Development of Predictive Models for Respirator Service Life

Jay Snyder

Project Goal

Develop mathematical models to predict respirator cartridge service lifetime

Partnerships

National Paint & Coatings Association; Los Alamos National Laboratory 1943-2003, Ideas That Change the World; ISEA, Who We Are; Organization Resources Counselors, Inc.; American Petroleum Institute

Background

- OSHA requires that service life determination for air-purifying cartridges be included as part of an employers respirator program.
  - OSHA standard 1910.134(d)(3)(iii)(B)(2)
- 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

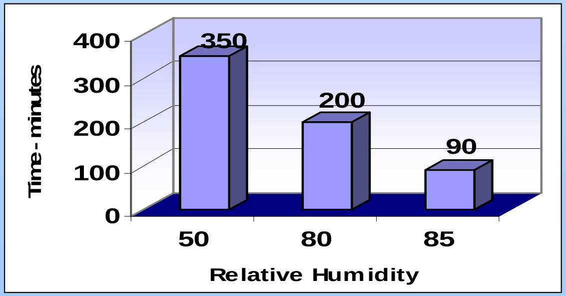


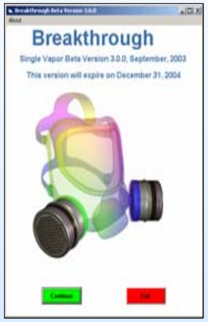
Figure 1. Effect of relative humidity on the estimated service time of 100 ppm Toluene

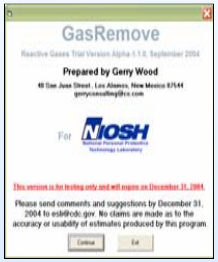
Example Model: Single Vapor + Humidity

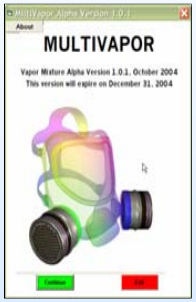
$$W_e = W_o d_L \exp\left[-\left(\frac{RT}{\beta E_o}\ln\frac{P}{P_{sat}}\right)^2\right]$$

$$t_b = \frac{W_e W}{Q C_o} - \frac{W_e \rho_B}{k_v C_o}\ln\left(\frac{C_o - C_b}{C_b}\right)$$

Summary of Results







- 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

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

- http://www.osha.gov/SLTC/etools/respiratory/advisor_genius_wood/breakthrough.html
- G. O. Wood, "Estimating Service Lives of Organic Vapor Cartridges II: A Single Vapor at All Humidities," Journal of Occupational and Environmental Hygiene, 1: 472-492 (2004).
- G. O. Wood, "Estimating Service Lives of Air Purifying Respirator Cartridges for Reactive Gas Removal," Journal of Occupational and Environmental Hygiene, 2, 414-423 (2005).

Preliminary – Not for Citation

Development and Integration of Sensor Technology for Determination of Respirator Service Life

Jay Snyder

Project Goal

Produce an intelligent respirator with ESLI to improve health of air-purifying respirator users and comply with OSHA regulations.

Partnerships

U. S. Air Force

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

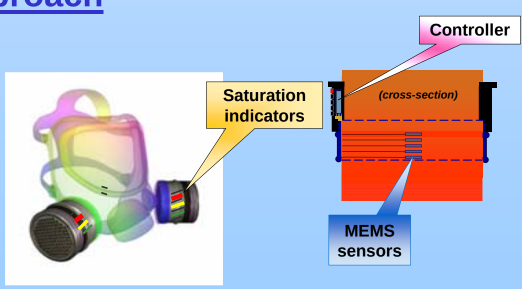


Figure 1. Respirator with ESL indicator system

Near-Term Technology

Cyrano Sciences

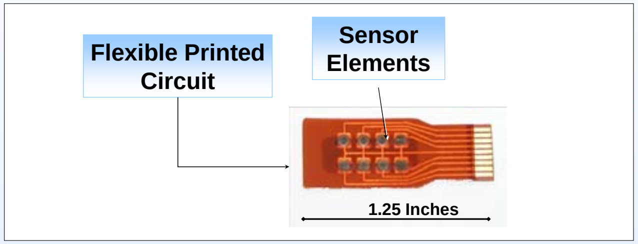


Figure 2. Example of flexible sensor element strip

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

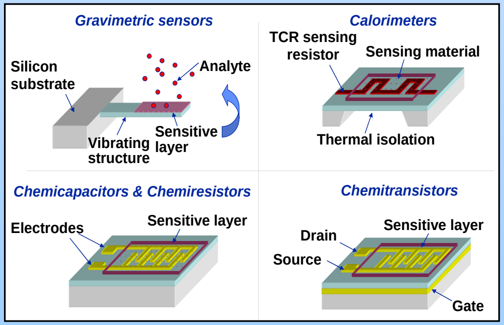


Figure 3. Multiple sensor types

Regioregular poly(alkylthiophene)

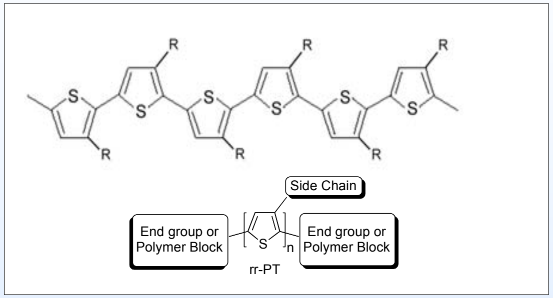


Figure 4. Family of conductive polymer compounds

Preliminary Results

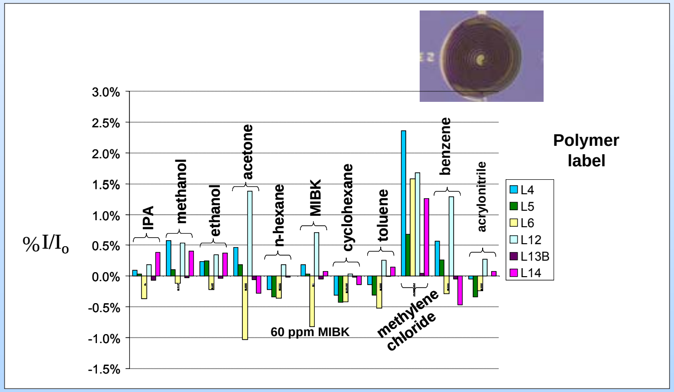


Figure 5. Response of an example detector showing PT selectivity and sensitivity. A close-up view of the sensor coated with PT is also shown.

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.

Preliminary – Not for Citation

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

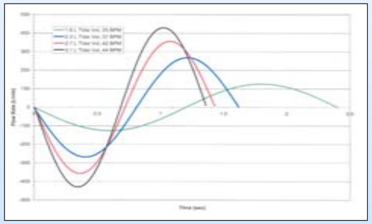
- Simulation of respiratory parameters for heavy workload conditions with a breathing machine
- Aerosol particle analysis - Scanning Mobility Particle Sizer (SMPS) and Aerodynamic Particle Sizer (APS)
- *Bacillus globigii* (BG) and MS2 (wet and dry particle preparations) penetration and reaerosolization

Breathing Flows

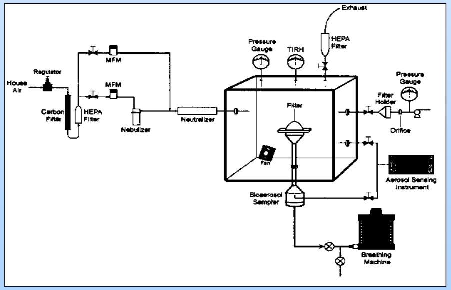
Breathing Rate (breaths/min)	Tidal Volume (L)	Minute Volume (L/min)	PIF[a] (L/min)	MIF[b] (L/min)
25	1.6	40	130	85[c]
37	2.3	85	270[c]	175
42	2.7	115	360[c]	230
44	3.1	135	430	270[c]

(a) Peak inspiratory flow rate assuming ideal sinusoidal waveform
(b) Mean inspiratory flow rate assuming ideal sinusoidal waveform
(c) Selected for constant flow testing

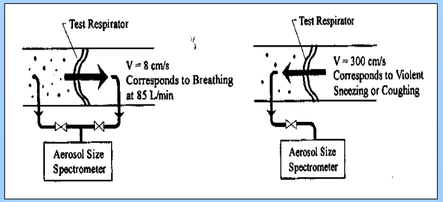
Sinusoidal Waveforms



Bioaerosol Filtration Test System

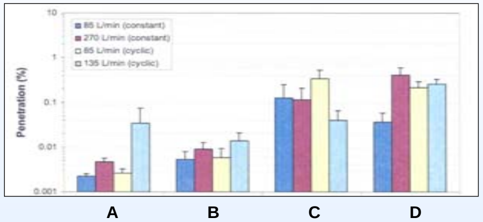


Reaerosolization Test System

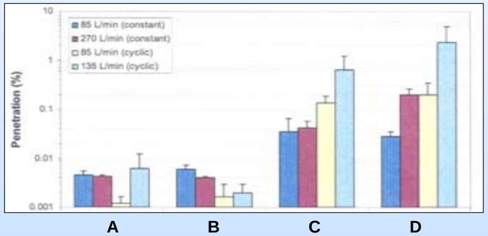


Results

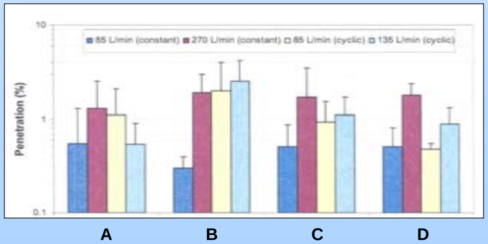
BG (Wet) Aerosol Penetration through N95 Filters



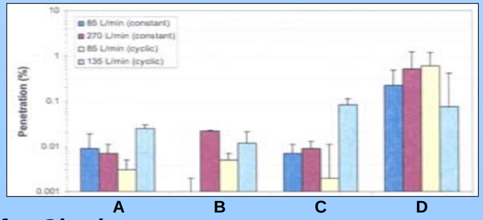
BG (Dry) Aerosol Penetration through N95 Filters



MS2 (Wet) Aerosol Penetration through N95 Filters

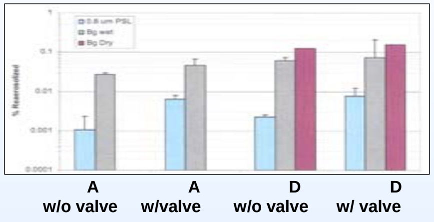


MS2 (Dry) Aerosol Penetration through N95 Filters

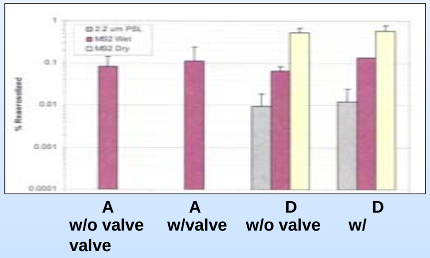


Results (Cont'd.)

Reaerosolization of PSL vs. BG particles



Reaerosolization of PSL vs. MS2 particles



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.

Preliminary – Not for Citation

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

Partnerships

- Anthrotech
- Dennis Groce (WVU)

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

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

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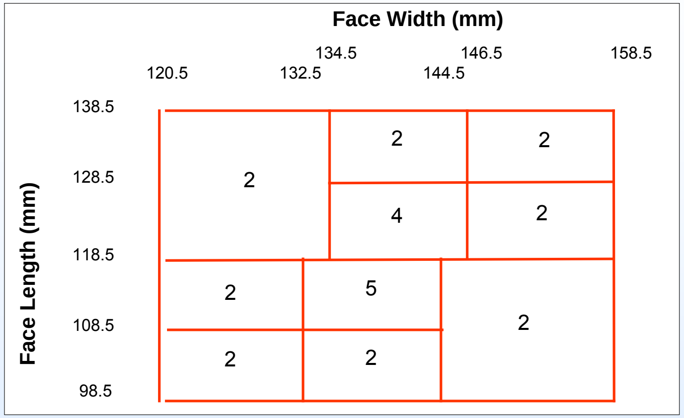


Figure 1. New NIOSH 25-member bivariate panel for testing respirators

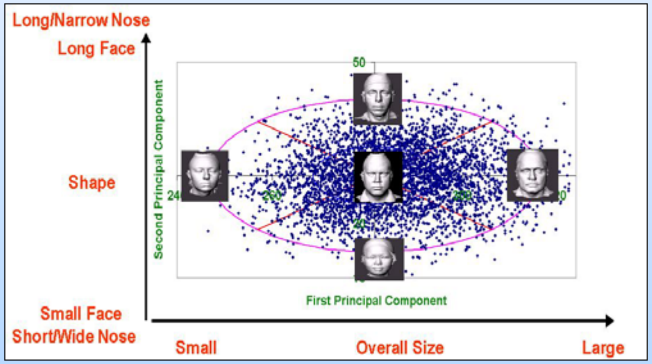


Figure 2. Scatter plot of PCA scores capturing size and shape

Publications

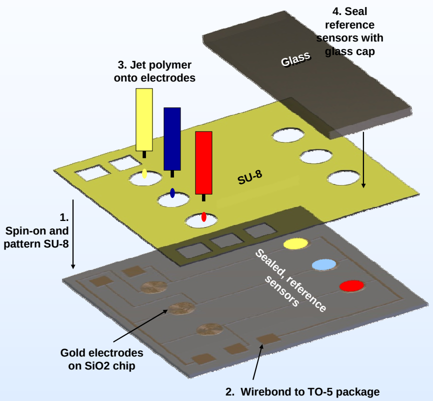
1. Zhuang Z, Guan J, Hsiao H, and Bradtmiller B [2004]. Evaluating the Representativeness of the LANL Respirator Fit Test Panels for the Current U.S. Civilian Workers. Journal of the International Society for Respiratory Protection, 21(III-IV):83-93.
2. Zhuang Z and Bradtmiller B [2005]: Head-and-Face Anthropometric Survey of U.S. Respirator Users. Journal of Occupational and Environment Hygiene, 2, 567-577.
3. Zhuang Z, Coffey C, Berry Ann R [2005]. The effect of subject characteristics and respirator features on respirator fit. J. Occup and Environ Hyg, 2, 641-649.

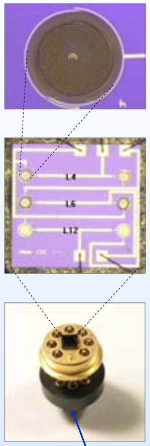
Polythiophene-Based Chemical Sensors for Detecting Respirator Cartridge End-of-Service Life

Jay Snyder

Sensor Chip

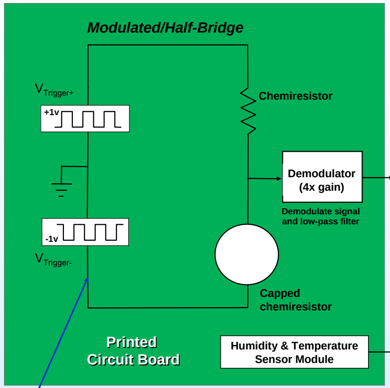
Inkjet Polymer Deposition System

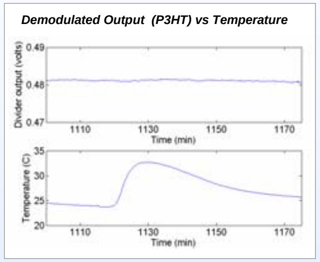




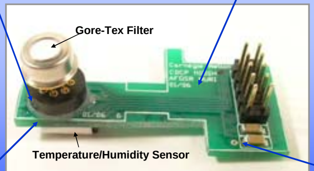
A sensor chip, packaged in a TO-5 housing, incorporates 3 matched sensor-pairs, each fabricated with a different polythiophene-based polymer. Each sensor pair includes one device that is exposed to the analytes, and one capped device to act as a reference in a bridge circuit to minimize sensitivity to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

Sensor Circuit



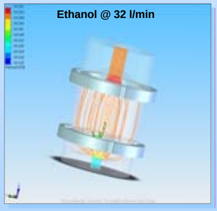


The TO-5 sensor package is mounted on a PCB containing sensor conditioning circuitry and a humidity & temperature sensor module. Matched sensor pairs are configured in a half-bridge to cancel common-mode temperature variations. The bridge is driven by a 1 Hz square wave, and the bridge output is demodulated 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.

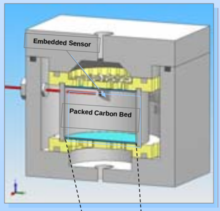


Sensor in TO-5 package, mounted on PCB with modulator/bridge circuit

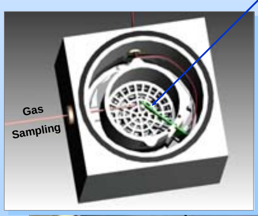
Cartridge Simulator Test-Bed

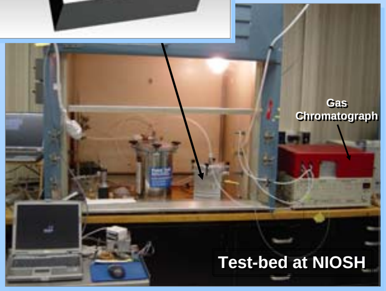


Floworks Computational Fluids Model



Cross-sectional View of Cartridge Simulator

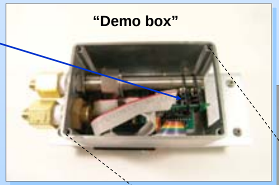


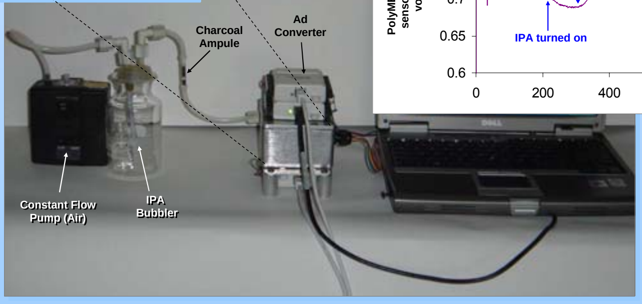


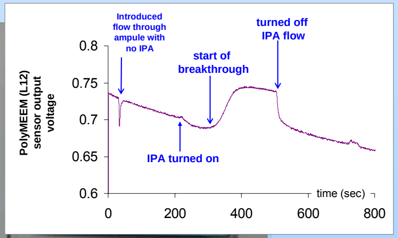
Test-bed at NIOSH

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.

Preliminary Testing







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.

Preliminary – Not for Citation

CDC Workplace Safety and Health
NIOSH
NPPTL Research to Practice through Partnerships

Improved Criteria for Emergency Medical Protective Clothing

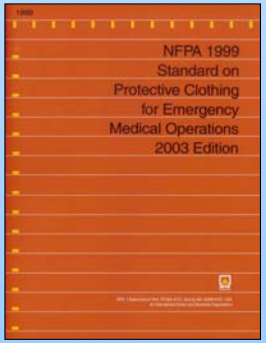
Angie Shepherd

Project Goals

- Identify the specific hazards and use conditions related to EMS protective clothing.
- Determine the performance properties needed to demonstrate protective clothing effectiveness for emergency medical operations.
- Select and develop test methods to measure performance properties for EMS clothing.
- Establish design and performance criteria for protective clothing items that ensure an appropriate level of protection for emergency medical personnel.
- Directly support standards development by communicating recommended test methods and criteria to the NFPA Technical Committee (TC) on Emergency Medical Operations Protective Clothing and Equipment for use in proposed standards including NFPA 1999, *Standard on Protective Clothing for Emergency Medical Operations.*
- Fulfill the TC's request to develop head protection criteria and flammability requirements.

Stakeholders

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



Partnerships

- International Personnel Protection, Inc.

Single Use Garment

Cleaning Glove

Eye/Face Protection Device

Background

- 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.

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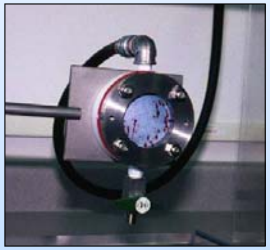
Method/Plan

- **Task 1** Learn first responder needs; determine hazards →
- **Task 2** Identify acceptable/ unacceptable products →
- **Task 3** Determine relevant PPE properties →
- **Task 4** Select or develop test methods; set parameters →
- **Task 5** Establish test plan →
- **Task 6** Carry out test plan; analyze findings →
- **Task 7** Prepare suggested criteria →
- **Task 8** Document study findings

Tensile Strength Test



Viral Penetration Test

Project Milestones

Activity	Completion
Project Planning and External Peer Review	Apr 2006
Determine Hazards and First Responder Needs	Jun/July 2006
Identify Products and Relevant PPE Properties	July/Aug 2006
Select Tests and Conduct Test Plan	Sept/Oct 2006
Analyze Findings and Complete Final Documentation	Nov 2006
Present Final Recommended Criteria to TC Through Public Comments	Feb 2007

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
- AIHA
- ISEA
- OSHA
- Emergency responders
- 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

Fig 1. Permeation Testing

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: 100ºC for 16 hours

  Water/Detergent: Alcojet wash, automatic dishwasher rinse, followed by drying

  Self-decontamination: Incorporate halamine functional groups in clothing material

Typical Results

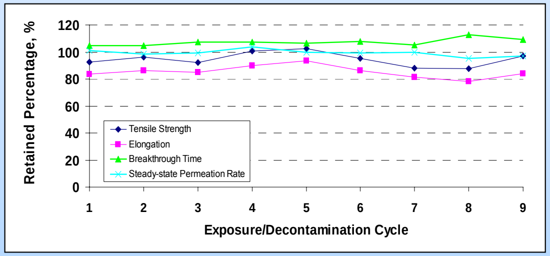


Fig 2. Reusability of nitrile gloves against acetone. Both chemical and physical properties retained ≥ 80% after 7 exposure/heat extraction cycles

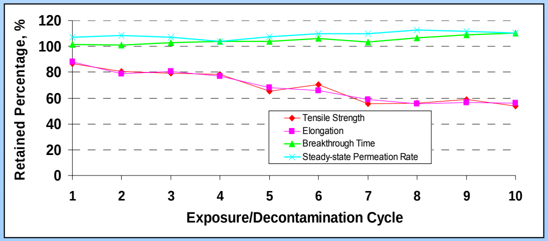


Fig 3. Reusability of neoprene gloves against acetone. Both chemical and physical properties retained ≥ 80% after 4 exposure/heat extraction cycles

Preliminary – Not for Citation

Project Outcomes

- Developed a guideline with the AIHA Protective Clothing & Equipment Committee for decontamination of CPC and equipment, which was published by AIHA Press in December 2005
- Developed a computer program, "Permeation Calculator," to provide faster and more consistent results for permeation testing data analysis. A provisional patent application has been filed by CDC Technology Transfer Office and is available for commercial licensing. A new ASTM standard practice titled "Standard practice for permeation testing data analysis by use of a computer program" was proposed for development under ASTM Work Item # WK9186

Fig 4. AIHA guideline for CPC and equipment decontamination

Fig 5. Permeation Calculator

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

- Gao P, El-Ayouby N, Wassell JT [2005]. Change in permeation parameters and the decontamination efficacy of three chemical protective gloves after repeated exposures to solvents and thermal decontaminations. American Journal of Industrial Medicine *47*(2):131-143
- Gao P, Tomasovic B [2005]. Degradation of neoprene and nitrile chemical protective gloves after repeated acetone exposures and thermal decontaminations. J Occup and Environ Hygiene, *2*(11): 543-552
- Xin F, Gao P, Shibamoto T, Sun G [in press]. Pesticide detoxifying functions of N-halamine fabrics. Archives of Environmental Contamination and Toxicology. In Press

CDC Workplace Safety and Health | NIOSH | NPPTL Research to Practice through Partnerships

Next Generation Structural Firefighting PPE – PROJECT HEROES®

W. Jon Williams, Ph.D., Ron Shaffer, Ph.D., Angie Shepherd, Raymond Roberge, M.D., William Haskell, M.S.

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 that 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

Partnerships

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

Figure 1. Bootie interface prototype design

Figure 2. SCBA interface prototype design

Preliminary – Not for Citation

Project Milestones

Activity	Start	Finish
Project planning and criteria development	Apr 2004	Jul 2004
Materials identification, testing and selection	Jun 2004	May 2005
Ensemble/interface designs	Jun 2005	Oct 2006
Ensemble laboratory testing	**Feb 2006**	**Dec 2006**
Field testing	Aug 2006	Feb 2007
Project final documentation	Feb 2007	Apr 2007

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.

Figure 3. Project HEROES prototype

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

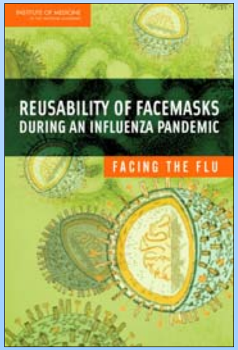
- Healthcare Workers
- Healthcare Facility Administrators
- Pandemic/Infection Control Policy Makers
- General Public
- Respirator Manufacturers

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



IOM Report

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

www.dhs.ca.gov
Sneeze-generated aerosol

N95 Filtering Facepiece Respirator (FFR)

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)

Proposed Studies (Cont'd.)

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

Respirator fit test experiment

3-D head scan of subject

Program Timelines

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

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

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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

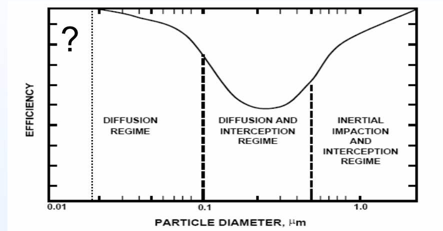


Fig 1. Schematic of filter efficiency vs particle size

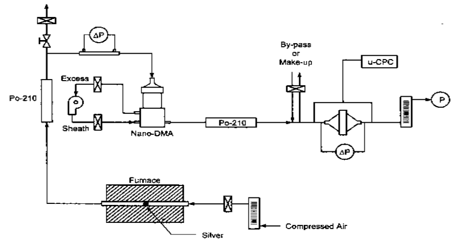


Fig 2. University of Minnesota test system for respirator filter penetration studies

Filter Media Testing

- HE 1079, 102
- H&V HF 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

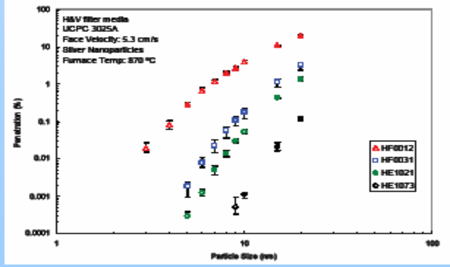


Fig 3. Particle Penetration – H&V Filter media

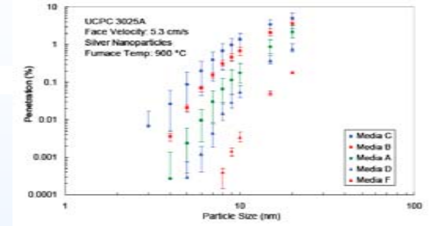


Fig 4. Particle Penetration - 3M and other filter media

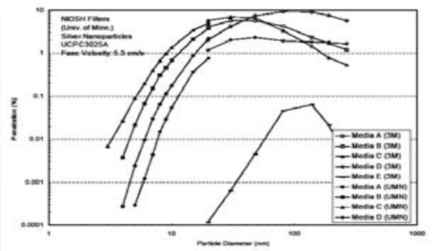


Fig 5. Particle Penetration – combined data

Protective Clothing Penetration

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

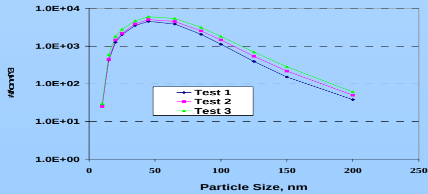
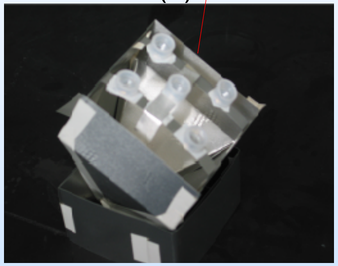


Fig 6. Generation of monodisperse nanoaerosols

(a)



(b)

Fig 7. Evaluation of PAS performance. (a) experiment setup; (b) five samplers inside the exposure section

Preliminary Findings

- Penetration of nanoparticles through filter media decreased down to 3 nm diameter as expected from traditional filtration theory. No evidence for thermal rebound of nanoparticles was observed.
- The prototype magnetic PAS can be used to measure nanoparticle penetration through fabric samples.

Schedule

FY06 - Project proposal development and peer-review

FY07-FY09 - Experimental work

FY10 - Final report

Preliminary – Not for Citation

Physiological Models and Countermeasures

W. Jon Williams, Ph.D., Raymond Roberge, M.D., M.P.H., and Edward Sinkule, M.S.

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

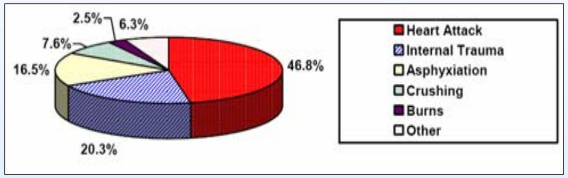


Figure 1. Firefighter fatalities in 2002 by Nature of Fatal Injury (Source: IAFF, 2003)

- 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 VO_2max determination
  - Exercise testing at a % of VO_2max

Current Studies

Physiological Sensors

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

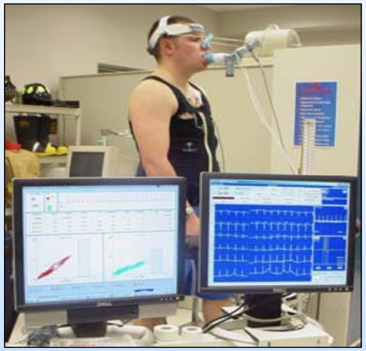


Figure 2. Test subject in the physiology lab wearing the sensor vest and making metabolic measurements

Cooling Systems

- Goals–Study effects of cooling systems alone and in combination on the physiological stress caused by wearing PPE
- Cooling systems
  - Convective cooling (HEROES)
  - Conductive cooling via shortened whole-body undergarment (Figure 3)
  - Conductive cooling (head/neck only)

Current Studies (Cont'd.)

- Test Conditions:
  - Chamber (35ºC, 50% RH)
  - Treadmill exercise at intermittent high intensity work loads-3 sets of 20 min work at 75% VO_2max followed by 10 min rest

Figure 3. Example conductive cooling garment.

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)

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