Validation of Fire Fighting PPE Cleaning Procedures

"How Clean is Clean"

NFPA 1851 Second Draft Meeting

January 11, 2018

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Background

- Original work conceived by NFPA 1851 Cleaning Task Group
- Project funded by DHS under Firefighter Research Grants
  - Began in late 2015; 3-year project to conclude July 2018
- Led by Fire Protection Research Foundation
  - Partners: NIOSH NPPTL/HELD, International Personnel Protection, Intertek, Selected ISPs
- Policies
  - Activity is separate from NFPA codes and standards process
  - Provides basis for recommendations to standards
  - Open and transparent communications

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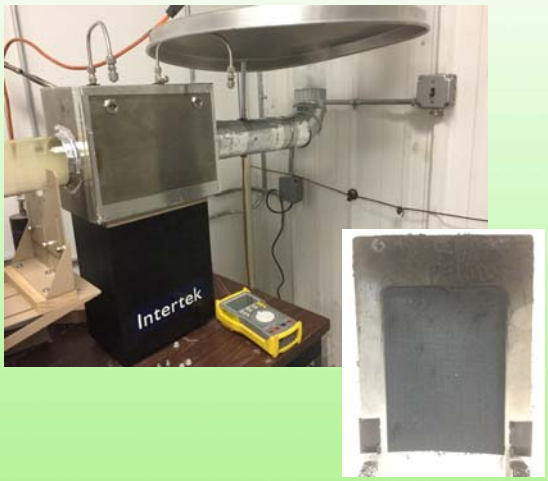
Early FPRF Work

- Pre-DHS project with Intertek
  - Investigation of possible contamination methods
  - Early work to pioneer extraction/analysis techniques
- Findings used to guide DHS project but significant changes made in direction



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Purpose of the Study

- Create a tool to validate an ISP's cleaning process
  - While it would be ideal to test every set of gear an ISP cleans to test effectiveness that is neither practical, possible, nor cost effective
  - This tool will provide a standard kit with standardized contamination and standardized materials so every ISP is measured based on the same basis to allow for a true test of their cleaning procedures
- Test multiple variables of cleaning to aid in identifying a best practice, generic cleaning procedure

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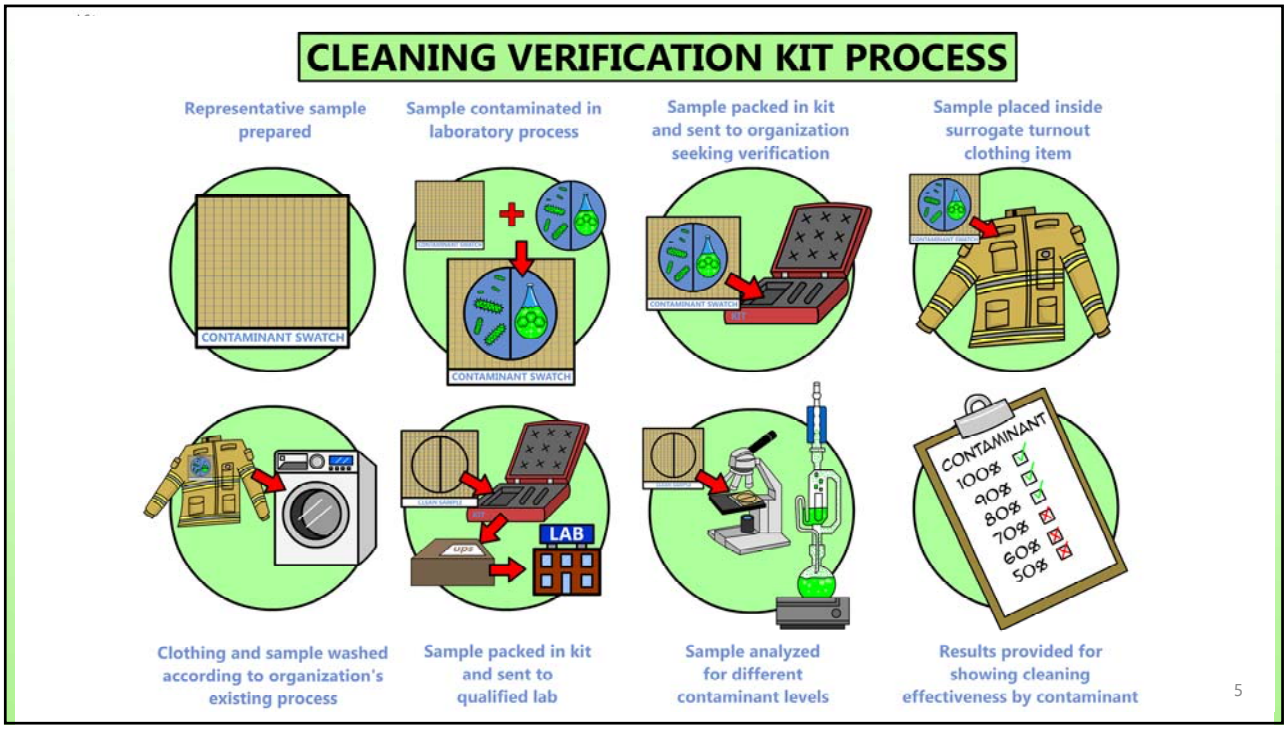

Key Kit and Process Elements

- Contaminant selection
- Contamination sample and condition
- Sample contamination process
- Wash load materials (ballast)
- Wash load assembly
- Sample containment and transfer
- Sample extraction and analysis
- Interpretation of test results

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General Contaminant Selection Factors

- Focus on persistent contamination
  - Many substances are volatile and are transient
  - Persistent contaminants leave clothing and cause exposure
- Intent to cover a wide range of harmful contaminants
  - Firefighter exposed to very wide range of different substances
- Selected contaminants must
  - Allow for reproducible methods of contamination
  - Be easily extracted from clothing materials
  - Be subject to robust, repeatable analytical methods for quantification

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Biological Contaminant Selection

- ASTM E2247 established standard for qualifying effectiveness of laundry disinfectants and sanitizers
  - Provide procedures for preparing contaminated fabric samples
  - EPA referenced protocol for antimicrobial registration
- Specified bacteria include:
  - *Klebsiella pneumoniae*
  - *Staphylococcus aureus*
  - *Pseudomonas aeruginosa*
- *Bacillus subtilis* (spore producer)

K.pneumoniae

S. aureus

Resistance to Germicidal Chemicals

Bacterial Spores: *Bacillus* species, *Clostridium* species

Mycobacteria: *Mycobacterium tuberculosis*

Nonlipid or Small Viruses: Poliovirus, Coxsackievirus, Rhinovirus

Fungi: *Trichophyton*, *Cryptococcus*, *Candida* species

Vegetative Bacteria: *Pseudomonas aeruginosa, Staphylococcus aureus*, *Salmonella choleraesuis*, Enterococci

Lipid or Medium-size Viruses: Herpes simplex virus, Hepatitis B, Hepatitis C, Human immunodeficiency virus (HIV), Hantavirus, Ebola virus

Increasing resistance

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Heavy Metal Contaminant Selection

- Metal contamination through a number of sources
  - Vaporization of salts/metal
  - Organometal complexes
- Some metal more prevalent at fire scene than others
- Not all heavy metals are skin exposure threats
- Some metals have detection issues (Hg, Fe, Zn)

Metal	TRI 1995	UL 2010*	UKy 2014*	IPP 2015*	EKU 2015†
Aluminum (Al)		140		324	
Antimony (Sb)		5.2	52.2	9.5	
Arsenic (As)		0.45	20.7	2.1	
Barium (Ba)	885	20.5	297	35.5	
Cadmium (Cd)	106		4.12	10.5	1.5
Chromium (Cr)	119	11	76.9	11.6	61.8
Copper (Cu)		21	89.2	34.4	31.5
Iron (Fe)			1620	373	
Lead (Pb)	1085	80	922	32.5	150
Manganese (Mn)		7.8	41.9	7.43	
Nickel (Ni)	19	3.9	31	5.99	
Silver (Ag)			1.29	0.83	
Zinc (Zn)	1309	120	1110	253	

** Firefighter hoods; † Evaluated by wipe samples*

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Organic Compound Contaminant Selection

Analyte	Stock [ug/ml]	Analyte	Stock [ug/ml]	Analyte	Stock [ug/ml]
Sigma 48741 Phthalate Esters		**Sigma 458905 PAH Mix**		**Sigma 86-1253 Phenolics**	
Dimethyl phthalate	200	Naphthalene	2000	Dinoseb	2000
Diethyl phthalate	200	Acenaphthylene	2000	Pentachlorophenol	2000
Di-n-butyl phthalate	200	Acenphthene	2000	Phenol	2000
Bis(2-Ethylhexyl) phthalate	200	Fluorene	2000	2-Chlorophenol	2000
Di-n-octyl phthalate	200	Phenanthrene	2000	2-Methyl-4,6-dinitrophenol	2000
		Anthracene	2000	2-Methylphenol	2000
		Fluoranthene	2000	2 Nitrophenol	2000
		Pyrene	2000	2,3,4,6-Tetrachlorophenol	2000
		Benzo(a)anthracene	2000	2,4-Dichlorophenol	2000
		Chrysene	2000	2,4 Dimethylphenol	2000
		Benzo(b)fluoranthene	2000	2,4-Dinitrophenol	2000
		Benzo(k)fluoranthene	2000	2,4,5-Trichlorophenol	2000
		Benzo(a)pyrene	2000	2,4,6-Trichlorophenol	2000
		Dibenz(a,h)anthracene	2000	2,6 Dichlorophenol	2000
		Benzo(g,h,i)perylene	2000	3-Methylphenol*	1000
				4-Chloro-3-methylphenol	2000
				4 Methylphenol*	1000
				4-Nitrophenol	2000
				*coelute	

Key Categories:

- **Phthalates (plasticizers)**
- **Polynuclear aromatic hydrocarbons (PAHs)**
- **Phenolic (substituted phenols)**
- Polybrominated diethyl ethers (PBDEs)
- Polychlorinated biphenyls (PCBs)
- Perfluoroalkyl substances (PFASs)

- Multiple known categories of semi-volatile organic compounds (SVOCs)
- Compound selection based mainly on stability and analytical discrimination

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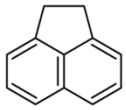
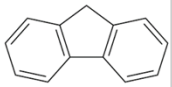
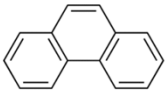
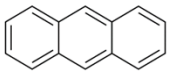
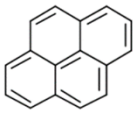
Name	Acenaphthene	Fluorene	Phenanthene	Anthracene	Pyrene
CAS No.	83-32-9	86-73-7	85-01-8	120-12-7	129-00-0
Category	Polynuclear aromatic hydrocarbon	Polynuclear aromatic hydrocarbon	Polynuclear aromatic hydrocarbon	Polynuclear aromatic hydrocarbon	Polynuclear aromatic hydrocarbon
Molecular formula	$C_{12}H_{10}$	$C_{13}H_{10}$	$C_{14}H_{10}$	$C_{14}H_{10}$	$C_{16}H_{10}$
Molecular weight	154.21	166.22	178.23	178.23	202.25
Structure					
Appearance	White or pale yellow crystalline powder	White crystalline powder	Colorless solid	Colorless crystalline solid	Colorless solid
Density (g/cm3)	1.024	1.202	1.18	1.28	1.271
Melting point (C)	93.4	116	101	215.76	145
Boiling point (C)	279	295	340	339.9	404
Vapor pressure (mm Hg at 20 C)	0.011	0.014	0.0005	0.0019	<0.0001
Water solubility (mg/L)	4	1.992	1.6	0.044	0.135
NIOSH retention time	19.27	21.06	24.35	24.53	29.22
Carcinogen status	Non-classified	Non-classified	Non-classified	Non-classified	Non-classified
Other hazards	Unknown	Toxic	Toxic	Toxic	Toxic

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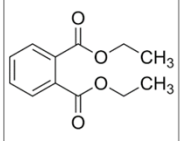
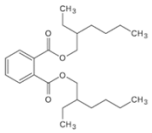
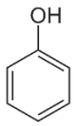
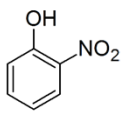
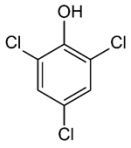
Name	Diethyl phthlate	Di-n-octyl phthalate	Phenol	2-Nitrophenol	2,4,6-Trichlorophenol
CAS No.	84-66-2	117-84-0	108-95-2	88-75-5	88-06-2
Category	Phthlate	Phthlate	Phenol	Substituted phenol	Substituted phenol
Molecular formula	$C_{12}H_{14}O_4$	$C_{24}H_{38}O_4$	C_6H_6O	$C_6H_5NO_3$	$C_6H_3Cl_3O$
Molecular weight	222.24	390.56	94.11	139.18	197.45
Structure					
Appearance	Colorless oily liquid	Colorless oily liquid	Colorless crystalline solid	Clear pale yellow liquid	Yellow whitish powder
Density (g/cm3)	1.12	0.99	1.07	1.495	1.68
Melting point (C)	-4	-50	40.5	44	69
Boiling point (C)	302	385	181.7	215	246
Vapor pressure (mm Hg at 20 C)	0.002	1.42 (E-07)	0.4	0.7	0.008
Water solubility (mg/L)	1080	0.27	8300	2000	500
NIOSH retention time	20.79	26.5	8.5	12.2	16.7
Carcinogen status	Non-classified	Known carcinogen	Non-classified	Non-classified	Probable carcinogen
Other hazards	Teratogenic,Toxic	Toxic	Corrosive, Toxic	Toxic	Toxic

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Contamination Sample and Condition

- Focus on outer shell material – primary contaminated material
- Original work focused on Gemini; limited study of scoured Pioneer; other materials considered but not evaluated
  - Finishes on material interfere with contamination process
  - Initial findings showed finished material harder to contaminate but also harder to decontaminate
- Study undertaken to examine outer shell liquid wicking/ absorption characteristics
- Decision on applying multiple launderings (25X) on fabric samples for conditioning samples

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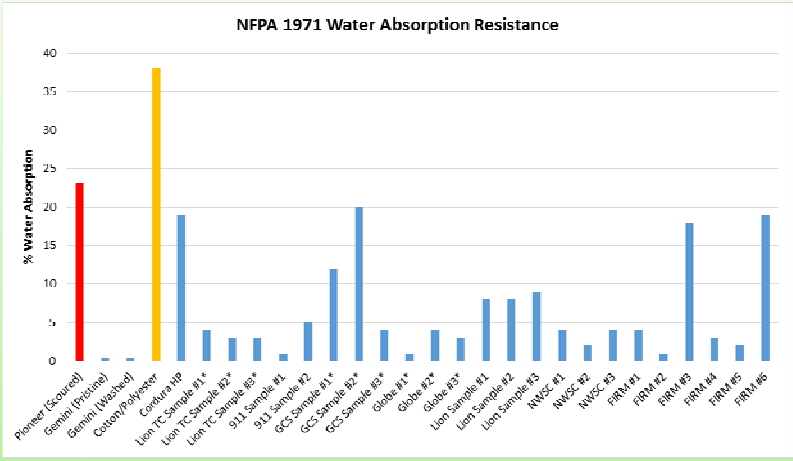
Sample Fabric Water Absorption

- Baseline fabrics evaluated
- Samples from 7 different groups
  - 24 samples
  - Range of conditions
  - Represented
- Wide range of performance



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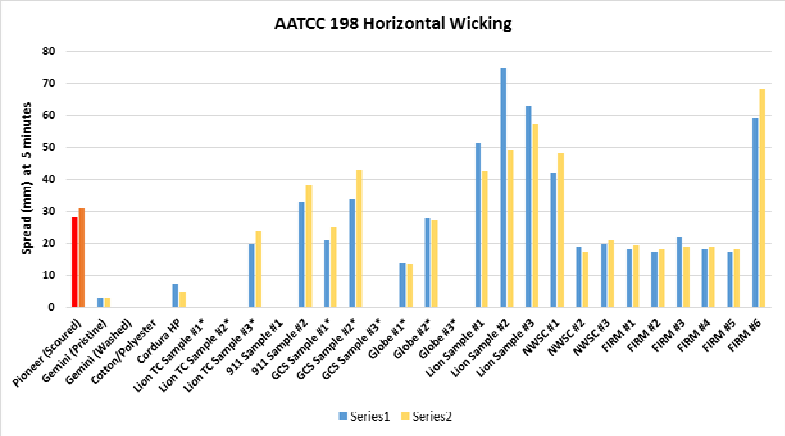
Sample Fabric Horizontal Wicking

Many used or washed clothing have performance between Gemini and scoured Pioneer



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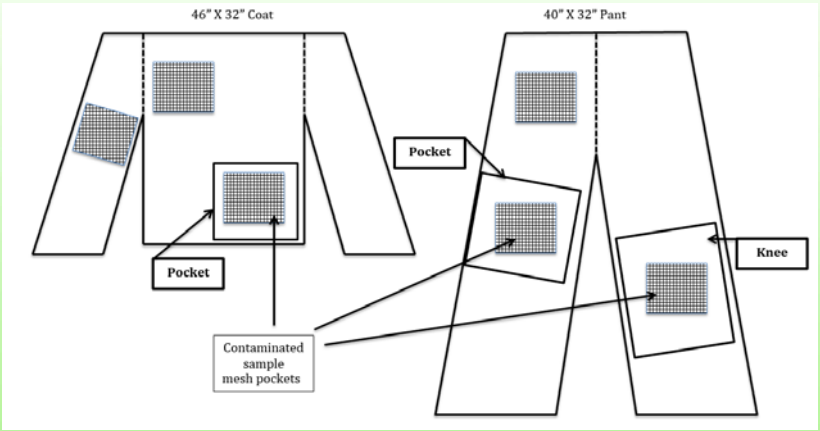
Surrogate Clothing Panels



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Wash Load Materials (Ballast)

- Key considerations:
  - Uniformity; known history
  - Ability to represent shell material
  - Cost
  - Liquid absorption characteristics
  - Durability

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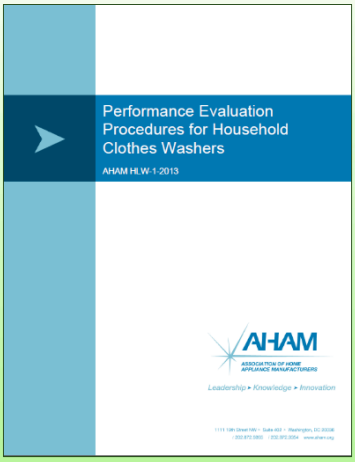
Wash Load Approach

- Objective to achieve simulated load and contact characteristics
- Based on standardized procedures applied in domestic laundering
  - Modified fire service laundry approach
- Adaptable based on machine type and ISP wash procedures
- Demonstrated at three different ISPs and NIOSH



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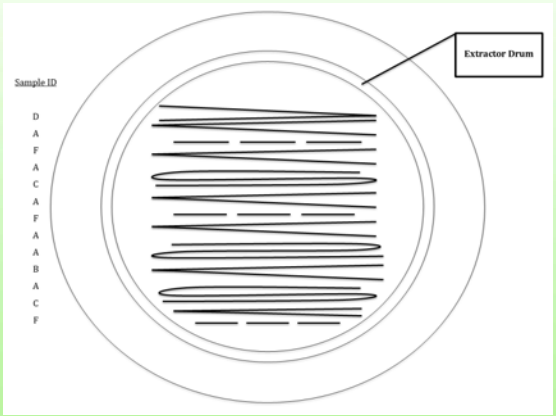
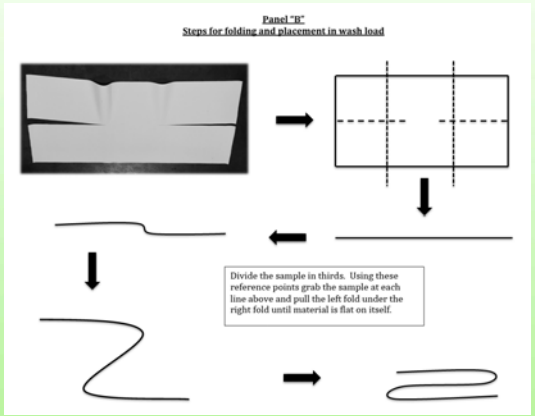
Wash Load Assembly





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Sample Containment and Transfer

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

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Sample Preparation and Analysis - Bacteria

Current Procedures

- 1" x 1" specimen
- Prewet specimen
- Inoculate specimen with bacteria (10^6)
- Follow modified ASTM E2274
- Extract specimen with DNA-free water
- Analyze by PCR/plating

Other Work Performed

- Approach demonstrated on *Staphylococcus aureus* and *Klebsiella pneumoniae*
- Procedures being extended to *Bacillus subtilis*
- 7-day shelf life demonstrated (with samples on ice)

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Sample Preparation/Analysis – Heavy Metals

Current Procedures

- 1" x 2" specimen
- Soak specimen in 1 mL metals solution (µg each) for 2 hours
- Let specimen dry
- Add acid to specimen, microwave, and filter solution
- Analyze solution by ICP-MS

Prior Investigations

- Use of contaminated soil with grinding application
- Spray method
- Pipetting of liquid on specimen
- Use of dry versus wet specimen

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Sample Preparation/Analysis - SVOCs

Current Procedures

- 3" x 6" specimen
- Pipette 500 µL of 30 ppm solution onto specimen
- Dry specimen in oven
- Extract specimen with solvent mixture
- Filter extract
- Analyze extract by GC-MS

Specific Investigations

- Evaluated nebulizer for applying chemical solutions
- Switched to micropipetting technique
- Demonstrated sample stability
- Undertook work to resolve contamination consistency; ensure adequate controls

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Interpretation of Results

- Determine results for each specimen
  - Unwashed samples
  - Washed samples
  - Controls
- Types of results
  - Biological: # bacteria
  - Chemical: mass of contaminant
- Calculations:
  - Biological: Log reduction
  - Chemical: Cleaning efficiency

$$Cleaning\ Efficiency = 1 - \left[\frac{(C_C - C_M) - (C_W - C_P)}{(C_C - C_M)}\right] \times 100$$

C_C = Contaminated specimen

C_M = Material specimen (unwashed, not contaminated)

C_W = Contaminated specimen Washed

C_P = Material specimen (washed, not contaminated)

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Development of Acceptance Criteria

Metal and Chemical Contaminant	Product Class			
	I	II	III	IV
Sb (Antimony)*	30.0	30.0	30.0	
As (Arsenic)*	0.2	1.0	1.0	1.0
Pb (Lead)*	0.2	1.0	1.0	1.0
Cd (Cadmium)*	0.1	0.1	0.1	0.1
Cr (Chromium)*	1.0	2.0	2.0	2.0
Sum of all pesticides (2,4-D, Chlorpyrifos, and Parathion*)	0.5	1.0	1.0	1.0
DEHP*, BBP*, and sum of regulated phthalates	0.1	0.1	0.1	0.1
Benzo[a]pyrene	0.5	1.0	1.0	1.0
Benzo[e]pyrene	0.5	1.0	1.0	1.0
Benzo[a]anthracene	0.5	1.0	1.0	1.0
Chrysene*	0.5	1.0	1.0	1.0
Benzo[b]fluoranthene	0.5	1.0	1.0	1.0
Benzo[j]fluoranthene	0.5	1.0	1.0	1.0
Benzo[k]fluoranthene	0.5	1.0	1.0	1.0
Dibenzo[a,h]anthracene	0.5	1.0	1.0	1.0
Sum of PAHs	5.0	10.0	10.0	10.0

* Specific target contaminant

OKEO-TEX Standard 100 for Textile Quality

- Placeholder criteria:
  - Biological: Log 3
  - Chemical: 70%
- Approaches for setting criteria:
  - Biological: Based on EPA registration
  - Chemical
    - % by contaminant
    - % by group
    - Other index

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Validation and Supporting Efforts

- **Part I** – Ensure reliability/reproducibility of kit procedures and ease of use
  - Initial work with one ISP
  - Further verification with at 2 other ISPs
- **Part II** – Establish comparisons with actual contaminated turnout gear
  - Conduct analysis of decontamination efficiency for field-soiled gear
- **Part III** – Establishment of industry laboratory capabilities

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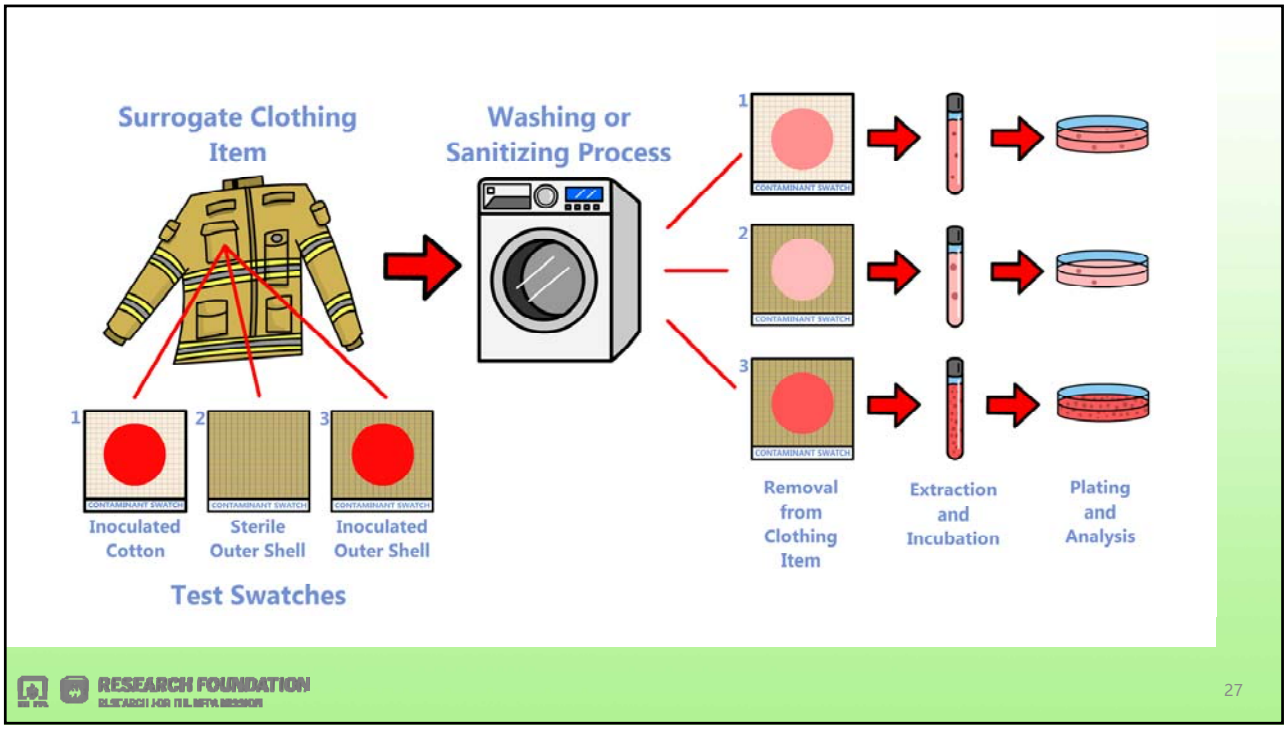
Surrogate Clothing Item
Washing or Sanitizing Process
1
2
3
Inoculated Cotton
Sterile Outer Shell
Inoculated Outer Shell
Test Swatches
Removal from Clothing Item
Extraction and Incubation
Plating and Analysis
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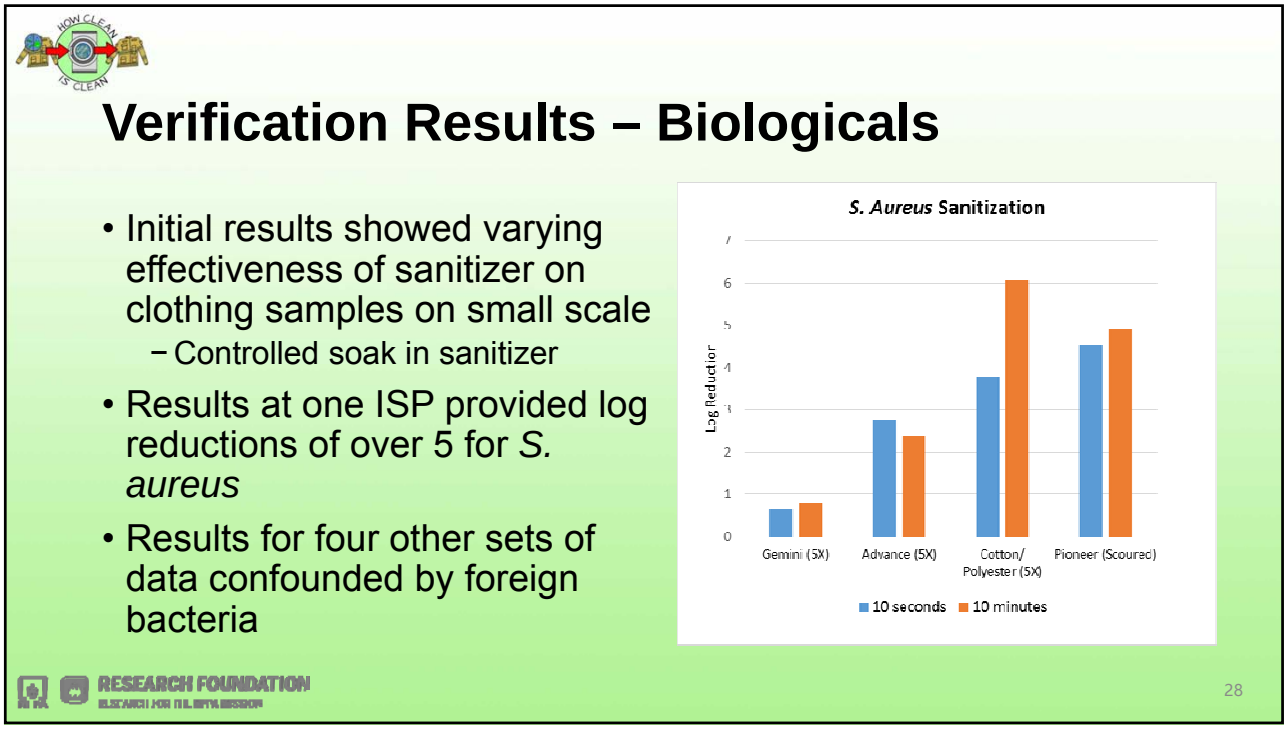
Verification Results – Biologicals
• Initial results showed varying effectiveness of sanitizer on clothing samples on small scale
– Controlled soak in sanitizer
• Results at one ISP provided log reductions of over 5 for *S. aureus*
• Results for four other sets of data confounded by foreign bacteria
S. Aureus Sanitization
Log Reduction
0
1
2
6
Gemini (5X)
Advance (5X)
Cotton/ Polyester (5X)
Pioneer (Scoured)
10 seconds
10 minutes
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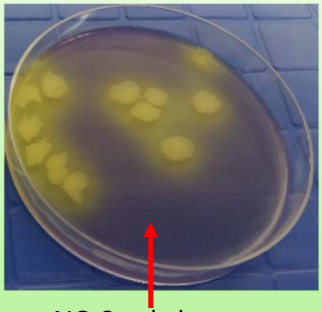
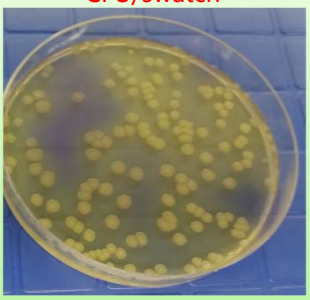
Successful vs Problematic Results

Cross contamination on TEST swatches LOW



NO Staphylococcus
100% Reduction

Cross contamination on STERILE swatches 10^4 CFU/swatch



Foreign bacteria on sterile swatches at each ISP

ISP	Colony Counts
1	27,500
2	6,700
3	162,917

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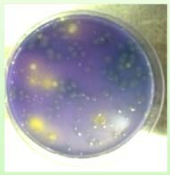
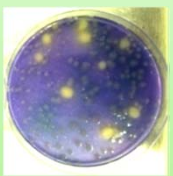
Differences in Sample Bacterial Levels

TEST SWATCH



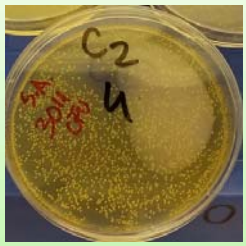


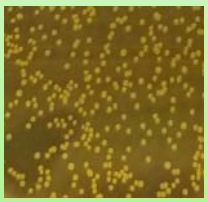
Interference in Counting EXTENSIVE

Different bacteria, but no Staphylococcus.

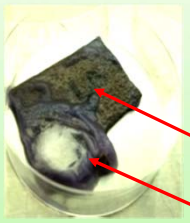
Vs.

CONTROL SWATCH





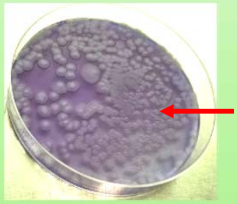
STERILE SWATCH



Cross contamination on sterile swatches

Swatch

Fungus



Bacteria / Fungus

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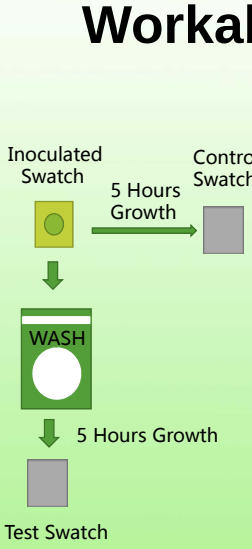
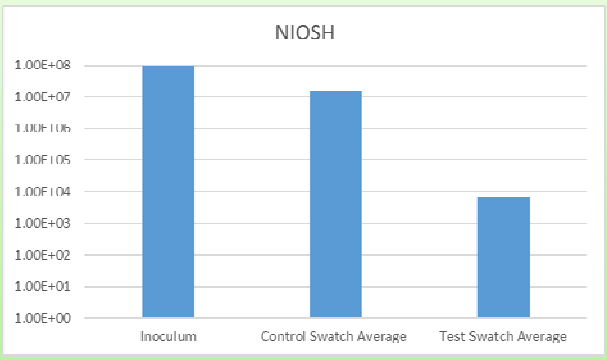
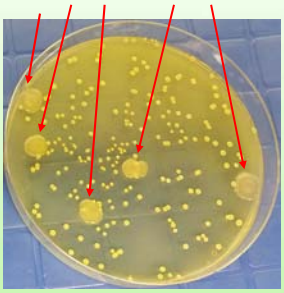
Workability of Test



Inoculum	Control Swatch	Test Swatch	% Reduction
9.6×10^{7}	1.6×10^{6}	6.8×10^{3}	99.58



Interference in Counting



Example of *P. aeruginosa* cross contamination of swatch during washing machine test

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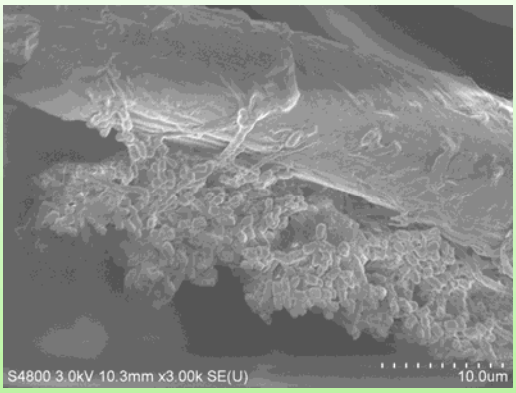
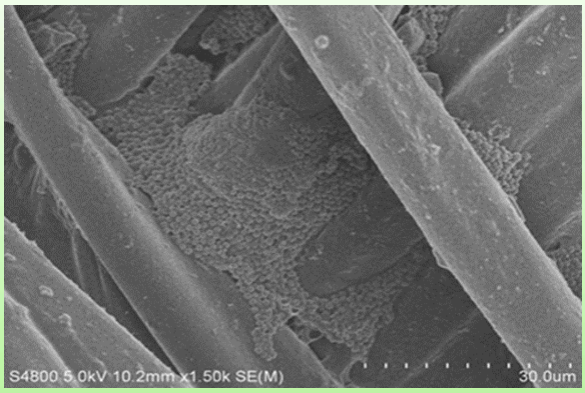
Example of Adjunct Study Findings





Klebsiella. P. and *Staphylococcus. A.* attachment on fabric's fibers (for biofilm formation)

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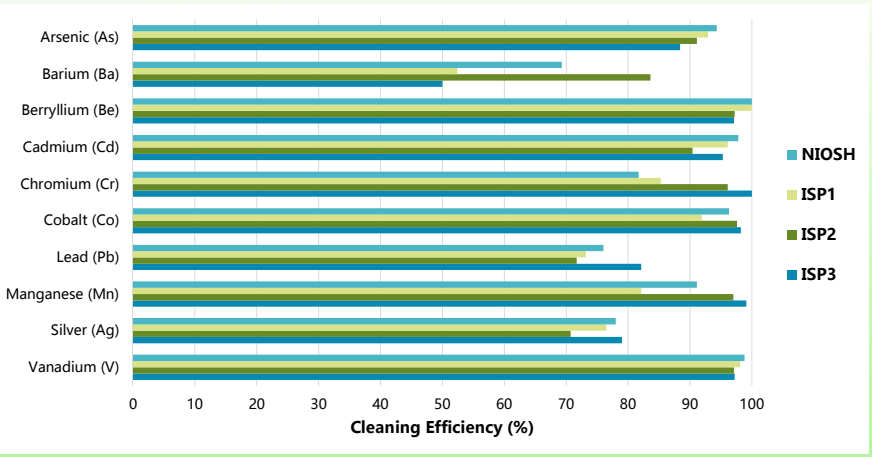
Verification Results – Metals



- Most efficiencies comparable between facilities
- Recommend downselect of 6 metals, to include Sb (Antimony)

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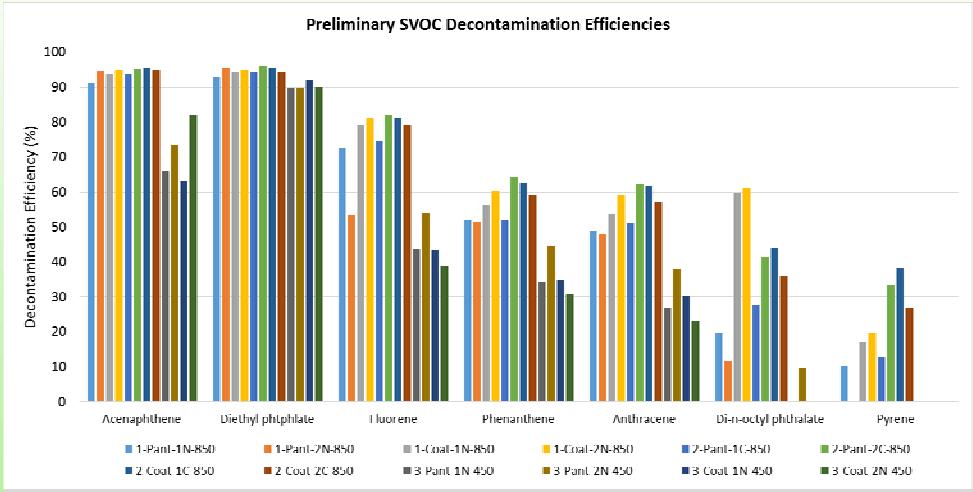
SVOC Verification Results – Early Work



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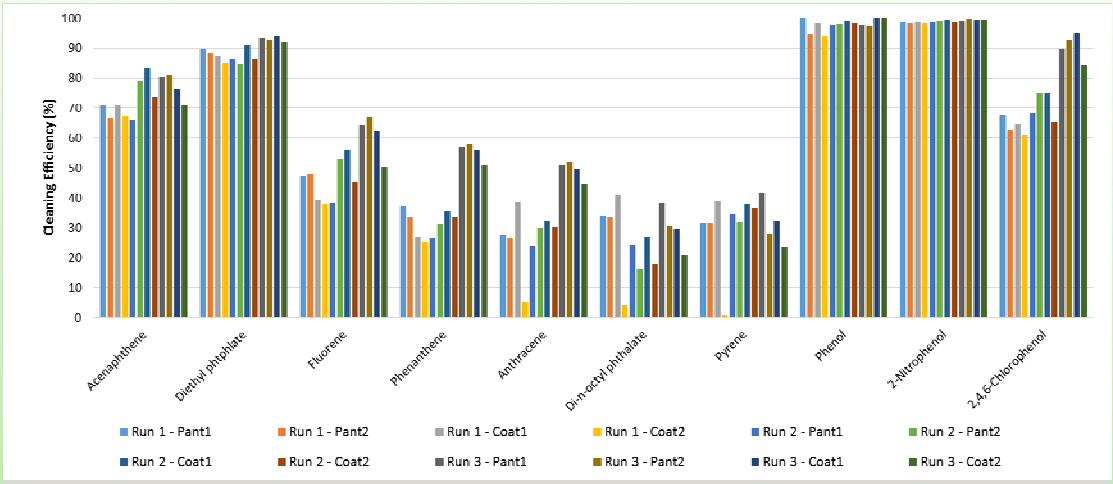
SVOC Verification Results – Repeatability



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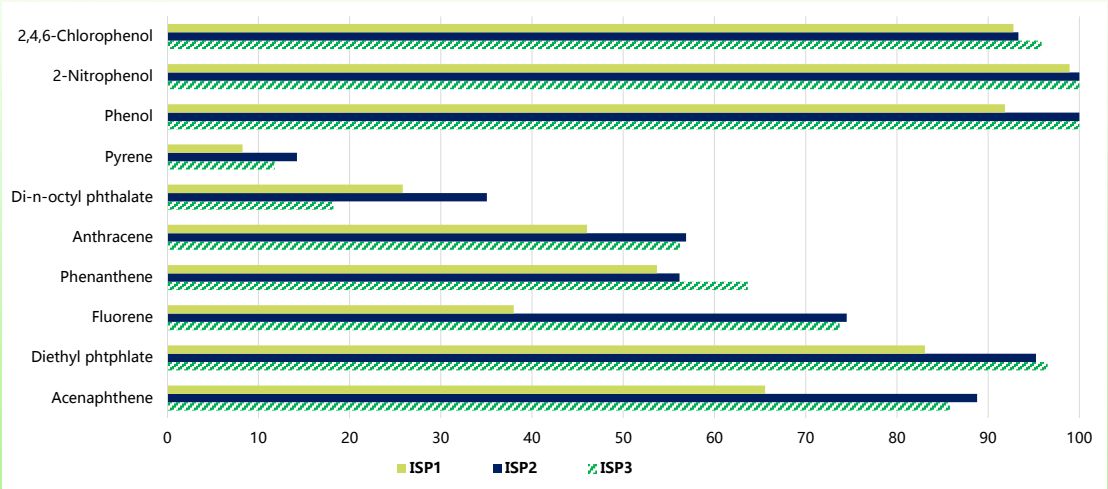
SVOC Validation Results – Different ISPs



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Proposed Test Method / Criteria Status

- Methods have evolved; converted to NFPA format
  - Small refinements still needed
- Proposed criteria
  - Biological: Log 3 reduction, two bacteria (*S. Aureus, K. pneumoniae*)
  - Metals: 70% reduction (each metal)
  - SVOCs: 50% reduction (average over group of chemicals)
- Proposed phased-in implementation (minimum of 2 years)
- Further testing validation efforts in progress
- Project will be continuing through July 2017

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Structure/Consequences of Requirement

- Verification organizations will need to set up capability or contract laboratory
- ISPs will be required to go through annual verification of cleaning capabilities
  - Add on service for verification
  - Kit use to be supervised during audit process

Possible Test Costs

Service	Est. Cost
Ballast material/preparation	$500
Contaminated specimen prep.	$250
Biological analysis	$600
Metals analysis	$400
SVOCs analysis	$1600
Shipping	$200
Auditor time	$200
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Total Cost	$3,750

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VISPA Criticisms

1. Test uses an insufficient number of test materials
2. Test does not use real gear
3. Contaminated swatches should be soiled
4. Detergent levels should match contamination levels
5. Biological samples are dangerous
6. Biological samples are subject to cross contamination
7. All ISPs should be permitted to participate in round robin

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Support for Incorporation of Test

- Overwhelming question by industry on the effectiveness of cleaning
- Currently there is no "yard stick" to assess cleaning effectiveness
- Other research is showing limitations of cleaning; without measurement technique, there can be no improvements
- Without standardization, nothing will happen
- Effort designed to comply with Correlating Committee requirements for criteria and test method validation

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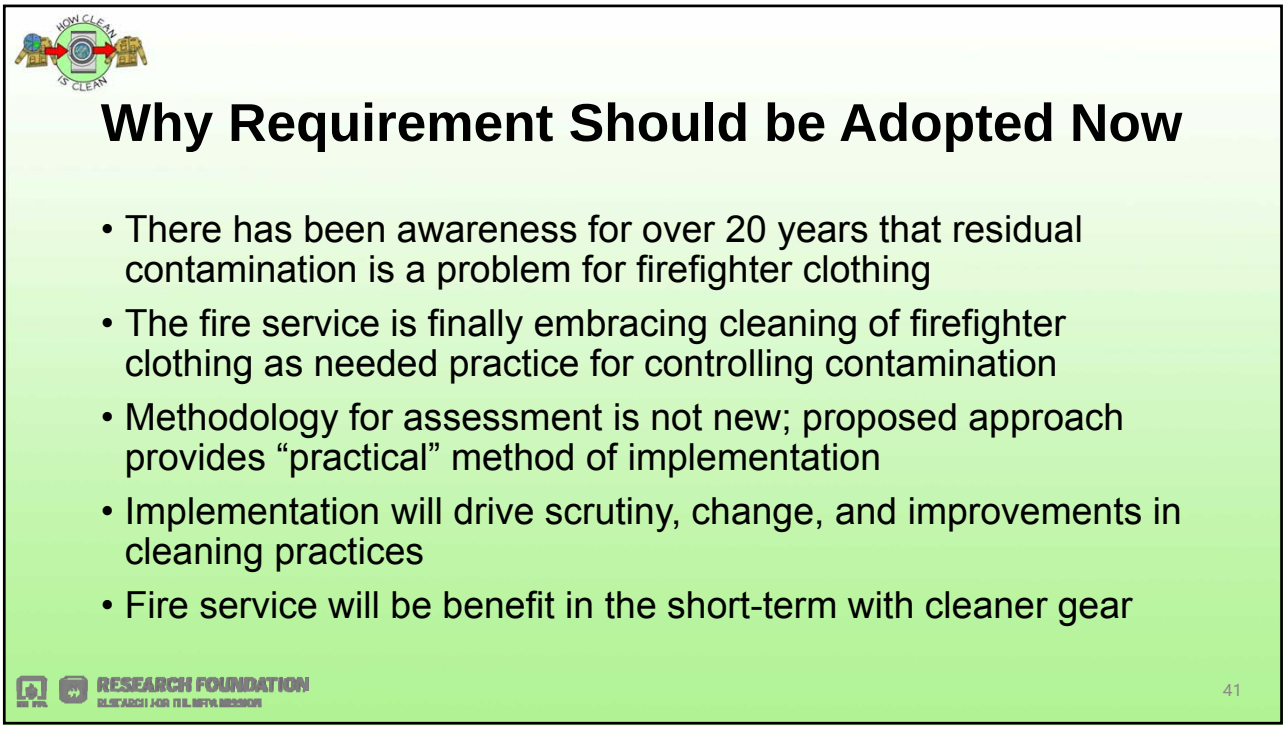
Why Requirement Should be Adopted Now
• There has been awareness for over 20 years that residual contamination is a problem for firefighter clothing
• The fire service is finally embracing cleaning of firefighter clothing as needed practice for controlling contamination
• Methodology for assessment is not new; proposed approach provides "practical" method of implementation
• Implementation will drive scrutiny, change, and improvements in cleaning practices
• Fire service will be benefit in the short-term with cleaner gear
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