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PPE: Expanding Fire Service PPE Cleaning Practices

New Science Plus a Standards Guide for Appropriate Use and Care of Firefighter PPE

BY JEFFREY O. STULL

THE FIRE SERVICE IS BEGINNING TO embrace a transition in its practices for recognizing the need for contamination control. This subject has become a leading area on which to focus for implementing new practices to improve firefighter health and safety. Key components of this approach are the proper use and care of personal protective equipment (PPE), which enable a level of protection against harmful contaminants and at the same time do not contribute to the continuation of exposure hazards. Thus, understanding contamination and decontamination is important, and it follows that implementing the best procedures for ensuring contamination control with respect to PPE should be based on the evolving science and what can be practically achieved.

"How Clean Is Clean?" (PPE Supplement, *Fire Engineering*, January 2018) initially provided guidance on a series of topics relating to treating structural fires as hazmat incidents, understanding PPE contamination and exposure, beginning contamination control on the fireground, properly triaging PPE cleaning and decontamination, applying appropriate cleaning methods, and assessing/validating cleaning effectiveness. This information was expanded in the 2019 supplement "PPE: Reshaping Contamination Control" *(Fire Engineering*, January 2019), which described new requirements being brought forward in industry standards, examined garment cleaning in greater detail, covered the challenges of cleaning other types of PPE, and reviewed how cleaning verification would impact the fire service.

This 2020 PPE supplement addresses the evolution of fire service practices related to improved cleaning of firefighter protective clothing and equipment with a focus on how new requirements in National Fire Protection Association (NFPA) 1851, *Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*, are already affecting the PPE industry. Other activities that are having an impact include broadening the scope of study to improve current cleaning procedures, better understanding contamination hazards and risks, and identifying decontamination approaches for cleaning items other than the outer shell of coats and pants such as helmets, gloves, footwear, and self-contained breathing apparatus (SCBA).

The Emerging Impact of a Revised NFPA 1851 Standard

The 2020 edition of NFPA 1851 became effective on August 25, 2019, and will forever change the way fire departments and industry address the cleaning of PPE. It marks the fourth edition and a complete overhaul of a standard that was first published in 2001, at a time when the fire service was just waking up to the fact that its gear needed to be washed regularly. The transformation of PPE selection, care, and maintenance in the fire service over this time frame has been significant and has been advanced through the following:

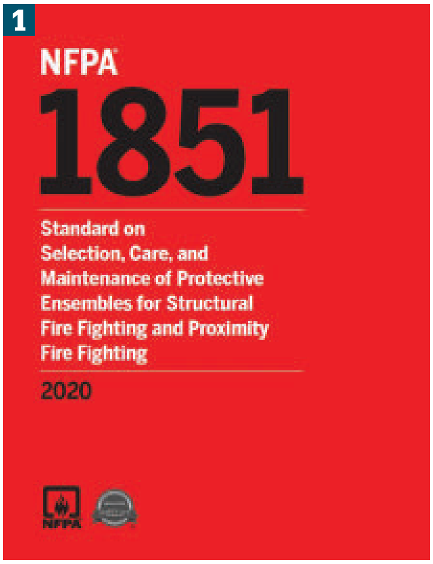
- Strengthening the responsibilities of fire departments and setting requirements to properly select, track, inspect, clean/decontaminate, repair, store, and retire their PPE.
- Establishing specific frequencies for when to carry out specific forms of PPE care and maintenance.
- Separately qualifying outside independent service providers (ISPs) that inspect, clean, and repair fire department gear.
- Providing separate, detailed guidance to fire departments for how to comply with the standard.

Using NFPA 1851 as the Basis for Fire Department Practices

Like all NFPA PPE standards, NFPA 1851 has a one-year grace period, meaning that the new changes in the standard will not become mandatory until August 2020. There is also a one-year grace period for ISPs to become verified to the new cleaning effectiveness and updated repair requirements, described in item 10 below. Unlike the PPE standards, which are applied to manufacturers, full compliance with the NFPA 1851 standard is uncommon for most fire departments, the principal intended audience for these requirements.

Instead, many fire departments attempt to comply with the standard as much as possible within their available resources. Still, some areas of the country, like Texas, mandate that career fire departments follow NFPA 1851 requirements and are inspected annually for compliance. Regardless, it is important to understand the changes that are part of the new edition of the standard and that fire departments should strive to meet these requirements to the best of their abilities so that they can achieve improved contamination control through appropriate PPE selection, care, and maintenance.

Complying with NFPA 1851 does not come without increased burdens on fire departments, many of which are financially strapped for funds to operate properly. Over its history,



(1) Cover of NFPA 1851.

NFPA 1851 has not been without controversy, as it also specifies a 10-year maximum service life for all forms of protective clothing and equipment used by fire departments. An NFPA survey conducted in 2015 showed that 28 percent of U.S. fire departments had at least some gear that was more than 10 years old, which would suggest that some departments struggle to prioritize their responsibility to provide updated gear, much less maintain it. Nevertheless, priorities are changing within the fire service as the mounting evidence strengthens the link between contamination and exposure events and the resulting impacts on health and demands proactive measures for controlling that contamination. Thus, compliance with NFPA 1851, particularly in terms of cleaning and contamination control, becomes a more justified priority for departments as they become aware that their future health and well-being may depend on it.

Understanding the Key Changes in NFPA 1851 for 2020

Although NFPA 1851 had been a maturing standard, the recent focus on fire service contamination control related to cancer and fireground exposure issues created significant modifications to the standard. Below are 15 changes that are considered the most noteworthy in the new edition:

(1) Products of combustion = contamination exposure = require Advanced Cleaning. A fundamental change has been to define exposure to products of combustion as contamination, which always warrants Advanced Cleaning. The new edition presents two flow charts that aid fire departments in how to decide on the appropriate types of cleaning and decontamination. The simple guidance is that if firefighters are exposed to smoke by virtue of having to wear an SCBA and be on air, then they have been exposed to products of combustion and their gear needs to be cleaned. Departments can argue the need for greater flexibility in making this determination, but the reality is that if you can smell smoke, you are contaminated and that the contamination associated with that smoke needs to be removed.

(2) Minimize your exposure on scene. A requirement has been added for fire departments to undertake preliminary exposure reduction (PER), which many in the fire service now call "gross decontamination." Fire departments are required to either rinse firefighters off at the scene while still on air or use dry brushing to remove exterior contaminants, followed by bagging and isolation of the gear for later Advanced Cleaning. It is understood that such procedures may not always be practical, but detailed provisions are included in the annex of the standard with specific recommendations for how the procedures can be applied under different circumstances. A later section within this supplement goes into significantly more detail on this topic and is augmented by a sidebar showing the successful implementation of these procedures combined with measurable impact to the respective department.

(3) Subject PPE to Advanced Cleaning every six months. Advanced Cleaning is now required every six months instead of once per year. This is the minimum frequency for machine cleaning of garments, which may also include hoods and detachable textile components of helmets. Other PPE items (helmet shells, gloves, and footwear) generally are cleaned manually. An increased frequency of thorough cleaning is specified because even soiling, repeated contact with the public, and staging create hygiene and potential contamination issues.

(4) Use the proper equipment for washing garments. Advanced Cleaning of garments must be performed in a programmable washer extractor with a specified maximum acceleration. These washing machines use a special cycle with controlled temperatures, multiple rinse cycles,

(2) Any exposure on the fireground requiring wearing of SCBA is considered contamination and requires Advanced Cleaning. (*Photo courtesy of Honeywell.*)

(3) NFPA 1851 now requires washer/extractors with specific attributes for Advanced Cleaning of garments. *(Photo by Tim Tomlinson.)*

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Progress Achieved: How NFPA 1851 (2020 edition) Impacts the Fire Service

BY TIM TOMLINSON

Great progress is made in the 2020 revision of NFPA 1851, *Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*. The foundation is set for advancement in firefighter contamination reduction, cleaning of personal protective equipment (PPE), disinfection of microbial contamination, and specialized cleaning considerations such as handling asbestos-contaminated PPE and bulk chemicals. We now have the tools to better determine efficacy of the processes, technologies, and formulations used for addressing such exposures. This allows the industry to dig even deeper into these crucial topics and to answer questions. It's time to answer, How do we reduce and remove firefighter contamination? How do we encourage data-driven improved technologies? Processes? Manufacturing improvements? Personal protective clothing?

Significant Overhaul. The NFPA 1851 committee spent significant time, effort, and resources on this revision and was afforded considerable support for research. This facilitated many enhancements and the detailing of sections, making them more understandable and practical. Now, they match pace with the growing risk and health effects surrounding contamination and exposure effects on firefighters. Priority was given to reducing risks within the reality of emergency operations. Additionally, the impact of new or enhanced requirements on the performance and ongoing serviceability of PPE was examined thoroughly. Extensive attention was given to protecting firefighter health and promoting safety within the confines of the technology availability and limited resources of fire departments.

New Definitions. In Chapter 3, considerable effort was put into the definitions in the standard. New definitions were included; others were expanded and revised. This provided needed clarity of the standard. As an example, terms such as "soiling," "contamination," and "exposure" are now clearly defined, minimizing the possibility of misinterpretation and facilitating end users' ability to apply the standard appropriately.

PPE Program Management. Important changes were made to the requirements for fire department PPE programs. This includes vendor standards departments must use should they choose to send out their PPE for cleaning and disinfecting services. A department may use a third-party service provider *only* if the entity is a verified cleaner (representing a new standard category) or a manufacturer-trained organization for the ensemble and ensemble elements owned by the organization. A manufacturer-trained organization is one that has received training from a manufacturer of the same element type as the gear owned by the organization or from an independent service provider (ISP) who has received verification from one of the two verifying labs in the industry. If the training is received from an ISP, the training can be used by any manufacturer of PPE.

Recordkeeping. As part of the program, the list of records a fire department must maintain was revised to include date; reason for; and findings of Disinfection, Sanitization, and Specialized Cleanings in addition to Advanced Cleaning. Previously, only records for Advanced Cleaning were required with respect to cleaning of PPE. As reflected below, extensive language, procedures, and methodology are also included for handling Disinfection, Sanitization, and Specialized Cleaning Exposures, all of which should be documented and included with the records of the PPE for its service life.

Selecting PPE on the Basis of a Risk Assessment. Risk assessment considerations were updated for departments. Departments are to consider response activities and distinguish more specifically the types of incidents requiring response. This allows a department to better determine more accurately the PPE specifications, designs, and performance level needs of its team. We've come to understand that it is easy to get caught up with what another or larger department provides as PPE outfitting for its firefighters, but this may not be what is best for your department. Consider your responses, your risk, and the types of events for which your PPE would be used. Allow this information to guide your specifications on the best-suited selection of PPE.

Cleaning Frequency. Further, with the increased requirement of Advanced Cleaning of PPE twice per year (instead of once a year) and recommendations for cleaning after every exposure, the recommendation of providing members with two sets of ensemble elements should also be considered in your risk assessment. This allows PPE to be cleaned more often and conveniently. Departments should consider what is deemed an exposure: Is it anytime units respond to an incident with ignition? What about a vehicle accident with fuel, oil, dirt, and debris that contaminate your PPE? Language in the 2020 revision of NFPA 1851 reflects that PPE shall be cleaned when soiled or contaminated. What does this mean? Soiling is "the accumulation of sweat, dust, dirt, debris, and other nonhazardous materials on or in an ensemble or ensemble elements." Contamination is defined as "the accumulation of products of combustion and other hazardous materials on or in an ensemble that includes carcinogenic, toxic, corrosive, or allergy-causing chemicals, body fluids, infectious microorganisms, or CBRN [chemical, biological, radiological, or nuclear] agents." Case in point: If the question of whether your PPE should be cleaned enters your mind, clean it.

Care for Barrier Hoods. With the introduction of particulate-blocking hoods in the last revision of NFPA 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*, optional inspection criteria were included in NFPA 1851 (2020 edition), providing fire departments with the means to assess the particulate-blocking layer of these products for ongoing performance. Two options are provided in the standard: a light evaluation or a smoke evaluation. Language for both requirements, procedures, and equipment to perform the evaluations can be found in Chapter 12: "Test Procedures."

Preliminary Exposure Reduction (PER). PER was introduced and replaced routine cleaning in the 2014 edition of NFPA 1851. Common sense informs us that the sooner we remove the exposure, the lower the amount of contamination that can be absorbed. This should start at the incident scene. Do not confuse this with gross decontamination, which traditionally is a hazmat term. PER is a less formal method of washing off products of combustion, soot, ash, dirt, and debris from the PPE at the incident with a garden hose or low-pressure hoseline. You can supplement this process and break down contamination by using a soft bristle brush and a spray-on solution that is safe to use on PPE. Institute this procedure at the incident scene, and set it as a benchmark when exiting interior firefighting operations and prior to reporting to rehab or demobilization. The intent is to reduce contamination from your PPE as soon as possible and lessen the opportunity for cross-contamination of contaminates.

Advanced Cleaning. Extensive efforts were expended in the development of a tool to evaluate the efficacy of Advanced Cleaning processes. The 2020 revision of NFPA 1851 now includes an extensive protocol and testing procedures for determining the effectiveness of individual products or complete systems used for cleaning PPE. The accomplishment of the efficacy protocol allows you to measure the degree of contamination reduction after PPE is cleaned using any variation of detergents, equipment, or applications. This is a major milestone in the cleaning of PPE. Traditionally, the industry depended on individual suppliers' testing, claims, and even opinions for how well we were cleaning.

(1) The new edition of NFPA 1851 places additional responsibilities on the fire department for tracking gear and the types of cleaning that are applied as part of PPE recordkeeping. *(Photo by author.)*

Cleaning Verification. The verification requirements of independent service providers, manufacturers, and organizations were revised. A new category of verification was added for verified cleaners, those entities that would perform only Advanced Cleanings and Disinfection or Sanitization. The intent behind including a verified cleaner is to enable more fire departments across the country to have access to cleaning for their PPE if they are not able to initiate it internally at the department level.

Validation requirements of cleaning procedures and processes for PPE are now included in Chapter 11: "Verification of NFPA 1851" and will be applied to ISPs, manufacturers, and organizations that choose to become third-party verified for cleaning. Validation requirements of Microbial Disinfection or Sanitization are also included in the verification chapter; ISPs must comply with them to be classified as verified. This testing is optional for manufacturers and organizations that choose to add cleaning validation to their verification.

To clarify, this does not mean that every fire department that chooses to perform cleaning internally at fire stations or at a central quartermaster facility must complete verification or testing to validate processes they use. This would not be fiscally effective for individual fire departments. The intent is that processes verified by ISPs or manufacturers be shared with fire departments through training provided by these entities. This testing can also be performed by individual product manufacturers such as detergent or disinfectant manufacturers; machine manufacturers; or any other maker of a product intended for cleaning, disinfecting, or sanitization of PPE.

It is intended that this structure will encourage departments to institute cleaning practices internally and build confidence in the level of cleaning effectiveness achieved. A fire department can now select a process for cleaning its PPE and receive scientific results of its effectiveness. This should minimize the use of nonscientific claim and opinion-based approaches that exist across the industry.

Specialized Cleaning. Important language and resources were assigned to the topics of asbestos, bulk chemicals, fentanyl, and other hazardous exposures not included under Advanced Cleaning; they are under the category of "Specialized Cleaning." Previously, specialized cleaning was a category that lacked depth and awareness of necessity. This section now addresses many of the topics fire departments have more commonly seen or experienced. It provides procedures and identifies resources for handling such events and for testing for the presence or removal of the associated contaminants. This includes methods practiced and regulated by the Environmental Protection Agency, the Centers for Disease Control and Prevention, and other federal or related organizations.

Future Outlook. The progress accomplished in the revision of NFPA 1851 (2020 edition) has set the foundation for further development of decontamination, cleaning, disinfecting, and sanitizing practices. This was led by analytical work for developing the cleaning validation tools. Unfortunately, these efforts were performed only for structural firefighting coats and pants outer shells. This leaves much research to be done for the remainder of our ensemble liners and ensemble elements. The same analytical methods and validation protocols are being adapted to look at processes, technologies, and equipment for use on the individual elements of PPE. These efforts will be extended into other applicable pieces of firefighting equipment such as hand tools, SCBA harnesses, face pieces, and possibly items like apparatus seat covers. The 2020 revision of NFPA 1851 serves as a blueprint to develop standards and practices to better protect firefighters relative to PPE products, ensembles, and equipment that are subjected to similar contamination exposures.

The industry is now challenged to continue forward in a timely manner and to allocate more resources for research and development of products, equipment, and manufacturing of protective clothing and equipment. The ongoing testing and development of protocols and the analyzation of firefighter protective clothing and equipment will present data to steer the industry in an informed manner, ultimately increasing your protection and that of the public.

The next decade will likely see a major shift in how we operate, respond to, and handle emergency operations at incidents and what we wear while doing it. Efforts have been extended to allow for having a diverse group of industry experts collaborate as members of an NFPA committee focused on occupational health on a more global level, enabling the continuation of standard development and solutions for improving the health and safety of the fire service and the public. The more we know, the more we can do to protect.

TIM TOMLINSON is a driver operator/paramedic with the Addison (TX) Fire Department and chairman of the NFPA Technical Committee responsible for NFPA 1971 and NFPA 1851.

water levels, and cycle times to address the proper washing of turnout clothing. The use of top-loading machines is now prohibited. Industry research has shown that cleaning effectiveness is linked to the use of washing machines that can demonstrate the best removal rates for fireground soils and contaminants without damaging the clothing.

(5) Apply appropriate drying procedures. Drying of garments in an air-drying cabinet is now an option that is based on industry response to fire service needs. The use of air drying (i.e., hanging clothing up to dry) is still an option for drying garments but may be less effective in terms of drying time. If machine drying is used, it has to be on a no-heat setting, but there is a greater likelihood for clothing damage over time based on the repeated tumbling action.

(6) Properly clean other PPE. More complete default cleaning procedures have been established for the other elements, including helmets, gloves, and footwear, which involve cleaning in a utility sink with specific outlined procedures. A large amount of detail is provided in the accompanying annex material, where suggestions have been included for specific factors affecting the cleaning of these elements.

(7) Distinguish between cleaning and sanitization/disinfection. There are now requirements for Sanitization and Disinfection of protective clothing when contaminated with blood, bodily fluids, and other biological contaminants (e.g., flood water). Sanitization applies to removing microorganisms to a safe level on textile-based elements, whereas Disinfection applies to a more aggressive removal of microorganisms on hard surfaces, such as helmet shells. Sanitization is supposed to precede Advanced Cleaning but can also be part of the Advanced Cleaning procedures (Advanced Cleaning is still needed after Sanitization or Disinfection because sanitizers and disinfectants only neutralize or kill the microorganism but do not remove the associated fluids such as blood or body fluid residue). The sanitizers and disinfectants used must comply with Environmental Protection Agency registration requirements.

(8) Recognize the need for Specialized Cleaning. A new section has been established in the standard for Specialized Cleaning, which addresses specific types of contaminants, such as asbestos, fentanyl (opioid drugs), and bedbugs. Suggested procedures are provided in the annex. Organizations are supposed to have some means of verifying whether Specialized Cleaning is effective—either prior experience, subject matter expertise, or testing. The annex also explains how to decide if testing is warranted and offers specific recommendations for how the testing can be conducted.

(9) Use qualified organizations for PPE care and maintenance. The qualifications for organizations that can conduct Advanced Inspections, Cleaning, and Repairs of protective clothing have been made more rigorous. They include manufacturers, ISPs, and trained organizations (fire departments trained by manufacturers or ISPs on care and maintenance). There is now a new category of verified cleaners—ISPs that provide Advanced Cleaning but not Advanced Inspections or Advanced Repairs.

(10) Verify outside Advanced Cleaning and Sanitization. Relatively detailed and rigorous requirements have been put in place for verifying the effectiveness of Advanced Cleaning and Sanitization for manufacturers, ISPs, and verified organizations (fire departments that choose to be verified). The requirements demonstrate that the procedures being used in Advanced Cleaning adequately reduce the amounts of chemical contaminants in turnout gear and appropriately kill or neutralize bacterial contamination as part of Sanitization. This testing has to be carried out one year after the effective date of the standard, then every two years afterward. This is by far one of the more significant changes in the standard that affects manufacturers and ISPs but that is not being applied to fire departments.

(11) Perform a complete assessment to anticipate exposure hazards. Fire departments are now supposed to conduct their hazard assessments to take into account the type of fireground operations. This is principally intended to distinguish between structural and proximity firefighting since many departments with airport firefighting stations are now electing to use structural gear in lieu of proximity gear. In addition, factor in fireground contamination exposure, especially as it applies to the interface and interoperability of all ensemble elements.

(12) Fully inspect garments, including liners, at least annually. Complete liner inspections for garments have been folded into the Advanced Inspection procedures and are now required to be done every year instead of waiting for three years into the garment's life. The Liner Light Test and Puddle Test have been removed from the routine inspection procedures since the specified hydrostatic testing is understood to be a better assessment of moisture barrier quality and is more commonplace in Advanced Inspections. Advanced Inspections are required to be performed once a year or whenever a routine inspection reveals damage that bears closer scrutiny.

(13) Check barrier hoods for effectiveness. With the introduction of new barrier hoods to the fire service and their recognition in the 2016 edition of NFPA 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*, that sets requirements for minimum design and performance of turnout clothing, new routine and Advanced Inspection provisions have been added to NFPA 1851 to address particulate-blocking hoods. For Advanced Inspections, there is the choice between a method using light inside a head-form or other fixture on which the hood is mounted to identify damage or a slightly more sophisticated smoke test that involves a modified hydrostatic tester with a smoke generator.

(14) Ensure that trained personnel perform PPE repairs. Any


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training for repair of protective clothing has to be provided by a manufacturer of the same element type or verified ISP that is experienced in providing these types of repairs. It is not enough to assume that an ISP can perform all repairs. Check the qualifications of the ISP or organization performing repairs to ensure that it has the right training and materials to properly repair affected PPE and that the repairs are permitted by the manufacturer.

(15) Properly transport contaminated PPE. PPE is contaminated until it has been subjected to Advanced Cleaning. To prevent cross-contamination of the apparatus interior or personal vehicles, contaminated ensemble elements are not permitted to be transported inside the apparatus cab or other vehicle interior unless they are in a protective bag or case. The annex in NFPA 1851 provides suggestions for the type of bags or containers that can be used for this purpose.

No changes were made to the maximum 10-year service life requirement. Instead, the committee reaffirmed the requirement, providing further information from research findings from relevant industry studies indicating the lack of nondestructive field-based test methods to verify the continued protective performance of certain elements. The committee also cited the accumulation of potentially harmful contamination in respective PPE elements over time.

Establishing Approaches for Implementing NFPA 1851

The overhaul of NFPA 1851 is intended to promote better care and maintenance practices to ensure adequate levels of protection and limit the accumulation of fireground contamination to firefighters. NFPA 1851 is prescriptive in its requirements, but it is also intended to be informative, as evidenced by the vastly increased levels of guidance provided in the accompanying annex material in the new edition. As such, this standard, along with other newer editions of other standards, such as the upcoming 2020 edition of NFPA 1500, *Standard on Fire Department Occupational Safety, Health, and Wellness Program*, are leading the way for transitioning fire service contamination-control practices.

These transitions will not be easy, but they do not have to be overly complicated. Following are a number of ways departments can move toward maximum, practical compliance with NFPA 1851 and other emerging standards on contamination control related to PPE and other fire service practices.

(1) Create awareness for contamination hazards through department education. If firefighters are repeatedly taught that contamination is potentially harmful, see the statistics for health disorders likely related to lack of contamination control, and understand the link between repeated exposure and serious medical problems, then they, collectively and individually, will more completely embrace the changes needed for their long-term protection from unnecessary, continued contamination exposure.

(2) Look to other department successes for implementing changes based on NFPA 1851 requirements. Many fire departments have already implemented practices that meet or exceed NFPA 1851 criteria for demonstrating compliance. A lot can be learned by examining how other organizations have attempted to implement change across the country and realizing the different options that can be employed to achieve the same net result. A variety of innovative solutions, ranging from the simple and inexpensive to the more sophisticated and expensive, have been applied and are available. Networking through various forums and looking to your neighbors are good ways to identify the right approach for making positive changes toward contamination control.

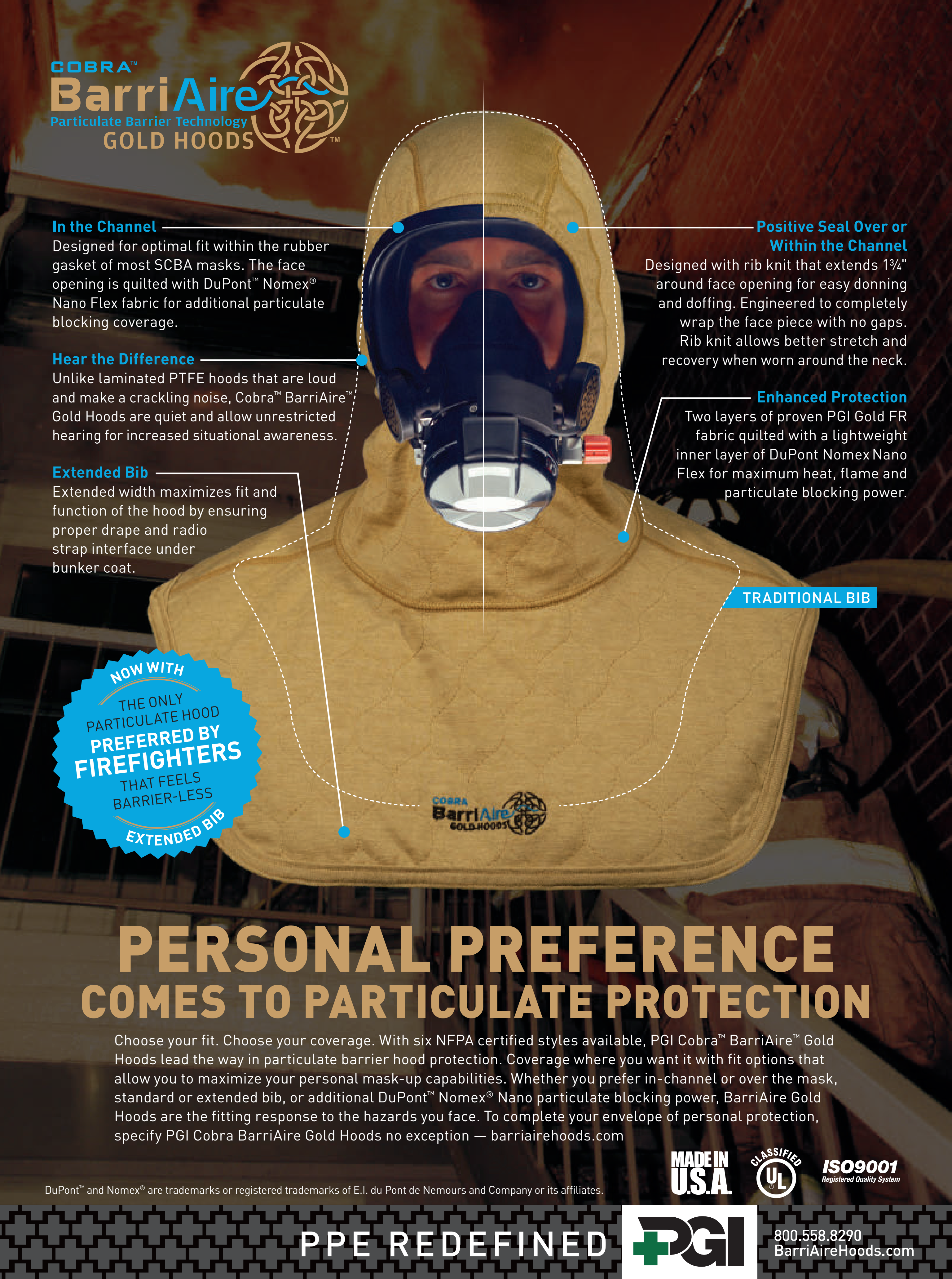
(3) Base implementation decisions on scientific evidence wherever possible. Most of the NFPA 1851 criteria and information have been based on the best available information provided by research or fire service/industry experience. However, as with most campaigns for significant change, there is the promotion of well-intentioned new products and techniques that have not been validated. Although NFPA 1851 has established procedures for validating Advanced Cleaning and Sanitization of garment outer shell materials for ISPs and manufacturers, there are still gaps in requirements for substantiating claims on specific products, whether for PER or full-fledged decontamination products. Consequently, broad-based, independent, and relevant testing must be combined with their demonstrated effectiveness for fire departments to adopt new processes and aids aimed at contamination control.

Understanding Contamination and Decontamination

More and more studies that highlight firefighter exposures to different types of contaminants are being published. These studies fall into several categories that include information on the following:

- The identification and concentrations of contaminants on the fireground during different firefighting operations.
- The levels of contaminants found on the surfaces of PPE generally collected by taking "wipe" samples.
- The quantities of contaminants contained in one or more layers or components of PPE obtained by extracting the various materials using a solvent or other means for detecting and measuring specific chemicals.
- The levels of contaminants on individual areas of the respective firefighter's skin, also gotten from wipe sampling.
- The concentrations of contaminants found in firefighter blood or urine, directly or as substances that have been changed by being absorbed within the body (metabolized forms of the chemicals).

There is a succession of contamination implied by this information: Contamination is first present, then it collects on the surface of PPE, it penetrates or permeates into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Ottawa Firefighters' Chemical Exposures During Emergency Firefighting

BY JENNIFER KEIR

Firefighters are aware of their smoke exposure by the simple fact that they smell of smoke sometimes days after attending a fire. However, the extent to which firefighters are exposed to carcinogens (i.e., cancer-causing chemicals) during fire suppression is not fully understood. Previous studies often looked at firefighters' exposures to carcinogens during live fire training or research burns.[1,2] The exposures from these fires can differ significantly from emergency fires because of the differences in the fuel and firefighter behavior. As a result, a study led by the University of Ottawa in collaboration with the Ottawa Fire Services was conducted to assess occupational exposures to combustion emissions while on shift and from emergency firefighting.

Smoke contains hundreds of chemicals, many of which are hazardous to health. When studying exposure to smoke, researchers must choose which chemicals to measure based on what they believe is most important and feasible. For this study, researchers focused on polycyclic aromatic hydrocarbons (PAHs) and metals (i.e., cadmium, antimony, and lead). These chemicals have been measured in fires before and have known or possible carcinogenic properties.

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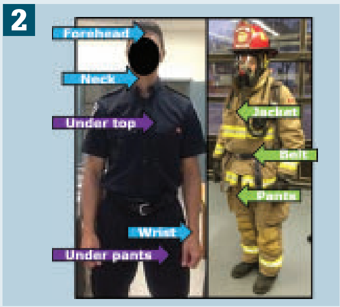

(1) Ottawa firefighters at a house fire. (*Photo by Scott Stilborn©*). **(2)** Surface samples were collected from firefighter participants before and after emergency fire suppression. *(Photo by author.)*

Chemical Exposures During Firefighting

Urine and wipe samples of skin, personal protective equipment (PPE), and clothing worn under bunker gear were collected from Ottawa firefighters at the start of their shift and again after they returned from a fire, if one occurred. Firefighters, after a fire, showed the following results:

- Three to five times the number of metabolites (i.e., by-products) of PAHs in their urine.[3]
- More than four times the mutagenic potency of the urine, which reveals the potential for genetic mutations.[3]
- More than three times the number of PAHs on skin and five times the amount on PPE.[4]
- Nearly double the cadmium levels on clothing worn under PPE and more than five times the amount on the skin.[4]
- Nine times the amount of lead on the skin and nearly four times the amount on PPE.[4]

A link was found between the increase of PAHs on firefighters' skin after a fire and the increase in by-products of PAHs in urine.

Researchers also measured indicators of lung injury, which would suggest respiratory exposure. They did not find significant differences between pre- and postfire levels.[3] These two results suggest that with proper self-contained breathing apparatus use, exposure to these chemicals may be primarily through the skin.

Fire Station Contamination

Air samples were collected and measured for PAHs and metals inside truck cabs, vehicle bays, and offices. Air concentrations of PAHs and antimony inside truck cabs were the highest, followed by the vehicle bay and office. On average, antimony concentrations inside truck cabs were 50 times higher than those in the vehicle bay and more than 26 times higher than for PAHs. However, all measured air concentrations were well below occupational exposure limits; therefore, they were not of immediate concern, but they highlight a potential source of exposure.[4]

PPE Cleaning

Surface wipes from contaminated PPE from emergency fires were collected before and after laundering. Researchers found that washing was effective in removing, on average, 61 percent of PAHs, 55 percent of antimony, 97 percent of lead, and 90 percent of cadmium.[4] These results illustrate the effectiveness of washing PPE in reducing personal exposure and cross-contamination. Although many departments are pushing to have personnel clean their PPE after each fire, these protocols are not always adhered to. It is hoped that these results provide proof to skeptics that laundering of PPE is, in fact, effective and should be implemented.

What It All Means for PPE

Several of these findings have significant implications for PPE. It is evident that current PPE is not effective at fully protecting firefighters from chemical exposures. This is shown by the increases, after emergency firefighting, of by-products of PAHs in urine and surface contamination of skin and clothing worn under PPE. Surface contamination may affect the individual's exposure levels and may also contribute to the potential for cross-contamination such as to colleagues and into the truck cab. The fact that air concentrations of the measured chemicals were highest in the truck cab (compared to the vehicle bay and office area) suggests that contamination is occurring from outside of the station. It is not known whether this contamination is from firefighters bringing contaminated PPE and equipment into the cab, being in proximity to fires, or other factors. The good news is that laundering of PPE was found to reduce a significant amount of the contaminants found on the PPE. In the same way that dirty gear could lead to cross-contamination, knowing that laundering of PPE removes a significant amount of these hazardous compounds could reduce the potential for cross-contamination, which may reduce individuals' and others' exposure levels.

Preventing exposures before they happen (i.e., rather than trying to remove contamination from skin and clothing afterward) is likely to be the most effective way to reduce a significant amount of firefighters' exposures to chemicals. Some chemicals are absorbed within minutes, and the hot environment of firefighting increases this rate.

As is the case for many health-related issues, prevention is key. Creative, novel PPE will be needed to ensure such solutions are effective in reducing individuals' exposures to chemicals while also being practical on the fireground.

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the PPE, it gets on the firefighter's skin, and it finally gets into the firefighter's body. One example of a study that exemplifies this type of information gathering is provided in "Ottawa Firefighters' Chemical Exposures during Emergency Firefighting," by Jennifer Kier of the University of Ottawa, on page 8. Each step of this process is important to understanding contamination; further elaboration is provided in the sections below.

Recognizing Contamination Pathways

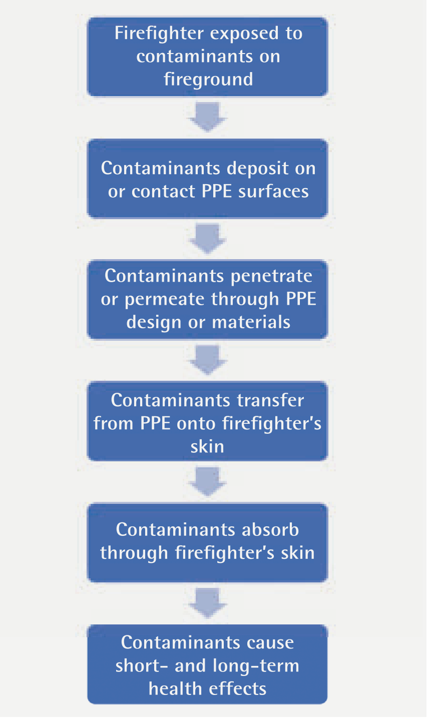
The fireground environment creates a highly hazardous set of contaminant exposure conditions. Burning products release a myriad of chemicals that decompose into airborne substances or react with air and other chemicals under the high heat conditions, sometimes to form new compounds. The combustion of different fuel loads further leads to creation of relatively small carbon particles, the soot that makes up the majority of visible smoke. Firefighter exposure in this type of environment is direct just by being inside or adjacent to burning materials. The three main routes for chemical exposure are (1) inhalation, (2) skin absorption, and (3) ingestion. All three can occur as a result of firefighting activity.

Inhalation. This is the most common and direct route of contamination entry into the body. Inhaled contaminated air brings smoke particles and fire gases directly into the firefighter's lungs, where particles generally in the range of 0.001 to 10 microns in diameter (0.00000004 to 0.0004 of an inch) can deposit on different parts of the airway tissues; the smallest particles can reach the alveoli, the air sacs where oxygen is absorbed into the individual's blood chemicals, and can be transported to different parts of the body.

Fire gas chemical molecules, which are even smaller, easily reach this part of the lungs; their effects on individual health depend on their relative toxicity and their ability to permeate the lung tissues. Fortunately, wearing SCBA in a contaminated environment provides nearly complete respiratory protection to the wearer. However, it is important to realize that inhalation exposures can still occur after leaving the fireground; any retained contamination in the clothing can off-gas, creating further exposures.

Skin absorption. This is another obvious route for contaminants to enter the firefighter's body even though the skin is a natural barrier to many substances. The quantity of contaminants absorbed can be significant, depending on the amount and characteristics of the chemicals and the length of the exposure. One reason for this is that the human body has a large amount of surface area, although not all areas of the body are equally receptive to absorbing chemicals. For example, areas near the jawline and scrotum are more prone to chemical absorption than the palm of the hands or the bottom of most individuals' feet. Wearing a protective ensemble with appropriately designed and properly worn interfaces between ensemble elements can attenuate much of the smoke particle penetration, but not all clothing systems are equal.

Figure 1. Body Entry Routes for Contaminants and Steps Affecting Skin Absorption



Source: Jeffrey Stull.

Any elements such as garments, helmets, gloves, and footwear have barrier layers that prevent direct particle penetration through the skin, but closures and areas where elements interface generally allow pathways for particulate penetration. You can help minimize absorption by paying attention to these areas, such as wearing a particulate-blocking hood as part of the ensemble. On the other hand, fire gases that include various sizes of chemical molecules can penetrate some barrier materials and permeate others, again depending on the characteristics of the chemical, the type of material, and the exposure conditions. Thus, some exposure to fire gases is always expected in a contaminated fire environment. Skin absorption exposures can occur long after the fire is out since retained contaminants can still contact skin through continued handling and wearing of uncleaned clothing.

Ingestion. Ingestion may not seem to be a likely source of exposure, but it can occur by your touching the contaminated surfaces of clothing before touching food or by cross-contaminating other surfaces; when eating and drinking later, some chemicals will enter the mouth and digestive system. Some chemicals have an affinity for entering the body in this way. You can eliminate this route of contamination best by practicing good hygiene following a fireground exposure: Carefully remove all contaminated clothing; use moist wipes, especially on your face and hands; and take a shower as soon as practically possible following the incident.

Injection. A fourth route of contamination—injection—is much less common, but it can happen if a contaminated object accidentally punctures your skin.

Determining Relevant Chemicals

Through research we have identified more and more chemicals that have severe toxic effects or that are known or suspected carcinogens. In fact, the International Agency for Research on Cancer (IARC) has classified firefighting as *possibly* carcinogenic to firefighters for three forms of cancer (testicular, prostate, and non-Hodgkin's lymphoma)[1]; many in the fire service expect that this classification will be upgraded to *probably* carcinogenic.

Other studies, including the landmark research by the National Institute for Occupational Safety and Health (NIOSH), have definitively associated increased rates of certain cancers with firefighting. Yet, the study of clothing-protective capabilities against contamination and the subsequent effectiveness of cleaning generally rely on specific chemicals or classes of chemicals. Moreover, the causal link between specific cancers (and certain health effects) and exposure to particular chemicals is often difficult to establish, given the wide range of propensity for cancer based on nonwork environmental exposures, lifestyle habits, and genetic factors. One exception is mesothelioma, which is directly linked to asbestos exposure; NIOSH reports a very high elevated rate of cancer incidence for firefighters as compared with the general population.

Just as different properties of chemicals affect their pathways for exposure, other chemical properties will determine if short- or long-term exposure will occur. On the fireground, especially at high temperatures, many chemicals have more energy because they can be in a vapor phase. Under ambient conditions, they would normally be liquids or solids and have less chance for contact with firefighters. More volatile chemicals, such as benzene and formaldehyde, can be abundant on the fireground and may off-gas for a limited time following the fire. They are less likely to present for extended periods following the fire unless these gases or vapors are absorbed into the multiple pores of soot particles, which tend to hold many contaminants in place but still allow their evaporation following the fire event.

On the other hand, chemical substances that are much larger molecules can be persistent contaminants because they are less likely to evaporate and may not be water soluble. Another significant factor is the likelihood of certain chemicals to be absorbed through the skin. Not all chemicals easily permeate skin, or they permeate at widely differing rates. Thus, persistent chemicals that are relatively volatile and water insoluble and have high rates of skin absorption are of greatest concern for long-term firefighter exposures.

The majority of studies that address PPE wearing or cleaning effectiveness focus on specific chemical substances because it is extremely difficult to fully characterize all contaminants in the fireground environment and because each situation widely varies even when the same apparent exposure conditions exist. Common classifications of dangerous substances include the following:

- Volatile organic chemicals.
- Semi-volatile organic chemicals.
- Complex organic chemical mixtures.
- Inorganic chemicals.
- Other substances, such as asbestos.

Multiple types of analysis are needed to identify and quantify the levels of contaminants at the fire scene, so the focus is usually on the chemicals expected to be prevalent and likely to remain as residual contamination coming off the fireground and remaining on clothing and equipment for an extended period afterward. That is why many studies have highlighted polycyclic aromatic hydrocarbons (PAHs), phthalate plasticizers, and substituted phenols as classes of semi-volatile organic chemicals that are known carcinogens or skin toxins. Certain heavy metals such as arsenic, antimony, cadmium, chromium, lead, and mercury are also of interest as persistent inorganic chemical contaminants. Still, there are far-ranging additional groups of highly toxic substances such as polybrominated diphenyl ether flame retardants (PBDEs) and polychlorinated biphenyls (PCBs).

The reality is that fires can involve any number of hazardous substances in widely varying quantities for a range of times. Focusing on just a few substances, although practical, does not fully capture the total exposure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MSA
The Safety Company
To request information go to fireeng.hotims.com

risk. Yet, there is no universal method of environment, PPE, or firefighter blood/urine analysis that indicates all levels of "bad" substances (i.e., harmful contamination) that are known at the present time. Ongoing research is examining whether certain chemicals can be used as broad indices of contamination to more easily determine exposure risk.

Overall, chemical effects on health are generally the result of frequent or continued contact with substances that accumulate in the body if the body does not effectively eliminate them. Thus, dose in terms of the exposure concentration and time does matter in terms of overall exposure risk.

Lowering Exposure Risk

Based on the pathways for exposure and the likely relevant chemical hazards associated with potential contact, the fire service has established ways by which firefighters can lower their exposure risk relative to PPE use and care:

(1) Choose PPE that is well integrated. Although PPE manufacturers sell ensemble elements, fire department end users create full ensembles. One reason for this is that ensemble elements are typically purchased from different manufacturers because no manufacturers currently are selling a complete system of fully integrated protective ensembles and SCBA for which protection from contamination is predicated. Fire departments endeavor to provide their members with good choices of PPE for protection, but ensuring correct functional fit over expected firefighter movement is a key part of limiting much of the particulate or liquid fireground contamination from reaching the skin. Some manufacturers have tested their garments for overall protection with unique features for improved integration with specific helmets, hoods, gloves, footwear, and SCBA, but NFPA 1971 certification of these systems remains elusive because particulate testing of full systems is expensive and requires designating the entire system, as tested, to be worn to achieve that certification. Therefore, fire departments can begin opting for particulate-blocking hoods and garment or ensemble features that have demonstrated that they provide some attenuation of particulate penetration.

(4) The head/neck area of the protective ensemble involves the most integrated elements of PPE and requires specific attention to achieve optimal protection.

(2) Properly wear and deploy all features of the PPE until the hazardous exposures are reduced. Even if appropriately designed, the best PPE can fail to protect unless it is correctly integrated and appropriately worn in accordance with the manufacturer's instructions. A significant integration area, and one that contains vulnerable parts of the firefighter's body, is the head and neck area where the helmet, SCBA face piece, hood, and collar of the garment all come together. These ensemble elements must properly come together with all features properly deployed: wearing a properly fitted SCBA face piece, helmet ear covers down over the hood, the hood properly positioned around the face piece, the collar extended in an upright position, and the collar closure flap secured. Interfaces at the coat to pants, glove to sleeve, and pants to footwear ensemble areas all should be properly donned. It goes without saying that coat and pants closures should also be secured. Firefighters must wear the full ensemble correctly even after exiting the vicinity of the fire; exposures can still occur until steps have been taken to reduce surface contamination.

(3) Take active measures to reduce contamination exposure after leaving the fireground. After leaving the fireground, firefighters need to go through some form of PER. These procedures should be applied while firefighters are still wearing their full ensemble and are on air. In wet techniques, the firefighter is rinsed off with a hose, scrubbed with a brush and soapy liquid, and then rinsed again. Dry techniques are simpler; they involve brushing without liquid, but they generally remove less surface contamination. PER is discussed further in the next section and is covered in the annex of NFPA 1851. Once the exposure reduction procedure is completed, remove the ensemble components so that there is no cross-contamination; isolate and bag them so they can be transferred for Advanced Cleaning.

(4) Apply up-to-date Advanced Cleaning procedures to remove contamination from PPE. Contaminated PPE must be subject to Advanced Cleaning. That is the only way to remove as much contamination as possible from all surfaces, layers, and components. When done repeatedly after fireground exposures, the accumulation of contamination and continuing exposure to that contamination are significantly reduced. It is important to include all PPE worn on the fireground. Garments and hoods may be relatively easy to launder, but you have to apply manual or other recommended procedures to helmets, particularly textile or leather suspensions, as well as gloves and footwear, which tend to be more heavily contaminated PPE elements. Follow the latest requirements in NFPA 1851, and look to the annex for suggested cleaning guidelines for all elements. The techniques listed in the annex don't shorten the life of the respective clothing or equipment.

(5) Practice good hygiene; don't put PPE back into service until it is clean and dry. Although not a PPE practice per se, avoiding contamination also includes hand cleaning, using wipes, and taking a shower; they are all good practices for eliminating potential routes of exposure. Ensure that clean and dry station/work uniforms are available, and change into them. Additionally, wear a second set of PPE once it is available. Finally, do not put PPE back in service until it is clean and dry.

The Role of Preliminary Exposure Reduction

Undertaking the start of the cleaning process on scene is one of the essential steps in controlling contamination. To this end, the practice of PER was established to provide procedures to minimize contaminant exposure and the transferring of contaminants to firefighters and others nearby.

Defining Preliminary Exposure Reduction

In NFPA 1851, the term "preliminary exposure reduction" is used in lieu of the more common industry term "gross decontamination" because it more accurately describes the activities specified by NFPA 1851 for initially addressing contaminated firefighting protective ensembles and ensemble elements. Although PER is likely to remove some contamination from the surface of the protective ensemble or ensemble elements, it does not guarantee full cleaning or decontamination for the removal of all contaminants. The use of the term PER reduces the possible inference that gross decontamination might be the only activity needed to render clothing safe for reuse and free from contamination. In hazardous materials operations, the types of protective clothing might be better designed to resist contamination and allow for easy cleaning given the clothing design and materials. This is not necessarily the case for structural or proximity firefighting protective clothing, particularly after exposure to products of combustion.

PER is an essential first step in minimizing cross-contamination preceding the cleaning of ensembles or ensemble elements. PER by itself is not considered to be cleaning or decontamination of ensembles or ensemble elements. Rather, it is intended to provide a means for helping to reduce the exposure of firefighters to soils and contaminants that arise from exposures occurring during structural or proximity fires or other emergency response events. PER is also required to aid in minimizing the transfer of soils and contaminants from the emergency scene to the apparatus, station, and personal vehicles. Other forms of cleaning, such as Advanced and Specialized Cleaning, are required to provide full cleaning of the ensemble or ensemble elements.

Putting PER into Practice

PER is an attempt by the end user to remove some exterior soiling and contamination from ensembles and ensemble elements to minimize transfer of soil and contaminants outside the incident scene. Whenever possible, conduct PER as soon as personnel exit the emergency scene and before entering the rehabilitation area. In this manner, preliminary exposure is likely to be more effective than if applied later, particularly in terms of reducing cross-contamination.

NFPA 1851 defines two forms of PER: dry mitigation and wet mitigation. The specific provisions within the standard that address the respective techniques appear in "NFPA 1851 Requirements for PER" at right.

Recognizing the Ramifications of PER

The implementation of preliminary exposure is not without consequences and requires up-front planning to address several of the logistical concerns as listed below:

(1) Assess each response for timeliness of applying PER. PER after the termination of an incident can remove substantial amounts of surface contaminants before they have a chance to set in and can help limit the transfer of contaminants to apparatus, personal vehicles, and stations. Many of the contaminants that can cause damage to visibility markings and other materials and components of ensembles or ensemble elements also can be removed if PER is done as soon as possible after an exposure to those contaminants. It is recognized that it is not always practical for organizations to carry out PER on scene because of constraints in personnel, on-scene resources, the availability of spare gear, weather, and other operational factors. Nevertheless, it is important that organizations implement some form of PER procedures as soon as practically possible, particularly following any event where ensembles or ensemble elements are contaminated.

(2) Properly locate the site for PER. PER should be close enough to the fireground so that firefighters don't have to transverse too far and also away from any further exposure to products of combustion. The philosophy used in hazmat of creating a "contamination reduction zone" or "warm zone" is useful here. Also consider access to other contamination-control practices and postfire rehabilitation. Organizations performing wet mitigation should consider the runoff of any contaminated rinse water to minimize the spread of contamination to the environment.

(3) Have a plan for spare clothing and firefighter cleanup following PER. Some organizations may consider having spare gear available for members or alternatively other spare clothing, such as disposable clothing, to be worn until the member can shower and change into clean clothing. Removing ensemble elements at the scene may require additional clothing be present, particularly under inclement or cold weather conditions. Portable facilities

NFPA 1851 Requirements for PER

Step 1. End users carry out PER immediately after exiting the emergency scene at any incident where their protective ensemble or ensemble elements could have become soiled or contaminated.

Step 2. On exiting the emergency scene, the end user remains on SCBA air or switches to ambient air if the cylinder is empty. The purposes of remaining on air are to minimize the end user's exposure to products of combustion that may off-gas from the ensemble or ensemble elements following contaminant exposure during a structural fire and to avoid breathing in any particulates that may be dislodged from the ensemble or ensemble elements during dry mitigation.

Step 3. If returning to the emergency scene after an air cylinder change, brush off any dry debris from the helmet, face piece, and SCBA prior to changing out the cylinder.

Step 4. If the end user is completing his time on scene, perform dry or wet mitigation techniques prior to removing any ensemble or ensemble elements, including the SCBA.

Step 5. The dry mitigation technique is performed by brushing debris from the exterior of the ensembles and ensemble elements with a soft bristle brush prior to the ensembles being removed. For best results, start at the top of the end user's ensemble and work downward.

Step 6. The wet mitigation technique is performed by gently rinsing the exterior of the ensembles and ensemble elements using low-pressure and low-volume flow water and a mild detergent. Start at the top of the end user's ensemble and rinse downward. Follow with a gentle rinsing. Do not use heavy scrub or spray with high-velocity water jets such as a power washer.

One method for performing wet mitigation is to use a reducer from the apparatus pump panel to supply a small hoseline, such as a forestry hose or garden hose, with an adjustable nozzle at low pressure and volume. When using ordinary hose and nozzles, be careful to use the lowest possible flow rate. Most departments may have a "booster line" or "trash line" that is usually 3/4- or 1-inch in diameter that can be applied at a low pressure (less than 30 pounds per square inch). Some departments also have used portable decontamination showers. Some of them may conform to ANSI/ISEA 113, *American National Standard for Fixed and Portable Decontamination Shower Units*.

Note: Whether to use dry or wet mitigation will depend on the resources available to the organization and the conditions at the emergency scene or other location. Work by the Illinois Fire Service Institute under an Assistance to Firefighters Research Grant from the U.S. Department of Homeland Security showed that wet mitigation techniques were more effective in removing surface contamination than dry mitigation techniques (see Reference 2 on page 20). Wet mitigation techniques remove a significant amount of surface products of combustion; dry mitigation techniques remove only a portion of this contamination. Avoid techniques that involve blowing air (from a leaf blower, for example) onto ensembles or ensemble elements. They are not very effective and may only redistribute contamination at the emergency scene and create inhalation hazards for unprotected personnel.

Step 7. If used in combination, dry mitigation precedes wet mitigation.

Step 8. Following dry or wet mitigation, isolate and bag ensemble and ensemble elements. Where possible, do not transport the ensemble or ensemble elements, even when bagged, in the passenger areas of apparatus or personal vehicles.

Step 9. Following PER, the ensemble elements are subject to the appropriate cleaning and decontamination procedures.

You can use a variety of approaches for applying preliminary exposure techniques.

may be needed for end users to change. In addition, personnel should use disposable wet wipes to clean portions of their face and skin when they know they were directly exposed to contaminants; they should change into a clean station/work uniform and take a shower as soon as possible.

(4) Choose the "right" methods for containment of isolated PPE. Use airtight protective containers or bags to isolate contaminated ensembles and ensemble elements. Examples include disposable polyethylene bags or sealable plastic cases, which are cleanable. If a plastic bag is used, it is recommended that the bag be clear/transparent to ensure that the contents of the bag can be readily identified. Do not transport ensembles or ensemble elements from the incident scene in the passenger areas of apparatus or personal vehicles. This helps to reduce personnel's further exposure to contaminated ensembles and to reduce cross-contamination of apparatus or personal vehicles.

(5) Don't allow PPE to remain wet for extended periods of time. If the protective ensemble elements are wet, remove them from the bag as soon as possible following transport from the fire or other emergency scene. Ensembles and ensemble elements that remain wet under closed conditions can result in the growth of mold and mildew, which damages the gear. Also, following their transport, store protective ensembles and elements under conditions where they can dry until they can undergo appropriate cleaning procedures.

The Evolution (and Revolution) of PPE Care and Maintenance

NFPA 1851 provides a significant amount of detail on the procedures used for cleaning different elements of PPE as mandatory steps and as recommended guidance that appears in the nonmandatory annex. The 2019 PPE supplement (*Fire Engineering*, January 2019) provided information synopsizing these recommended approaches for helmets, hoods, gloves, and footwear. Nevertheless, as research continues to look beyond garment contamination with new concerns and research findings that better define contamination concerns and how cleaning might be more effectively performed, several avenues of investigation have been taking place that are expected to achieve better contamination control.

Identifying Areas of Contamination Concern

It should come as no surprise that firefighter turnout clothing is not equally contaminated on the fireground. It is expected that certain items will be more contaminated than others simply by how the specific ensemble element is worn. For example, gloves and footwear are more likely to have greater levels of contaminants than garments, hoods, and helmets, given their more frequent contact with contaminated surfaces. In fact, an Underwriters Laboratories study done 10 years ago showed specific

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A Success Story for the Tucson (AZ) Fire Department

BY JOHN GULOTTA

Exposures at the fire scene have been of great concern for the fire service. This became very personal to the Tucson (AZ) Fire Department (TFD) with the loss of fire cause investigator Tom Quesnel to a presumptive cancer (photo 1). The TFD wanted to understand the ongoing exposures to personnel at the fire scene and identify potential interventions that would reduce this exposure. To ensure that this was done properly, through evidence-based research, the University of Arizona (UA) Mel and Enid Zuckerman College of Public Health and the TFD partnered in the four-year Federal Emergency Management Agency (FEMA)-funded study "Cancer Prevention in the Fire Service," grant number EMW-2014-FP-00200. This research was concluded in 2019.

(1) Tom Quesnel, fire cause investigator, died of presumptive cancer in 2015. *(Photos by author.)*

The overall aim of the study was to identify the exposures that firefighters were receiving while on the fire scene and then to identify and test intervention techniques to reduce the exposures. More than 80 percent of the firefighters within the TFD (545 of 633 members) participated in the study, which involved the collection of blood, urine, and buccal cells for baseline measurement and the collection of urine samples and questionnaires after responding to structural fires. To evaluate the exposures, the UA measured metabolites of polycyclic aromatic hydrocarbons (PAHs) in the urine. These PAHs can enter the body through dermal, respiratory, or ingestion routes. One of these metabolites was 1-naphthol, the metabolized version of naphthalene, which was quantified as a marker of exposure.

Postfire testing without interventions clearly showed elevated levels of 1-naphthol in urine samples collected three hours following the structural fire (baseline vs. postfire) (Figure 1). These data were grouped by on-scene fire operation functions, which included captains, engineers, firefighters, and paramedics, to assess the impact of different interventions. All the categories showed a concerning increase of exposure. It was thought that the primary route of exposure for engineers was respiratory, while the exposures of firefighters and captains were thought to be a combination of dermal and respiratory. Having few data points for the paramedics, it was presumed their exposure was from rehab being staged too close to vehicles that had their motors running, smoke from the fire, or contaminants transferred from crew members during rehab.

Based on these observations, the interventions that were implemented and tested were the following:

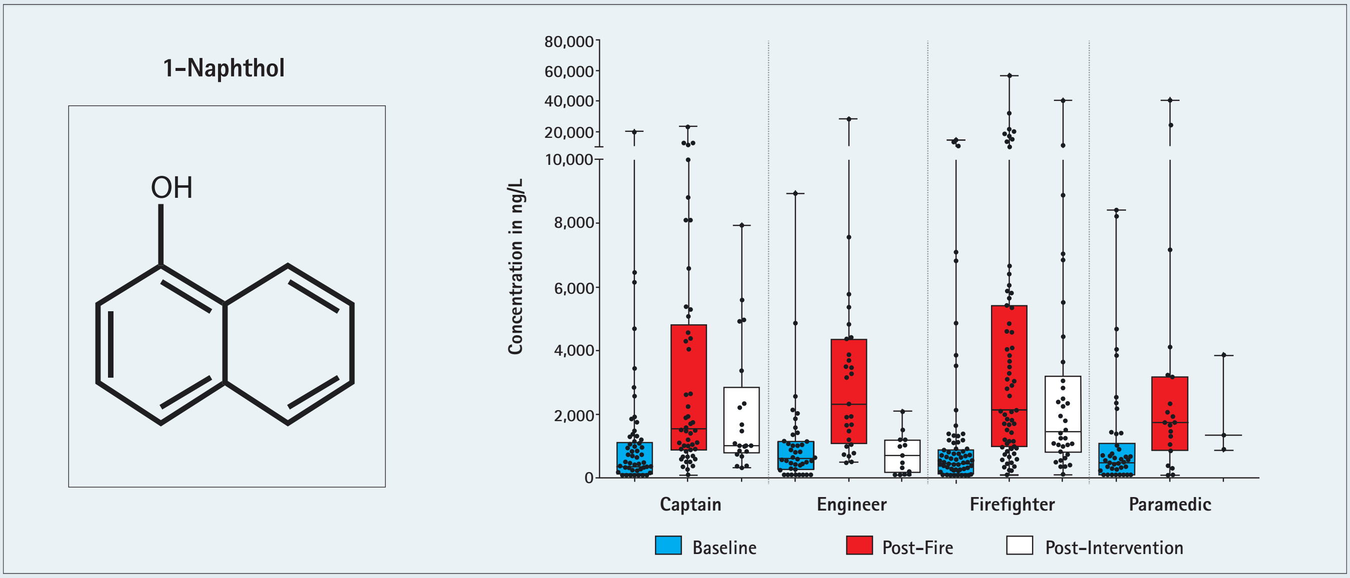
1. *Wash down/exposure reduction.* Fire attack teams conducted a fire scene washdown.
2. *On air.* Engineers (pump operators) wore their SCBA (were on air) during fire operations. There were no other changes to their normal PPE use.
3. *Clean cab.* Contaminated PPE and equipment that could not be stored in an outside compartment for transportation were bagged and taped closed for transport.

The TFD implemented the contamination-reduction procedures that the National Institute for Occupational Safety and Health had previously researched, where it found that 80 percent of PAHs can be removed by using Dawn® soap, water, and a scrub brush for agitation.[1] It was found that the use of Dawn soap was important, as it contains surfactants that remove the PAHs, which have hydrophobic properties.

Although the science is important, the TFD found it imperative that a good procedure be in place with a top-down approach that can easily be followed. Therefore, the washdown procedure begins with a designated area assigned by command that is prepared for exiting crews with a five-gallon bucket filled with water, 1 ounce of Dawn soap, and a scrub brush. While all crew members remain on air and with all PPE in place, they take turns, starting from the helmet to the boots, washing and rinsing their partners (photo 2). The crews are then directed to a doffing area where they carefully remove their gear to avoid cross-contamination with the skin. Then, using simple wet wipes or soap and water, they wash exposed skin,

(2) Washdown. Dermal Intervention. **(3)** Engineer on air.

Figure 1. Concentrations of 1-Naphthol in TFD Firefighters' Urine



focusing on susceptible areas such as the neck, arms, and hands. Finally, they continue on to rehab, where they receive a clean hood as part of a hood-exchange program.

Another intervention conducted involves having the engineer on air (photo 3). It is presumed that the engineer's exposure is primarily respiratory. The SCBA is a piece of equipment that is already dedicated to firefighters and on which they are trained, which makes it a simple intervention to implement and test.

The final intervention was based on research conducted by Dr. Kenneth Fent at NIOSH, where it was determined that exposed gear can off-gas volatile contaminants and lead to increased exposures.[1] The intervention involved bagging in a 55-gallon clear heavy mil plastic bag that was taped shut to prevent potential cross-contamination and exposure any PPE or equipment that could not be transported back to the station in an outside compartment or hosebed (photo 4). Once back at the station, the equipment was taken off the truck and placed outside of the bay for cleaning or replacement (photo 5). All turnout gear was washed in the station's extractors, and the second set of turnouts was placed on the truck. All crew members showered as soon as possible but before going back into service.

With the interventions in place, urine samples were collected from the TFD personnel after responding to structure fires. When comparing the postfire samples without intervention with the samples after the interventions were in place, there was a decrease in 1-naphthol by about one-third in engineers, firefighters, and captains; the greatest decrease was observed in the engineers (Figure 1).

On the basis of these results, TFD firefighters have shown the value of these three interventions and their effectiveness in reducing exposures. The department is further embracing a culture change by recognizing that dirty gear is not a "badge of honor." To change the culture, it is important to include good training, explain the research effectively, and understand that it takes many small consistent processes and procedures to reduce these fireground exposures. More detailed findings of this research are in the process of being peer-reviewed for publication.

(4) Clean cab. All equipment that cannot be stored in outside compartments is bagged and taped. **(5)** Equipment cleaning postfire.

ENDNOTES

1. Kenneth W. Fent, Barbara Alexander, Jennifer Roberts, Shirley Robertson, Christine Toennis, Deborah Sammons, Stephen Bertke, Steve Kerber, Denise Smith, and Gavin Horn. (2017) Contamination of firefighter personal protective equipment and skin and the effectiveness of decontamination procedures. *Journal of Occupational and Environmental Hygiene*, 4:10, 801-814, DOI: 10.1080/15459624.2017.1334904. Other members of the research team included Deputy Chief Darin Wallentine and Deputy Chief Paul Moore of the Tucson Fire Department; Jeff Burgess, MD, MS, MPH; and Shawn C. Beitel of the University of Arizona Mel & Enid Zuckerman College of Public Health.

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contaminant levels for gloves to be more than 10 to 100 times greater than those found in protective hoods for the same fireground exposures.[3] Yet, the amount of contamination picked up and retained by the respective PPE item will also have a lot to do with the materials used in its construction and the item's geometry and design features. Very simply, textiles and leather contaminate differently than hard surfaces such as the helmet shells and garment trim. The following is a review of contamination differences and issues for the principal PPE items.

Garments. The protective coat and pants comprise the largest surface area of the PPE items worn by the firefighters; they, consequently, can accumulate various forms of contamination readily. Even with the general attention for cleaning and decontamination of firefighter garments, there is still a lack of information on how different materials and components in the construction of turnout clothing affect contamination and the associated residual levels following cleaning.

In the United States and in Europe, multiple studies have shown that while the outer shell would be expected to become more contaminated than any of the underlying layers, including the moisture and thermal barrier, it is actually the moisture barrier that takes up an equal, if not larger, amount of the persistent contamination.[4,5] The reason for this is that the outer shell material, although treated with finishes to repel liquids, is still a porous textile material. The moisture barrier, on the other hand, includes a highly specialized thermoplastic film layer that better retards penetration of particles and liquids but also traps the chemicals associated with those particles and liquids. This is generally evident on the textile side of the moisture barrier when the liner is removed from the outer shell. This means that the same attention must be given to cleaning liners as outer shells, although outer shells and liners are required to be washed separately because the hardware and self-closing fasteners on the outer shell portion of the garments can damage liners through the mechanical actions of machine washing and drying.

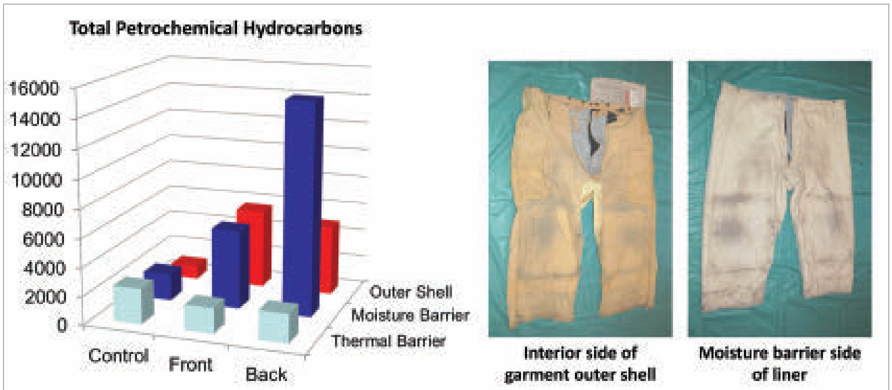
Other components like trim or exterior reinforcements have had less study. Knit materials in the wrist cuffs are a lot like hoods (see below) but generally will have more liquid absorption compared to the outer shell material. These items represent a smaller area of the clothing, and their general contamination and decontamination properties remain unknown. Further investigation is needed since some parts of the clothing may be less effectively cleaned and may result in disproportionate cleaning effectiveness.

Helmets. The smooth exterior surface of helmets is relatively resistant to most fireground contaminants, and it would be expected that these surfaces would be relatively easy to clean. However, multiple areas of the helmet routinely contact the firefighter's head, especially when worn at responses other than structural fires. These areas include the internal suspension, retention system (chin strap), and ear covers. As primarily textile components, NFPA 1851 permits separate machine washing of these components. However, there is no requirement in the NFPA 1971 product standard to allow for easy removal of these components, which can complicate the ability to clean them effectively. Being textile components, these components are likely to have heavier levels of soiling and contamination that are more difficult to clean compared to the other areas of the helmet. Face shields attached to the helmet are another hard surface with low likelihood of contaminant penetration into the materials. On the other hand, goggles, sometimes worn on the top of the helmet, can become contamination repositories, potentially problematic because portions of the goggles can subsequently be worn against the wearer's face. Goggles also have textile/elastic straps that will absorb contaminants differently than the lens or housing.

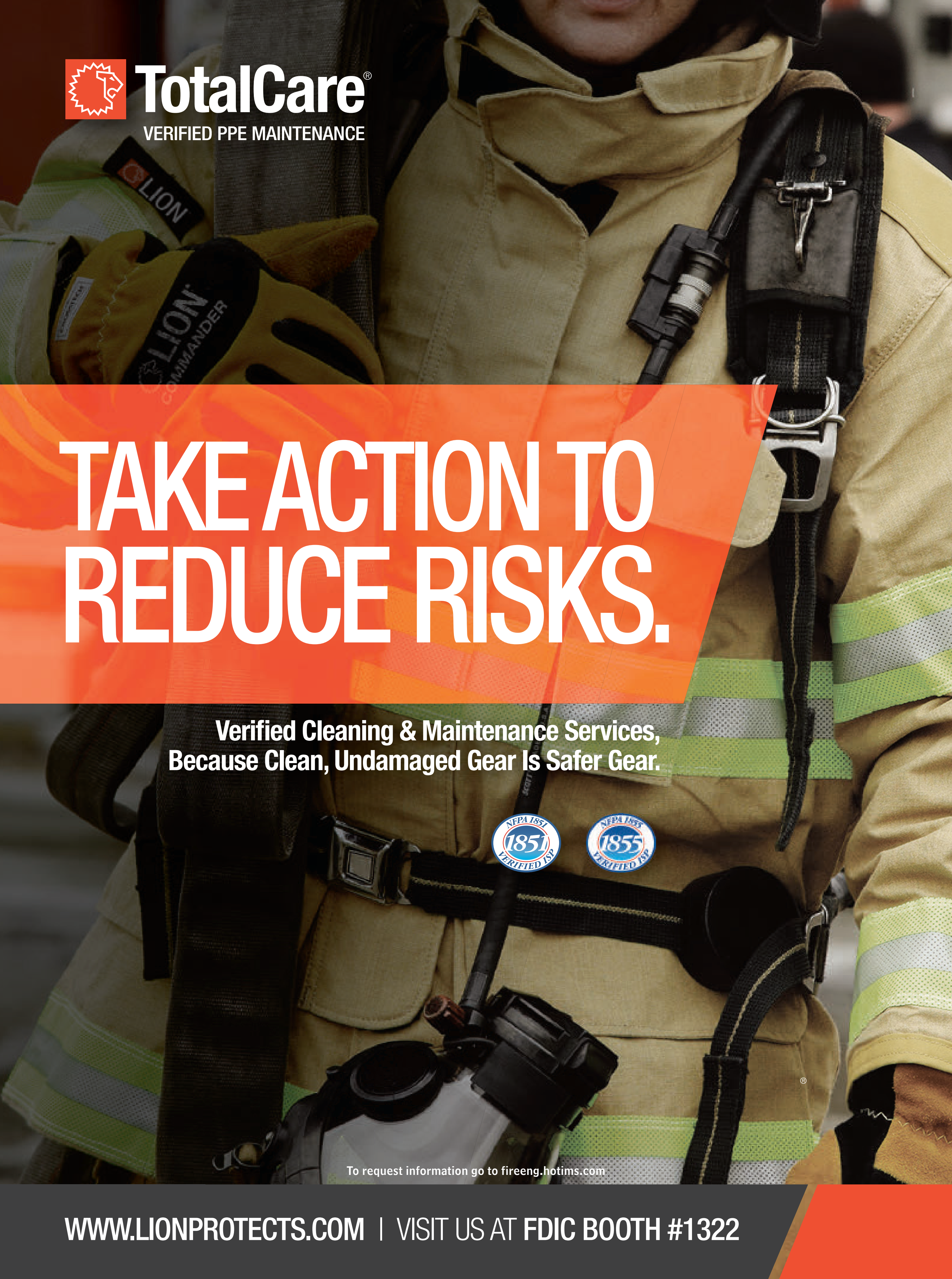
Hoods. Traditionally, two or more ply-knit fabric hoods are a relatively simple form of PPE. The highly porous nature of the knit textile (compared to shell and lining materials) makes for relatively more accessible fiber surfaces for the deposition of soot and solid contaminants, but it also affords better penetration of wash water for cleaning. The introduction of particulate-blocking layers in the new class of optional barrier hoods prescribed by NFPA 1971 lessens contamination penetration in a manner virtually similar to the garment moisture barrier but with slight differences. The ability to remove contamination from the particulate-blocking layer and the differences between conventional and barrier hoods have not been completely characterized.

Gloves. As an item of structural firefighting PPE, gloves are perhaps the most complex, given their geometry, multilayered construction, and small relative size. Most gloves share

Figure 3. Petrochemical Hydrocarbons Measured on Different Sides of the Three Layers of Turnout Clothing



The measurements include all chemicals such as body oils and finishes, not just harmful contaminants. (Courtesy of International Personnel Protection, Inc.)


TotalCare®
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LION
LION COMMANDER
TAKE ACTION TO REDUCE RISKS.
Verified Cleaning & Maintenance Services, Because Clean, Undamaged Gear Is Safer Gear.
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the same layering as garments with some form of shell, usually leather but possibly textile; a film-based moisture barrier; and a knit or nonwoven fabric thermal barrier for insulation. However, unlike garments, the lining is not separable so that contamination penetrating gloves is likely a lot more difficult to access for cleaning if the contamination goes through the shell layer. Knit cuffs on gloves will act very similar to the knit cuffs on garments. The glove leather is a variable for contamination absorption. Leather, like human skin, has certain barrier properties that may be enhanced by specific tanning and treatment processes. Still, it is a porous material and is not expected to behave the same as textiles relative to how contamination occurs and may allow different amounts of contamination to be retained after cleaning. At the very least, leather is expected to age differently on the fireground when compared with textiles. Gloves with a gauntlet design are expected to allow more contaminant entry into the glove opening, given the degree of glove closure around the wearer's wrist. Taking gloves off and putting them back on while operating on the fireground also represents a probable pathway for introducing contamination directly to the gloves' interior. The seriousness of this issue is sometimes partly attenuated by the fact that for many fire departments, the service life of gloves is relatively short compared to other elements of the ensemble.

Footwear. Like gloves, footwear is multilayered depending on the construction. It also has a multitude of exterior components that include the outsole, pull loops, and reinforcements and many other components internal to the footwear's construction. The prevailing questions on footwear involve the degree of contamination and ease of decontamination for rubber vs. leather boots. According to information one industry source provided more than 10 years ago, leather footwear has advantages when it comes to cleaning, but the contaminants are neat hazmat-type chemicals as opposed to typical fireground contaminants.[6]

There is also a lack of information on just how much contamination gets into the footwear's interior and if the amount of contamination, the manner in which the footwear is contaminated, and the method of cleaning change with footwear construction such as pull-on vs. lace-up boots or other design features. The complete lack of contamination or cleaning effectiveness for firefighter footwear is an especially obvious gap in understanding contamination control for the entire protective ensemble.

Determining the Efficacy of PPE Cleaning Approaches

Very little is known about PPE contamination outside of garments, which are machine washed as compared to items that mainly have to be addressed through manual cleaning methods. There are many factors and variables in cleaning processes, and the industry is just beginning to understand some of the attributes that relate to the optimum ways for cleaning different ensemble elements.

Wash Temperature. NFPA 1851 limits the maximum wash temperature for machine washing of garments, hoods, and other textile materials to 105°F. Historically, this limitation has existed because there were concerns that certain components could be adversely affected by hotter water temperatures under slightly alkaline conditions that occur in laundering. Yet, it is a well-established fact that the cleaning effectiveness for many detergents improves with higher wash temperatures. The Centers for Disease Control and Prevention specifically advocates wash temperatures at 140°F for sanitization of textile medical products.[7] Higher wash temperatures are also more effective for dealing with nuisance contaminants such as bedbugs. In a recent investigation of the effects of wash temperature on firefighter protective clothing by the technical committee responsible for NFPA 1851, it was found that after a relatively large number of wash cycles (40 to 60 cleanings), certain materials and components of turnout clothing physically broke down. They included mainly secondary components as opposed to the primary outer shell, moisture barrier, and thermal barrier fabrics, which hold up relatively well over repeated cleaning. NIOSH is completing research whose preliminary findings show that greater rates of contaminant removal occur with increasing the temperature above the NFPA 1851 prescribed maximum temperature of 105°F. NFPA 1851 does permit higher wash temperatures for Specialized Cleaning, where warranted, but the limitation remains for Advanced Cleaning. Thus, cleaning efficiencies have to be weighed against degradation impacts of repeated washing on protective gear at higher temperatures, or clothing materials and components will have to be made more durable.

Machine vs. Manual Cleaning Methods. For garments and hoods, the washer/extractor type of machine is the prescribed technique for cleaning. This type of machine affords a great deal of flexibility in setting wash conditions in terms of water temperature, water level, number of cycles, cycle length, and types of cleaning chemicals to be used. There is a substantial amount of proprietary information associated with various machines, products, and processes, but the NFPA 1851 standard does include recommended process formulations (the series of steps that makes up the washing process) for fire departments to consider if no other information is available.

Many machine manufacturers that cater to the fire service have developed their own formulations that are readily available to individual end users. In contrast, manual methods of cleaning, typically using a utility sink also with the 105°F maximum wash temperature (in this case to protect the wearer from being scalded with hot water), are much more variable depending more on operator attention to detail than to process parameters.

Because manual methods are the methods to be most often applied to certain PPE elements such as helmets and boots, results for cleaning effectiveness can be highly mixed for different types of PPE. Some manufacturers provide some level of detailed cleaning instructions, but the associated variability with types of soiling and contamination makes it difficult for those organizations to provide highly prescriptive and detailed procedures. Consequently, there is a fundamental need for understanding contamination levels and the ability to remove that contamination in the different forms of PPE. To this end, the NFPA's Fire Protection Research Foundation is now engaged in a subsequent project to investigate how different PPE is contaminated and how generalized cleaning methods remove persistent contamination. An overview of this effort as a continuation of prior DHS-supported research that led to the proposal of cleaning verification procedures for garments that were adopted in the new edition of NFPA 1851 is in "New Research Efforts for Investigation of Cleaning Fire Gear" on page 18.

Novel Cleaning Technologies. The new cleaning verification requirements that have become part of NFPA 1851 are expected to have a significant impact for being able to understand and compare cleaning effectiveness. While directed toward protective garment outer shell material cleaning by ISPs and manufacturers, procedures are expected to be useful by general industry for advancing new cleaning technologies that have the promise for promoting higher levels of contaminant removal. Even before the NFPA 1851 procedures were officially published, several groups with novel processes used cleaning verification techniques as the basis for asserting lower levels of the surrogate contaminants following the application of the respective processes.

As an example, one group touting a new dry cleaning method based on using nonconventional solvents has shown relatively high rates of contaminant removal using the NFPA 1851 procedures. Another company demonstrated reasonable levels of chemical removal using a water-saving machine and cleaning agent technology.

The existence of standardized procedures helps to set benchmarks and establish goals for improvements or optimization. The interest for finding better ways for cleaning items of protective clothing other than garments and hoods will also benefit from standard assessment methods for cleaning effectiveness that can then become the basis of substantiated claims from manufacturers or service providers.

Addressing SCBA and Other Fire Service Contaminated Items

In the PPE world, there is a division between wearing apparel/equipment (garments, helmets, hoods, gloves, and footwear) and everything else that might be worn, carried, or contacted by firefighters wearing PPE. This is partly because NFPA 1971 (structural firefighting PPE) covers the first group while other product standards—e.g., NFPA 1981 (fire service SCBA), NFPA 1936 (rescue tools), and NFPA 1901 (fire apparatus)—cover the related items, which only in the case of SCBA are considered PPE. Nevertheless, just focusing on conventional PPE creates

a large gap in fire service contamination control. These other items need to be equally addressed as part of the strategies used to minimize firefighter exposure to contamination. Three of these items are examined below.

SCBA. As part of the ensemble, the SCBA is perhaps the most significant item of protective equipment protecting the firefighter. High protection factors for this equipment afford effective protection from the inhalation of atmospheric contaminants; but because the SCBA is worn externally and is also part of the protective envelope over the end user's face, the SCBA with its complicated geometry is exposed to contamination and must be cleaned like any other item of protective clothing. NFPA 1852, the standard for the selection, care, and maintenance of SCBA, has minimal requirements in cleaning and decontamination and is not as advanced as NFPA 1851. Manufacturers of SCBA provide varying levels of detail for

New Research Efforts for Investigation of Cleaning Fire Gear

Overview. A new Department of Homeland Security Assistance to Firefighters Research Grant has funded the Fire Protection Research Foundation to establish a validated and scientifically based cleaning methodology for the primary spectrum of potentially contaminated fire service personal protective equipment (PPE) and equipment, including PPE not addressed by previous work such as helmets, gloves, and footwear, and other key components subjected to contamination such as hand tools, radios, and apparatus seat covers. This study is important because it provides a critical contribution to effective contamination control, which is believed to be a significant contributor to firefighter long-term health concerns (e.g., cancer).

This effort is a logical extension of an earlier research project that established validated cleaning procedures focused on PPE textile garments that are traditionally cleaned in commercial laundering extractors. The focus of the earlier baseline work optimized turnout clothing cleaning procedures and provided solutions relative to minimizing contaminant exposures that result in long-term adverse health conditions. This earlier study further established a methodology that can evaluate the effectiveness of cleaning and decontamination processes for removing both chemical and biological contaminants from garment outer shell materials. The cleaning processes for other gear are significantly different, and information is lacking on validated methods for removing contamination from this gear. This research established the "kit process" for putting known amounts of specific contaminants on representative clothing samples and subjecting those samples to cleaning in surrogate clothing with a full wash load and then analyzing both cleaned and noncleaned samples for levels of the contaminants to establish decontamination efficiencies (photo 1).

1

(1) Samples being prepared as part of the cleaning verification test kit process. (*Photo by author.)*

Purpose and Objectives. The overall goal of this project is to improve firefighter health and safety by reducing repeated exposure to harmful contaminants in unclean or inadequately cleaned PPE and related equipment. Specifically, this effort will answer new questions about turnout clothing contamination removal to further refine recommended fire service Advanced Cleaning and Sanitization procedures to levels of greater efficiency with conventional laundering/treatment approaches. Equally important, this project will create new evaluation methods for the consistent measurement of cleaning effectiveness for other items of PPE and related response equipment. The direct benefit to the fire service of the research is the broader validation of PPE/equipment cleaning that increases the assurance that firefighters are not unnecessarily exposed to persistent harmful contaminants through their PPE or tools.

Project Output. Expected outcomes from this project include the following:

- Determining principal areas of contamination retention for other types of PPE (beyond coat/pants outer shells) and fire service equipment and characterizing the mechanisms by which exposure to contamination occurs.
- Characterizing current cleaning processes applied to various forms of PPE and equipment.
- Adapting current contamination, extraction, and analysis techniques for evaluating cleaning, disinfecting, or sanitizing effectiveness of other types of PPE and equipment against chemical and biological contaminants.
- Demonstrating the reliability and appropriateness of proposed evaluation approaches through correlation using an extensive field validation process involving fire departments, application at independent service providers, and through verification organizations for turnout clothing cleaning and care.
- Evaluating the effectiveness of selected processes now used for cleaning other fire service PPE and equipment using refined project procedures for verifying removal of contaminants and determining those process parameters that provide the greatest efficiencies.
- Preparing industry guidance for cleaning, decontamination, and disinfecting or sanitizing procedures of fire service PPE and equipment.
- Facilitating proposed specific test methods for evaluating decontamination effectiveness related to the cleaning of PPE, including SCBA, for potential adoption as part of the next editions of NFPA 1851 and NFPA 1852.
- Determining proposed design, construction, and textile considerations for improved contamination resistance and reduction pertinent to PPE in relevant product standards.

What About SCBA Cleaning?

BY JAMIE LITTLE

On November 13, 2019, the Fairfax County (VA) Fire and Rescue Department (FCFRD) and the National Fire Protection Association Fire Protection Research Foundation (FPRF) conducted initial testing to assess the ability of wet preliminary exposure reduction (PER) techniques to remove surface contamination from self-contained breathing apparatus (SCBA). This work was conducted as part of a Department of Homeland Security grant that is supporting the research, which will assess how both PER and Advanced Cleaning remove general and specific types of contamination from SCBA. It is our understanding that no other scientist in the United States (and possibly the world) has conducted extensive testing to determine residual levels of contaminant chemicals such as polycyclic aromatic hydrocarbons (PAHs) on SCBA.

Unfortunately, the number of firefighters being stricken with cancer is rapidly on the rise. Through a variety of research and studies, it has been learned that the firefighting PPE that protects firefighters in a fire also tends to retain harmful carcinogens, which are then brought back to the fire station.

The FCFRD has taken a holistic approach to cancer reduction through education, providing firefighters with a second set of PPE, beginning to conduct on-scene gross decontamination (PER), and now looking to use a specialized decontamination "washing machine" for SCBA and other equipment to reduce exposure to fireground carcinogens. The department also appears to be the first in the U.S. fire service to use the washer on fire helmets.

In the first part of its research, FPRF worked with Intertek[1] to use a fluorescent surrogate contamination agent to determine how well PER removed the contamination from the SCBA and other parts of the PPE. Relatively simple equipment and procedures were used for this testing, which included the following.

Firefighters wore their full ensemble with SCBA (while on air) and were subjected to a spray of a nontoxic, fluorescent aerosol (GloGerm MIST) to simulate fireground exposures to heavy particulate smoke.

The firefighters then went through PER (on-scene gross decontamination) involving an initial rinse with a handline, light scrubbing with a soapy water (using a dishwashing soap-based solution), and a final rinse.

A bank of fluorescent (UV) lights was used to view and photograph the outfitted firefighters before and after PER to

(1) A firefighter in full ensemble with SCBA being sprayed with fluorescent agent in black light. (*Photos by Jeffrey Stull.)*

(2) Application of preliminary exposure reduction at FCFRD.

(3) The remaining fluorescent surrogate contaminant on firefighter PPE following preliminary exposure reduction. **(4)** A close-up of the head/neck region showing fluorescent contaminants on the firefighter face piece and collar area following preliminary exposure reduction.

Great Training Tool

The testing also proved to be an effective training tool for demonstrating the value and completeness for PER that any fire department can set up for a minimal investment. The following items are needed to perform this testing:

- Bottles of a fluorescent liquid agent, such as GloGerm MIST (not the gel or oil). One eight-ounce bottle can provide coverage for approximately two firefighters, depending on the spraying time and spray delivery rate.
- A paint sprayer or similar device that delivers the undiluted fluorescent liquid agent in a very fine mist, the finer the better. A compressed air source will also be needed to support the spraying process.
- Fluorescent UV (black) lights. Viewing is best performed with multiple 18- or 24-inch-long tube bulbs mounted vertically in custom-made wooden stands that will illuminate the fully outfitted firefighter.
- Supplies for performing preliminary exposure reduction that include a handline connected to a low water source with an appropriate spray nozzle, a set of different bristle brushes, a bucket for creating a soapy solution with a mild liquid dishwashing soap, and an area to control runoff.

Typically, firefighters, in a standing position with arms slightly away from their bodies, should be sprayed both from the front and the back over approximately 10 seconds, starting at the top and working down. It will take some trial and error to determine the amount of spraying needed to replicate fireground contamination. This is best accomplished under black light conditions to see the area of coverage during the spraying process.

The FCFRD plans to use the information from this initial testing to perform more sophisticated measurements of contamination levels and removal rates for SCBA. Future work will involve assessing SCBA exposure occurring as the result of use in live burns. The research team will use a combination of different sampling methods to determine gross levels of decontamination as well as target specific contaminants such as PAHs on SCBA before and after burn building exposures and after various forms of cleaning. The research team intends to further investigate the contamination removal rates for preliminary exposure and then examine different types of Advanced Cleaning that is manual with different detergents in addition to the use of new decontamination washing machine technology recently made available within the department.

determine if any areas with fluorescence were present, indicating the specific areas of the SCBA that remained contaminated following PER.

An iterative process was followed by trying different types of brushes and rinsing techniques to find the most effective methods for removing all signs of residual contamination.

Based on this testing, FCFRD found there were certain areas of both the SCBA and other PPE that would show fluorescence under UV light, which required further attention during the wet-down and scrubbing techniques. For example, relatively stiff bristle brushes worked well on the textile strap and harness components but were less effective on hard surfaces. It was also found that some parts of the ensemble such as the underside of the SCBA face piece and palm side of gloves were typically missed for removing surface contamination. The testing further allowed the research team to map out the areas where contamination would typically reside. Through successive trials, the FCFRD was able to obtain results with very little to no apparent remaining surrogate contamination on the PPE.

ENDNOTE

1. Intertek is an independent assurance, testing, inspection, and certification services provider and has been a leader in the PPE industry for more than 30 years. Testing for this project was performed by Pam Kavalesky, a staff engineer at Intertek in Cortland, New York, who has 13 years of experience in PPE testing and certification.

JAMIE LITTLE, a 10-year veteran of the fire service, has been a firefighter at the Fairfax County (VA) Fire & Rescue Department for the past five years. He is assigned to Fire Station 415 (Chantilly) and works in the department's PPE/SCBA shops.

cleaning instructions, but not much is understood about the levels of contamination on different parts of the SCBA that result from their use in structural fires.

There is now an interest across the U.S. fire service for the potential use of new machines, like dishwashers, which are set up to clean SCBA. Some manufacturers have indicated their general approval for using these machines, but those approvals are based only on the determination that the machines will not degrade or otherwise harm the SCBA and do not address how well cleaning effectiveness is attained. Emerging research in this area is highlighted in "What About SCBA Cleaning?" on page 20.

Radios. One large metropolitan fire department had attempted to have its radios cleaned following engraving using a specialized cleaning agent, but it later learned that the agent caused the radio casing to crack. An investigation by the radio manufacturer determined that the cleaning agent resulted in premature degradation of the radio housing material, and it suggested alternative cleaning procedures. This set of circumstances demonstrates that specific attention must be given to the selection of surface cleaning agents. Radios are extensively used on and off the fireground and have mixed applications; radios may or may not be subject to periodic cleaning. Just like

PFAS and Firefighting: Is There Cause for Concern?

BY DR. CHRISTINA M. BAXTER

Per- and polyfluoroalkyl substances, or PFAS, are chemicals that contain one or more perfluoroalkyl moieties.[1,2] While they do not occur naturally, there are more than 3,000 available on the global market.[3-5] The first PFAS, Teflon™, was synthesized by Plunket in 1938.[6] These materials are highly stable, have extremely low surface tensions, bioaccumulate in the environment, and are environmentally persistent.[7]

PFAS can be separated into polymers and nonpolymers.[8] In a firefighting context, both the polymers and the nonpolymers are of interest. Nonpolymer PFAS, such as PFOA and PFOS, are of high interest, as they are found in firefighting foams (fluorinated surfactants) and other environmental sources. PFAS polymers, like PTFE, are also of interest as moisture barriers within turnout gear certified against NPFA 1971 contain them. PFAS are also present in treated carpets, clothing, cosmetics, food preservatives, and oil- and water-repellant products.

In recent years, firefighter, community, and regulatory concerns regarding the potential for long-term health impacts arising from the use of AFFF have increased. Releases of fluorinated chemicals, including foams, into the environment have generated increased concern about the environmental fate and persistence of PFAS. During the recent past, a number of regulatory programs started to restrict the manufacturing approaches and use of PFAS.[9-11] Unfortunately, despite the research efforts, many uncertainties about their chemistry and distribution in the environment remain. The uncertainty also extends to understanding the exposure and health impacts on people.

Health Effects

Studies have reported associations between PFAS concentrations and adverse health effects such as fetal development, alterations to lipid metabolism, and thyroid disease.[12-14] Barry reported a link to kidney and testicular cancer; and, more recently, the International Agency for Research on Cancer classified PFOA as a Class 2B carcinogen—i.e., possibly carcinogenic to humans.[15,16] Further information about the toxic effects of perfluorochemicals has been published by de Witt and, more recently, by the Expert Health Panel for per and polyfluoroalkyl substances.[17,18]

Exposure and Exposure Pathways

Human exposure to PFAS can be via ingestion, inhalation, injection, and skin absorption. The largest sources of PFAS are found in food, drinking water, household dust, and indoor air. While PFAS can be found in materials contained within turnout gear, the dermal exposure route is insignificant, mainly because of the time required for a material to penetrate the skin. Dermal routes of exposure to PFAS materials have been estimated to account for less than 1% of the daily uptake.[19] Operationally, dermal exposure to PFAS has shown limited penetration or absorption into the skin within the first five hours of contact.[20] In addition, less than 75% of all challenge material was able to penetrate or absorb into the skin in a 24-hour period.[20] The predominant mode of exposure is via food sources, accounting for greater than 95%.[20] To put it all into context, Fromme et al. found that the average person has a PFOA dietary uptake rate ranging from 0.6 to 4.4 ng/kg body weight/day and a PFOS dietary uptake rate of 1.1 to 11.6 ng/kg body weight/day.[21] The dermal route of exposure accounts for 11 pg/kg body weight/day for PFOA and 3.6 pg/kg body weight/day for PFOS. These data were further backed up by Kim, et al in 2019.[22]

Firefighter Studies

There are several firefighter exposure studies ongoing as well as three recently completed studies. One of the major findings is that firefighters tend to have elevated PFAS levels (up to 15 times higher) when compared to the general population.[23] For firefighters who have been on the job for more than 10 years, the levels are considerably higher than for those who have been on the job less than 10 years.[23] The authors theorize that this finding is due to the "phasing out" of PFOA-containing materials in 2012.[23] No information is currently available on the dermal route of exposure of PFOS; therefore, it is assumed from the PFOA data.

How Can We Minimize Our Exposure?

- Wear your SCBA to minimize potential for inhalation exposure.
- Wash skin immediately following any firefighting activities to minimize length of exposure. Remember, it takes up to five hours for any material to penetrate the dermal barrier.
- Avoid foods known to contain large amounts of PFAS.
- Do not bring contaminated gear into the fire station living quarters.
- Avoid food packaging materials containing antistain or antigrease repellant materials.
- Avoid drinking water in areas that may have received high contamination from AFFF runoff.

PPE, validated methods of cleaning are needed to avoid inadvertent effects of the equipment that manifest in other problems. Moreover, some cleaning agents may not remove certain contaminants from various types of PPE and related equipment. It is important that cleaning be effective for decontamination and not cause adverse effects on the equipment that will cause premature failure.

Apparatus Seat Covers. Although the specific recommended practice in many departments is to avoid having contaminated PPE in apparatus cabs, this approach is not always followed. Wearing or placing contaminated PPE in end user compartments can result in cross-contamination that allows continued exposure whenever a firefighter is inside the apparatus. A fire department trying to investigate alternative approaches to the clean cab concept (no transport of contaminated gear inside the apparatus cab) used a wet vacuum to clean seat covers was not totally surprised when the collected wastewater was nearly black. Standardized testing for evaluating this type of contamination, whether by a surface wipe or some sort of extraction method, can be telling when making comparisons among different seat materials and cab interior spaces.

How Contamination Control Will Reshape Future PPE

Practices for the control of fireground contamination are already having an impact on PPE design and care. Many of the provisions that went into the new edition of NFPA 1851 were not just requirements conceived by the committee responsible for the standard but rather a reflection of procedures already devised by progressive fire departments, industry, and researchers seeking to minimize firefighter exposure to harmful substances coming from structural fires and other exposure events. Although increased fire service awareness has evolved over the past decade, the reality is that most changes toward contamination control are incremental or adaptive to allow desired transitions of firefighter behaviors and fire operations to occur more readily. Yet, taking a step back and looking at the big picture can lead to the fire service's complete rethinking of PPE. Here are some of the ideas being discussed in various organizations.

Reexamining Material Choices and Performance. The materials used in PPE have evolved over the past 40 years in response to the needs of the fire service to identified hazards. At first, the principal objective of protecting from heat and flame contact was achieved with intrinsically flame resistant materials. It was also important to keep firefighters dry, prompting the use of waterproof or water-resistant materials. To protect linings from absorbing water, lessening their insulation and adding weight, "vapor barrier" materials were later used as an intermediate layer in clothing. Though these new layers worked reasonably well, they stifled the release of heat, creating greater physiological burdens on firefighters. Vapor barriers tran-

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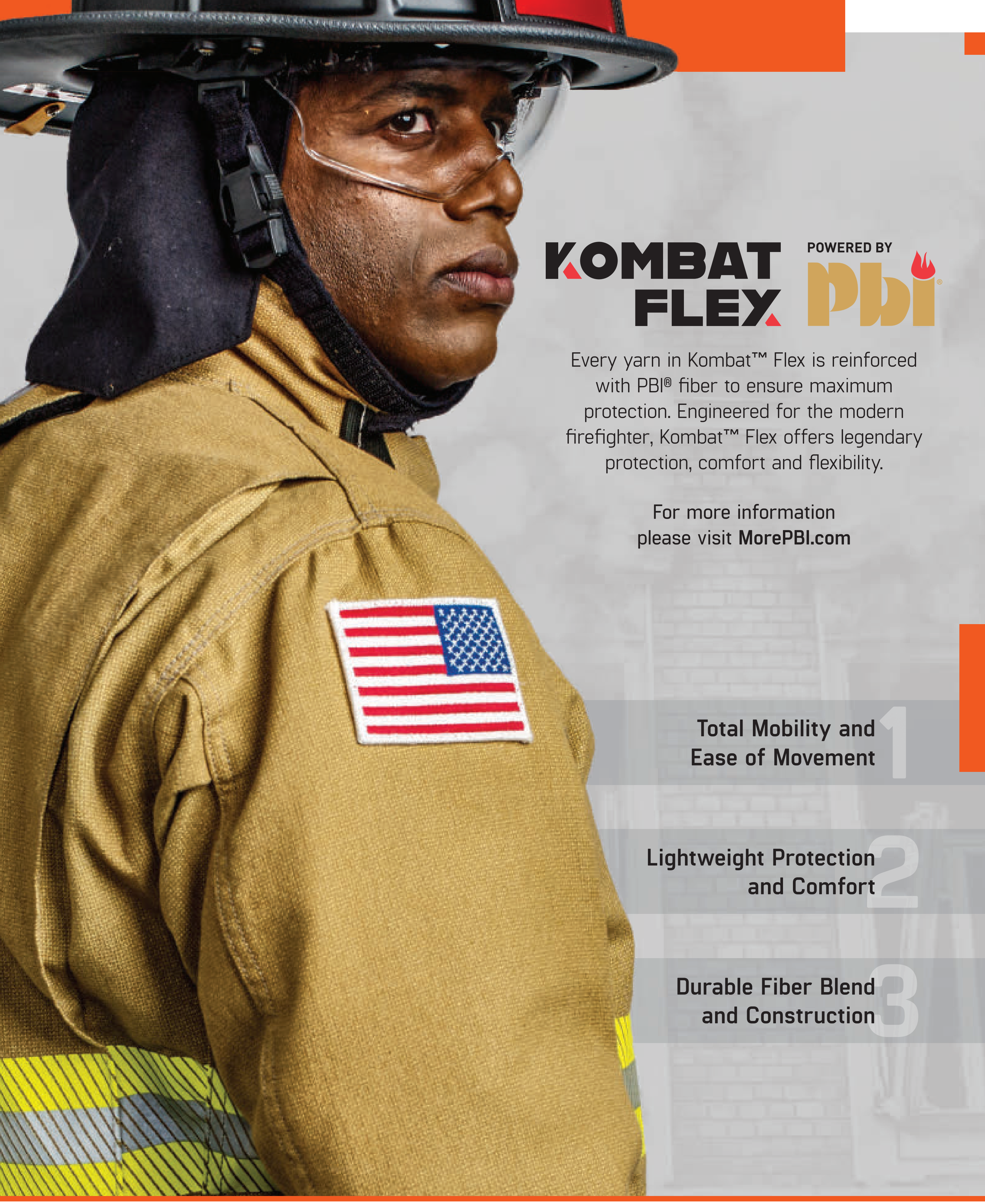
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sitioned to moisture barriers, which were required to be "breathable" to reduce heat stress. Concurrently, exposure to bloodborne pathogens emerged as a prevalent concern, demanding increased barrier material performance. This set of circumstances resulted in tradeoffs between protection from exterior fireground heat and allowing the release of internal body heat. All of this established the current landscape for protective clothing materials.

The prospects for contamination exposure and retention are now just beginning to influence PPE material choices. It is recognized that the moisture barriers now used in garments, gloves, and footwear or particulate-blocking hoods retard the penetration of smoke particles. Yet, the ability to remove contaminants from these same materials has not been a major factor in their selection. Other than the requirement that garment outer shells absorb very little water, not much has been done to make protective clothing materials more resistant to contamination or easier to clean. To move the PPE industry forward in this regard, heat protection and heat stress relief must now be balanced against resisting contamination or ease of removing contaminants.

Durable water repellent (DWR) finishes used on garment outer shells and other PPE materials are thought to help clothing resist contamination. However, certain previously used, but highly effective, perfluoroalkyl substances (PFAS) have been voluntarily discontinued from use in firefighter PPE for the past several years. The replacement chemicals, shorter chain but different PFAs with no known current exposure hazards, still aid in preventing chemical absorption, but they have become the center of controversy surrounding the general use of PFAS in a variety of industrial applications (see sidebar below).

Certainly, the PPE used for protection should not become a source of its own contaminants, but serious consideration, and, more importantly, substantiated scientific research are needed to balance true risk from wearing PPE with its ability to resist contamination. To this end, it has been recommended that not only should the topic be studied but also that the industry proactively apply its own requirements for ensuring that safe levels of any restricted substances that exist in established standards as described in the inset for Oeko-Tex® (mentioned later).

Addressing Restricted Substances in PPE

Restricted substances are those chemicals that should either be significantly restricted or eliminated from process because of their potential toxicity, carcinogenicity, or other health effects on the user or general population. Control of restricted substances results from outright bans of certain chemicals by local or national jurisdictions or increased public concerns

relative to the use of these substances. For the most part, specific laws call out these restrictions, and industry is obliged to comply. Demonstration of compliance has generally fallen to the manufacturer, but the use of independent, third-party assessments can greatly facilitate consumer confidence in properly addressing restricted substances.

Fortunately, there are organizations 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 Standard 100 by Oeko-Tex®, an independent certification system testing apparel textiles and components for "harmful substances." When an item of apparel has been certified to this standard, it means that it has met certain criteria: It contains no illegal substances (carcinogenic colorants); it has only a certain amount of other legally regulated substances (formaldehyde, heavy metals, phthalates, etc.); and it contains only a certain amount of substances that are known to be harmful but are not yet regulated (pesticides and allergenic dyes).

The Standard 100 by Oeko-Tex® is far stricter than 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 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 by the fire service PPE industry would seem to offer the solution to provide broad benefits to the fire service.

Revamping PPE Design. Contamination control has already begun to impact the design of PPE. Particulate-blocking hoods first appeared at the 2017 Fire Department Instructors Conference International. Some PPE manufacturers are designing their products for ease of cleaning. Examples include making it easier to detach textile components including suspensions, chin straps, and ear covers from helmets and harness straps from SCBA. Several recent garment designs have improved the effectiveness of interfaces, which historically have not been well addressed in clothing designs. These products are being designed with the goals of minimizing head stress for firefighters while not compromising protection from other fireground hazards.

Designing for the combined factors of modulating conventional fireground hazards (heat and physical), physical stress, and contamination control may drive significant rethinking of how PPE is configured and evaluated as an overall protective system. This probably would be possible only if new methodology is proposed as part of the product standards to evaluate full ensembles for each of the areas of heat protection, liquid protection, particulate protection, heat stress, contamination resistance, and decontamination effectiveness. New tests are needed to allow manufacturers to make appropriate base claims of performance in these areas. Equally important are simple evaluation tools that fire departments can use to assess their choices for protective ensembles they configure.

The focus on PPE integration and interoperability is likely to promote entirely new approaches to fire service PPE that have other benefits including cross-functional performance (utility in multiple types of operations or convertibility of ensembles for different missions). In another 10 years, PPE may transform entirely to a different appearance with an entirely evolved set of expectations.

Changing How PPE Care Takes Form. The frequency of cleaning turnout gear has been on the rise over the past decade. This increased cleaning by fire departments is straining the current resources for providing cleaning. Reliance on information and cleaning capabilities from ISPs combined with the emergence of new cleaning technologies and practices are expected to radically affect PPE care and maintenance.

The fire service is demanding greater levels of information on PPE, particularly when involved in unusual structural fires and exposed to different problematic contaminants. PPE is a significant expense for any organization. Fire departments generally turn to their own internal experts or manufacturers for guidance and recommendations for getting the maximum service life of the clothing and equipment. One expected trend is for ISPs to broaden their services for training firefighters in cleaning and care. Some ISPs already support fire department PPE needs by offering reserve gear or maintaining PPE inventories for these organizations. Though applied in a few limited cases, one future model for PPE may encompass leasing programs as opposed to directly purchasing PPE. If correct sizing and fit issues can be adequately addressed, such an approach could lead to fire departments spreading their costs out over a longer period and employing easier ways to update PPE.

On the fireground, departments are devising ways to implement PER. As suggested by the recommended new version of NFPA 1500, contamination control and PER are being integrated with fireground rehabilitation. Fire departments are using PER approaches that range from the very simple to the more sophisticated solutions such as using a form of rehabilitation/decontamination service apparatus. Industry offerings of new or adaptive equipment or supplies are also being introduced. This includes systems for isolating, bagging, and transporting contaminated PPE. For example, though not PPE, fire apparatus are now being designed for clean cab concepts to address contaminated PPE.

There is plenty of evidence for new technology to address PPE cleaning. Already mentioned in this supplement is that new forms of dry cleaning as well as special washing machines for SCBA and other PPE are starting to become available. The development of metrics for readily assessing contam-

ination and better ways for verifying decontamination will become the basis of future process, product, and service claims. It is anticipated that the combination of improved PPE contamination resistance, ease of cleaning, and various product or service enhancement will begin to dramatically lessen manual cleaning and significantly reduce both fireground and continuing exposure to contamination.

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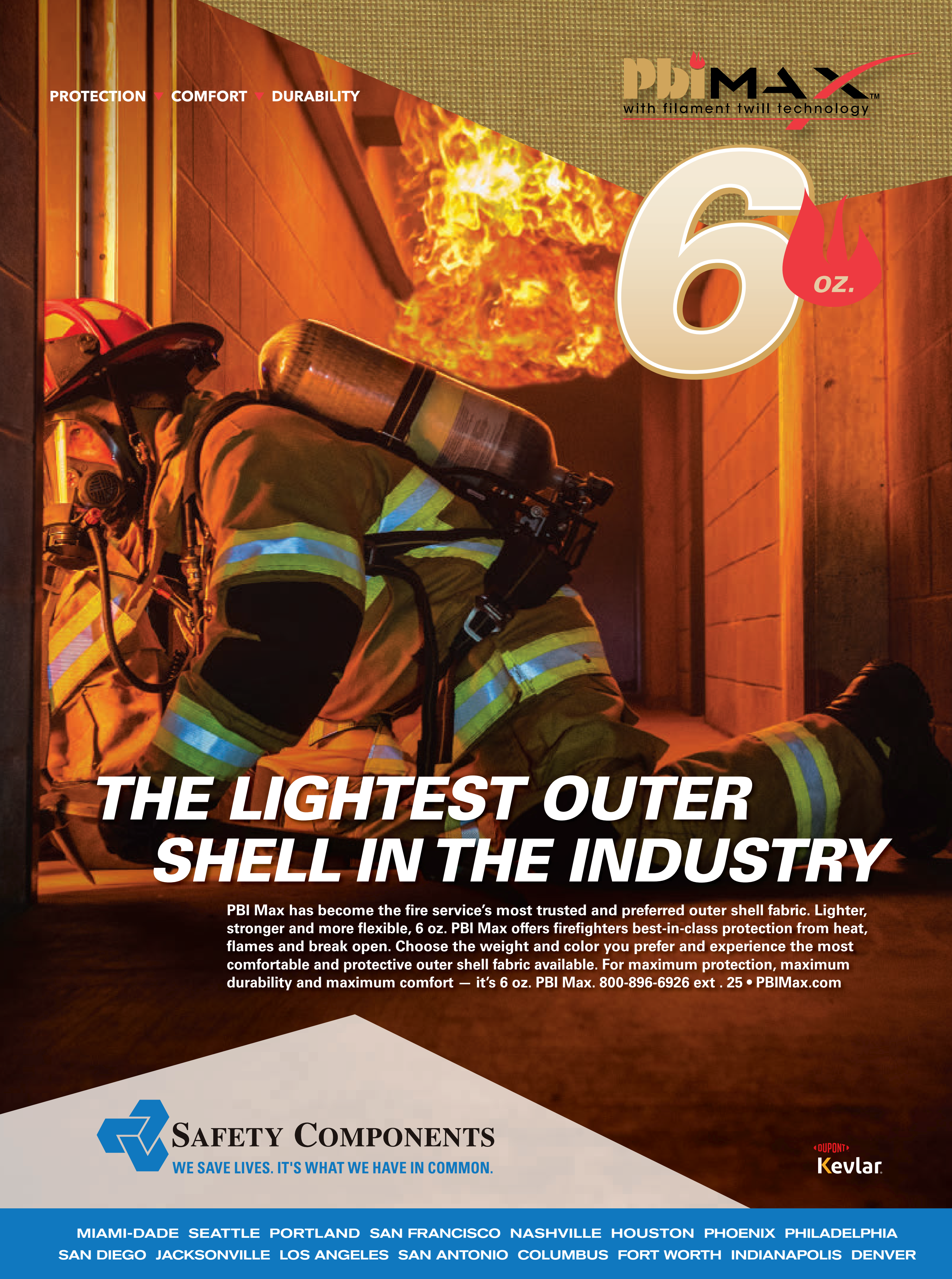
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