Cleaning, Decontamination, and Its Effectiveness Applied to Firefighter PPE

JOIFF Shared Learning Online Seminar:
Firefighter Health and Well Being
Tuesday 25 August 2020

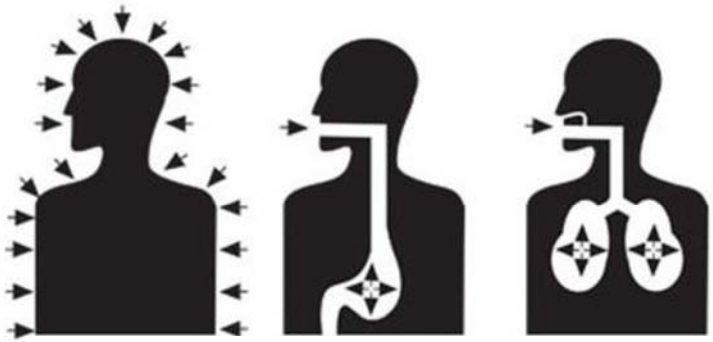
Jeffrey O. Stull

International Personnel Protection, Inc.™

Understanding Fireground Exposures: Role of PPE

Contamination Basics

Routes of Entry



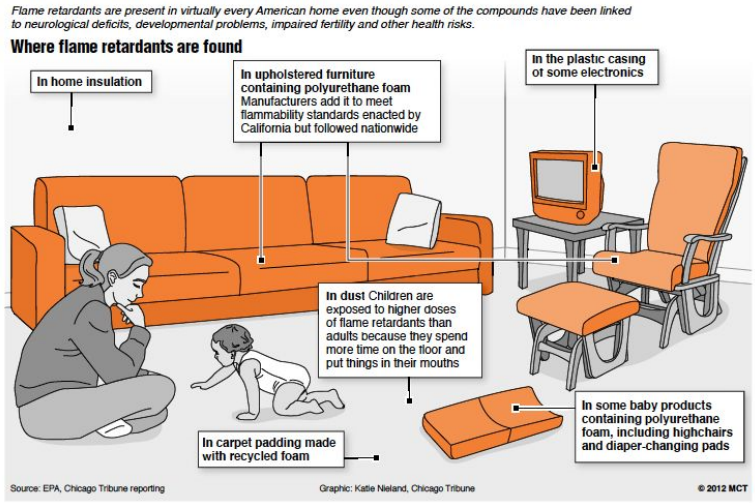
Skin Contact ***Ingestion*** ***Inhalation***

Impact of contaminant depends on substance properties

- Most common ways firefighters are affected:
  - Smoke and fire gases are inhaled
  - Direct skin contact with corrosive or harmful chemicals
  - Fire gases and liquids absorb through skin
  - **Smoke particles stay on skin long enough to release chemicals that then absorb through skin**
  - Smoke particles or other substances on hands/face contaminate food

Common Contaminants of Concern

- Volatile organic compounds
  - e.g., benzene, formaldehyde
- Semi-volatile organic compounds
  - e.g., polynuclear aromatic hydrocarbons (PAHs), phthalates, various fire retardant chemicals
- Heavy metals
  - e.g., Arsenic, Cadmium, Chromium
- Dangerous particulates
  - e.g., asbestos, lead dust, fentanyl



Research | Review

Brominated Flame Retardants: Cause for Concern?

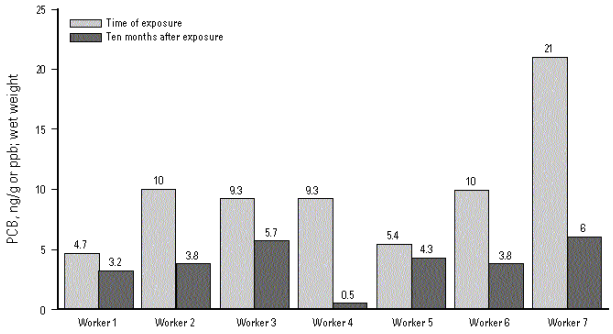
Linda S. Birnbaum[1] and Daniele F. Staskal[2]

[1]U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Experimental Toxicology Division, Research Triangle Park, North Carolina, USA; [2]University of North Carolina, Curriculum in Toxicology, Chapel Hill, North Carolina, USA

Various chemicals are present of different persistency and toxicity in all fire environments

Case Study: 1980 PCB Transformer Fire

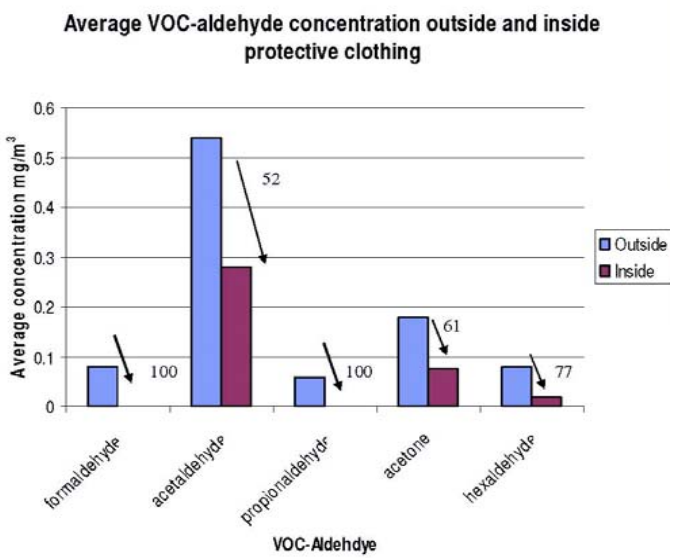
- Transformers caught fire in basement of state office building
- Dioxins in smoke produced by burning of PCB-containing oil spread throughout building
- Firefighters responded in normal turnout gear; bodies covered with contaminated soot

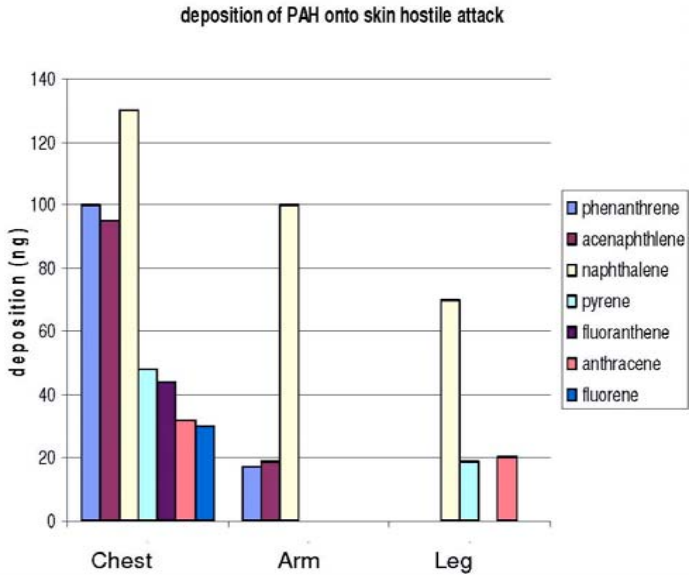


PPE in Preventing and Causing Exposure

- Historically PPE is used for heat and physical protection
- New shift to full ensemble protection against contamination exposure
- While providing protection, clothing itself becomes source of exposure
- Additional shift to more frequent effective cleaning and controlling contamination on fireground and at the station

Firefighter Exposure Study Results



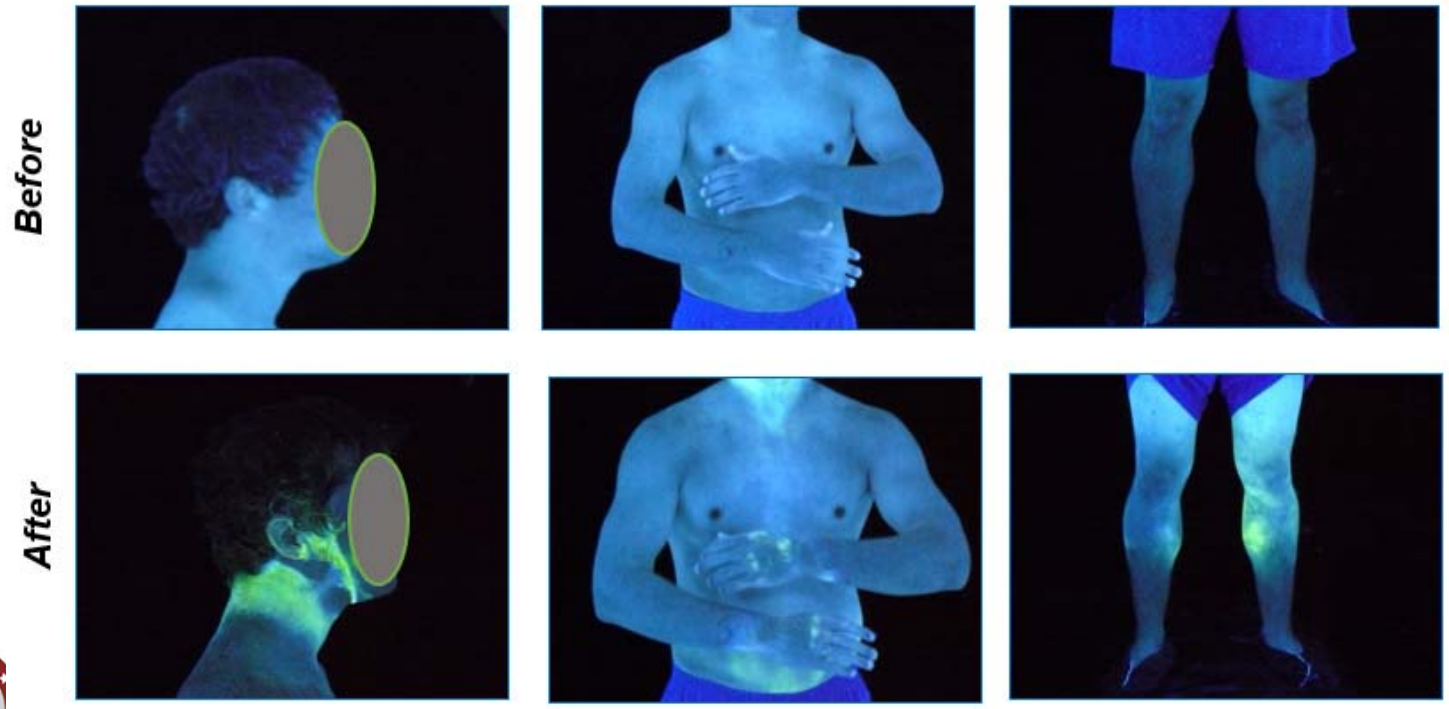


- Clothing attenuates some chemical exposure
- Many dangerous chemicals deposited onto firefighters' skin

IAFF Assessment of Particulate Exposure

- IAFF conducted particulate exposure study in 2015
- Military method used to simulate smoke exposure
- Full, used turnout gear evaluated
- Particles tagged with fluorescent tracer to allow observation under UV light

Key Visual Findings from IAFF Particulate Study



Initial Focus on Protective Hoods

- Hoods originally considered most vulnerable interface owing to porous fabrics
- NIOSH study found:

  "Better protection to the neck could reduce dermal absorption of combustion products."

- Efforts were launched to create industry criteria in NFPA 1971 for particulate blocking hoods

Hood Contamination Following Fire Simulation

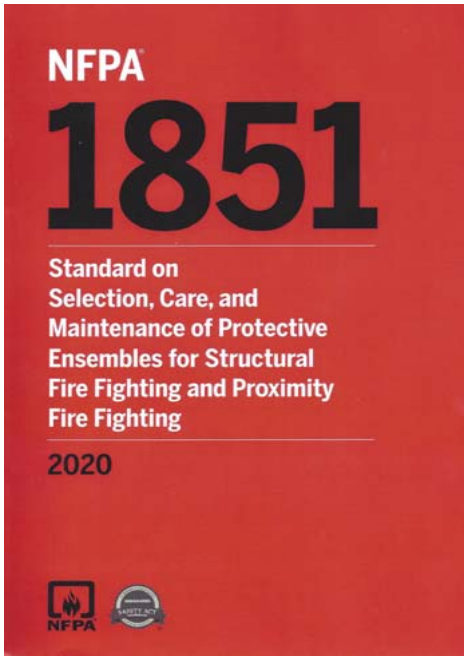
New Particulate-Blocking Hood

PPE Solutions for Reducing Overall Exposure

- Industry efforts to address other interfaces
- Further innovation needed to account for increased encapsulation
- Good “metrics” still not in place

The Transformation of NFPA 1851 and What It Means to Firefighters

Revised NFPA 1851



- Cleaning chapter overhauled
  - Decision matrix to support cleaning and decontamination decisions
  - Distinctions made between advanced cleaning and sanitization (biodecontamination)
  - Use of PPE on fireground requires advanced cleaning (**SMOKE = CONTAMINATION**)
  - Extensive guidance in annex
- Cleaning verification requirements applied to ISPs and manufacturers

Figure A – Basic Decisions

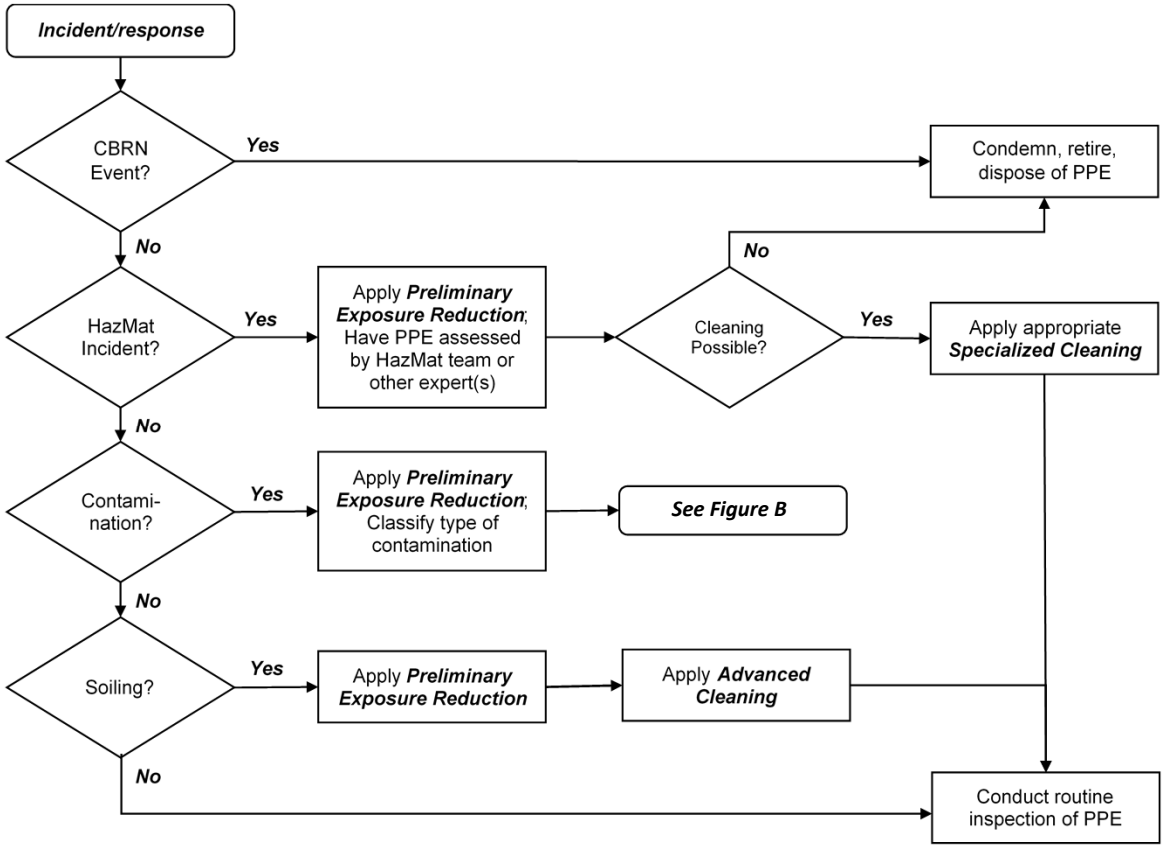
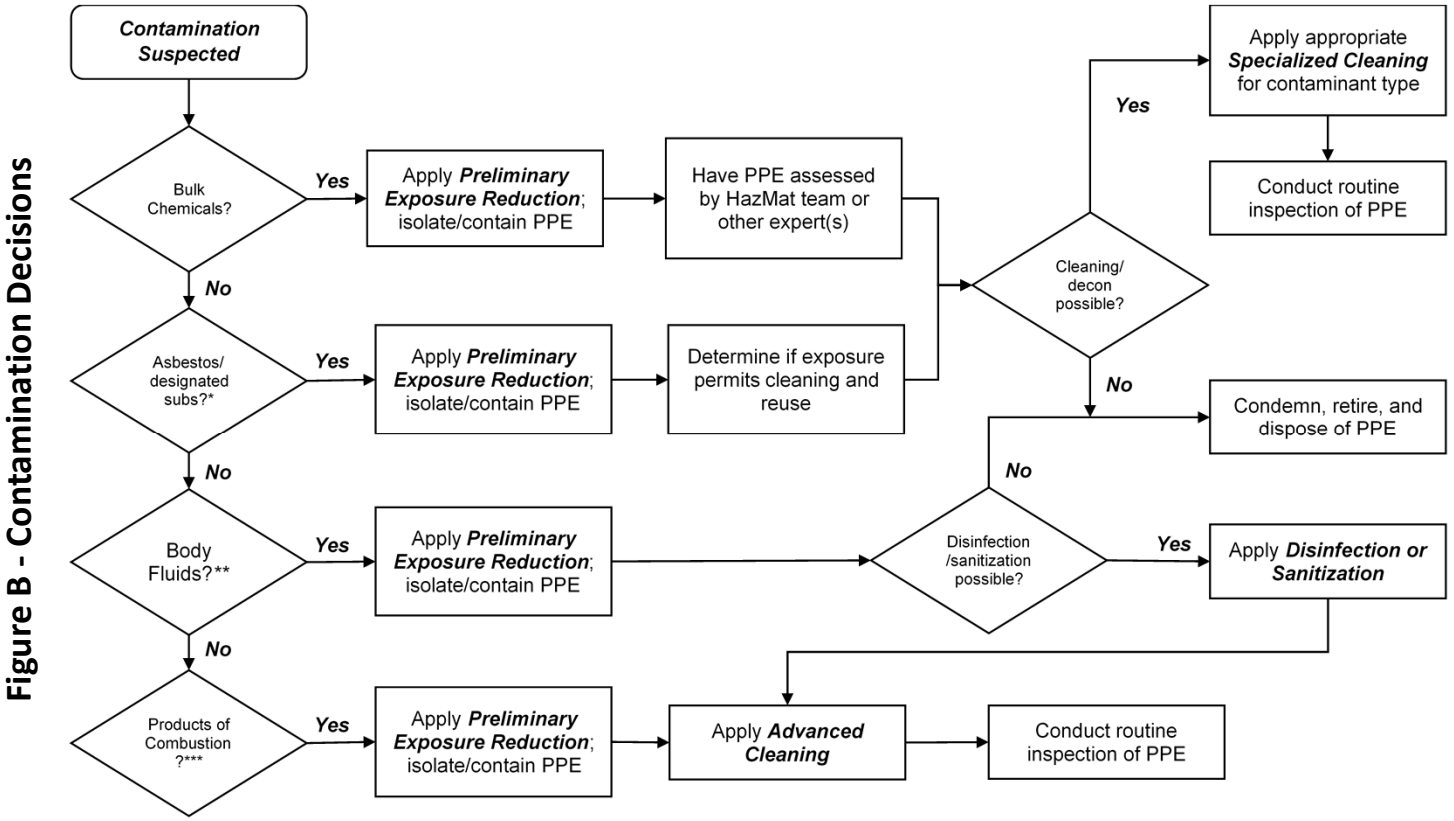


Figure B - Contamination Decisions



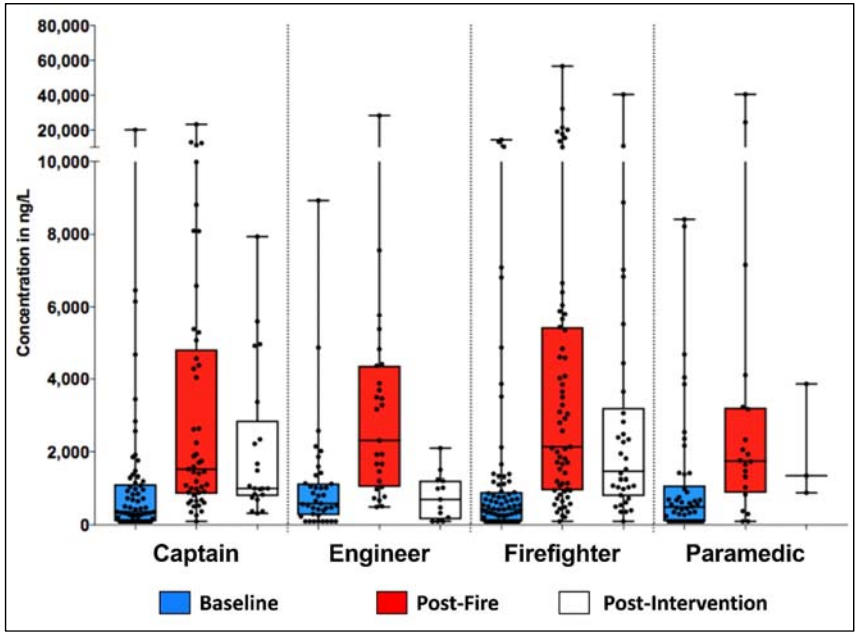
** And other designated substances; ** Includes other microbial contamination; *** Includes any significant structural fire exposure*

Preliminary Exposure Reduction (PER)

- Integrate “gross decontamination” as part of rehabilitation process
- Use rinsing and wash firefighter while still in full PPE at fire scene
  - Intended to remove surface contamination and minimize transfer of contamination to fire fighter when doffing PPE
- Apply variants in procedures depending on circumstances and resources

Tucson FD / University of Arizona Study

- Three interventions examined
  - Use of PER
  - Engineers wear SCBA
  - Bag PPE for transport
- 80% of FD participated in study
  - 545 of 633 members
  - Blood, urine, buccal cell collection
- Measure of 1-Naphthol (PAH metabolite) in urine before and after exposure



Handling of Contaminated PPE

- Properly remove PPE to avoid contamination transfer
  - Specific attention glove and hood doffing
- Isolate and bag contaminated PPE for later cleaning
  - Use of >3 mil bags
- Provide clean clothing for personnel at scene
- Avoid transporting contaminated PPE in apparatus cab or personal vehicles

Advanced Cleaning Requirements

- Can only be performed by:
  - Manufacturer verified in cleaning
  - Verified cleaner
  - Manufacturer-trained organization
  - Verified organization
  - Verified ISP

- Must be applied whenever PPE is soiled or contaminated
  - At least twice a year
- Specific procedures to be followed
  - Machine-based cleaning for garments, hoods, and helmet textiles
  - Utility sink procedures for other elements

Advanced Cleaning Limitations

- Only washer/extractors can be used
  - Must be programmable
  - Acceleration cannot exceed 1000 Gs
- Top loading machined prohibited
- Detergents
  - pH (undiluted) between 6 and 10.5
  - No known degradation of PPE
- Drying
  - No heat machine drying
  - Ambient air drying
  - Use of drying cabinets permitted

Added Fire Service Guidance

Suggested Formulation for Garment Outer Shells

Operation	Time (min)	Temperature		Water Level
		± 3°C	± 5°F	
Fill		40	105	Low
Add suds/detergent				
Agitate	8	40	105	Low
Drain				
Fill		40	105	Low
Add suds/detergent				
Agitate	8	40	105	Low
Drain				
Fill/agitate	5	30	85	High
Drain				
Fill/agitate	5	30	85	High
Drain				
Fill/agitate	5	30	85	High
Drain				
Extract at 100 Gs	6			

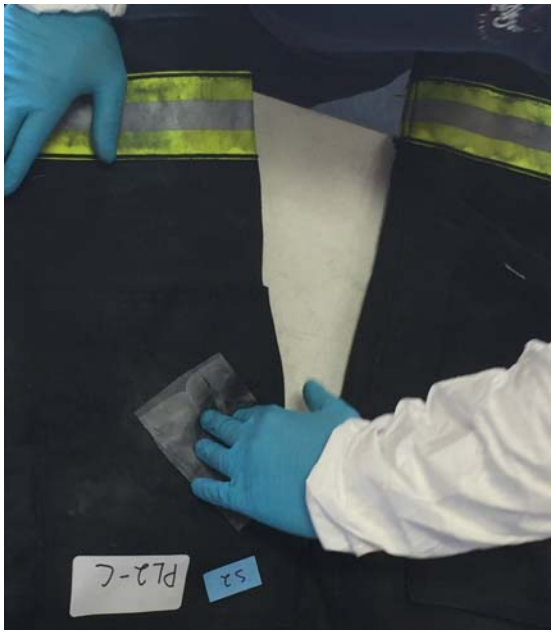
- Specific recommended procedures:
  - Machine selection/loading
  - Sanitization of garments exposed to blood/body fluids
  - Non-destructive analysis of garments for asbestos
  - Decontamination procedures for bed bugs

How Clean is Clean?
Cleaning Effectiveness, Progress and the Future

Question

What is the best way to tell if turnout clothing is “clean”?

A. I see no visible soiling
B. It smells clean to me
C. The rinse water looks dirty
D. I wipe a small white cloth against it and the cloth shows no dark residue
E. I run an analytical test on the clothing and it shows no chemicals
F. None of the above

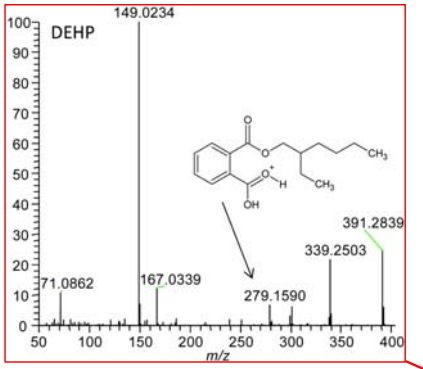


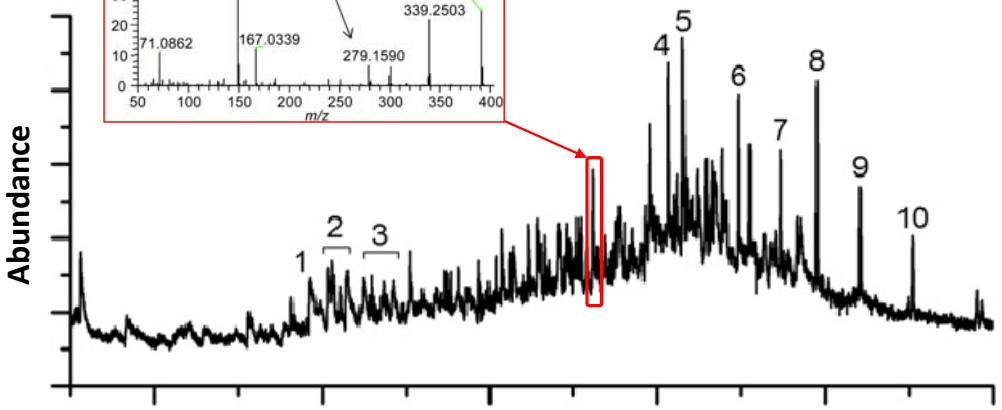
Wipe Sampling of Turnout Gear

Chemical Analysis of Outer Shell Fabric

Fabric Extraction

GC-MS





Other chemicals that show up

- Fabric finishes
- Environmental contaminants
- Laundry additives
- Body oils

Why Cleanliness is Hard to Define

HazMat

Real HazMat

- Cleanliness is more than soiling
- Enormous number of different contaminants
- Difference sources for contamination
- Lack of acceptable levels of exposure for majority of substances

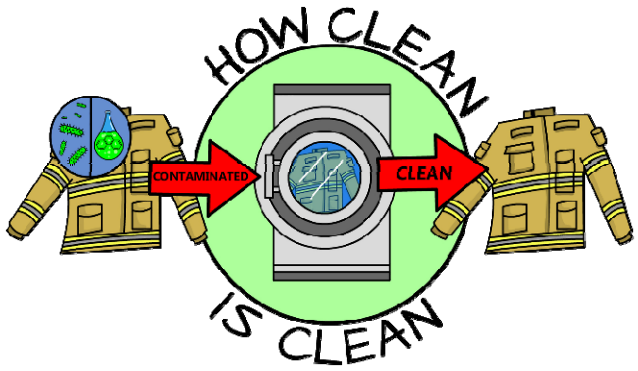
Quick Project Overview

- Started Aug. 2015/Completed Dec. 2018
  - Followed earlier Foundation project aimed at turnout clothing cleaning practices

- Project Team

NFPA RESEARCH FOUNDATION
RESEARCH FOR THE NFPA MISSION

National Institute for Occupational Safety and Health NIOSH



Project Logo

Updated project information at:
http://www.nfpa.org/ppecleaning

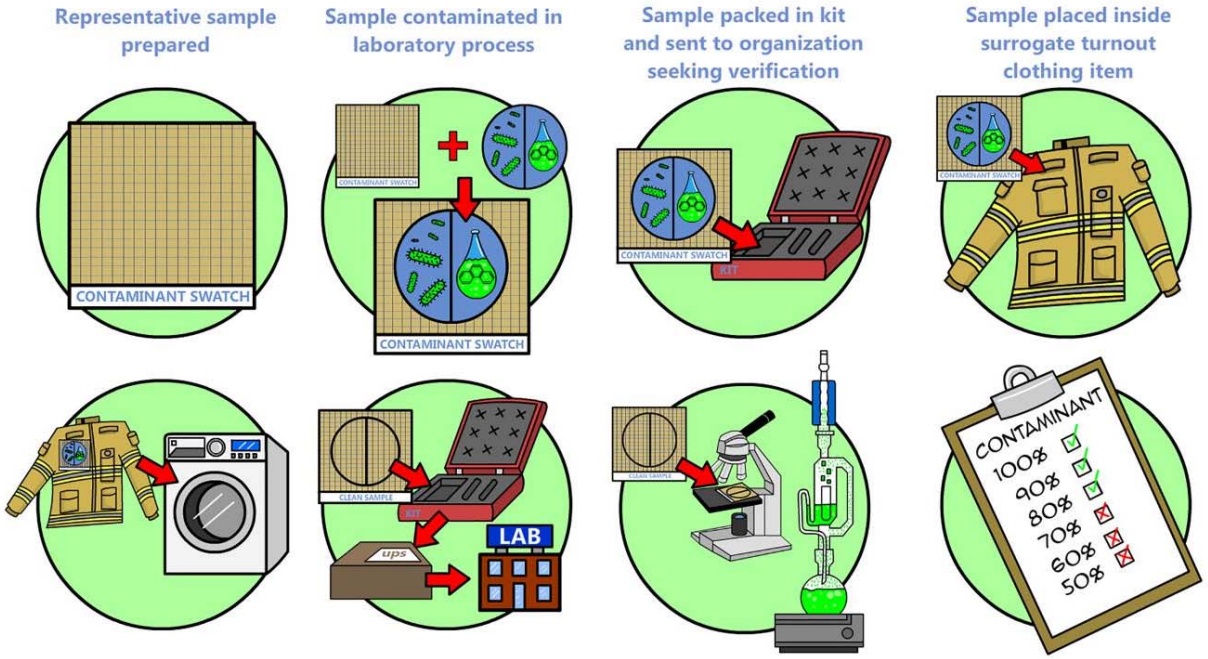
Project Goal

Reduce firefighter exposure to harmful contaminants in unclean or inadequately cleaned PPE

- Key questions being answered:
  - Can better gear cleaning guidance be provided to the fire service?
  - Does cleaning adequately remove chemical and biological contaminants?
  - When do departments know their gear is clean?
  - How can research findings best be transitioned to practice?

Comprehensive project to validate cleaning procedures

CLEANING VERIFICATION KIT PROCESS



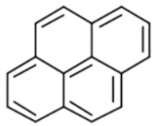
Contaminant Selection

- Principal factors
  - Persistency
  - Representative
  - Easily extracted/analyzed
- Biological
  - Derived from EPA regulations

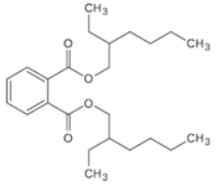
K. pneumoniae

S. aureus

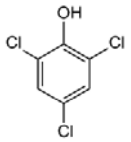
- Inorganics
  - Focus on common toxic and skin absorbing heavy metals (Antimony, Arsenic, Cadmium, Chromium, Cobalt, Lead)
- Semi-volatile organic compounds (SVOCs)
  - PAHs
  - Phthalates
  - Phenols



Pyrene

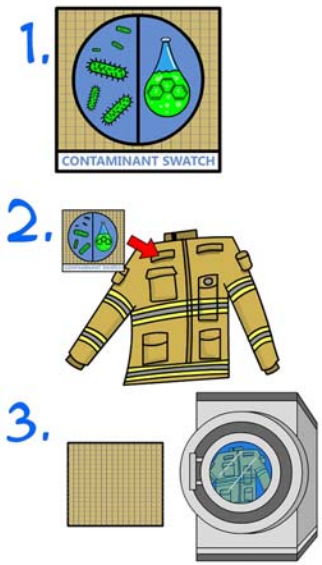


DEHP



TCP

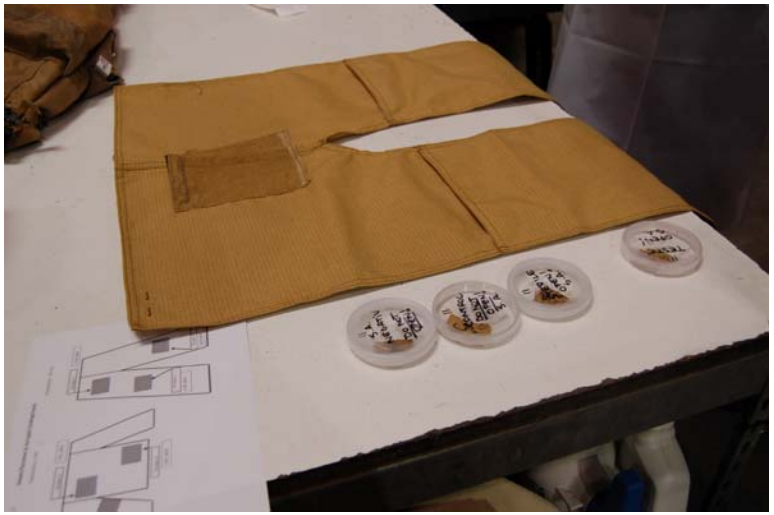
Sample Processing at Wash Facility



- Key Challenges and Solutions
  - Wide range of clothing materials
    - Choose single representative material in suitable condition
  - Clothing is highly complex
    - Use surrogate, simplified clothing samples
  - Wash procedures generally different between facilities (machine, detergent, process)
    - Establish consistent wash load to remove variability
    - Allow for adjustment depending on facility procedures

Overall theme: *Promote uniformity of procedures for reliability and reproducibility*

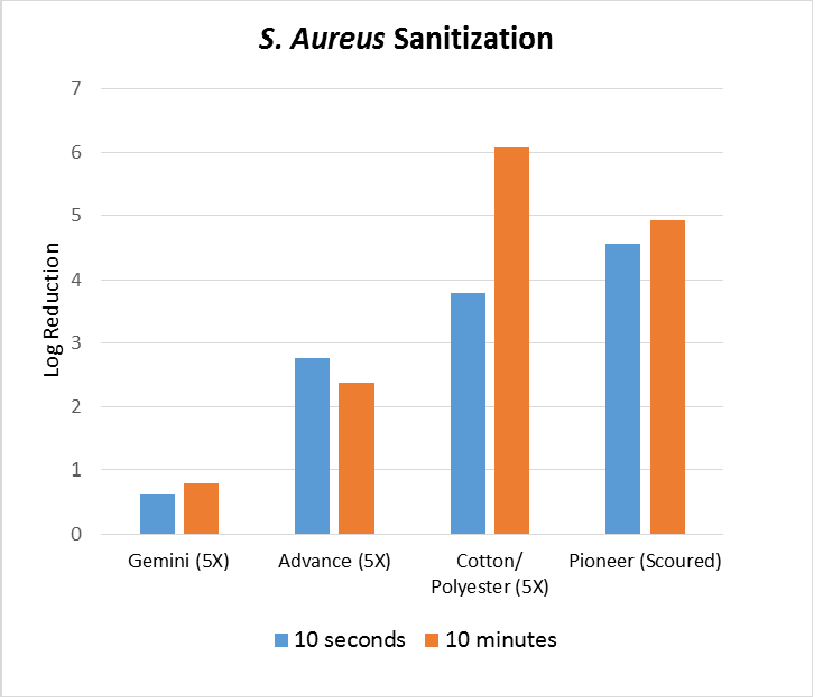
Sample Containment and Transfer



Specific procedures for shipping, handling, and returning specimens and clothing

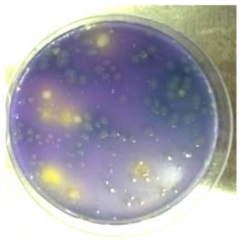
Evaluation of Biological Contamination

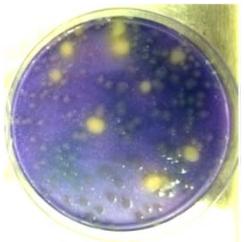
- Initial results showed varying effectiveness of sanitizer on clothing samples on small scale
  - Controlled soak in sanitizer
- Results at one ISP provided log reductions of over 5 for *S. aureus*
- Results for tests at other ISPs confounded by foreign bacteria



Differences in Sample Bacterial Levels

TEST SWATCH



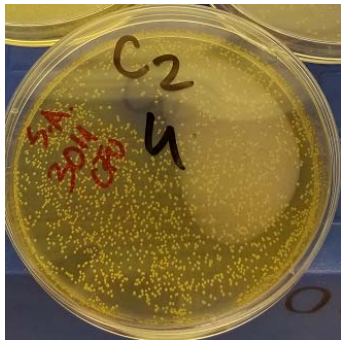


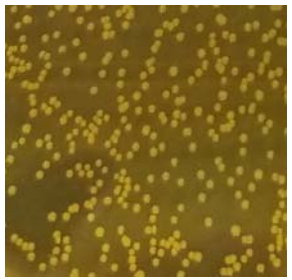
Interference in Counting EXTENSIVE

Different bacteria, but no Staphylococcus.

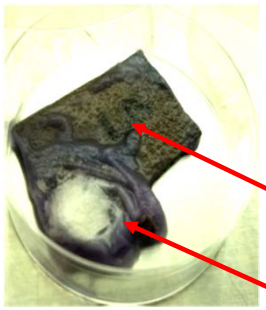
Vs.

CONTROL SWATCH





STERILE SWATCH



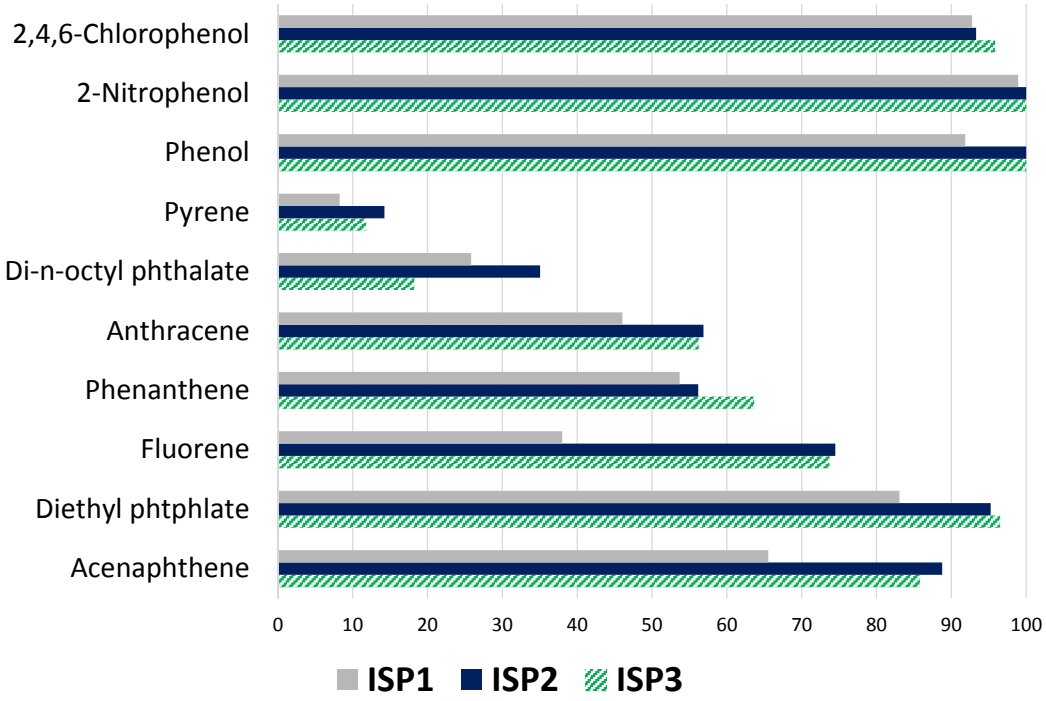
Cross contamination on sterile swatches

Swatch

Fungus

Bacteria / Fungus

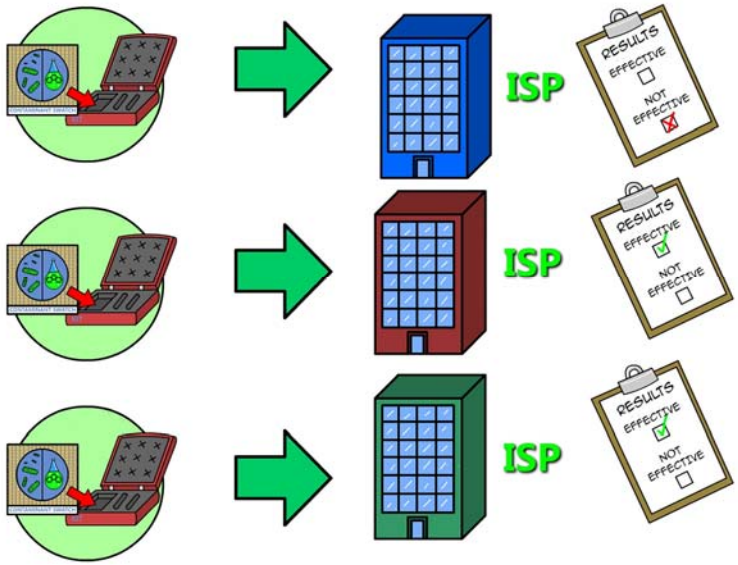
Decontamination Efficiency at Different ISPs



- Average chemical removal efficiency at 50 to 60%
- Few differences with changing temperature or wash conditions
- Findings consistent with washing of field-contaminated clothing

Application of Test Results within Fire Service

- Translation of cleaning results into standard requirements
- Key questions
  - Which test results are most important?
  - How should criteria be set as minimum requirements?
  - What organizations should be held accountable?

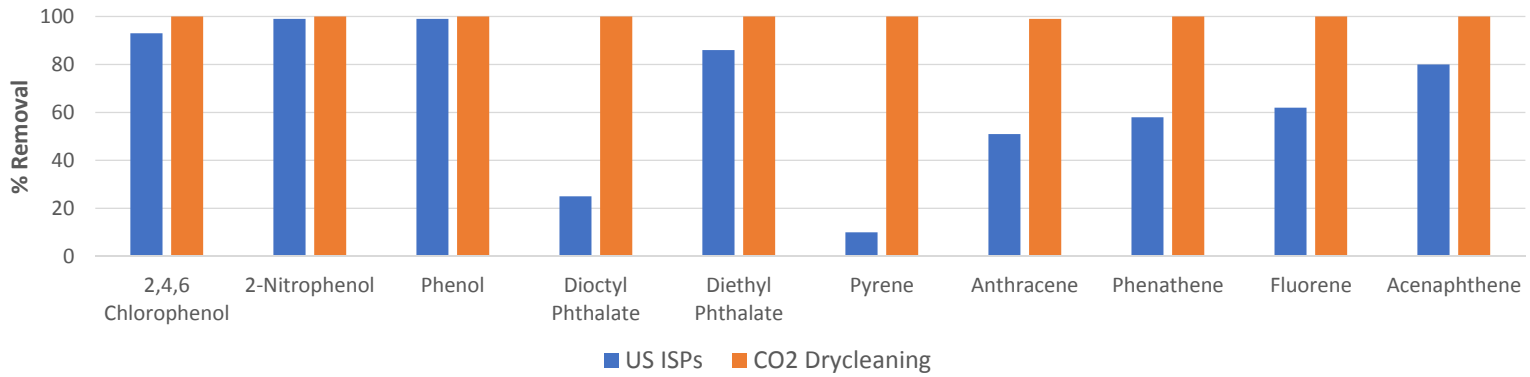


Accomplishments for the Fire Service

- "Measuring stick" provided to assess cleaning processes
- Cleaning verification of ISPs mandated
- Benchmarks performance established to encourage industry improvements
- Fire service awareness on PPE contamination increased

Fire Department Cleaning Facility

Implementation of Procedures



- Two organization “verifying” ISPs in US and Canada
- Significant interest generated by suppliers of new agents, processes
- Work undertaken in Europe to examine unique process

Expanding Cleaning Verification to Other PPE and Equipment

Other Fire Service PPE Cleaning Issues

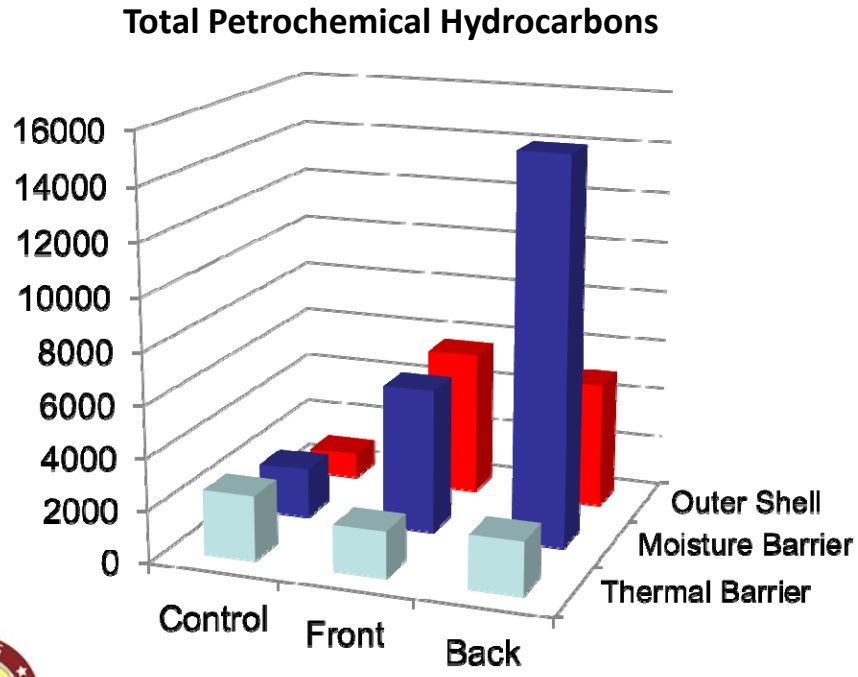
- Very little information for PPE other than garments and hoods
- Poorly defined cleaning procedures (most are manually performed)
- Limited to no research on effectiveness of cleaning

GORE
Creative Technologies Worldwide

Decontamination Effectiveness of Leather and Rubber Samples Specifically Treated for Fire Boot Applications

© 2009 W. L. Gore & Associates, Inc.

Layer by Layer Garment Contamination



Interior side of garment outer shell

Moisture barrier side of liner

Existing Project to New Project Scope

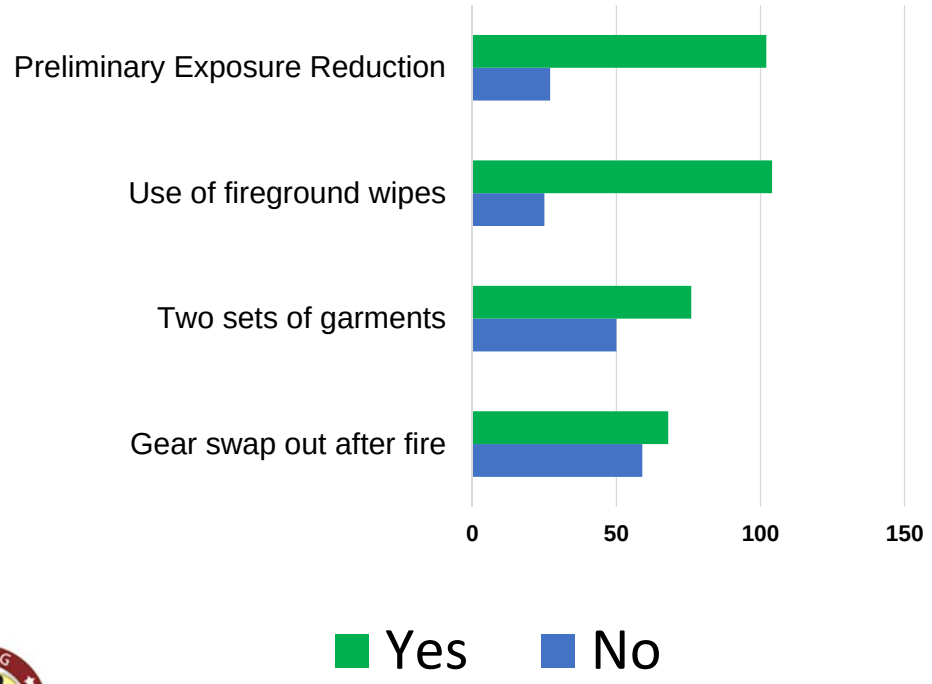
- Examine other garment layers and components for chemical decontamination
- Investigate contamination and cleaning as applied to gloves, footwear, helmets, & SCBA
- Determine if contamination/ cleaning assessments can be applied to other items (e.g., tools, seat covers, hose)

Fundamental New Project Questions/Goal

1. How does contamination vary in different PPE and related items?
2. Are manual cleaning methods effective in removing contamination?
3. What new best practices can be transitioned to fire service?

Extend cleaning validation procedures to other PPE

Fire Service Survey – Practices



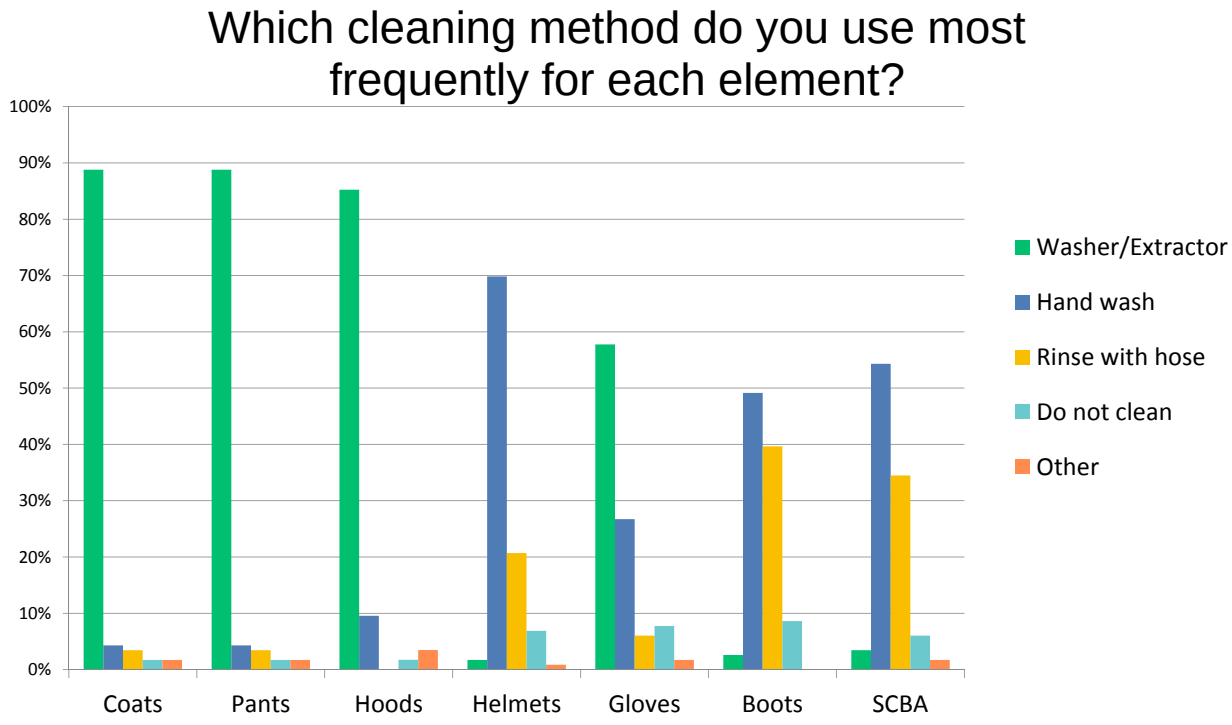
Belief in wipe effectiveness

- Yes (55.3%)
- No (10.7%)
- Unsure (34.0%)

Second items for other PPE

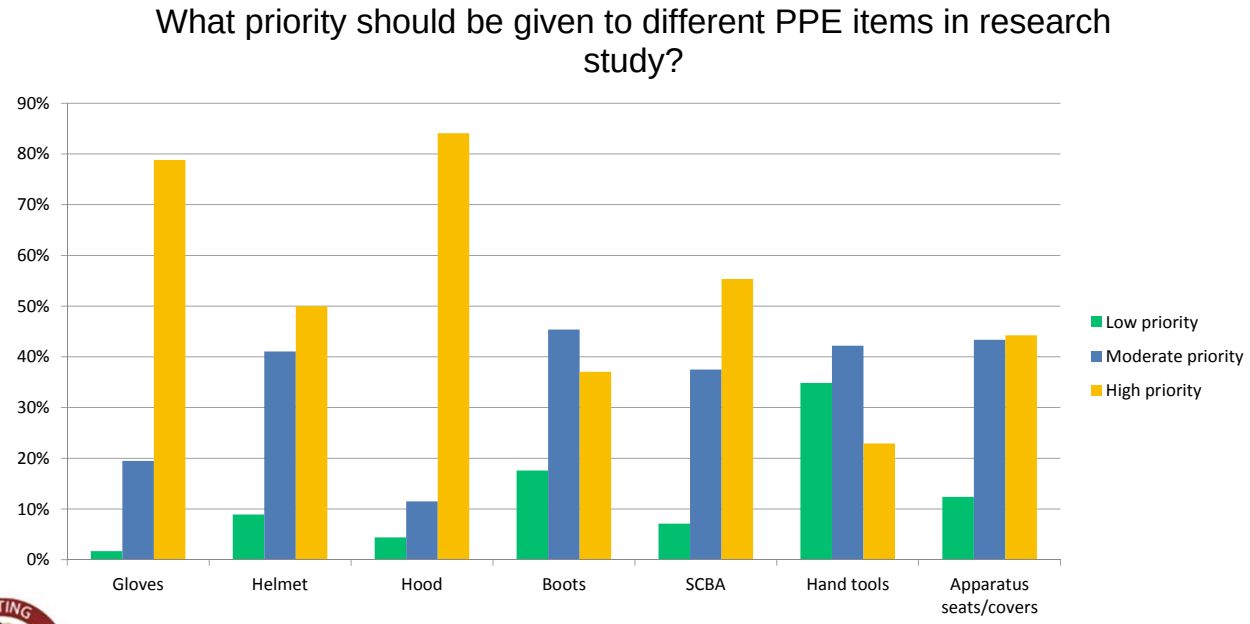
- Structural gloves (52.8%)
- Structural footwear (18.1%)
- Protective hoods (79.5%)
- None (18.1%)

Fire Service Survey – Cleaning Approach



Individual firefighters more likely to perform own cleaning, especially for helmets and boots

PPE Cleaning Research Priorities



Rank Order

1. Hoods
2. Gloves
3. SCBA
4. Helmet
5. Seats
6. Hand tools

Specific Technical Challenges

- Current procedures were optimized for water-resistant textiles
  - Other materials (coated fabrics, leather, plastics) expected absorb contamination differently
  - Levels of contamination unknown
- Ability to apply kit-like approach requires significant adaptation of procedures
- Objectives of research likely to change with different items

Further Garment Cleaning Investigation

Gear Presoaking

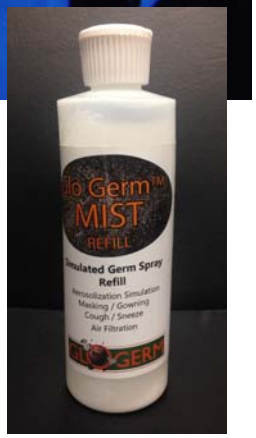
- Map contamination levels through layers and on different components
  - Assess key areas of risk
  - Determine needed process differences
- Look at differences in wash processes
  - Impact of presoak / cycle times
  - Specialized detergents / machine differences
- Examine contaminant transfer in machine and from clothing

SCBA Cleaning

- Level of disassembly required
  - Specific regulator components
  - Textile straps
- Approach to cleaning different components (e.g., individual facepieces)
  - Changes in types of cleaning agents
- Techniques for ensuring complete cleaning
  - Hand washing
  - Emerging machine washing approaches

Investigation of Field Cleaning of SCBA

- Initial Testing
  - Fire fighters wear ensemble with SCBA
  - While on air, fire fighters sprayed with GloGerm (approximately 10 seconds)
  - "Contaminated" fire fighter viewed under UV lights
  - Preliminary exposure reduction applied
  - "Decontaminated" fire fighter view under UV light
- Further Testing
  - Adjustments made to spraying and preliminary exposure reduction
  - Gear and SCBA subjected to "advanced cleaning"



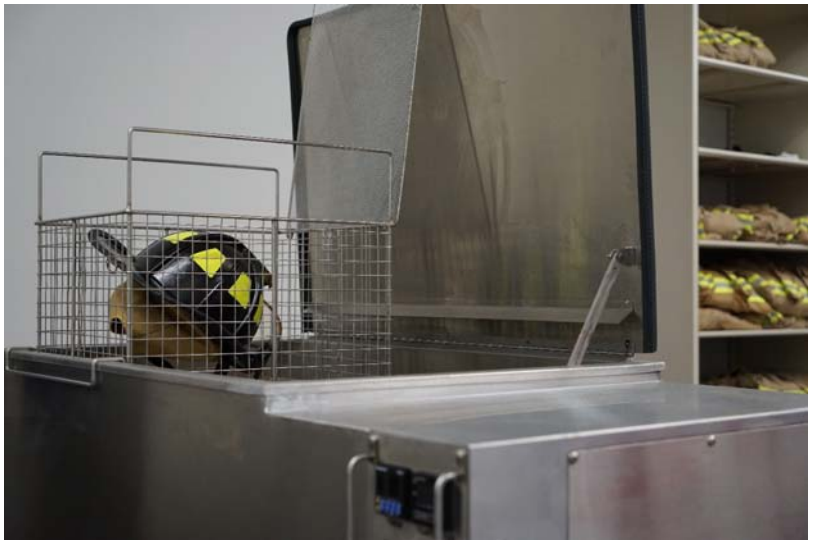
Spraying of GloGerm Solution onto Ensemble

Post-Contamination PER

Post PER Residual Contamination

Overall Project Direction

- Answer fundamental questions about cleaning other PPE elements
- Conduct experiments to show levels of contamination in different PPE elements
- Create standard methods that enable determination of clothing cleanliness
- Apply methods to identify best practices for PPE cleaning



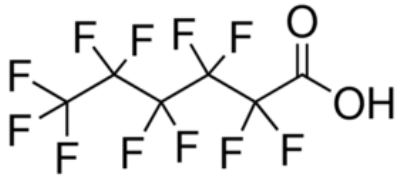
Ultrasonic Cleaning of Helmets

TESTING
RESEARCH
EXPERTISE
TM

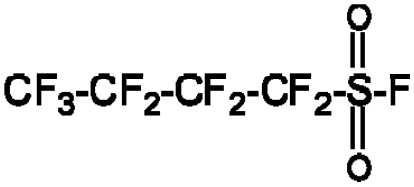
PFAS, PFOA, and PFOS: Deciphering Exposures, Hazards, and Emerging Regulations

What are PFAS

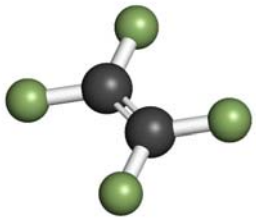
- Per- and Polyfluoroalkyl Substances
  - Long-chain organic molecules with multiple fluorine atoms
  - Over 5000 different known, characterized PFAS
- Examples:



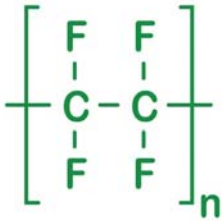
Perfluorohexanoic acid (PFHxA)



n-perfluorobutanesulfonyl fluoride



Monomer



Polymer

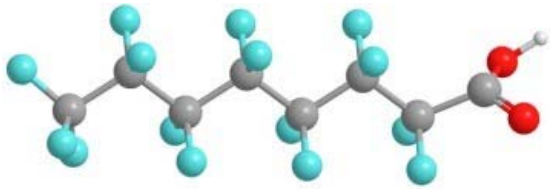
Perfluorotetraethylene (PTFE)

- Used in variety of consumer and industrial items including non-stick products, food packaging, textiles, and fire fighting foams (AFFF)

Specific Hazardous PFAS

PFOA

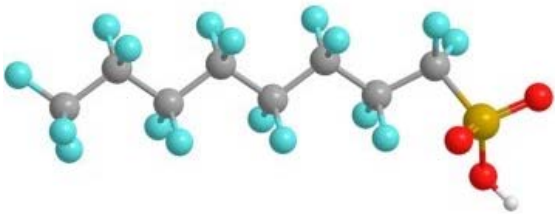
- Perfluorooctanoic acid



- Industrial surfactant, material feedstock
- Associated with certain forms of cancer (kidney, testicular)

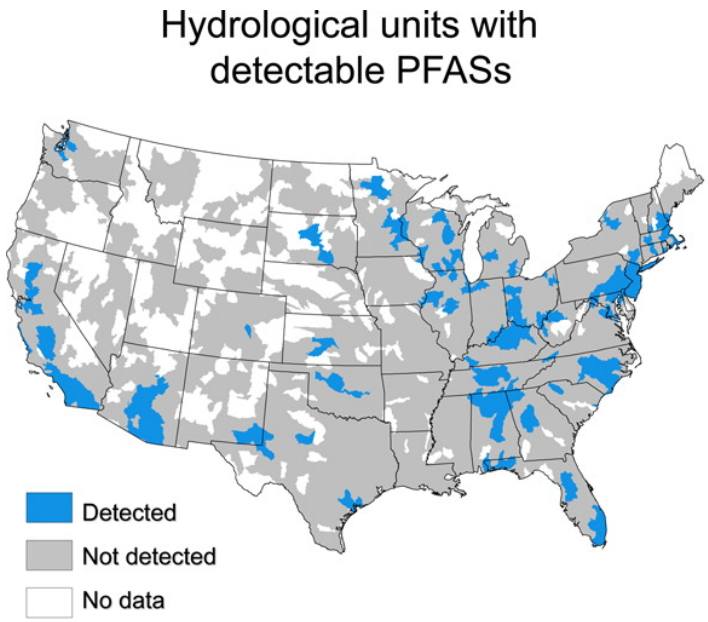
PFOS

- Perfluorooctanesulfonic acid



- Primarily used as a stain-repellent treatment
- Associated with thyroid hormone disruption

Exposure to PFAS



- Primary exposure routes
  - Ingestion (drinking contaminated water or eating contaminated food)
  - Respiration (inhalation of contaminated dust)
  - Skin absorption of PFAS chemicals is VERY LOW
- Most exposure occurs through drinking water contamination
- Primary problem: persistency
- Overlooked: Very large PFAS do not enter body

PFAS in Firefighter PPE

- Inert PTFE is used as a principal component of moisture barriers
- Durable water repellent (DWR) finished used on outer shells and some other PPE materials
  - C8 chemicals transitioned out over last decade
  - Replacement DWR PFAs (C6) at low levels in cursory testing of garments (<25 ppb)
- IAFF studies will be completed later in 2020 with analysis of current and legacy gear
- **KEY FACT:** Deployed firefighters show higher levels of PFOA and PFOS than non-deployed firefighters

California Proposition 65

OEHHA
California Office of Environmental Health Hazard Assessment

CALIFORNIA PROPOSITION 65 WARNING

WARNING: This product contains chemicals known to the State of California to cause cancer and birth defects or other reproductive harm. (California law requires this warning to be given to customers in the State of California.)

For more information: www.watts.com/prop65

- List of chemicals known to cause cancer, birth defects or other reproductive harm
- Prohibits discharge of listed into chemicals into sources of drinking water
- Businesses are required to provide warning if substances are used in product

Controlling Restricted Substances in PPE

Standard: STANDARD 100 by OEKO-TEX®

OEKO-TEX®
INSPIRING CONFIDENCE

Annex 4 / Anhang 4

Limit values and fastness, part 3 / Grenzwerte und Echtheiten, Teil 3

(The testing procedures are described in a separate document / Die Prüfverfahren sind in einem separaten Dokument beschrieben)

Product Class / Produktklasse	I Baby	II in direct contact with skin / mit Hautkontakt	III with no direct contact with skin / ohne Hautkontakt	IV Decoration material / Ausstattungsmaterialien
PFCs, Per- and polyfluorinated compounds / Per- und polyfluorierte Verbindungen[10,22]				
PFOS, PFOSA, PFOSF, N-Me-FOSA, N-Et-FOSA, N-Me-FOSE, N-Et-FOSE; Sum / Summe [µg/m2]	< 1.0	< 1.0	< 1.0	< 1.0
PFOA [µg/m2]	< 1.0	< 1.0	< 1.0	< 1.0
PFHpA [mg/kg]	< 0.05	< 0.1	< 0.1	< 0.5
PFNA [mg/kg]	< 0.05	< 0.1	< 0.1	< 0.5
PFDA [mg(kg]	< 0.05	< 0.1	< 0.1	< 0.5
PFUdA [mg/kg]	< 0.05	< 0.1	< 0.1	< 0.5
PFDoA [mg/kg]	< 0.05	< 0.1	< 0.1	< 0.5
PFTrDA [mg/kg]	< 0.05	< 0.1	< 0.1	< 0.5
PFTeDA [mg/kg]	< 0.05	< 0.1	< 0.1	< 0.5

Proposed Path Forward

- Address broad range of restricted substances that include certain PFAS within PPE Standards
  - Apply risk assessment similar to ISO 13688
- Model approach after OKEO-TEX® 100 standard
  - Require regular independent testing of components for specific restricted substances, as appropriate
  - Require that concentrations of restricted substances be below specific levels considered safe for “new” products
  - Require specific labeling of products showing compliance