in this poster are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.
Nanotechnology: Efficacy of Personal Protective Equipment
Samy Rengasamy, Ph.D., Pengfei Gao, Ph.D., and Ron Shaffer, Ph.D.

Program Goals
- Understand the effectiveness of personal protective equipment (PPE) for protection against exposure to engineered nanoparticles
- Develop test methods to study penetration of nanoparticles through respirator filter media and protective clothing
- Contribute to NIOSH Nanotechnology Research Center (NTRC)

Stakeholders
- Manufacturers of PPE
- Workers exposed to nanoparticles
- Industrial hygienists
- Research community
- Other government agencies

Partnerships
- NIOSH NTRC
- University of Minnesota, Center for Filtration Research
- ISEA
- NOSH Consortium (DuPont, P&G, and others)
- ASTM E56, ISO TC229, AIHA

Background
- Astounding growth in nanotechnology applications and increased production of unbound engineered nanoparticles in workplace settings
- Possible health risks associated with exposure to nanoparticles
- Sparse information on nanoparticle penetration through respirators, protective clothing, and glove materials

Respirator Filtration

Fig 1. Schematic of filter efficiency vs particle size

Fig 2. University of Minnesota test system for respirator filter penetration studies

Filter Media Testing
- HE 1079 HEPA filter
- H&V HP-0031, 0012
- Media A - Corona charged blown fiber
- Media B - Highly charged blown fiber-1
- Media C - Split film fiber
- Media D - Highly charged blown fiber-2
- Media H&V E - HEPA Paper, Grade 3398F-S
- Media F - GORE membrane filter

Fig 3. Particle Penetration – H&V Filter media

Fig 4. Particle Penetration - 3M and other filter media

Fig 5. Particle Penetration – combined data

Protective Clothing Penetration
- FeNdB magnet - passive aerosol sampler (PAS)
- Iron oxide (II,III) - challenge nanoparticle
- Bench-top system for swatch testing

Fig 6. Generation of monodisperse aerosols

Fig 7. Evaluation of PAS performance.

Schedul
- FY06 - Project proposal development and peer-review
- FY07-FY09 - Experimental work
- FY10 - Final report
Project Goals
- Develop quantitative human subject test protocols to assess the physiological burden from various stressors with various PPE ensemble components and configurations
- Develop physiological countermeasures (e.g., cooling systems) to heat stress imposed by wearing PPE ensembles
- Incorporate physiological testing protocols and data from physiological models and countermeasures into relevant PPE standards (ASTM, ISO, NFPA)

Stakeholders
- Structural firefighters (IAFF, IAFC)
- Standards development organizations (NFPA, ISO, ASTM)
- PPE manufacturers
- Government (TSWG, NIST, USFA)

Background
- According to NFPA, there are 286,000 career firefighters and 777,350 active volunteer firefighters
- Overexertion and heat stress are among the most common causes of firefighter injuries and deaths
- In 2004, RAND reported:
  - ~ 3200 injuries/yr due to thermal stress
  - ~ 1200 cardiac events/yr
  - Nearly half of all firefighter fatalities are “cardiac” in nature. Most of these are heart attacks.

Background (Cont’d.)
- Research has shown that severe injuries due to thermal stress could lead to heart attack without the proper protection or prevention and is one of the leading causes of fatalities for firefighters
- Integrated cooling systems can enhance safety and improve performance while wearing protective clothing and equipment
- Cooling may reduce thermal stress and mitigate some of the cardiovascular risk
- Standards development organizations should utilize physiological data and test procedures to set PPE ensemble performance requirements

Test Methods
- Physiological Parameters
  - Core body/skin temperature
  - Metabolic measurements
  - Cardiovascular (heart rate/blood pressure)
- Treadmill
  - Initial graded exercise test for VO₂max determination
  - Exercise testing at a % of VO₂max

Current Studies
- Physiological Sensors
  - Goal–Assess whether portable physiological sensing instruments provide adequate data
    - Vivometrics® Sensor Vest
    - CorTemp® Pill

Current Studies (Cont’d.)
- Test Conditions:
  - Chamber (35°C, 50% RH)
  - Treadmill exercise at intermittent high intensity work loads-3 sets of 20 min work at 75% VO₂max followed by 10 min rest

Timeline
- FY05-07:
  - Evaluate the physiological “burden” imposed by a prototype firefighter ensemble (TSWG/IAFF funded)
  - Assess portable physiological instruments
- FY06-08:
  - Develop a physiological model of heat stress imposed by ensembles
  - Evaluate the efficacy of various cooling technologies
  - Integrate physiological signals to actuate cooling technologies (i.e., biofeedback loop)