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New Gear/Old Gear: What Lies Ahead

CLARION|UX

Photo by Tim Olk.

The Coming Transformation of PPE Clothing Products and Care

What You Need to Know About Possible Upcoming Changes That Affect How You Select and Clean Turnout Gear

BY JEFFREY O. STULL

THIS SUPPLEMENT MARKS THE FIFTH year of *Fire Engineering* supplements that have been dedicated to firefighter personal protective equipment (PPE) and related safety equipment. In the past four years, a great number of recommended approaches to PPE selection, protection, and care have been presented. Most of these focus on ways that firefighters and fire departments can limit their exposure to fireground contamination. These suggestions have generally been presented using highlighted individual approaches that have been intended to convey the most important steps or understanding on specific topics. They are summarized in a comprehensive checklist in "A Summary of 2018-2021 PPE Supplement Recommendations."

In this 2022 PPE supplement, we focus on upcoming changes that are expected to affect fire service protective clothing/equipment and the care and maintenance requirements for these elements. National Fire Protection Association (NFPA) 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting,* which sets the design and performance criteria for turnout clothing, is being revised, and several new requirements are being considered that are likely to have profound impacts on both the materials and the ensemble configuration if accepted by the technical committee.

Changes under consideration include new metrics for durability, contamination resistance, ease of cleaning, and hazards posed by the clothing itself. All these proposals have been developed in response to emerging issues identified by the fire service. Concurrently, new advances are being made through multiple research initiatives with respect to understanding clothing decontamination effectiveness that will begin to expand clothing cleaning choices and practices. This supplement will address the following:

- New learning for contamination exposure of firefighters at the modern fire scene, particularly as it relates to the wide range of contaminants being encountered, how this contamination occurs on individual clothing and equipment elements, and the persistency of several contaminants.
- The relationship between clothing contamination resistance and the ability for that contamination to be removed. This relationship accounts for changing expectations for how clothing materials are finished and is likely to create some trade-offs in the ways that clothing becomes contaminated and can be cleaned.
- Increasing concerns about restricted substances that may be used in protective clothing and a description of possible strategies for how the fire service and industry can address these emerging issues.
- New methods that can be applied to address current gaps or areas for PPE needing improvement. Attention is given to new techniques that measure heat insulation/breathability, clothing function, and overall clothing integrity with the aim of evolving to full ensemble testing.
- New findings related to PPE, particularly the impact that cleaning verification has had on independent service providers and the fire service, and the ongoing need to qualify cleaning technologies and agents that potentially offer improvement in turnout gear cleaning and decontamination practices.

Changing PPE Requirements

Every five years or so, the NFPA undertakes a revision of its standards to keep them up to date, reflect the prevailing fire service needs, and consider any emerging technology in terms of having materials and products evolve as well as the manner of how the industry demonstrates their performance qualities. This is the case this year (beginning in late 2021 and early 2022), as responsible committees begin considering changes to NFPA 1971 on turnout gear as well as NFPA 1975, *Standard on Emergency Services Work Apparel*; NFPA 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services*; and NFPA 1982, *Standard on Personal Alert Safety Systems (PASS)*. All four standards have formally entered the next cycle for revision, with the expected finalized versions to become available in the summer of 2023. What is different this time is that there are transformative issues confronting the fire service and the fact that all four standards identified above will be consolidated into a single volume. One year later, a similar move will be made to consolidate the selection, care, and maintenance standards of NFPA 1851 (turnout clothing) and NFPA 1852, *Standard on Selection, Care, and Maintenance of Open-Circuit Self-Contained Breathing Apparatus (SCBA)*, with likely equal major impacts. We hope that efforts result in positive changes to better address PPE product and care options where the following subsections are intended to provide the ramifications of the upcoming consolidation and potential changes in the standard.

(1) Accept Standards Consolidation as Potentially Offering Benefits to the Fire Service. Even though the NFPA made the decision to consolidate contrary to the recommendations

A Summary of 2018-2021 PPE Supplement Recommendations

**BY DR. CHRISTINA BAXTER, EMERGENCY RESPONSE TIPS;
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The checklist below combines information from the past four *Fire Engineering* PPE supplements into a single list of considerations for minimizing your overall exposure risk.

1. Recognize fires as hazardous materials incidents; products of combustion are hazardous materials.
    - □ Minimize exposure on scene.
    - □ Establish control zones at the emergency scene.
    - □ Wear self-contained breathing apparatus (SCBA) during all firefighting activities, including overhaul.
    - □ Wear turnout gear in the warm and hot zones.
    - □ Consider other PPE as an alternative to turnout gear in the cold zone.
    - □ Minimize potential for secondary contamination.
2. Select, don, deploy, and doff the appropriate PPE.
    - □ Wear properly fitted PPE.
    - □ Choose PPE that is well integrated.
    - □ Properly wear and deploy all features of the PPE until the hazardous exposures are reduced.
    - □ Practice and implement doffing of contaminated PPE.
3. Begin contamination control on the fireground.
    - □ Remain on air until it is safe to remove turnout gear.
    - □ Properly locate the site for preliminary exposure reduction (PER).
    - □ Effectively apply PER.
    - □ Have a plan for spare clothing and firefighting cleanup following PER.
    - □ Address personal hygiene risks.

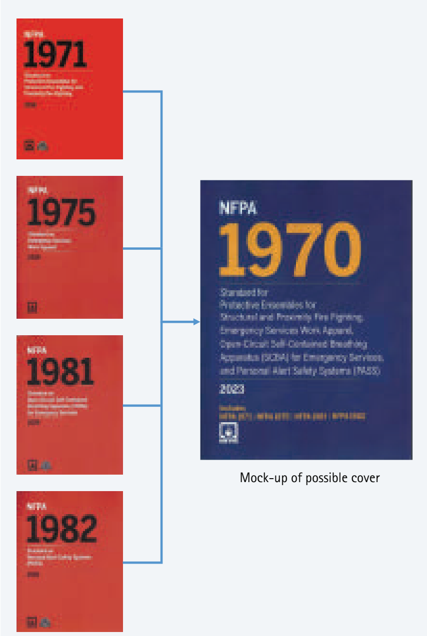
Figure 1. Previous PPE Supplements

2018 2020 2019 2021

4. Minimize the potential for secondary contamination by isolating and containing soiled or contaminated PPE.
    - □ Brush/rinse, isolate, and bag PPE following contaminated doffing.
    - □ Properly transport contaminated PPE.
5. Establish and implement a cleaning approach for all PPE.
    - □ Determine cleaning locations, department responsibilities, and independent service provider responsibilities.
        - —Use qualified organizations for PPE care and maintenance.
        - —Verify outside advanced cleaning and sanitization. Request verification of the cleaning process in accordance with NFPA 1851, *Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting.*
    - □ Carefully review new cleaning products and service claims. Be wary of claims of universal effectiveness.
    - □ Apply appropriate cleaning methods for all fireground soiled or contaminated PPE.
        - —Properly prepare the clothing for washing.
        - —Use a sanitizer or disinfectant if needed.
        - —Use the correct washing machine.
        - —Identify the appropriate detergent.
        - —Apply a comprehensive wash cycle.
        - —Dry clothing in a drying room or drying cabinet.
        - —Inspect clothing after cleaning.
    - □ Institute hand-washing procedures for other PPE (helmets, helmet liners, boots, etc.).
    - □ Use sanitization for bloodborne pathogens and other microbial exposures.
    - □ If PPE can be decontaminated, use specialized cleaning for hazardous materials exposure.
    - □ Practice good hygiene. Do not put PPE back in service until it is clean and dry.
        - —Do not allow PPE to remain wet for extended periods of time.
    - □ Do not reuse PPE that cannot be properly cleaned.
    - □ Subject PPE to advanced cleaning at least every six months.
    - □ Fully inspect garments, including liners, at least annually.
6. Shower as soon as feasible following firefighting activities.
7. Establish best practices for wearing PPE outside of firefighting activities.
    - □ PPE should not be worn in the living quarters of stations.
    - □ Turnout gear should only be used for firefighting activities. Consider other PPE as an alternative to turnout clothing.
        - —Recognize that turnout gear is a potential secondary source of contamination even *after* laundering, as current laundering techniques are not 100% effective.

of many committees involved in developing standards, it was recognized that the large number of individual fire service standards was becoming increasingly difficult to manage and maintain. Based on this decision, the NFPA is pursuing the amalgamation of many of its standards in similar topical areas, with the plan to reduce the approximately 130 fire service standards down to approximately one-third that number. In the realm of PPE, this has included some sensible combinations such as putting all the hazmat PPE documents in one place within the new NFPA 1990, *Standard for Protective Ensembles for Hazardous Materials and CBRN Operations,* which combined the former NFPA 1991, NFPA 1992, and NFPA 1994 standards into a fully consolidated standard. In that case, a single responsible committee endeavored to truly streamline and update the requirements for the full range of hazmat and CBRN. The result was harmonized requirements and test methods that established a document that was 143 pages instead of the combined 236 pages of the preceding editions that NFPA 1990 replaced. This served as an early example for what consolidation could possibly achieve.

Figure 2. NFPA PPE Standards Being Merged into Single Comprehensive Standard



Mock-up of possible cover

For turnout clothing, the immediate benefits of consolidation will need to unfold, as this process is just starting. The current approach is that the new replacement standard—NFPA 1970, *Standard on Protective Ensembles for Structural and Proximity Firefighting, Work Apparel, Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services, and Personal Alert Safety Systems (PASS)*, a newly numbered standard to prevent confusion with prior standards, will have a shared introductory chapter, reference list, and set of definitions but otherwise have the separate chapters for each of the existing standards, including certification, labeling, design, performance, and test methods separately sequenced in the new standard. This is intended to preserve the separate identity associated with labeling products to the existing standards (for example, products will still be identified as being certified to NFPA 1971, NFPA 1975, NFPA 1981, and NFPA 1982) and to also ease in the transition to a more comprehensive standard. This is complicated by the fact that the new document will be the result of four separate technical committees trying to assemble a significant amount of content into a comprehensive specification on a complex group of products. While this approach may not fully achieve the same benefits of consolidation as NFPA 1990 attained for hazmat gear, it will address the entire ensemble—everything a firefighter wears for structural firefighting—in one document. This becomes the first step toward full harmonization of requirements.

(2) Use Consolidation as a Means for Making Improvements to PPE. It is entirely possible that the different NFPA technical committees involved may attempt some harmonization in bringing the individual turnout clothing system standards together. Some possibilities include ensuring that the certification process used to qualify product and allow labeling to show their compliance be made fully uniform between products. This aids the manufacturing industry, particularly for companies that make products addressed by multiple standards. These realignments also remove meaningless differences, which can potentially pass some cost savings to end users.

Consolidation also creates some interesting opportunities that otherwise would not be possible without combining standards. Consider that station/work uniforms could be permitted, under very special circumstances, to be part of the overall insulation provided by the turnout clothing system for purposes of protection. Having NFPA 1971 (turnout gear) and NFPA 1975 (station/work uniforms) in the same "umbrella" standard makes that possible.

Another possibility is to finally address the system as a whole with all the equipment in one place. There is now the basis for full ensemble testing for garments, helmets, hoods, gloves, footwear, SCBA, and PASS collectively to be evaluated for different forms of protection, interface effectiveness, and interoperability. The potential exists to address a variety of equipment integrations such as helmets that integrate SCBA components and garments that incorporate various types of electronics such as electronic tracking systems. A new NFPA 1970 platform can permit this approach. Moreover, it also could lead to better consideration of integrated products, particularly for emerging electronic sensors and related equipment, to become part of the overall ensemble for future fire service use.

(3) Address Prevailing PPE Issues Facing the Fire Service through Consolidation. In this revision cycle, it is also expected that many new issues facing the fire service and PPE industry will be up for debate, with the potential for various changes to change the look and availability of turnout clothing-based products. For example, the resistance of PPE to contamination and how easily it can be cleaned or decontaminated are now important topics. These are combined with the need to address improvements that better demonstrate PPE durability as well as finally addressing restrictive substances such as perfluoroalkyl substances (PFAS) in meaningful ways. All the new issues will be debated in the upcoming 18-month period that will result in what decisions will be made in establishing the minimum requirements for turnout gear. The NFPA 1971/1851 committee chairman and secretary share their thoughts on the overall process and its ramifications that are now just beginning in the sidebar "Overall Advances in Firefighter PPE Through Standards."

Overall Advances in Firefighter PPE Through Standards

BY TIM TOMLINSON, ADDISON (TX) FIRE DEPARTMENT; AND MARNI SCHMID, FORTUNES COLLIDE LLC

As the chairman and secretary of the technical committee for NFPA 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting,* and NFPA 1851, *Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*, we have witnessed how the NFPA revision cycle has resulted in positive changes for the fire service with a focus on firefighter health and safety.

The most recent revision to NFPA 1851 is the result of applying science to cleaning requirements in a way that allows organizations to become verified and to have faith that verified providers have been audited based on their ability to meet cleaning expectations.

Empowering organizations to manage part or all of the cleaning and repair functions for their PPE with tested procedures is key to promoting contamination reduction and improving firefighter health and safety. The 2020 edition of NFPA 1851 clearly identifies which providers can perform which functions and the requirements for each. These requirements touch all aspects of the cleaning process including PPE-related training, record keeping, completing advanced inspections, cleaning and decontamination (with default advanced cleaning procedures that have been verified), and verification.

The technical committee also included decision trees in this edition of the standard to help organizations make PPE decisions in a timely way. This was all done through the NFPA revision process with voices from all areas of the industry represented on the committee (about one-third from the fire service) and public participation (primarily from the fire service).

As of press time, NFPA 1971 is in the first part of the revision cycle and, during this cycle, will be consolidated with three other standards (1975, 1981, and 1982) into a new standard, NFPA 1970. Not only will the committee be acting on items specific to the consolidation, but major revisions are expected that focus on improving the health and safety of firefighters.

The technical committee started working on topics of interest immediately after the previous revision closed. As always happens, some topics were not ready for inclusion in the last revision and required further study. In those cases, the committee began its work on those issues almost immediately. In the case of NFPA 1971, nine different task groups were created, and relevant topics were assigned to them to research with the expectation of finding solutions for the next (upcoming) revision. Those task groups include design and performance, test methods, ensemble testing, helmets, hoods, gloves, correlation, scope, and editorial. Because other issues came to light before Public Inputs closed, additional task groups related to hazardous substances and evaporative resistance testing were formed. Individuals from the task groups and from the public submitted requests for changes to the standard through the Public Input process (which closed on November 10, 2021). The technical committee has started to process those public inputs through the First Draft process (which closes in March 2022).

Some topics that will be discussed through this process include conditioning equipment and procedures used in certification testing, evaporative resistance testing as a contrasting measure of breathability to the current total heat loss test, several aspects of addressing restricted substances (e.g., PFAS and other chemicals), the addition of a "cleanability" index, glove fit and sizing, and more. How these topics are being considered is described below.

- Changes to conditioning equipment and procedures include replacing top-load washers that use center agitators with washer/extractors now specified in NFPA 1851. This makes sure that the requirements are appropriate assessments of how gear is affected by cleaning and wear because current specified equipment is becoming obsolete and unobtainable.
- Evaporative resistance testing of garment composites is being reviewed to provide additional information to firefighters about how gear allows moisture to escape as a form of heat loss under different climatic conditions that are not currently addressed in NFPA 1971. This is important because this aspect of gear performance is tied directly to heat strain.
- Restricted substances are a hot topic, and several avenues for addressing restricted substances will be considered. Multiple tests have been proposed through the Public Input process and will be discussed and acted on by the technical committee.
- A "cleanability" index has been recommended so that the fire service has more information about how materials differ in their ability to have contaminants removed by standard cleaning procedures.
- Previous changes to glove sizing did not solve the glove fit problems for some populations that the technical committee was trying to solve in the last edition, so new proposals have been studied and will be discussed through the First Draft process.

It is critical that these items were submitted as Public Inputs; otherwise, the committee has no mechanism to formally discuss the topic and get to a solution that puts firefighter health and safety at the forefront. Public Inputs were submitted both by individual committee members as well as members of the public. Once the First Draft process is closed, committee actions will be incorporated into the standard and will be published as a First Draft. Once the draft is open for Public Comment, anyone can submit a Public Comment to address any action the committee took. The technical committee must discuss and act on each Public Comment during the Second Draft phase before the new edition is approved and published.

Throughout the process, the technical committee performs a balancing act of assessing multiple hazards and maximizing positive impact to the fire service. The NFPA 1971/1851 standards are part of a larger project, all overseen by a correlating committee. Not only are Public Inputs and Public Comments addressed by the technical committee, but those actions are reviewed by the correlating committee (another balanced committee with perspectives from all parts of the fire service) and then reviewed by the NFPA Standards Council.

At every level, firefighter health and safety are at the forefront. Being a consensus standard, not everyone is going to be happy with every outcome. In general, however, the technical committee, correlating committee, and Standards Council all provide a balanced perspective that is, if anything, weighted toward the fire service. This dynamic process, although sometimes slower than the industry would like, has allowed this and other technical committees to refine and revise standards that, it cannot be denied, have improved firefighter health and safety and will continue to do so.

One example of a significant change is whether particulate-blocking hoods should become mandatory as opposed to staying optional as they currently are. During their introduction in 2018, optional requirements were added for firefighter hoods to provide for particulate blocking, especially after ample evidence became available about firefighter neck and face exposure to smoke particulates readily coming through the commonly available two-layer porous knit hoods. A large part of the fire service has moved to the new types of hoods and additional research, including that conducted by North Carolina State University as part of a federal grant, has added to the information for the utility and performance of these products (see "Protection and Contamination: Understanding the Roles of the Turnout Ensemble in Firefighter Cancer Prevention" later in this supplement). The question is, should the fire service go entirely to these newer products now available from a wide range of manufacturers?

There has been an ongoing, decades-spanning debate about eye and face protection provided with helmets typically as face shields, goggles, and various forms of retractable or flip-down visors. A principal question is whether eye/face protection should be a separate item or part of the helmet, particularly when the SCBA face piece is part of the ensemble and provides primary eye protection for structural fires. A related question is just how much coverage is needed, as significant differences can exist for both eye and face protection between different currently accepted eye/face protection products provided with the helmet. There have obviously been two or more sides to this issue, but some advancements are being made in understanding product utility and protection, so it is expected that this perennial issue will come up again with new angles and new proposals for attempting to mirror the true needs and preferences for the fire service.

Another controversial area is the mandatory requirements for drag rescue devices (DRDs) installed into the protective coat. This feature has been a mainstay of the NFPA 1971 requirements since it was introduced in 2007. Since that time, there have been few, if any, reported instances where the DRD has been used for the rapid extrication of firefighters. Many firefighters complain that under emergency circumstances, the DRD simply is not readily accessible and that there are easier ways to accomplish removing a down firefighter from the fireground, particularly under the conditions of a relatively complicated physical environment. In fact, the last edition of NFPA 1500, *Standard on Fire Department Occupational Safety, Health, and Wellness Program,* recognized in one of its use requirements that organizations should have standard operating procedures specific to rapid firefighter extrication and the DRD was only one of the approaches that can be established. Still, there are others in the fire service who believe that unless the DRD is mandatory, it won't be available to firefighters when needed under emergency conditions. The question here is whether the DRD should remain mandatory or become an optional feature for which requirements are applied when present in the clothing.

Figure 3. A Firefighter Demonstrates the Use of a Coat Drag Rescue Device (DRD)

Should the drag rescue device remain a mandatory component of turnout coats? *(Photo by Marni Schmid.)*

Additionally, some argue that new metrics are needed to judge thermal insulation for protection as balanced against physiological stress imposed by the clothing. To this end, proposals for supplementing both thermal protective performance (TPP) and total heat loss (THL) are expected to change how the industry defines these clothing characteristics. Some firefighters argue that the current system does not need to be changed, yet the TPP test itself is more than 35 years old and the TPP requirement of 35 has remained in place for that same time. Despite that, fireground conditions have been shown to be evolving with more modern material and their consequent hazards, and there is still a need to better balance heat insulation and physiological comfort. This topic is addressed later in the sidebar "Applying a Systems Approach and New Metrics for Key PPE Characteristics."

(4) Make Your Needs Known to the Responsible Technical Committees. There are many, many more areas of change that will be considered in the next edition of NFPA 1971 to be under the new consolidated NFPA 1970. How these changes are considered will be determined over the next 18 or so months, but it is very likely that some large changes that transform PPE will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probably occur. Even though there are a great number of fire service members who serve on the committees that will be responsible for these changes, the fire service as a whole should take an active part in shaping how the turnout gear requirements are modified rather than waiting to see what emerges from this process. It is important that individual organizations weigh in for what they think should happen with turnout clothing. Although many individuals and some organizations don't necessarily welcome change, a transformation is coming through new awareness and technology to ensure that firefighters are afforded the best possible protection that meets minimum requirements for their safety and health.

Fire Service Participation

It is possible to convey your perspectives on PPE in several ways. NFPA meetings are open to the public and all guests. The NFPA staff liaison, committee chairperson, or committee secretary can provide information on when meetings are being held and how to participate. Information for contacting these individuals is on the NFPA Web site at www.nfpa.org/Codes_and_Standards, where you can select the appropriate standard from the list in the NFPA codes and standards link and then identify the individuals through the tab for "Technical Committee." For NFPA 1970, nearly all meetings will be held virtually, making participation easier.

There will also be a period of Public Comment once the First Draft is completed, which will show all the contemplated changes to each standard as part of the overall NFPA 1970. This will provide you with the opportunity to agree, disagree, or offer an alternative approach to any proposed new requirements. The ability to submit Public Comments will likely occur sometime in the summer of 2022 and will similarly be accessible through the same links on the NFPA Web site but under the consolidated standard NFPA 1970 at https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1970&tab=nextedition.

Better Understanding Contamination Pathways

It is now very much recognized that firefighters are exposed to hazardous substances not only on the fireground but in their continued contact and handling of PPE and other equipment or tools that have been contaminated as part of the response to structural fires or other events where hazardous substances are encountered. The increased understanding for how contamination and exposure occur is essential for making decisions on how to select clothing and "build" an ensemble; understanding the limitations of protective ensembles in keeping contamination out as well as the trade-offs; and applying practices for preliminary exposure reduction, advanced or specialized cleaning, and sanitization or disinfection, depending on the form of contamination encountered.

This understanding further must account for not only the sources of contamination but how hazardous substances enter the body. Just as different hazardous substances don't penetrate or permeate protective ensemble elements equally, the assumption cannot be made that all hazardous substances will readily be inhaled; be absorbed through the skin; be accidentally ingested; or, in very remote instances, be injected. Therefore, the pathway from hazardous substance source to getting inside the body must be accounted for with respect to the PPE and the actions of the firefighter during and following exposure to truly minimize and practically limit the safety or health effects of contamination.

(1) Be Aware of the Principal Pathways for Contamination Entry Through PPE. Effectively reducing fireground exposure is only partly controllable where the current nature of structural firefighting clothing will allow fire gases and some particulates to enter through various parts of the ensemble, primarily through closures and interfaces. Several studies have been undertaken that report how fireground exposures result in the measurement of metabolized chemicals in firefighter blood, urine, or other body samples.[1-5] Most often, these studies target specific substances, and the form of exposure can be quite varied, depending on the substance, where PPE inhibition of exposure will vary with the state of the substance—small particles (solids), fireground liquids, or fire gases. The ability of the ensemble to attenuate exposure will differ based on the form of the contaminant.

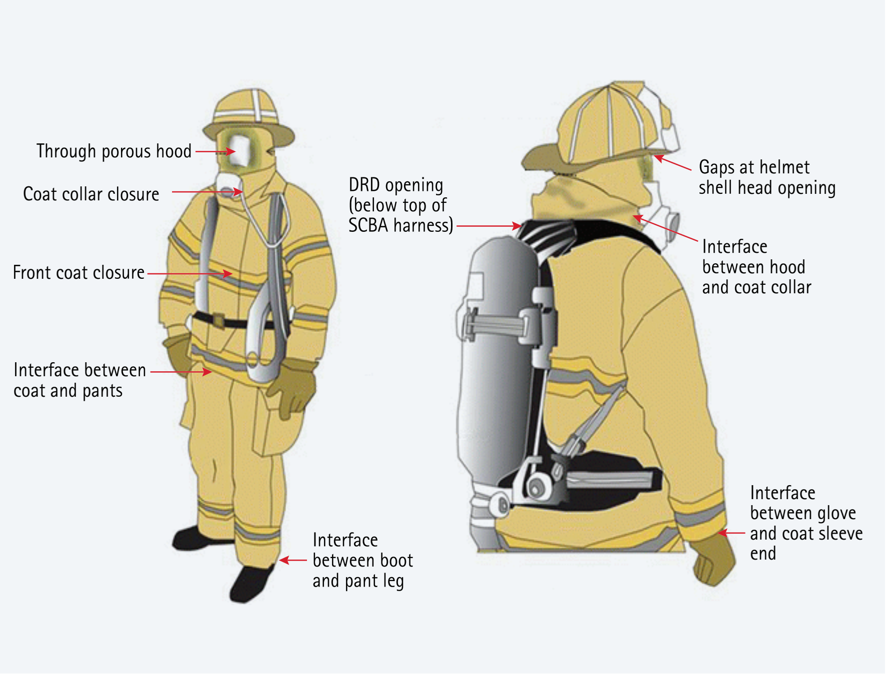
Exposure to soot particles is of concern to firefighters because although mainly plain carbon, smoke particles have the ability capture fire gases on their surfaces and thus become significant carriers of hazardous substances that contact the firefighter's skin or remain in the clothing. Recognized pathways for entry of particles include the following parts of the ensemble:

- Gaps between the hood and the face piece on the firefighter's head.
- Standard knit hoods (not the case for particulate-blocking hoods).
- Underlying areas of the helmet where rising heat can waft particles into the helmet interior.
- The opening at the collar closure.
- The coat front closure.
- The interface of the coat sleeve ends with gloves.
- Knit glove wristlets.
- The interface between the coat and pants.
- The fly closure of the pants.
- The interface of the pant legs with the footwear.

In general, anywhere air can pass through is an avenue for particle penetration. The gaps do not have to be large since the particles are extremely small—many less than a micron in diameter (0.00004 inch) and often numerous in quantity. Moreover, firefighter movement inside the clothing as well as thermal gradients in the operating environment create a "bellows" action to pump particles into the ensemble as firefighters bend, crouch, and change positions. Areas of the clothing that include hard surfaces or barriers prevent particle penetration such as the SCBA face shield; helmet shell; and moisture barriers found in the substantial portions of garments, gloves, and footwear.

Since air passage takes the path of least resistance, having correctly fitted clothing (to reduce effects of movement); choosing good interfaces between ensemble elements; and ensuring that all clothing features, particularly at

Figure 4. Principal Penetration Pathways for Fireground Contaminants



closures and interface areas, are properly deployed are the best ways to minimize exposure to particles. Options do exist for manufacturers that have attempted to create more effective interfaces and closures to reduce particulate penetration, which always includes the wearing of a particulate-blocking hood. Test methodology exists for demonstrating these characteristics, which is further defined in this supplement in the sidebar "Applying a Systems Approach and New Metrics for Key PPE Characteristics."

Liquid penetration will follow the same pathways that are available for particulates with certain differences. Liquid contamination of clothing is affected by finishes on outer shells and whether clothing materials "wick" contaminants. Liquid transport in clothing is heavily dependent on the liquid characteristics. Liquid chemicals that have low surface tensions are more likely to wet fabrics and then spread throughout the clothing layer, sometimes finding gaps in protection where penetration can occur. High liquid viscosity (ease of flow) can further impact whether liquid can get through the ensemble opening. A prior study has found that liquid originating in one part of the clothing, such as the hood, can lead to movement of the liquid further into the ensemble from the point of entry.[6]

Fire gases are much harder to stop. Instead of bulk liquids or solid particles, fire gases exist at the molecular level, which is considerably smaller. The size of molecules enables entry into the ensemble through much smaller gaps, including everything itemized for particle penetration but also the potential for permeation through barrier layers, including the moisture barrier layers of garments, gloves, and footwear. Fire gas penetration through relatively thick plastic or resin-based layers (such as for trim and helmet shells) is much less likely. Fortunately, SCBA is tested for protective performance of breathing air and ocular exposure to warfare agents as specified by NFPA 1981 and more recently demonstrated against various toxic industrial chemicals in a separate government project.

In addition to the different forms of fireground contaminants, it is important to point out that the condition of the clothing itself has a large impact on how clothing becomes contaminated. As clothing is worn, any degradation that takes place can create additional pathways for fireground substances to penetrate different areas of clothing. Further, the buildup of soot in clothing acts as a "magnet" to capture and hold certain fire gases more so than if the clothing is clean. When clothing becomes wet, this can also increase how certain contaminants can penetrate or be absorbed by clothing materials.

The key takeaways are that vulnerability for exposure to hazardous substances does exist in the various forms that they appear on the fireground and that gear is limited in how much of these substances can be stopped. This raises the issue of not only how well PPE is designed for stopping penetration of contamination but also how fireground operating practices affect how firefighters are exposed.

(2) Recognize Where PPE Contamination Is Likely to be Greatest Following Fireground Exposures. Once fireground exposure occurs, PPE becomes contaminated, but the locations of this contamination and the likelihood of continued exposure depend on the specific ensemble element and the nature of materials used in the construction of the element. Some research has been conducted to measure contaminants in various part of the ensemble following exposure to either actual or controlled structural fires.[7-9] These studies have shown grossly varying amounts of contaminants in different parts of the ensemble. For example, some early research has shown gloves to be more heavily contaminated than hoods. Other studies have delineated how certain forms of contamination can penetrate through different layers of the clothing.

A more recent study still in its preliminary phases of analysis has shown characteristic differences in broad contamination levels by part of the ensemble.[10] These differences were measured for all parts of the ensemble including interior layers using a combination of extraction and wipe samples, with the following generalized findings:

- Specific areas of high contamination included knee reinforcements, helmet suspensions, and glove outer shells.
- In many cases, the contamination of the garment moisture barrier layer was equivalent to the garment outer shell, though substantially lower levels of contamination were observed for the thermal barrier.
- Significant differences existed between the outer glove shell (leather) and the glove lining.
- Footwear contamination was generally

the same for the exterior or interior layers, though this information was found exclusively through wipe samples as opposed to extracted contaminants.
- Unexpectedly, hood interior layers for barrier hoods could be more contaminated than hood exterior layers.
- Surface contamination of hard surfaces such as helmets and parts of the SCBA tended to be lower than textile- or leather-based materials.
- Some components such as trim had low levels of residual contamination.

These initial observations are definitely linked to the actual type of clothing item used in the study and the fireground conditions, based on staged fires with only pallet and straw fuel loads. Nevertheless, the findings provide insight on contamination penetration and hazards that require attention following fireground exposure. At the very least, they point out which items demand the greatest scrutiny for cleaning. They may also point to areas where secondary, persistent contamination is most likely to create exposure to firefighters such as helmet suspension bands or through the unprotected handling of contaminated gloves.

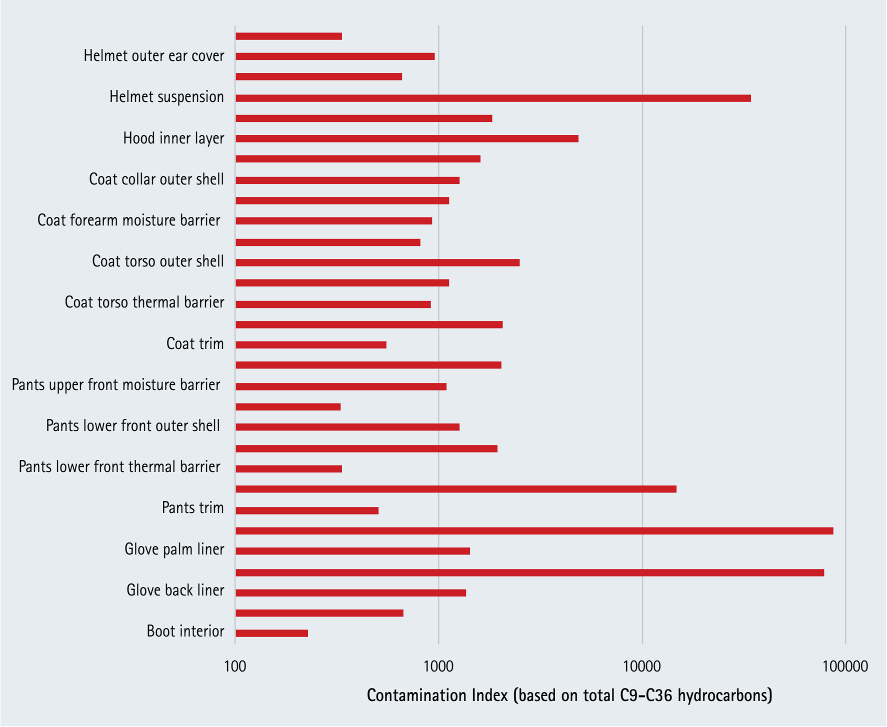
In terms of PPE, there are no mandatory requirements for protection from fireground products of combustion-based contaminants in NFPA 1971. Yes, there is an optional requirement for a particulate-blocking hood (which, as the name indicates, blocks particulates but may or may not limit the penetration of fire gases), and there is also an optional full ensemble set of requirements that look at the entire ensemble in preventing surrogate smoke particles and liquids from getting onto the firefighter's skin. However, there are no other requirements that address contamination resistance of clothing or its ease of cleaning other than a relatively perfunctory test that requires the removability of helmet ear coverings and other textiles for easier cleaning.

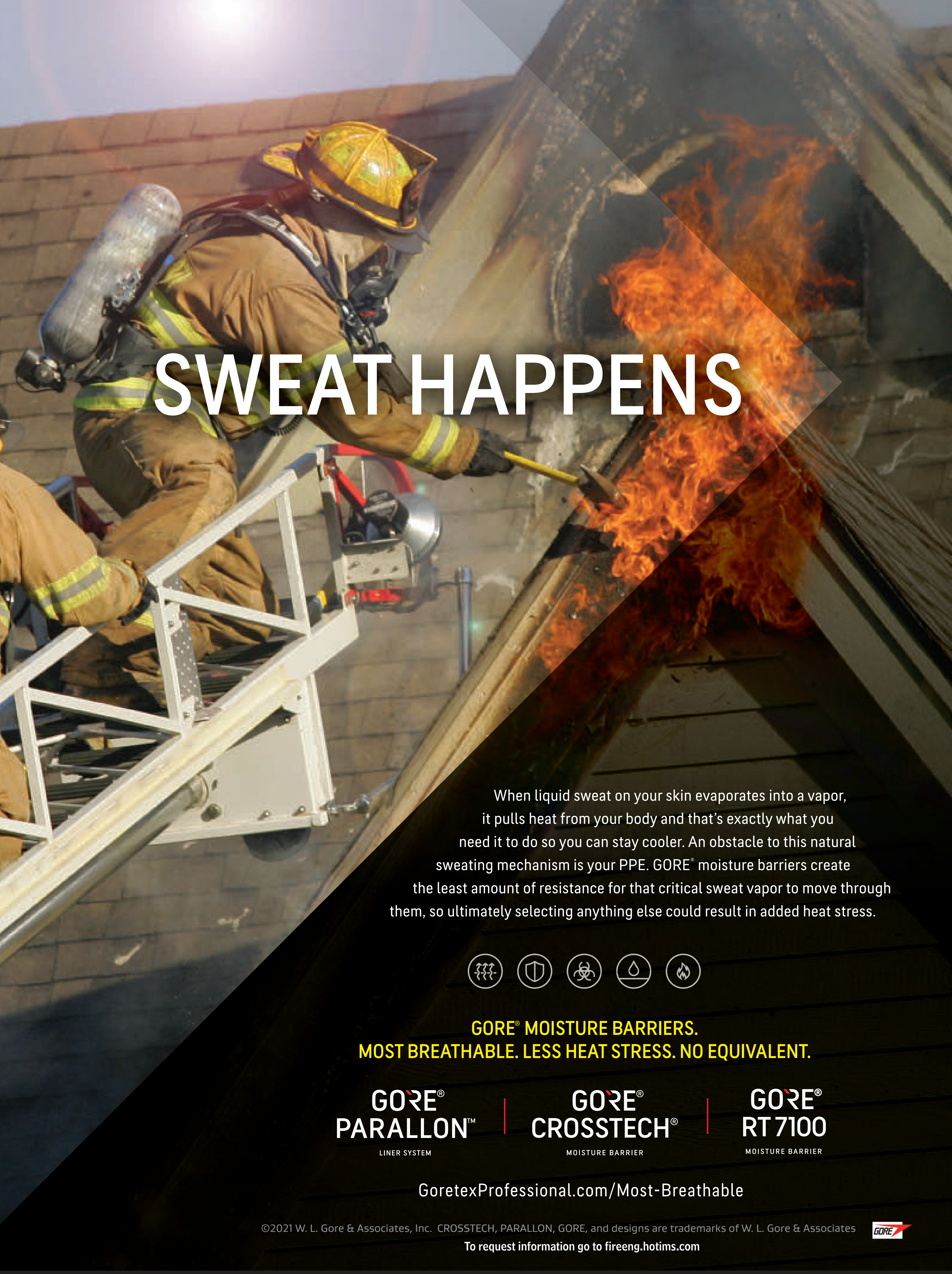
The absence of contamination resistance metrics in view of the current major concerns within the fire service should be addressed but, in reality, it is also very difficult to attain good test methods and establish reasonable and implementable requirements for addressing such matters. This issue raises several questions that should be considered in the next standard for turnout clothing. For example, since gear is likely to be washed more frequently, which, in turn, affects service life and some protection attributes, should clothing performance be measured after more than five wash cycles as currently specified? Is there a need to look at the contamination resistance of materials including their oil resistance? Should the ability to remove contamination from clothing and equipment through standard cleaning be addressed and preferences be given to those materials or designs that can be more easily decontaminated? And finally, if these metrics are examined, how do these other measurements supplement or contradict existing requirements? This leads to finding the right balance between thermal/physical protection, physiological impact, and contamination control.

(3) Take Steps to Lessen Potential Routes of Contamination Resistance into Your Body. During or following contamination exposure, hazardous substances can take a variety of different pathways from the source to getting into your body where the health effects can be short or long term, depending on the contaminant. The ability of the contaminant to cause harm depends on how the contaminant enters and interacts with the body, which intensifies if the substance is highly toxic, persistent, or both. Many substances are further carcinogenic (responsible for cancers), mutagenic (causing mutation), or teratogenic (affecting the development of offspring). While these routes of body entry are few, realizing which chemicals are likely to cause health effects through one or more routes affects PPE choices, the length of time you remain protected, and the relative need to clean or decontaminate PPE. Dr. Christina Baxter examines these in "Chemical Routes of Entry."

Baxter describes the types of testing that may be associated with contamination control relative to PPE. A variety of evaluations can be used to demonstrate the barrier performance and integrity of ensemble elements but, as previously acknowledged, PPE is typically not assessed for its resistance to becoming contaminated or its ability to release that contamination after appropriate cleaning. The pursuit of these tests is noteworthy because, as with any new form of evaluation, attaining positive

Figure 5. Relative Contamination Levels Found in Selected Areas of Firefighter Protective Ensemble




SWEAT HAPPENS
When liquid sweat on your skin evaporates into a vapor, it pulls heat from your body and that's exactly what you need it to do so you can stay cooler. An obstacle to this natural sweating mechanism is your PPE. GORE® moisture barriers create the least amount of resistance for that critical sweat vapor to move through them, so ultimately selecting anything else could result in added heat stress.
GORE® MOISTURE BARRIERS.
MOST BREATHABLE. LESS HEAT STRESS. NO EQUIVALENT.
GORE® PARALLON™
LINER SYSTEM
GORE® CROSSTECH®
MOISTURE BARRIER
GORE® RT 7100
MOISTURE BARRIER
GoretexProfessional.com/Most-Breathable
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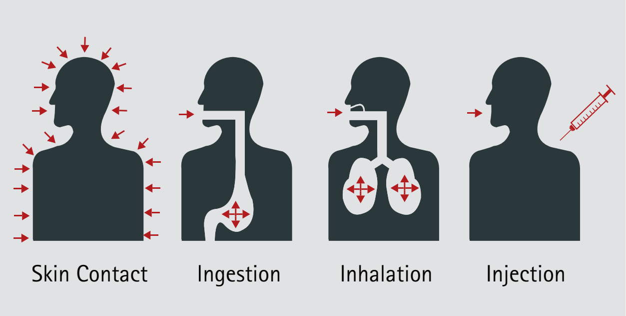
Chemical Routes of Entry

BY DR. CHRISTINA BAXTER, EMERGENCY RESPONSE TIPS

In a perfect world, there would be no elevated risk to firefighters for cancer from their operational environment. The routes of exposure of airborne contaminants into the body generated in a fire include inhalation, ingestion, dermal, and injection, with inhalation being the most significant of the routes. However, the significance of this route of exposure should be greatly reduced with the use of SCBA on all scenes. Ingestion can be minimized by following the preliminary exposure reduction (PER) principles followed by good personal hygiene. Dermal exposure is greatly reduced by taking a shower as soon as feasible following an exposure to combustion by-products and laundering the turnout gear. Injection is minimized by wearing appropriately fitted PPE including turnout gear, gloves, boots, and helmets. With all that said, why are we still spending so much time on this issue? Are we doing enough? Are the best practices being followed? Is it a combination of factors, or are we trying to simplify a very complex issue? The intent here is to pose a series facts and residual questions about firefighter exposure for departments to consider when developing a comprehensive plan to minimize occupational exposure.

Contamination Routes of Entry into Firefighter



Inhalation

Although inhalation of combustion by-products on a fire scene is likely the highest and most complex primary route of exposure, there are many issues that need to be addressed.

1. Are all personnel within the smoke plume wearing the appropriate respiratory protection starting at search, through suppression, and continuing through overhaul?
2. Is the pump operator within the smoke plume? What about the diesel exhaust fumes from the vehicles themselves? Is the pump operator wearing the appropriate respiratory protection or is some type of continuous monitoring in place to ensure that the operator is not above recommended occupational exposure limits? Note that many combustion by-products cannot be monitored in real time.
3. Are the personnel, including command staff, who are not wearing respiratory protection located in a space where the exposure is less than the recommended occupational exposure limits?

Each of these questions has simple answers and solutions—wear an SCBA or provide continuous monitoring to demonstrate that it is not necessary. The bigger, more complex, issues arise when looking at the secondary exposures—exposures not from the fire itself but from the deposition of particulates or entrapment of gases in PPE, equipment, and apparatus.

1. Has the gear gone through a PER cycle to remove as many particles as possible and to remove entrapped gases?
2. Is the contaminated gear bagged on scene and transported for proper cleaning?
3. If laundering is not required, is the gear "aired out" on scene to minimize the entrapment of fire gases?
4. If laundering is performed "in house," is respiratory protection worn when opening the bags of contaminated gear or is monitoring in place to ensure occupational exposure limits are not exceeded?
5. Are the bottoms of boots cleaned thoroughly to remove all fire debris prior to leaving the scene? If not, what is in place to minimize the transfer of fireground contamination into the apparatus and back to the fire station where it becomes part of the station dust that is available for inhalation?
6. When the gear comes back from laundering, how clean is it? NFPA 1851 only requires the removal of 50% of the contaminants for verification of an Independent Service Provider's (ISP) cleaning process. Do personnel understand that the PPE has residual contamination remaining following laundering? Is this residual contamination available for a secondary exposure, or is it bound within the gear?
7. Are personnel wearing structural PPE for reasons other than structural firefighting? If so, is there an alternative in place to minimize this practice?

Ingestion

Ingestion is often thought of only on the fireground during the rehabilitation process. However, ingestion continues in the apparatus and back in the station, as much of the fireground contamination is still making it back to the station. This is most evident in the recent studies on contaminated dust in fire stations. The ultrafine dust particles are available for inhalation, but the particles larger than 10 microns are generally ingested. How can the movement of contamination from the fire scene be minimized?

1. Are boot treads cleaned before leaving the fire scene? Are they again cleaned in more detail on returning to the apparatus bay? Unfortunately, although boots are not likely to carry fire gases back to the station, they are able to carry and disperse a great deal of particulate contamination containing polyaromatic hydrocarbons (PAHs), phthalates (plasticizer chemicals), flame retardants, stain repellants, water repellants, and more.
2. Is the passenger compartment of the apparatus cleaned at a

frequency commensurate with the movement of contaminants?

3. Are there processes in place to ensure that the apparatus bay does not become contaminated with fireground contaminants that then make their way into the living quarters?
4. After laundering gear, is the residual contamination that was not removed available for secondary contamination?

Dermal

It has been evident since the time of Percival Pott that dermal exposures to fireground contaminants can cause exposures leading to cancer. Pott's study of scrotal cancer in chimney sweeps was published more than 200 years ago. It is well established that polycyclic aromatic hydrocarbons, volatile organic compounds, aldehydes, diethyl phthalates, and acid gases will be absorbed directly from the vapor phase and penetrate the skin. The penetration rate is dependent on many factors, and the dose is also affected by the body's ability to detoxify and excrete the contaminant. To date, the guidance has been to wear properly fitted turnout gear to minimize the ingress of hot, combusted air; shower as soon as possible following firefighting activities (preferably within an hour); and launder gear more frequently. These recommendations still hold true, but are they enough?

1. Are personnel fitted for turnout gear annually or whenever a significant change in body size occurs? If the turnout gear is to properly minimize the ingress of hot, combusted air, it must be properly fitted. Note that the skin in the scrotal area is more than ten times more permeable than that of the forearms. Turnout gear that is not properly fitted will have increased penetration of materials around closures from both the bellows and the chimney effects.
2. Are personnel rotated on fire scenes or as fire instructors to allow for showering as soon as feasible? Although skin permeation is generally considered to be a slow process, it has been demonstrated that dermal exposures do contribute to the overall firefighter exposure on the fireground. When showering, it is important to remember to take a *temperate shower* with the temperature not exceeding the skin temperature. *Increased temperatures also increase surface blood flow, increase perspiration, and open the skin's pores.* Increased perspiration can increase the permeability coefficient for a chemical through the skin while also increasing the residence time of the chemical on the skin, especially if the chemical is water soluble.
3. Again, are personnel wearing structural PPE for reasons other than structural firefighting? If so, is there an alternative in place to minimize this practice? If the total cleanliness of the gear cannot be verified below 50% contaminant removal, is the gear a potential secondary source of contamination?
4. Are helmets along with the suspension system and liners being cleaned after each fire? Is the helmet being donned without a firefighting hood prior to cleaning the liner? The skin in the areas of the head in contact with the helmet suspension system and liner is approximately five times more permeable than the forearms.
5. Are gloves being washed to minimize potential for secondary exposure? Remember, the skin of the hands is slightly more permeable than that of the forearms.

Injection

Injection has the lowest potential for exposure on the fire scene, but it should not be completely ruled out. Wearing PPE certified to NFPA standards minimizes this potential by placing minimum requirements on puncture, cut, tear, and burst resistance to ensure firefighter safety.

Many of the topics discussed here can be done at the operator or department level. Unfortunately, there are still lingering questions that remain unanswered related to the primary and secondary contamination potential of turnout gear itself. NFPA 1971 (now part of the NFPA 1970 consolidation process) just completed its first round of Public Inputs. Leading up to this period of comments, a task group was formed to try and address the issues concerning turnout gear as a source of exposure both primary from the gear materials and secondary as a source of residual contamination. Although there is a long way to go before the newest edition of NFPA 1970, and within it NFPA 1971, hits the streets, the following topics are proposed for consideration:

1. **Restricted substances disclosure.** Proposed reporting requirements for levels of restricted substances in principal materials and components. Restricted substances of interest include carcinogenic dyes, flame retardants, heavy metals, pesticides, phthalates, perfluorochemicals, PAHs, and others. This data will provide firefighters with information about the maximum potential primary sources of exposure from turnout gear. These tests will not determine how much of the materials is available for permeation toward the skin but will provide information on the maximum available.
2. **Determine "Cleanability Index."** Proposed test to determine the ability to remove contaminants from turnout gear following exposure to combustion by-products. This test is meant to provide the operator with an understanding of the secondary sources of contamination from the turnout gear materials and configurations. It would be applied to the outer shell, the moisture barrier, and thermal liner garments and potentially other elements of the ensemble.
3. **Quantify leachable substances**. Using a test modified from the EPA, determine the amount of target substances capable of leaching from the turnout gear into a surrogate sweat material at elevated temperatures and times. The goal of this test is to provide the operator with information about how much residual contamination (primary or secondary) is available for dermal exposure.
4. **Assess repellency properties**. Evaluate turnout gear outer shell materials for their repellency to fireground contaminants such as PAHs, phthalates, and fire retardants. There were two synergistic approaches proposed for this test: First was to record repellency and penetration indices for the fireground contaminants listed above. Second was to evaluate the residual flammability of contaminants such as diesel fuel following laundering.

There is still a long way to go before we can declare a fire service where increased cancer risk is not the standard. Over the past five years, we have seen increased activity in all areas of exposure reduction as evidenced by recent updates to NFPA 1851 and the first draft of the new NFPA 1585, *Standard for Exposure and Contamination Control*. Many departments have instituted PER practices and have taken steps to reduce total exposure. Unfortunately, there is still a long way to go.

performance in one area does not mean that performance in other areas is maintained. Trade-offs often arise that force decisions on priorities relative to which protective features need to be emphasized. Further, in some cases, performance criteria are not enough to achieve protection. Sometimes design requirements must be applied to ensure that contamination exposure is lessened. For example, the ease of removing textile components of helmets for separate cleaning given their propensity to become contaminated can be very important for lessening overall exposure.

Recognizing the Multiple Impacts of Restricted Substances in PPE

The fire service has been inundated with specific issues related to cancer-causing substances and practices for avoidance of exposure to carcinogens and other harmful substances. This subject has taken several different directions, one of which is to look at the PPE itself as a potential source of chemicals that, over time, get into the firefighter's body and contribute to long-term health problems. This becomes a matter of investigation relative to other dangers of fireground exposure that occur as a result of having contact with different substances through respiration (not wearing the SCBA all the time it is needed), by skin contact during emergency responses (problematic when dirty clothing is not removed after use or when showers are not taken after the fire event), or by the continued exposure to persistent contaminants that remain in unclean PPE (when firefighter clothing is not cleaned after fireground exposures). Nevertheless, several serious concerns have arisen with respect to certain substances leaching out from clothing components, evaporating from the clothing during use, or otherwise causing exposure of firefighters.

Understanding the threat of PPE as a chemical exposure threat has recently become a subject of study. Although certain substances may or may not be present in turnout clothing, the extent to which they are present and, more importantly, the manner in which they may present themselves as a hazard for exposure has not been fully determined. Several studies point to the existence of hazardous substances as building blocks or constituents of PPE materials. Studies are underway to definitively show whether substances can come out of the turnout clothing and then get into firefighters' bodies by any route of exposure. This does not mean to say that this does not happen; the topic simply has not been fully studied. This should not further imply that the industry should just wait for all the research to be done just because specific risks have not yet been quantified. Instead, industry should move forward with actions that minimize the potential risks to firefighters who already operate in ultrahazardous environments.

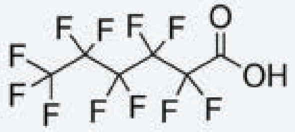
(1) Become Knowledgeable about Existing and Emerging Regulations on Restricted Substances. Large parts of the consumer textile and related product industries already address potentially hazardous substances that may be used in very small amounts as part of their products through what are called "restricted substances lists" (RSLs). These are lists of compounds with known adverse health effects that have either been banned or are being closely scrutinized by different jurisdictions whether by regions, countries, states, or even cities. RSLs include a variety of chemicals such as plasticizers, certain toxic heavy metals, different dyes, and other substances that have been discovered to have toxic or carcinogenic effects. Most often, the chemicals on RSLs are subject to certain limits, but these can vary from jurisdiction to jurisdiction.

Proposition 65 is an example of a state-legislated RSL that is well-established in the State of California. Its main intent is to protect drinking water from contamination by hazardous substances. The list now contains more than 800 naturally occurring and synthetic chemicals that are known to cause cancer, birth defects, or other forms of reproductive harm.[11] They include additives or ingredients in pesticides, common household products, food, drugs, dyes, and solvents. They can also be chemicals used in manufacturing and construction or by-products of chemical processes such as motor vehicle exhaust. The state regulations establish safe harbor levels for some of these chemicals in terms of a known concentration that does not cause harm or in the form of allowable daily dose. The regulations do not prescribe safe levels for products but do require manufacturers of products that contain these substances to provide warning that Proposition 65 substances are present.

Another example specific to the fire service and certain chemicals occurred when the State of Washington enacted new state regulations in July 2018 banning the use of Class B firefighting foams that contain PFAS, with certain exceptions, that further required manufacturers of firefighter PPE containing PFAS to disclose that information to the departments that purchase the PPE and to indicate the reasons PFAS are used in the product.[12] In this legislation, PFAS was broadly defined as a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom. Other states have enacted similar legislation for disclosure of PPE use of PFAS. At the national level, the National Institute of Science and Technology has specifically been tasked with creating a greater level of understanding for PFAS as part of firefighter PPE. In October 2021, the U.S. Environmental Protection Agency (EPA) announced a strategic roadmap to address PFAS through research, restriction, and remediation.[13] While not specifically targeting PPE, this direction would affect PPE that contains PFAS. For example, as part of this strategy, Congress directed the EPA to develop a process for prioritizing which PFAS or classes of PFAS should be subject to additional research efforts based on the potential for human exposure, toxicity of, and other available information.

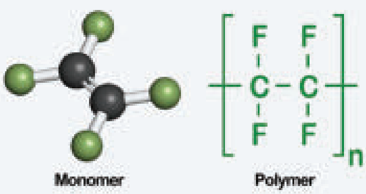
The fire service and the PPE manufacturers must comply with regulations in the respective areas to which they apply, but the reality is that these requirements are not uniformly applied across the U.S. fire service. Regulations affecting California and Washington are not the same elsewhere. Moreover, some areas of the country are in the process of

Figure 6. Selected Examples of PFAS



Perfluorohexanoic acid (PFHxA)

n-perfluorobutanesulfonyl fluoride



Perfluorotetraethylene (PTFE)

It is estimated that there are more than 9,000 chemicals that can be classified as PFAS.

setting different restrictions for specific substances that may vary dramatically. Although the intent of these regulations is laudable, the fire service is not achieving the overall benefit. Consequently, both the fire service and the PPE manufacturing industry should get ahead of this problem by working with standards organizations to create consistent requirements.

(2) Specifically Apply Restricted Substance Limits to Fire Service PPE. Instead of PPE manufacturers attempting to maintain their own RSLs that cobble requirements of different states or local areas and deciding when and where to disclose or control constituent parts of their products, a better approach would be to adopt a universally recognized set of criteria that can be applied to the entire industry. There is already comprehensive knowledge on restricted substances on textile and related products, but there are no specific requirements for testing and no uniform set of criteria for potentially hazardous components in clothing that are determined independently by testing.

Fortunately, organizations exist that offer these services and that have been in use primarily in the consumer field for indicating that products including the fabrics and other components are either free or have the lowest safe levels of pertinent restricted substances. One such organization has created the Oeko-Tex 100 Standard, which is an independent certification system for testing textiles for "harmful substances."[14] When a material and components are independently certified to the Oeko-Tex Standard, it means that they have met certain criteria: They contain no illegal substances (carcinogenic colorants), they only have a certain amount of other legally regulated substances (formaldehyde, heavy metals, phthalates, etc.), and they only contain a certain amount of substances that are known to be harmful but are not yet regulated at all (pesticides and allergenic dyes). A sampling of the types of restrictions applied to these substances appears in Figure 7, "Sample List of Restricted Substances."

The Oeko-Tex Standard is often far more strict than current legislation in the United States, and the amounts of these chemicals allowed in certain products depend on the article's use. There are four "product classes," each of which has its own limits for various substances. Moreover, there is a specific variant of this standard that addresses protective clothing. Although the standard originated in Europe, it has been adopted through various well-known product outlets, manufacturers, and suppliers in the United States including some component providers of turnout clothing. The adoption of this or similar practices within the fire service PPE industry would seem to offer the solution to provide broad benefits to the fire service. A specific proposed change to NFPA 1971 (turnout clothing) has been submitted to require that major materials and components of PPE be evaluated for a wide range of restricted substances, including PFAS, to be below certain limits and to be assessed through an independent certification process specific to the material and component suppliers. Separate requirements would then be set to have protective ensemble elements comprised only of compliant materials and components.

(3) Augment Restricted Substance Limitations with Test Methods to Assess Impact of Compliant Materials with Relevant Performance Requirements. By adopting new requirements as part of NFPA 1971 (within NFPA 1970) involving independent testing and certification of PPE for restricted substances, concerns over one path of potential exposure can be eliminated. This approach is no different than what is already done for establishing acceptable levels of protective performance by third-party certification. Requirements for measuring levels of restricted substances should be further coupled with investigations of the effects for deviations in materials or component performance resulting from the enforcement of these restrictions. Only in this fashion can confidence be established for the fire service in addressing overall chemical exposure safety from PPE.

The types of evaluation to be applied should account for several features of firefighter PPE. First, existing requirements should be examined to determine if certain test methods and criteria artificially mandate the use of specific restricted substances. This argument has been made for an ultraviolet light (UV) test method and criteria applied to moisture barriers. In concert, certain performance properties that characterize exposure to restricted substances or changes in product performance also warrant investigation. An example of these tests includes how various substances in PPE materials and components may be leached out under realistic fireground operating conditions that can then become exposure hazards for firefighters. These considerations further need to be enjoined by evaluating how certain restricted substances impact performance features such as contamination resistance, ease of cleaning, and durability. Information gained from this investigation is expected to become a factor that helps to understand the various trade-offs of performance as applied to firefighter PPE.

AIRBAG

PBI
OUTER SHELLS

HELMET

Figure 7. Sample List of Restricted Substances and Limits Applied in OEKO-TEX 100 Standard (Not a Complete List)

SUBSTANCE CLASS	SPECIFIC CHEMICAL	LIMIT – IN DIRECT CONTACT WITH SKIN	LIMIT – NO DIRECT CONTACT WITH SKIN
Aldehyde	Formaldehyde	75 mg/kg	300 mg/kg
Extractable heavy metals	Antimony	30.0 mg/kg	30.0 mg/kg
	Arsenic	1.0 mg/kg	1.0 mg/kg
	Cadmium	1.0 mg/kg	1.0 mg/kg
	Chromium	2.0 mg/kg	2.0 mg/kg
	Chromium (VI)	< 0.5 mg/kg	< 0.5 mg/kg
	Cobalt	4.0 mg/kg	4.0 mg/kg
	Copper	50.0 mg/kg	50.0 mg/kg
	Lead	1.0 mg/kg	1.0 mg/kg
	Mercury	0.02 mg/kg	0.02 mg/kg
	Nickel	4.0 mg/kg	4.0 mg/kg
Pesticides	Sum of all	1.0 mg/kg	1.0 mg/kg
Chlorinated phenols	Pentachlorophenols	0.5 mg/kg	0.5 mg/kg
	Tetrachlorophenols	0.5 mg/kg	0.5 mg/kg
	Trichlorophenols	2.0 mg/kg	2.0 mg/kg
	Dichlorophenols	3.0 mg/kg	3.0 mg/kg
	Monchlorophenols	3.0 mg/kg	3.0 mg/kg
Phthalates	Sum of all	0.1 mg/kg	0.1 mg/kg
Chemical residues	Aniline	100.0 mg/kg	100.0 mg/kg
	Bisphenol A	0.1 weight %	0.1 weight %
	Phenol	50 mg/kg	50 mg/kg
Chlorinated benzenes	Sum of all	1.0 mg/kg	1.0 mg/kg
Polynuclear aromatic hydrocarbons (PAHs)	Benzo(a) pyrene	1.0 mg/kg	1.0 mg/kg
	Benzo(e)pyrene	1.0 mg/kg	1.0 mg/kg
	Benzo(a)anthracene	1.0 mg/kg	1.0 mg/kg
	Benzo(b) fluorannthene	1.0 mg/kg	1.0 mg/kg
	Benzo(j) fluorannthene	1.0 mg/kg	1.0 mg/kg
	Benzo(k) fluorannthene	1.0 mg/kg	1.0 mg/kg
	Chrysene	1.0 mg/kg	1.0 mg/kg
	Dibenzo(a,h) anthracene	1.0 mg/kg	1.0 mg/kg
	Sum of all	10.0 mg/kg	10.0 mg/kg
Per- or Polyfluoro-alkyl substances (PFAS)	PFOS + analogs	< 1.0 µg/m^2	< 1.0 µg/m^2
	PFOA	< 1.0 µg/m^2	< 1.0 µg/m^2
	PFHpA	1.0 mg/kg	1.0 mg/kg
	PFDA	1.0 mg/kg	1.0 mg/kg
	PFUdA	1.0 mg/kg	1.0 mg/kg
	PFDoA	1.0 mg/kg	1.0 mg/kg
	PFTrDA	1.0 mg/kg	1.0 mg/kg
	PFTeDA	1.0 mg/kg	1.0 mg/kg

Notes: (1) OKEO-TEX® 100 Standard lists many other chemicals; current list is a sample of requirements. (2) Limits of restricted substances applied to mass or area of material.

Two Examples for How Restricted Samples Affect PPE Performance

In mid-2007, a voluntary phase-out of decabrominated diphenyl ether (DecaDBE) fire retardants was initiated by two states and then adopted on a national level by the EPA with the goal of removing the compound from products in 2013. This type of fire retardant was commonly used in a variety of products such as mattresses; it was also used in certain types of PPE. In one application, helmet manufacturers that used DecaDBE transitioned to a suitable alternative flame retardant. However, even though the use of the retardant was less than 1%, it caused changes in impact resistance that required reengineering of the helmet composite to overcome this substitution.

More recently, in early 2021, the EPA issued a final rule to regulate Phenol, Isopropylated Phosphate (3:1) (PIP 3:1) that would prohibit the sale and use of products using this substance. In the realm of firefighter PPE, certain Neoprene-containing materials were affected and replacements were needed, requiring reformulating of the coatings that had once used this substance primarily as a flame retardant.

Applying New Metrics/Systems Testing to Assess Key PPE Characteristics

Fire departments and firefighters look to the independent certification of their gear to NFPA standards as a way of assuring themselves that their PPE meets minimum requirements and will provide levels of safety consistent with their expectations. The governing standard, NFPA 1971, for structural gear, is a comprehensive and incredibly detailed standard that establishes extensive criteria in several aspects of protective clothing and equipment performance. These criteria have evolved over a 50-year period that now spans nine editions. Over that time, the standard's focus has been to find ways to best demonstrate PPE performance against relevant hazards that have been identified by the fire service. This ultimately led to an increasing number of test methods being specified in NFPA 1971 to address both prevailing hazards such as flame/heat exposure and physical trauma as well as account for emerging threats that have included physiological strain in wearing PPE, exposure to bloodborne pathogens and fireground chemicals, and now potentially contamination control. As a consequence, NFPA 1971 is undoubtedly one of the more rigorous voluntary standards for protective clothing in the world.

The need to periodically update NFPA 1971 creates changes that can often transform PPE products and their use when performance criteria and new test methods are added. This evolution of requirements sometimes means reexamining existing testing approaches to determine if they are still valid for appropriately evaluating PPE with methods that are still relevant and precise, and that correlate with observations of field performance or simply adding new evaluation approaches that fill gaps. Many firefighters believe that most clothing items are evaluated as whole items; this practice actually depends on the item and the type of evaluation, because most often testing becomes more difficult in evaluating whole items and the variability of results increase.

(1) Reexamine Existing Test Methods During Each Revision. Technical committees rely on fire service input to identify the hazards of greatest concern and then choose test methods that evaluate relevant PPE that can demonstrate needed levels of protection. As straightforward as this may seem, it is fraught with all sorts of complications. In a lot of cases, test methods that directly simulate the specific fireground hazards may not exist. This often means either adapting an existing test method to mimic relevant fire exposure conditions or creating a new test from scratch. As with products, the technology for testing improves over time. As an example, when the NFPA 1971 standard was first promulgated in 1975 (four years later than its predecessor standard by different number), the sole criterion for thermal insulation was the overall thickness of the composite making up the individual layers of the garment. A heat insulation test method introduced mainly for flame resistant single layer garments was modified to become the TPP test. Based on research at the time (1983-1986), a TPP rating of 35 calories per square centimeter was established as the minimum insulation requirements for garments, which has been the same ever since. Over the years, various arguments have been made to either lower or raise the TPP rating or that the TPP test does not completely characterize firefighter thermal exposures, so other tests such as stored energy have been added to the standard. Currently, the technical committee is evaluating the continued role of the TPP test and considering either alternative or supplemental evaluations (see "A New Approach for Measuring Turnout Clothing Insulation").

Long ago, arguments were made that firefighters could be better protected by raising the TPP ratings for garments. However, increasing protection without accounting for the potential trade-offs for encumbering firefighters is a dangerous principle. For this matter, increased thermal insulation, while better protecting the firefighter, also makes the gear heavier and more stressful. In fact, currently, other than cancer, cardiovascular events remain one of the leading causes of firefighter fatalities. This health condition has often been linked to the physiological strain of firefighting, which in turn can be related to the impact of heavy gear that does not allow heat release from the firefighter's body during periods of activity. In the late 1990s, the total heat loss (THL) test was added to get the fire service to choose more breathable clothing but consider the trade-off between thermal insulation and physiological stress. Now, limitations of the THL test have led to considering another supplemental test to address clothing impact on the firefighter in the form of something called evaporative resistance. This latter test provides a different way to measure how garments allow breathability that contributes to physiological stress in a way that is not accounted for by the THL test.

Other complications can arise over time. One current example is the fact that many garment, hood, and glove tests are performed after multiple cycles of washing. This preconditioning has generally been applied in the form of an old top-loading, agitator-based washing machine that is no longer available, more representative of how clothing is washed today. Moreover, with increased concerns for contaminated clothing and the need for frequent cleaning, the usual five wash cycles that are specified no longer seem relevant and instead should be increased to reflect what typically may be done to clothing over its intended service life. This type of change is important because firefighters expect their gear to continue providing performance at the same minimum levels as when new.

Another reason to reexamine existing criteria is to ensure that the testing technology itself does not become an impediment for product technology to move forward. Even though certain tests are designed to address specific hazards, the difficulty in setting meaningful criteria can be challenging. One such test—the UV light resistance test—was applied to moisture barriers in response to an industrywide failure of a certain moisture barrier technology in 1999-2000. Some within the fire service have concluded that this test may have had unintended consequences on the ability to have a variety of different moisture barrier types. While it is important to address use of UV light exposure as a potential source of degrading clothing materials, a reexamination of how the test is performed is being investigated to prevent artificial restrictions in different clothing material technologies.

(2) Identify/Validate New Tests and Criteria to Fill Gaps in PPE Performance. In other parts of this supplement, suggestions have already been made for adding new metrics for evaluating firefighter PPE for new areas of concern. Three specific areas warrant further attention:

In NFPA 1851, independent service providers are evaluated for their ability to have effective cleaning of outer shell materials. These criteria extend to heavy metals and certain semivolatile organic chemicals where at least 50% of the applied contamination must be removed by the ISP's procedures for advanced cleaning. A proposal has been made that analogous procedures should be

A New Approach for Measuring Turnout Clothing Insulation

BY BRIAN SHIELS, ARCWEAR

The currently used thermal insulation tests for PPE fabrics are limited in the information that they provide end users on the protective value of the fabrics and fabric systems ("composites"). These tests measure heat transfer through PPE fabrics and composites using different forms of heat exposure and specimen orientations while providing various types of results and information that can be related to protection. In the evolution of NFPA 1971, multiple tests have been established for setting the minimum requirements of turnout clothing in terms of protection from flame and heat. New testing technology has just recently become available to further advance this evolution of thermal insulation measurements.

The TPP test was first developed in the early 1980s and became the mainstay method for evaluating multilayer garment composite materials for thermal insulation in turnout gear since the 1986 edition of NFPA 1971. Since then, the TPP test has become the most widely used bench-scale test for defining minimum insulative performance of different firefighting applications as well as for worker protection against industrial flash fires. In NFPA 1971, the application of the TPP test has also been extended to helmet ear cover composite, hood composite, garment wristlet, glove composite, and glove wristlet materials, each with varying minimum performance requirements.

The TPP test uses a flat 6-inch x 6-inch fabric composite specimen and a single calorimeter, mounted in a weighted sensor assembly resting on top of the specimen to measure the amount of heat energy transfer, which in turn is used to determine the protection value for PPE fabrics. These specimens are subjected to an exposure of 84 kW/m^2 (2.0 cal/cm^{2}sec), representative of a flash fire or an emergency fireground condition, which is produced by the combination of two angled Meker burners and a bank of radiant lamps that are positioned below the horizontally mounted composite specimen. The specimen is exposed to this combination of convective and radiant heat until the sensor registers that sufficient heat has transferred through the composite that would cause a second-degree burn injury. Because the prediction of a second-degree burn injury will vary with the insulation provided by the composite, the exposure time varies for each composite. Nevertheless, the time to a predicted second-degree burn injury is used to calculate the TPP rating as the principal output of the test when multiplied by the exposure energy of 2.0 cal/cm^{2}sec. For structural firefighter protective clothing, garments and gloves are required to have a TPP rating of 35.0 cal/cm^2 while interface components such as garment wristlets, helmet ear covers, hoods, and glove wristlets are required to have a TPP rating of 20.0 cal/cm^2.

Although the TPP test has been used for structural firefighting protective clothing for nearly two decades, there are certain aspects of the test, like placing the full weight of the sensor directly on the test specimen, which can cause the test to overlook important fabric properties, like fabric shrinkage from heat and flame exposure, that have a significant impact on the thermal protection offered by PPE fabrics. For example, it is well known that glove composites with a leather outer shell "wrinkle" because of localized shrinkage from the intense heat exposure, and these wrinkles create air gaps between the glove shell and lining materials that result in artificially high TPP ratings. This type of predicted performance is contrary to what is observed in the field where firefighters facing emergency fireground conditions generally observe gloves to shrink, which should result in lower levels of thermal insulation. Shrinkage in the TPP test falsely adds insulation, whereas circumferential shrinkage in garments or gloves eliminates protective insulation—an exact opposite performance characteristic. There have also been other cases where material systems "fool" the TPP test by expanding in the high heat exposure and drooping toward the heat source from gravity, which also causes an increase in the air gap between the moisture barrier and outer shell, resulting in elevated TPP ratings that are not reflective of field experience.

The orientation and assumed shape of the composite specimens in the test can also be a concern for the TPP test. The horizontal position of flat fabric specimens in the TPP test with heat exposure from below the specimen is also not reflective of how garments and other protective clothing elements are worn. The human body more closely resembles a combination of cylinders (e.g., arms, legs, torso, etc.), rather than a group of flat planes. The flash fire manikin test, which is the most widely used full-scale test for PPE fabrics and as-sold industrial flame-resistant garments for thermal protection, makes use of a manikin form and more than 120 thermal energy sensors distributed around that manikin. However, the test is very expensive to run, and differences in garment construction and manikin form can lead to variability among test results. Its application to structural firefighting garments has been limited for these reasons as well as an inability to relate manikin results to composite ratings. This lack of correlation is significant because the manikin is presumed to be more realistic in comprehensively assessing the thermal insulation provided by garments under emergency fireground conditions.

The flash fire cylinder is a new bench-scale thermal test that aims to provide new and intermediate information between the TPP and manikin tests to provide a bridge to the knowledge gap that is currently present between these two tests. The test exposes a PPE test specimen (in the form of a sleeve that fits around a vertically positioned cylinder) to a uniform flamefront that produces an average heat flux of 84 kW/m^2, the same intensity as both the TPP and manikin tests. A total of 15 thermal energy sensors on the cylindrical form measure the heat that is transferred from the flames through the test specimen. This transferred energy data is compared to the incident energy data collected during the system calibration; the resulting value is called the Energy Ratio Value (ERV). This ERV has already shown to provide a repeatable test metric and offers much promise as a test method capable of predicting field performance of garments. The flash fire cylinder is capable of providing percent burn injury prediction as well, but the digital burn/no-burn nature of the result leads to imprecision with only 15 thermal energy sensors. The ERV provides a continuous spectrum of heat transferred through the specimen relative to the incident energy and proves to be much more informative about the actual protective properties of the specimen under test.

Test Apparatus for New Flash Fire Cylinder Method

This proposed new test method allows for repeatable bench-scale evaluations of flash fire protective performance of materials used in construction of multilayer protective garment composites, wristlets, helmet ear covers, shrouds, and hoods, including single layer knit hoods that are worn in contact with the skin. The TPP test only assesses the response of flat samples of composites continuously exposed to flash fire conditions of a combined convective-radiant heat flux of 84 kW/m^2 until a burn injury criterion is met, failing to account for heat transfer that occurs after the flame exposure ends. In contrast, the flash fire cylinder uses data acquisition software that calculates the total accumulated energy that passes through the material specimens both during a 10-second exposure duration and a data acquisition period that extends 120 seconds or more and presents the data in an easily readable report. It is believed that these results provide a more reliable indicator of how fabrics may perform as full clothing items.

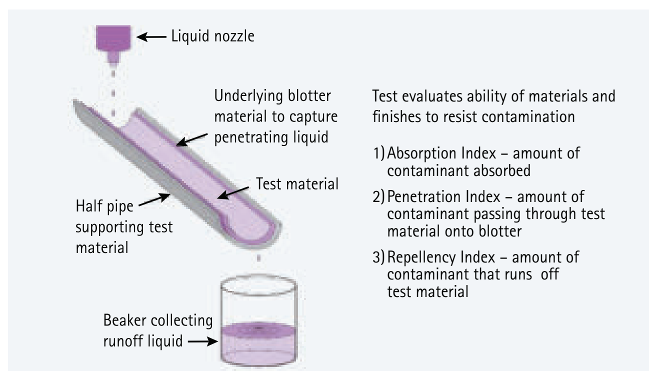
In addition to the flash fire cylinder, the device can be easily interchanged for an instrumented hand form (flash fire hand, or FFH). For the first time ever, this allows for evaluation of whole glove products for thermal insulation protection from flash fire exposures, using the same principles as the FFC. The FFH includes 10 thermal energy sensors, three each on the palm and back of the hand and two each on the wrist and forearm.

Initial testing has measured the energy ratio value for 30 turnout clothing composites. Comparison of these results with the TPP ratings for the same material systems shows that there is little correlation between the results of the two tests, indicating that the flash fire cylinder test provides different information than the TPP test. The new method is in the process of becoming a standardized method through ASTM International, and further work is expected to inform the NFPA technical committee for its possible inclusion within NFPA 1971 to supplement current TPP requirements.

performed on different materials used in the turnout clothing for information purposes so that in addition to other relevant properties, material choices can be based on how easily contamination is removed.

Historically, outer shell materials have been evaluated for their resistance to water absorption. This stems from several concerns that clothing can become waterlogged, significantly increasing its weight and causing additional physiological stress; wet clothing can lead to steam burn injuries under certain conditions where the pickup of water in the clothing composite can change the way heat transfer occurs. With concerns over gear contamination, there is an absence of understanding for how well these same outer shell materials repel various liquids that can be contacted on the fireground. Existing tests such as ISO 6530, if properly adapted, can evaluate whether chemical runoff (showing repellency) is retained by the outer layer (showing absorption) or passes through the outer layer to underlying layers (showing penetration) as shown in Figure 8. These liquids not only give rise to potential secondary contamination that may be difficult to remove but also can cause other hazards such as when oil absorbs into a shell material, is not effectively removed, and causes a flammability hazard for the firefighter wearing the clothing.

Figure 8. Proposed Test to Measure Turnout Gear Repellency to Different Fireground Liquids



Another new area of interest is how much of the finishes and other chemicals that may be within clothing materials can leach out under fireground conditions. Firefighter clothing is subjected to relatively harsh conditions involving exposure to high heat, UV light, wet conditions, abrasion to ordinary wearing, and repeated flexing. It is important for firefighters to know how clothing materials break down and if the constituent breakdown products can be a source of additional hazards when the clothing is worn. This proposed area intends to address that issue and set limits for any substances of concern.

(3) Judiciously Implement Systems Testing to Address PPE Integration and Interoperability. PPE performance tests are aimed at several relevant properties and designed to demonstrate protection within acceptable levels. These tests may be applied to the complete element, subassemblies or portions of the element, or individual materials or components that make up the element. For example, a number of the requirements applied to helmets are conducted with complete helmets, as it is the "test item" where the entirety of the product has to collectively function to provide protection (such as the attenuating energy from an impact caused by an object falling on the firefighter's head). Similarly, several footwear and glove tests are performed on whole items. However, for garments (coats and pants), there are only a couple of requirements that assess the full item. Currently, these tests include the overall liquid integrity test, the DRD function test, and optional requirements for a particulate inward leakage for the full ensemble.

For garments, testing tends to focus on materials, components, and assemblies because this approach makes the testing more manageable and accommodates manufacturers offering a greater diversity of options and features. Tests on flat materials or simple components are simpler to perform and can be more easily interpreted. For example, it is a lot easier to measure the strength of a material by pulling a cut rectangular fabric specimen in a testing machine until it breaks than it is to test the same piece of material while sewn into a protective coat. Test samples can be routinely prepared from rolls of material instead of being taken from finished products. This approach to testing also permits more consistent results and allows manufacturers to evaluate a variety of materials, material systems, and garment features. The firefighting protective clothing industry uses many outer shell, moisture barrier, and thermal barrier materials that collectively can yield hundreds of different combinations. A material and component testing methodology permits garment manufacturers to share costs by having the material and component suppliers provide the relevant testing for certification purposes.

In contrast, overall product or systems testing is harder to perform and is more expensive. Garments are relatively complicated products to test for a number of reasons. The items involve many materials and potential options and features, whether styling, pockets, trim type, closure systems, and several other options. This complexity of the design creates variables in testing that lead to less precise results (more scatter in the test data). When testing is performed with the garments placed on a person or manikin, testing becomes more variable because of fit issues and how individual movements may affect tests. Certainly, tests that consume full garments are also much more expensive than individual material or component tests as the cost of a full garment includes all materials, components, and the garment's assembly.

Nevertheless, there are some types of performance properties that simply cannot be assessed without full product testing. For many years, criteria existed in NFPA 1971 that dictated to the manufacturer that the garment had to be designed to afford complete thermal and liquid protection. It was relatively straightforward to consider continuous thermal protection full layering materials on the individual firefighter. Gaps in these areas create a potential weak area for the clothing that in turn makes the firefighter more vulnerable. Compliance with this criterion (continuous thermal protection) could be demonstrated by a thorough examination of the clothing through a full manikin-based thermal exposure test. However, liquid protection was more difficult to determine through an inspection of the clothing design. The overall liquid integrity test was introduced in NFPA 1971 during the 1997 revision to address overall garment liquid protection and overcome the shortcomings of a design requirement. The test, often referred to the "shower" test, involves subjecting sample protective clothing items to a liquid spray exposure to assess the overall liquid protection provided by the garments.

More recently, an optional test for evaluating whole firefighting ensembles, including SCBA, for inward leakage by particulates was put into the 2018 edition to allow the measurement of smoke infiltration for exposing firefighters to potentially dangerous soot particles. This inclusion demonstrated the difficulty of applying a full system evaluation because only by wearing all the very specific ensemble elements could the measurements be made. Yet by having a single system, the results were not translatable to other similar ensembles. Efforts are underway to examine more practical ways by which these assessments can be made given their relative importance for demonstrating effectiveness of interfaces between garments and other ensemble elements.

To date, many areas of overall ensemble testing have not been adequately addressed. Multiple testing approaches can be applied to full ensembles that assess integration for thermal protection and physiological impact on the firefighter. The Textile Protection and Comfort Center at North Carolina State University (NC State TPACC) has undertaken a large number of research projects that have examined full product testing that include manikin-based evaluation. For example, in one study, NC State TPACC found that areas of thermal insulation radically varied over the ensemble, particularly in garments, because of all the design features, including pockets, reinforcements, and trim, that show that protection dramatically changes with each part of the ensemble.[15-16] This research and testing group has further extensively studied the physiological impact with sweating manikins that are also capable of measuring differences in product designs and material choices.

(4) Ensure PPE Is Comprehensively Evaluated for Relevant Properties in a Balanced Way. The complexity and uncertainties of the fireground environment are ever changing and potentially present a multitude of hazards. Because of these factors, finding the right set of metrics for judging acceptability of criteria to establish minimum performance is daunting but also points to the need to maintain a balance among different protection needs. As already pointed out, increased thermal insulation comes at the expense of physiological stress and vice versa. When additional properties are added to this "mix" of requirements, the trade-offs become exceedingly more difficult to judge. The determination of the right balance must account for fire service protection needs, available product technology, and industry pragmatism, all of which should use comprehensive science and validation steps to set the appropriate limits. Multiple organizations are involved in taking this direction. An example of this approach is embodied in other programs at NC State TPACC as described by Dr. Bryan Ormond in "Protection and Contamination: Understanding the Role of the Turnout Ensemble in Firefighter Cancer Prevention."

Protection and Contamination: Understanding the Role of the Turnout Ensemble in Firefighter Cancer Prevention

BY DR. BRYAN ORMOND, NC STATE UNIVERSITY-TEXTILE PROTECTION AND COMFORT CENTER

Firefighters are continuously exposed to a myriad of cancer-causing agents in the smoke, soot, and other chemicals found on the fireground as well as those contaminants and hazards on or within their protective equipment. Regarding firefighter exposure to contamination, it is important to recognize the turnout ensemble's role in balancing the protection it provides while also being a source of contamination itself.

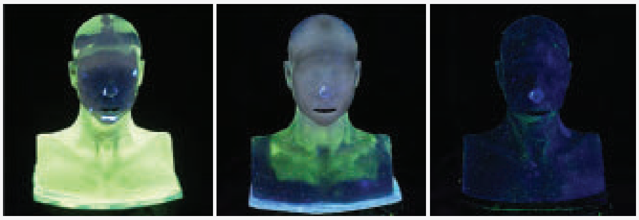
Recent research has focused on reacting to the contamination that occurs in PPE by identifying chemicals and their concentrations within the gear, enhancing cleaning methods to remove contamination post-response, and redesigning the turnout ensemble to block smoke and soot from reaching the firefighter's skin. Most of these studies have concentrated on reducing exposure to the more obvious external threats from the fireground. This external contamination includes particulate matter and toxicants found in smoke from structural fires as well as chemicals that are present in the fire environment such as cleaning products, industrial chemicals, fluorinated repellents, and flame retardants. It has been shown that many of these toxicants and particulates are being captured on the surface and within the structure of the turnout's outer shell, moisture barrier, and thermal liner as well as the surface of hoods, gloves, helmets, boots, and SCBA. Although this external contamination is undeniable, now attention is also rightfully being given to the less obvious internal hazards inherent to the manufacturing of the gear, such as the persistent and bioaccumulative PFAS, which are used as water and oil repellents as well as within the moisture barriers themselves. This type of potential exposure hazard is inherently different from the fireground contamination, as the manufacturing finishes are applied to impart a desired functionality to the ensemble. However, it is critical that this functionality cannot be included at the expense of potential unnecessary exposure to the firefighter.

Particulate-Blocking Hoods: An example of PPE Providing Protection from Contamination. Over the past six years, protective hoods have undergone a significant change with the introduction of particulate-blocking hoods. In 2018, NFPA 1971 was revised to include performance requirements and test methods for these new products. From the two initial hoods that were displayed at FDIC International in 2016, there are now more than a dozen options that range across manufacturers, fiber types, composite construction, design, fit, and particulate-blocking mechanism. Although it may appear like the market has a vast array of options available for firefighters to evaluate, when focused on the particulate-blocking technology, there are basically two main options that all current particulate-blocking hoods employ: a PTFE-based membrane layer or an inherently flame-resistant nonwoven filtration layer.

To provide perspective on the differences in protective performance of traditional and particulate-blocking hoods, the hoods can be evaluated through the fluorescent aerosol screening test. The images in Figure A show the results of this type of test for a headform with no hood, a traditional hood, and a particulate-blocking hood. All three conditions were tested with an SCBA face piece and firefighter helmet. With the "no hood" condition serving as the baseline and being the most exposed and least protected, the traditional hood provided a factor of ten times the protection, and the particulate-blocking hood added another factor of ten, or 100 times the protection of not wearing a hood. From a particulate-blocking perspective, these new hoods all provide significantly increased protection compared to their traditional counterparts. However, it is necessary to understand the performance trade-offs that may exist with different hood constructions and designs.

In 2016, a three-year research project was awarded to NC State University by the Federal Emergency Management Agency (FEMA) Assistance to Firefighters Grant (AFG) Program. This project's main purpose was to conduct a holistic assessment of firefighter protective hoods and compare the thermal protection, thermal burden, and particulate protection across hood types. Although a significant focus is on particulate protection and soot deposition, the main concern with these is the chronic, long-term hazards. From a trade-off perspective, it is also equally important to ensure that the hoods continue to provide protection from the high-intensity acute exposures to thermal threats. One of the key findings of the NC State study was that both traditional and particulate-blocking

Figure A. Fluorescent Aerosol Screening Test



No Hood | Traditional Two-Layer Knit Hood | Particulate-Blocking Hood

Note: All were tested with an SCBA face piece and traditional firefighter helmet. The brighter the yellow/green areas, the more particles were able to reach the skin of the headform.

hoods provide significant thermal protection when worn appropriately and in conjunction with the helmet, respirator face piece, earflaps, and jacket. Figure B shows the difference in damage to the hood when it is worn with and without the additional head equipment and tested on the PyroHead™ flashfire exposure manikin. A key takeaway here is that wearing the hood along with the helmet (earflaps down), SCBA face piece, and turnout jacket provides a high level of thermal protection to the firefighter.

The generally accepted relationship with protective clothing is that when you increase thermal protection, you decrease the thermal comfort, and vice versa. It is also well understood that when additional layers are added to a composite, the amount of thermal energy that can transfer through the layers decreases from the increased insulation of the additional trapped air layers. This means that going from a two-layer traditional knit hood to a three-layer particulate-blocking hood is expected to increase the thermal protection and negatively impact the thermal comfort of the hood.

Figure B. Hood Damage Comparison

Comparison of damage in a seven-second flash fire exposure in the hood only configuration (left) to a 12-second flash fire exposure with the full head ensemble (right) with helmet (earflaps down), SCBA face piece, and turnout jacket.

An interesting comparison can be made when looking at the ways in which manufacturers have constructed their particulate-blocking hoods. Some manufacturers opted to add the particulate-blocking layer as a third layer between the two outer knits, while other manufacturers decided to replace the inner knit layer with the particulate-blocking layer and effectively maintain the two-layer construction. In side-by-side evaluations, the two-layer particulate-blocking composites maintained a similar, although slightly lower, thermal protection compared to their traditional two-layer counterparts. By replacing the thicker knit layer on the inside with a thinner membrane-based blocking layer, the composite has less overall insulation. This change also resulted in higher total heat loss values for the two-layer particulate-blocking composites compared to the traditional hoods, which would theoretically mean that these particulate-blocking hoods should provide similar thermal protection and increased heat loss, all while providing near 100% particulate protection.

Contamination Resistance: The Turnout as a Source of Exposure. Firefighters need equipment to protect against exposure to chemicals, bloodborne pathogens, smoke, and penetration of water from fireground sources. As with hoods, new particulate-blocking turnout ensembles effectively block particles from getting to the firefighter's skin. However, those toxic particles don't just disappear; they collect on the surface and within the fabric structures where they can become a source of exposure. In addition to these fireground sources of contamination, turnout ensembles incorporate materials and treatments in their construction that contain potentially hazardous substances. Traditionally, turnout outer shell fabrics have been finished with versions of PFAS water and oil repellants, and fluoropolymer moisture barriers are used to inhibit penetration of liquids while offering enhanced levels of breathability. Recently, firefighters have led an intense effort demanding more accountability and transparency from organizations and manufacturers regarding the chemicals used in the production of their PPE. Although fluorine-free finishes are emerging, these alternatives need to demonstrate acceptable levels of protection, functionality, and in-use durability.

To improve firefighter health and safety, we must better understand the balance between how requirements for contamination resistance may impact firefighter exposures to hazardous products and how contamination may impact other performance metrics such as transfer of thermal energy. A more thorough understanding of this balance will provide the information necessary for firefighters to conduct risk assessments considering the costs and benefits of altering contamination resistance measures in their gear, such as increasing or decreasing oil or water repellency. Additionally, by incorporating this information in the NFPA standards, we can ensure that firefighters have access to ensembles that meet their needs and priorities.

In 2021, NC State University was awarded a three-year FEMA AFG research grant to thoroughly evaluate this issue of contamination resistance in turnout gear. Most of the research studies on PPE contamination have been reactive in nature, meaning that they have been mainly focused on reacting to the issue of contamination in PPE and on the fireground. However, it is time now to shift this focus to more proactive measures—to conducting research looking beyond how we handle contamination in gear and looking toward setting requirements that inhibit the gear from being contaminated in the first place. For this proactive research path to be taken requires a critical and independent evaluation of the NFPA 1971 and NFPA 1851 standards to delicately balance three essential factors: (1) the need to provide an essential level of inherent contamination resistance; (2) the need to maintain overall protective performance, usability, and durability; and (3) protecting the firefighters' health must be paramount regardless of whether the hazards are coming from the fireground or from the technologies used in the gear to achieve the desired level of performance.

The major outcome of this research will be a thorough and impartial scientific evaluation of the impacts that different levels of contamination resistance measures have on the ability to limit firefighter exposure to contaminants in or on the surface of gear and the protective performance and functionality of the turnout during its use-life. The main contamination resistance measures of concern for the research are fluorinated vs. fluorine-free treatments and materials, and since turnout gear is only new the first time it is used, this evaluation will also focus heavily on the durability of the contamination resistance measures following realistic aging of the materials to laundering, heat, and ultraviolet light. The knowledge gained from this research will be directly applied to revising the NPFA 1971 and 1851 standards to introduce appropriate contamination resistance measures to ensure firefighter protection from exposure to toxic substances is weighted equally alongside thermal protection and thermal burden.

Updating Cleaning/ Decontamination Practices and Expectations

NFPA 1851 was comprehensively transformed in late 2019 where requirements for cleaning turnout gear were significantly revamped with the comprehensive changes for all aspects of gear cleaning and decontamination and the installment of verification procedures for ISPs, organizations, and manufacturers that regularly clean gear. It has now been two years since those requirements were put into place. An assessment of how the industry has responded to the new standard is telling for how the fire service is embracing the new practices and placing an emphasis on keeping clothing clean.

(1) Treat PPE Contamination and Cleaning More Meticulously. The most important change to the 2020 Edition of NFPA 1851 affecting the fire service was the establishment of a systematic approach to cleaning and decontamination. This change embodied several new practices that included the following:

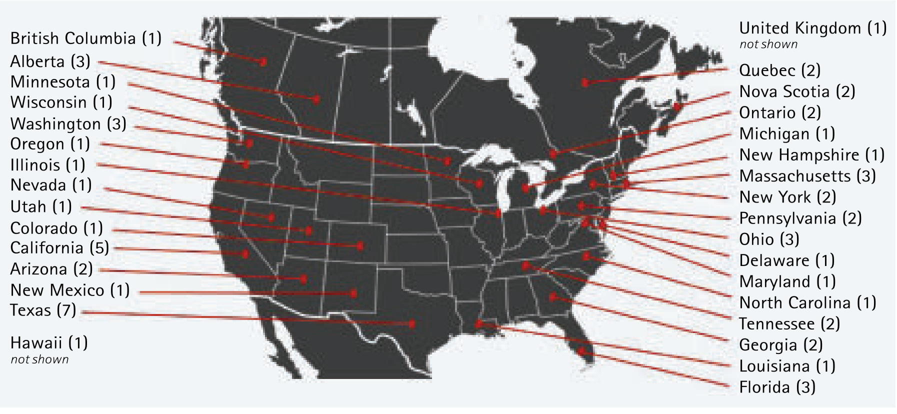
- Defining entry of fire structures (where SCBA is required) as exposure to products of combustion.
- Equating products of combustion as contamination warranting advanced cleaning of gear.
- Separately defining sanitization and disinfection, where sanitization is applied to soft goods with porous materials like garments, hoods, gloves, and some footwear while disinfection is applied to hard surfaces, each having different expectations for killing or neutralizing biological contamination.
- Differentiating between advanced cleaning and disinfection/sanitization, which kills or neutralizes pathogenic microorganisms associated with blood/body fluid or other biological exposures (such as contact with contaminated flood water) but not the removal of soils associated with these exposures, where disinfection and sanitization must be followed up with advanced cleaning or included as part of advanced cleaning.
- Better distinguishing specialized cleaning as addressing unique contamination hazards with the identification of recommended procedures for some unique contaminants that the fire service often encounters (e.g., asbestos, opioid drug residues, and bed bugs).

Probably some of the more useful information to the fire service also came in the vastly expanded guidance that is included in the annex. This includes recommendations on how to undertake specific cleaning procedures of more difficult-to-clean items such as helmets, gloves, and footwear. There are also details given for how to select an appropriate washing machine; set the correct load size; and apply a default, validated set of advanced cleaning and sanitization procedures for garments. This guidance further provides advice on how to select a garment sanitization approach and determine if advanced or specialized cleaning of gear is possible for difficult-to-remove contamination. Overall, the comprehensive annex is perceived as a tool for informing the fire service on better approaches for cleaning and decontamination.

Information coming back from the fire service is generally showing positive results for how these new requirements and practices are being put into place, though it is recognized that several departments still struggle to have the necessary resources to frequently clean their gear and address cleaning of the more problematic items such as helmets, gloves, and footwear.

(2) Make "Preliminary Exposure Reduction" the Rule, Not the Exception. One of the other significant additions to NFPA 1851 was the establishment of "preliminary exposure reduction" as a mandatory on-scene practice for starting the cleaning process, which is to be done before advanced cleaning or nearly every type of decontamination. It has helped that some of these practices evolved from the analogous "gross decon," which had been a mainstay for hazardous materials operations. Yet, this practice had already been seeing acceptance among many fire departments in recent years. A 2020 Fire Protection Research Foundation survey found that 80% of the 350-plus respondents indicated that their department had implemented some form of preliminary exposure reduction. NFPA 1851 helped to standardize some of these practices by setting minimum requirements for dry or wet mitigation techniques but more importantly points out some of the different options, values, and limitations of these procedures. As with advanced cleaning and forms of decontamination, guidance in the annex of NFPA 1851 framed these procedures and described the needed resources and considerations for their implementation as part of the department's standard operating procedures for emergency scene operations (similar changes that were made in NFPA 1584). These procedures are represented as valuable because they remove surface contamination that in turn lowers the chances for cross-contamination and makes for safer, later handling of gear. Nevertheless, it does often result in the garments having to come out of service with the need for spare gear. There are also considerations for applying these techniques under cold

Figure 9. Specific Verified ISP, Cleaner, and Organizations in North America (as of October 2021)



temperature conditions and other factors for applying preliminary exposure as defined in the NFPA 1851 guidance.

Overall, with supporting research studies that show high removal rates for wet-based techniques as well as reduced skin absorption of hazardous substances when fully implemented, preliminary exposure reduction is becoming a principal part of the PPE care philosophy for the fire service. Its fuller use is expected to yield reduced secondary contamination exposures for firefighters that hopefully will eventually manifest in reduced rates of long-term health problems for the fire service.

(3) Strive to Use Verified Organizations and Processes for Advanced Cleaning and Sanitization. One of the last principal changes to NFPA 1851 was the wholly new addition of cleaning verification. Before the 2020 edition of NFPA 1851, ISPs, which clean, inspect, and repair gear, were required to be "verified," where verification was akin to gear being certified—an outside certification organization assures that the service provider (or manufacturer) meets all the applicable requirements of the standard. While the efficacy of service provider repairs to gear were evaluated and audited, there were no analogous criteria for cleaning. This meant that there was no way to ascertain that cleaning was indeed effective.

In the new edition of NFPA 1851, specific criteria and procedures developed by the Fire Protection Research Foundation under a Department of Homeland Security Assistance to Firefighters Grant for research were incorporated into the standard. These procedures include "doping" representative garment outer shell material samples with specific known amounts of pertinent chemical and biological contaminants, placing these samples into surrogate clothing, subjecting the clothing and samples to the cleaning or sanitization process at the respective service provider facility, and then evaluating the contaminated swatches for levels of remaining contamination. By comparing levels before and after cleaning, the percentage of removal is determined for each applied chemical or biological substance.

These procedures specifically targeted ISPs, gear manufacturers that offer cleaning, and departments that wanted to be qualified. The category of a verified cleaner was also established as an organization verified in advanced cleaning and sanitization only. Since the standard came out in late 2019, there are now more than 60 organizations that have been verified to the new cleaning and sanitization requirements in NFPA 1851. These service providers are distributed throughout the United States and Canada (as shown in Figure 9). As both a firefighter and operator of a verified organization, Jeff Knobbe shares his experience for the verification process specified by NFPA 1851 in "One Fire Department's Experience with NFPA 1851 Cleaning Verification."

Specific ISPs can be identified through the listing of the two certification organizations that carry out the

One Fire Department's Experience with NFPA 1851 Cleaning Verification

BY JEFF KNOBBE, ALAMEDA COUNTY (CA) FIRE DEPARTMENT PPE MAINTENANCE FACILITY

NFPA 1851 was originally created with the organization in mind. The original and current focus is to provide guidance to the fire service on how to properly select, care for, and maintain PPE. While there are requirements for ISPs and manufacturers (for those organizations who use an outside service provider for cleaning and repair), we must never lose sight of the fact that this is a user document meant to be used directly by the fire service. If we do, we have failed the fire service.

Based on my experience building the Alameda County Fire Department PPE care and maintenance facility, and leading us through the verification process, I will focus on the care and maintenance portions of the standard. Many organizations start their cleaning practice by purchasing a new extractor. They likely have a front-load washing machine in the station and contact the same company they purchase their laundry soap from; that soap may or may not contain ingredients that are inappropriate to use on structural firefighting PPE fabrics, and that supplier may or may not know what is appropriate for firefighting PPE fabric from a detergent or mechanical basis.

Here, I will start with selecting the most appropriate detergent to use in your extractor, then I will share a cleaning process that your organization can follow.

Requirements for Advanced Cleaning. Keeping the focus on organizations, the current edition of NFPA 1851 (2020) established requirements that allow an organization to be verified for advanced cleaning (chapter 11) to the same requirements that are applied to a verified ISP or cleaner. To successfully pass the semivolatile organic compounds portion of the testing, you will need to have a cleaning efficiency of ≥ 50% average of all compounds listed below:

1. Acenaphthene (CAS No. 83-32-9).
2. Anthracene (CAS No. 120-12-7).
3. Diethyl phthalate (CAS No. 84-66-2).
4. Di-n-octyl phthalate (CAS No. 117-84-0).
5. Fluorene (CAS No. 86-73-7).
6. Phenanthrene (CAS No. 85-01-8).
7. Pyrene (CAS No. 129-00-0).
8. 2-Nitrophenol (CAS No. 88-75-5).
9. Phenol (CAS No. 108-95-2).
10. 2,4,6-Trichlorophenol (CAS No. 88-06-2).

To successfully pass the heavy metals portion of the testing, you will need to have a cleaning efficiency of ≥50% average of all compounds listed below:

1. Antimony.
2. Arsenic.
3. Cadmium.
4. Chromium.
5. Cobalt.
6. Lead.

Controlling Factors for an Effective Advanced Cleaning and Sanitization Process. To ensure that you have the most correct process, there a few keys areas you need to focus on setting this up. I refer to these as the four Ps:

(1) Select Proper [Cleaning] Products. In determining what detergent and cleaning agents will be most appropriate to use during the advanced cleaning process, NFPA 1851 identifies only a few areas with which need to be familiar:

- The pH range of the detergent must be between 6.0 and 10.5. The pH can be found on the product safety data sheet (SDS) or the original product container. You will notice that many manufacturer labels indicate a pH range of 7-10. This is important because if you use a product during your wash cycle that has pH that is too low (considered overly acidic with a pH of 6 on a scale of 1 to 14) or too high (highly alkaline with a pH above 10.5), then you could be inadvertently damaging your fabric. The farther you move away from a neutral pH of 7, you run the risk of possible degradation to the aramid fibers. In fact, literature from DuPont, the provider of Kevlar fabrics, indicates just how dramatic the impact of low or high pH can have on Kevlar breaking strength. This can be even more evident if your wash process has inadequate rinse cycles.
- Chlorine bleach, chlorinated solvents, or solvents CANNOT be used on PPE without the ensemble or ensemble element manufacturer's or verified ISP's approval. Additional information in the same DuPont Technical Bulletin for Kevlar shows how using sodium hypochlorite (bleach) left as little as a 0.1% concentration without rinsing, and leaving at 70°F for 1,000 hours (41 days) would degrade the aramid fiber by as much as 81%-100% of the original strength. In this scenario, fabric containing this type of aramid fibers will most likely tear like a wet paper bag.
- An organization CANNOT use detergents or cleaning agents that knowingly cause significant long-term degradation of the ensemble or ensemble elements.

Earlier this year, I assisted one of our local fire departments to better understand the process of reviewing potential detergent products and their wash process, with the results shown in the box on the next page.

(2) Put Together a Proper Process. To accomplish this, you have to load the optimum number of garments, use the correct temperature, and apply the right series of steps for the best amounts of time in the overall process.

Number of Garments: I first had to figure out how many garments could be loaded into the extractor and still have effective "Mechanical Action." If you overload the machine, you will have ineffective physical "drop" in the garments as the drum rotates. The rule of thumb

For well over 10 years, this department had purchased its extractor cleaning product from the city-approved commercial laundry soap distributor. Without identifying this company, we will take what we have learned so far to see if the products purchased are acceptable to use.

In reviewing the product's SDS, here's what we have:

Product #1

Primary detergent main ingredient:
Sodium hydroxide at a concentration of between 10-30%.
pH level was between 13-14. Maximum allowed pH is 10-10.5.

With this product, we've hit two trigger points:

1. Selected detergent will cause significant long-term degradation of gear.
2. With the pH so far over the maximum, it will cause significant long-term degradation of gear.

Product #2

Fabric softener/sour main ingredient:
None were listed, just says "Mixture." We are not able to determine what's even in it.
PH level 2.1-3.5. Minimum allowed pH is between 6-7.
This product is introduced during the rinse cycles to lower the pH levels used in product #1.
With this product, we've hit one trigger point and one area of concern:

1. pH is well below the minimum allowed.
2. There is absolutely no viable reason to use a fabric softener/souring agent during the advance cleaning process.

At this point, I think we can agree that this product has no business being used on structural firefighting PPE.

has been to not fill the extractor more than ¾ full (e.g., no more than 45 lbs. in a 60-lb. extractor); however, you still need to know how many garments. Many washer/extractors use a "two-way wash." During this process, the drum turns clockwise for a predetermined period, then counterclockwise. To have effective mechanical action while turning clockwise, garments will be carried to the 11 o'clock position in the drum, then dropped to the 5 o'clock position, then to the 1 o'clock position, dropping to the 7 o'clock while turning counterclockwise. Before going through this exercise, I used to wash 12 pieces in a 60-lb. extractor. Knowing this information, I loaded up 12 pieces of gear (six jackets and six pants) in the extractor and watched if I had effective drop. I then repeated this process with 10 pieces (five jackets and five pants), which actually had much better Mechanical Action.

Now, as part of our third-party verification, I needed to indicate what extractor capacity % I intended to use. This is what I put together to calculate the capacity percentage and to verify it was correct. For this, I rolled up a jacket, doing the same to a pant too; taped it into a burrito shape; and weighed our gear on a small food style scale to come up with an average weight per piece. Knowing that I wanted to wash 10 pieces per load, I used the average weight per piece times 10 pieces to come up with 33.6 lbs. To err on the side of caution, I rounded up to 36 lbs. or 60% capacity. By taking the average weight per item (remember to include DRDs for coats and suspenders for pants if not removed and washed separately), you can then determine the number of items that will equate to the capacity percentage you want to apply.

After going through this lengthy process, I came across an article in *Fire Engineering* that identified a good rule of thumb to follow: "One cubic foot of washer/extractor basket allows for one garment shell or liner. For example, a 30-pound washer/extractor has a basket volume of 4.1 cubic feet. Thus, a washer/extractor with this capacity would fit four pieces." This basket or drum volume can be found on your machine's data plate, typically located on the back of the machine.

Below are some common extractor sizes and associated drum sizes seen in the fire service.

Temperature: According to NFPA 1851, advanced cleaning water temperature shall not exceed 40°C (105°F). There are some situations where the standard does go as high as 60°C (140°F). These parameters are covered in chapter 7.5, Specialized Cleaning. These are the maximum temperatures allowed based on current understanding for how high wash temperature affects long-term durability.

Washer/Extractor Drum Capacities

EXTRACTOR SIZE (LBS.)	DRUM SIZE (Cu. Ft.)
40	6.14
60	9
65	9.7
70	9.9
80	12.37
85	13

Time: The series of steps that are part of the process for laundering the clothing items in the washer extractor are known as the "Formula" or "Formulation." Table A.7.3.9 in the Annex of NFPA 1851 provides a suggested wash formula guideline for fire departments to follow. These are repeated in this article. During our cleaning verification process, I used a modified version of this table. I wanted to use the least engineered process. So, any additional processes I added like Prewash, Pretreatment, or Presoaking would only increase the contaminant removal efficiency. During our third-party testing, I did not use a prewash cycle, nor did I use a pretreatment or a presoak process. In addition, I used a minimal amount of detergent, 6 oz. in total. I wanted the product and the process to do the talking. No gimmicks, no snake oil process, just to run what I normally run.

During my lengthy research, I also identified that I still had small particulates (I refer to them as "little floaties") in the recommended third and final five-minute rinse cycle water, so I added a fourth rinse cycle. To not increase the overall rinse time by very much, I reduced the first three rinses from five to four minutes each, with the fourth and final rinse cycle being five minutes. While this did increase the overall rinse cycle time by two minutes, it more importantly introduced an additional 18 gallons of water to rinse any possible "little floaties" in the fourth rinse. I was able to visibly confirm this by observing the appearance of the incoming water to the rinse cycle compared to the outgoing water from each rinse cycle.

Sanitization: With everything else we've gone through, this process was the easiest.

Suggested Default Washer/Extractor Formulations

SUGGESTED FORMULATION FOR GARMENT OUTER SHELLS			
OPERATION	TIME (MIN)	TEMPERATURE	WATER LEVEL
Prewash fill, flush		≤40°C (≤105°F)	High
Agitate	3		
Drain			
Fill		≤40°C (≤105°F)	Low–Med
Wash, add suds/detergent			
Agitate	12 – 15		
Drain			
Rinse, fill/agitate	5	Cold	High
Drain			
Rinse, fill/agitate	5	Cold	High
Drain			
Rinse, fill/agitate	5	Cold	High
Drain			
Extract at 100 G	6		

Note: Wash formulations assume a full load for the washer size.

SUGGESTED FORMULATION FOR GARMENT LINERS			
OPERATION	TIME (MIN)	TEMPERATURE	WATER LEVEL
Fill		≤40°C (≤105°F)	Low
Wash, add suds/detergent			
Agitate	15		
Drain			
Rinse, fill/agitate	4	Cold	High
Drain			
Rinse, fill/agitate	4	Cold	High
Drain			
Rinse, fill/agitate	4	Cold	High
Drain			
Rinse, fill/agitate	5	Cold	High
Drain			
Extract at 100 G	6		

Similar to before, the annex of NFPA 1851 provides a suggested process to follow that includes the following steps that preceded advanced cleaning in the washer/extractor:

1. Fill to a maximum of 35°C (95°F) on low.
2. Inject disinfectant.
3. Wash/soak for 10 minutes.
4. Drain for one minute.
5. Extract on low for four minutes.

(3) Assess the Results. So, we've put together the Four Ps. Now, let's see how we did. First, we're going to review our test results for heavy metal removal. Overall, we had an efficiency average heavy metal removal rate of 83%. I'd say this process worked very well. Next, we went through a similar verification but this time for semivolatile organic compounds. In this case, we had an efficiency removal rate of 53%. While we did pass, we still have a lot of room for improvement. However, these test results are without a prewash, pretreatment, or presoaking. For sanitization, we assessed how much our process was able to reduce levels of two different bacteria, which fortunately showed large-scale reductions of both types greater than the minimums required by NFPA 1851.

Alameda County Fire Department Verification Results (from Underwriters Laboratories)

Results for Heavy Metal Removal

METALS (CONT'D)	12.4
Facility Name	
Cleaning Process	See Ill 2 of Description for Details
DOES THE PROCESS COMPLY WITH THE REQUIREMENTS OF THE STANDARD (YES/NO)	YES

	Micrograms (ug)					Calculated Efficiency (%)				
	Cont. Spec. @ UL	Cont. Travel Spec.	Blank Travel Spec.	Coat Pocket 1 (Blank)	Pant Pocket 1 (Blank)	Coat Pocket 2	Pant Pocket 2	Coat Pocket 3	Pant Pocket 3	Avg
Chromium	1448.19	2145.13	58.25	43.61	44.84	83.68	79.88	77.60	76.42	79.40
Cobalt	1473.45	2113.18	2.44	1.96	2.03	87.81	85.06	78.32	74.26	81.36
Arsenic	1579.81	2248.65	2.42	1.69	1.53	98.19	95.03	94.86	94.75	95.21
Cadmium	1544.34	2280.63	0.44	0.27	0.64	83.72	79.86	72.38	68.86	76.16
Antimony	1513.29	2144.23	13.52	10.18	13.57	90.78	87.83	82.29	86.97	86.97
Lead	1467.70	2151.95	10.18	4.99	8.03	82.69	83.29	69.87	75.08	78.23
Average Cleaning Efficiency of all Contaminants (%)										83
Requirement (%)										≥ 50

Results for Removing Semi-Volatile Organic Chemicals

CHEMICAL DECONTAMINATION EFFICACY TEST – SEMIVOLATILE ORGANIC COMPOUNDS	NFPA 1851-2020, SECTION 12.4
Facility Name	
Cleaning Process	See Ill 2 of Description for Details
DOES THE PROCESS COMPLY WITH THE REQUIREMENTS OF THE STANDARD (YES/NO)	YES

	Micrograms (ug)					Calculated Efficiency (%)				
	Cont. Spec. @ UL	Cont. Travel Spec.	Blank Travel Spec.	Coat Pocket 1 (Blank)	Pant Pocket 1 (Blank)	Coat Pocket 2	Pant Pocket 2	Coat Pocket 3	Pant Pocket 3	Avg
Phenol	5.05	4.60	1.38	1.22	1.16	30.90	87.28	77.14	0.08	48.83
2-nitro phenol	2.41	2.39	2.39	2.33	2.39	89.45	100.00	96.48	0.08	71.48
2,4,6-Phenol	22.26	20.31	1.28	1.14	1.26	98.98	98.80	98.63	98.75	98.79
Acenaphthene	22.14	8.18	0.00	0.00	0.00	86.48	98.57	97.36	85.96	92.1
Diethyl phthalate	22.59	13.12	0.00	0.00	0.00	100.00	100.00	100.00	100.00	100
Fluorene	22.48	2.29	0.00	0.00	0.00	51.64	40.80	61.63	66.21	55.07
Phenanthrene	26.10	0.00	0.00	0.00	0.00	31.97	39.70	30.12	40.65	35.61
Anthracene	26.87	0.20	0.00	0.00	0.00	0.00	26.90	28.38	28.45	20.93
Pyrene	24.09	24.63	0.00	0.00	0.00	7.79	7.31	5.39	4.48	6.29
Di-n-octyl phthalate	26.12	24.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Average Cleaning Efficiency of all Contaminants (%)										53
Requirement (%)										≥ 50

Results for Sanitization Effectiveness

BIOLOGICAL DECONTAMINATION EFFICACY TEST	NFPA 1851-2020, SECTION 12.5
Facility Name	
Cleaning Process	See Ill 2 of Description for Details
DOES THE PROCESS COMPLY WITH THE REQUIREMENTS OF THE STANDARD (YES/NO)	Yes

Klebsiella pneumoniae (CFU)										
Inocculated Culture	Control @ UL	Travel Contro 1	Coat Pocket 1 (Blank)	Coat Pocket 2	Coat Pocket 3	Pant Pocket 1 (Blank)	Pant Pocket 2	Pant Pocket 3	Log_{10} Reduction	% Reduction
38,000	TNTC	TNTC	0	<1*	<1*	0	<1*	<1*	4.58	99.997
Requirement (% Reduction)									≥ 3	≥ 99.9

Staphylococcus aureus (CFU)										
Inocculated Culture	Control @ UL	Travel Contro 1	Coat Pocket 1 (Blank)	Coat Pocket 2	Coat Pocket 3	Pant Pocket 1 (Blank)	Pant Pocket 2	Pant Pocket 3	Log_{10} Reduction	% Reduction
16,500	TNTC	TNTC	0	<1*	<1*	0	<1*	<1*	4.22	99.994
Requirement (% Reduction)									≥ 3	≥ 99.9

In closing, do your research. When a detergent company says that its product has an efficiency removal of 86%, your first question should be, "Which contaminants are you referring to—semivolatile organic compounds or heavy metal? If a detergent company or ISP is making an efficacy claim, you have the right to see these test results. Your second follow-up question should be, "What was your process used to achieve these results—prewash, pretreatment, or presoaking?" As an end user, you should have access to these testing results for the ISP that you use. My department was able to succeed in getting verification, which means that if you follow the steps and are diligent in getting correct information, most fire departments should be able to achieve these same levels of effectiveness.

verifications—Intertek Testing Services (ITS) and Underwriters Laboratories (UL); their individual lists of verified ISPs to the new standard appear on their Web sites at the following links and instructions:

ITS: Direct link at http://intertek.com/nfpa-1851/.

UL: Go to http://productid.ulprospector.com/en; if you have not already joined, follow the instructions to join the application to be able to log in (it is free). After logging in, search for "NFPA 1851." A Dashboard will be displayed that lists the individual companies that are verified ISPs. By clicking on the name of the ISP, more information on the verification, including the address, will appear.

The industry's reaction to and acceptance of the NFPA 1851 requirements is significant in several respects:

Before the 2020 edition, there were 85 verified ISPs (evaluated for repair procedures only). Nearly 75% of the ISPs have stepped up to the new requirements. Some organizations have dropped out for a variety of reasons, including change in ownership, an inability to meet the verification requirements, and complaints of verification costs being too high.

Even though the requirements were set at moderate levels of contaminant removal (50% on average for the different target chemicals contaminants), some ISPs ended up having to modify or improve their procedures to attain these levels. This shows value in establishing metrics to verify cleaning.

Verified cleaning and sanitization procedures established at several different ISPs have been shared with the fire departments through training programs offered by ISPs for promoting effective cleaning at the department or station level. This helps to extend valuable cleaning expertise to the fire service without placing an undue burden on fire departments for the costs of cleaning verification.

(4) Continue to Advance Cleaning Practices for Better Effectiveness and Ease of Use. While significant progress has been made, these efforts are not done. Further work by the Fire Protection Research Foundation is underway that is expected to yield further understanding and improvements in both cleaning and decontamination approaches that will be made available to the fire service through additional future changes to NFPA 1851 (and NFPA 1852 for SCBA). Areas of this research are leading to the following:

- Similar ways to assess cleaning effectiveness for garment liners, helmets, gloves, footwear, and hoods as are currently applied for garment outer shells. It is expected that the methods developed for this purpose may not become mandatory parts of NFPA 1851 but instead provide the basis for manufacturers and ISPs being able to verify optimum cleaning practices.
- Creation of simpler and significantly less expensive testing tools that can enable individual fire departments to check the efficacy of their cleaning practices. With the mandated cleaning verification procedures targeting ISPs and manufacturers, the idea is to have an easier process that departments can use to voluntarily check how well their cleaning works to remove contaminants.
- On-scene methodology by which departments can check and document gear exposures to fireground contaminants. Not all fires are alike, and where it is possible to identify specific contaminants from individual fires, there can be value in then customizing a cleaning approach to achieve the best levels of contamination removal.
- Contributions to the establishment of more comprehensive PPE cleaning practices that allow improved cleaning of hard-to-decontaminate items such as SCBA, helmet suspensions, gloves, and footwear.

The hope is that eventually these practices will all be the "norm" in the fire service, and the threat of secondary exposure from contaminated gear will greatly diminish.

Summary and Future Direction

This supplement has presented a series of findings in several areas related to the design, performance, use, and care of firefighter PPE that are indicated as catalysts for change. Yet, not everyone is likely to embrace changes, particularly when some may think the status quo is okay. Further, there are also the concerns for increased uncertainty. Heading down a new path with new metrics creates an unease related to not knowing how new measurements and requirements will impact existing products, many of which are perceived as having correctly evolved to meet firefighter needs. Some manufacturers are reluctant to sign onto new approaches unless they have confidence that the changes don't adversely impact their products. Firefighters who like their current gear may not be willing to make the trade-offs necessary to embrace changes designed to aid in contamination control—and their organizations may see any increases in costs as hard to justify.

Still, from what we have learned, changes in PPE products and care are inevitable. We must move past any potential obstacles, though, as it is time to revamp how we test and measure firefighting protective clothing to address varying missions and new hazards. The upcoming revision of NFPA 1971 has already begun and will be well underway toward the end of 2021. On top of that revision is the consolidation of several standards into one that will ultimately encapsulate major firefighter protective clothing and equipment, including structural firefighting protective ensembles, work uniforms, SCBA, and PASS. Needless to say, this conglomeration alone may create the incentives to reinvigorate appropriate changes in the new standards. The result could end up shaking up PPE in the fire service and indeed result in a transformation of PPE as we know it today. ■

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