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eBook

Understanding Fireground Threats, Risks, and PPE

There have arguably been fewer collections of material more sentinel to the evolution of safer firefighting and firefighter health/wellness than the three pieces presented in this Fire-Dex-sponsored training digest. Understanding the increased risk associated with the off-gassing of PPE post firefighting presents several opportunities to evolve our postfire activities and reduce toxic exposure. Gaining a greater understanding of how our PPE specification may be contributing to heat stress is critical to future modifications, designs, and fabric choices. Understanding heat stress as it relates to cardiovascular risks provides critical insight into prefire, firefighting, and postfire activities.

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PPE, Heat Stress, and Cardiac Strain: a Study

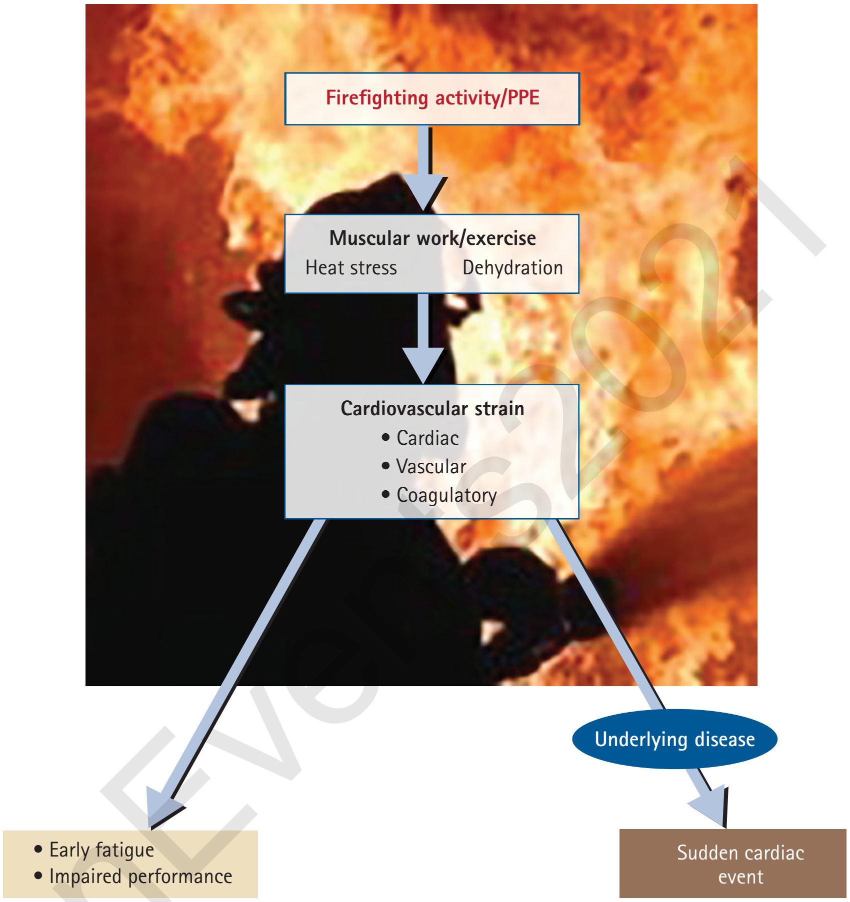
By **DENISE L. SMITH**, **JEANNIE HALLER**, **WESLEY K. LEFFERTS**, **ERIC M. HULTQUIST**, and **PATRICIA C. FEHLING**

FIREFIGHTERS PERFORM STRENUOUS work in dangerous and unpredictable environments. Despite the numerous dangers on the fireground, the leading cause of line-of-duty deaths (LODDs) among firefighters in the United States is sudden cardiac death, which accounts for approximately 50 percent of deaths.[1] Several research studies have shown that firefighting may serve as a trigger for a sudden cardiac event in susceptible individuals; however, the precise mechanisms by which firefighting may lead to a sudden cardiac event are not well defined.[2] Figure 1 presents a theoretical model that depicts the relationship between firefighting and cardiovascular strain and the relevance to the fire service.

Firefighting involves strenuous work and is performed while wearing personal protective equipment (PPE). Heat stress frequently occurs on the fireground because of the combination of muscular work, impaired heat dissipation associated with the wearing of PPE, and radiant heat. Heat stress results in profuse sweating, which often leads to dehydration. Muscular work, heat stress, and dehydration all contribute to cardiovascular strain (high heart rate, high cardiac output, enhanced blood clotting potential). Cardiovascular strain is a major concern for all firefighters because it can lead to the early onset of fatigue, which may impair performance or force firefighters to stop working. Additionally, high cardiovascular strain is a major safety concern in firefighters with an underlying disease because it may lead to a cascade of events (e.g., plaque rupture, clot formation, ischemia) that result in a sudden cardiac event.

Although numerous field studies have shown that firefighting leads to increased cardiovascular strain, these studies were not designed to isolate the independent effects of heat stress and dehydration on the cardiovascular system. A better understanding of the independent contributions of these two challenges may allow the fire service to develop targeted countermeasures to prevent and reduce injuries and deaths associated with cardiac strain.

Figure 1. Firefighting and Cardiovascular Strain



Therefore, we conducted a laboratory study that allowed us to investigate the independent effects of heat stress and dehydration on cardiovascular strain. Although the laboratory study did not include the physical and psychological strain encountered during actual firefighting emergencies, it allowed us to tightly control the level of work and standardize conditions. Importantly, we used an exercise/work protocol and conditions that were relevant to firefighting in terms of the intermittent nature of the work and the levels of heat stress and dehydration induced.

Study Design

This study was completed as part of a larger, comprehensive study to investigate the effects of heat stress and dehydration on cardiovascular function. A full description of the study design and the results can be found in peer-reviewed publications.[3,4,5]

Briefly, 12 healthy, physically active, college-age men completed three different experimental trials on separate days. Since heart rate is influenced by several factors, we standardized testing procedures by performing trials at the same time of day and imposing caffeine, alcohol, and strenuous exercise restrictions

Figure 2. Experimental Design and Conditions

Exercise Protocol:

- Three 20-min exercise bouts separated by 20-min rest (total =100 min)
- Work identical for all trials
  - a) Treadmill walking (5% grade; avg. speed 3.1mph)
  - b) Total weight of gear (avg. 41.2 lb)
- Thermoneutral laboratory

Condition	**Hydrated/No heat stress**	**Hydrated/Heat stress**	**Dehydrated/Heat stress**
How induced	• Cooling shirt + SCBA + weighted vest • Enough fluid provided to prevent dehydration	• Firefighting PPE • Enough fluid provided to prevent dehydration	• Firefighting PPE • Fluid restricted 24 hrs prior to and during exercise
Relevance	Allows for comparison with heat stress when work is the same but core temperature rise is limited.	Heat stress is routinely encountered during firefighting activity because of PPE and environmental conditions.	Dehydration commonly occurs during firefighting and exacerbates heat stress.

Note: The photographs depict the clothing worn during the heat-stress trials.

to keep these factors consistent for all trials. Additionally, all participants ate a standardized meal prior to each day of testing.

During each trial, the participant performed a 100-minute intermittent exercise (work) protocol; however, the degrees of heat stress and dehydration were manipulated by varying the clothing worn and the fluid intake to create three different experimental conditions: hydrated/no heat stress, hydrated/heat stress, and dehydrated/heat stress (Figure 2). We were interested in assessing the influence of heat stress (induced by walking in PPE) and the effect of a combination of heat stress and dehydration on thermal and cardiac strain. Thus, we included a condition in which participants did the same work (walking at the same speed and grade wearing the same weight), but in one condition we limited the increase in core temperature by having participants wear a cooling vest. The following section details how we manipulated these variables.

Manipulated Variables

Heat Stress

To mimic moderate heat stress (core temperature < 101.3°F) that has been reported during firefighter drills,[6,7] participants walked on a treadmill while wearing full structural firefighting PPE. Firefighting PPE was identical for all participants and consisted of turnout pants and coat, boots, gloves, hood, helmet, and self-contained breathing apparatus (SCBA) (average weight of gear: 41.2 pounds).

No Heat Stress

To minimize heat stress, participants walked on a treadmill while wearing a cooling shirt that circulated cool water next to the body through embedded tubing. Participants also wore a weighted vest and carried an SCBA. Thus, the total weight carried matched the weight of the heat-stress trials in which PPE (41.2 pounds) was worn. This ensured that the amount of work done in all trials was the same.

Hydrated

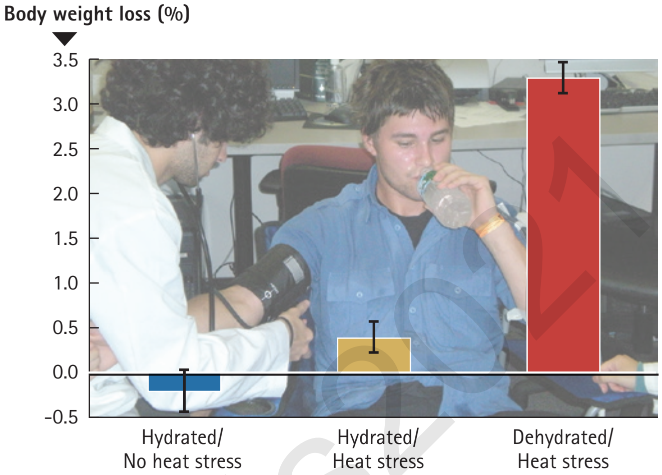
In the hydrated trials, participants started the trial fully hydrated, and the fluid lost through sweating during the protocol was replaced by fluid ingestion during recovery periods. To ensure proper hydration at the start of the exercise trial, participants were given between 34 and 50 ounces (between two and three liters) of water to drink in the 24 hours prior to testing, and urine specific gravity was tested to ensure participants were not dehydrated. Water and sports drinks were provided during testing to match fluid loss (as estimated during familiarization trials) and minimize the change in body weight.

Dehydrated

In the dehydrated trial, participants started the trial in a mildly dehydrated state (a one- to two-percent body weight loss), and additional dehydration was induced by restricting fluid during testing. Mild dehydration at the start of testing was employed because several research studies have shown that firefighters report to work or training in a dehydrated state.[8,9,10] Mild dehydration was achieved by providing participants with only between 17 and 25 ounces (between one and 1.5 liters) of water to drink during the 24 hours preceding testing. Minimal fluid [~1 cup (240 mL)] was provided during the testing protocol. The goal was to induce three-percent body weight loss between the end of the protocol and the previous

24-hour measurement of body weight.

Figure 3. Body Weight Loss



Exercise Protocol

The 100-minute protocol consisted of three 20-minute bouts of treadmill walking at a moderate intensity with a 20-minute rest between bouts to mimic the work/rehab cycles encountered during prolonged firefighting or training drills. For each participant, the work performed during each trial was kept constant. The grade was set at five percent, and the speed averaged 3.1 miles per hour.

Measurements

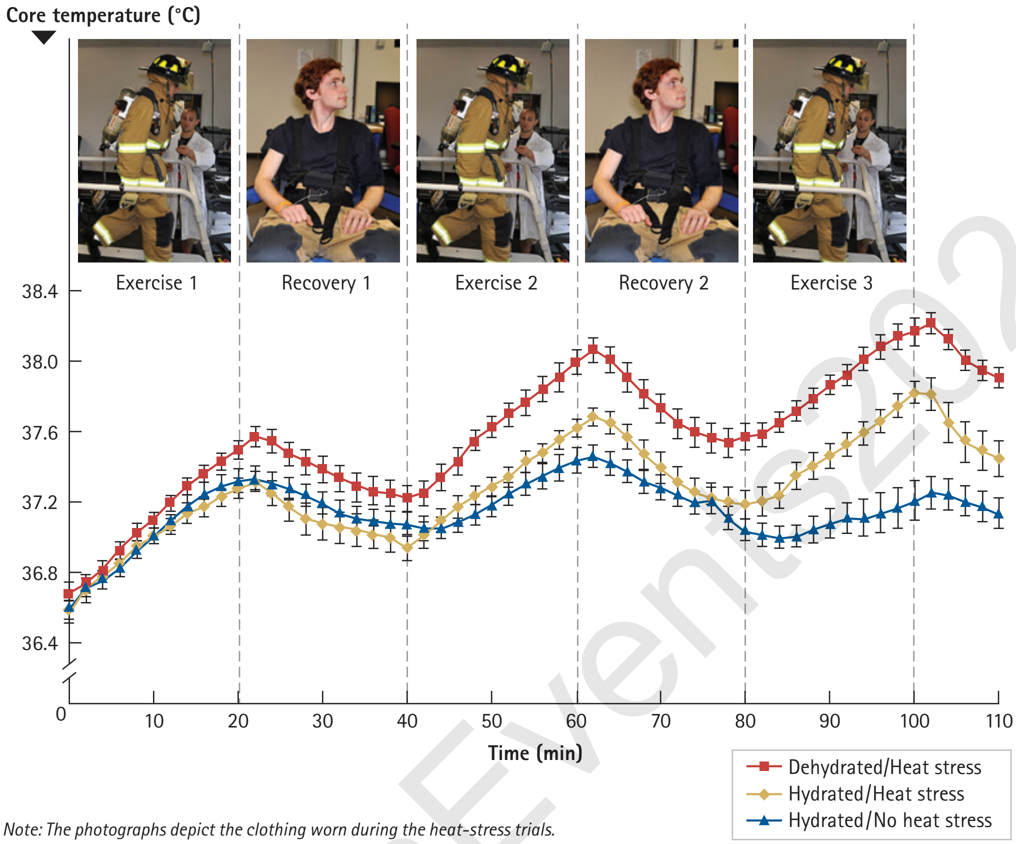
We assessed hydration status at the start of the experimental trial by measuring urine specific gravity. Body weight was measured 24 hours prior to the experimental trial, before the exercise protocol, and immediately after the exercise protocol. Heart rate was measured continuously throughout the 100-minute intermittent exercise protocol using a heart rate monitor. Core temperature was measured throughout the protocol using an ingestible pill.

Results and Discussion

Figure 3 shows total body weight loss between the 24-hour pretrial measurement and the postexercise measurement. Results indicate that the criteria for the hydrated and dehydrated conditions were met—body weight change was minimized (within 0.4 percent) for both hydrated trials, and body weight loss was approximately three percent for the dehydrated trial.

Core temperature rose during exercise and into the first two minutes of recovery and then decreased during recovery during all trials (Figure 4). By design, the core temperature was higher during the heat-stress condition than the no-heat-stress condition. Differences in core temperature among the trials were visible by the end of the first exercise bout and became more pronounced as the protocol

Figure 4. Core Temperature During Intermittent Exercise



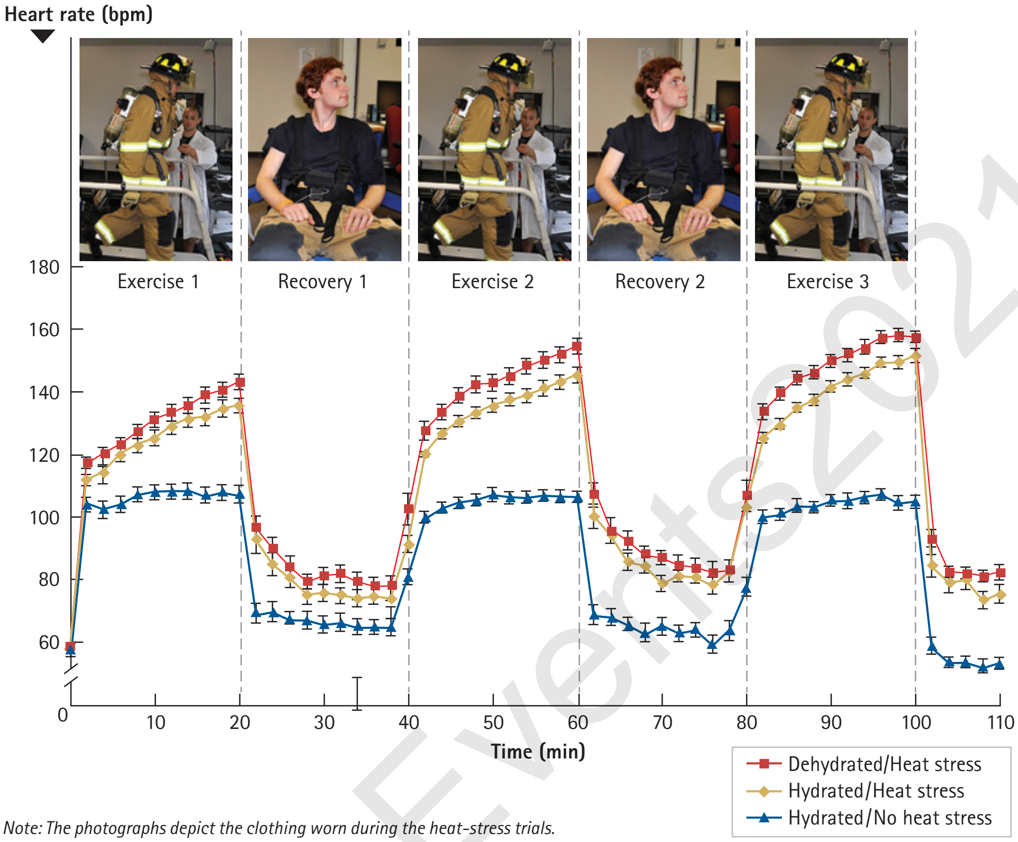
Note: The photographs depict the clothing worn during the heat-stress trials.

continued. In the hydrated/no heat stress trial, core temperature increased by 1.1°F between the start and completion of the protocol. In comparison, core temperature increases were between two and 2.5 times higher in the heat-stress trials; the core temperature increased by 2.2°F during the hydrated/heat stress trial and by 2.7°F in the dehydrated/heat stress trial. The ~0.5°F difference between the hydrated/heat stress and dehydrated/heat stress trials clearly indicates that dehydration exacerbates thermal strain.

The increase in core temperature that we found in the dehydrated/heat stress trial is similar to increases that have been reported with live fire training drills.(6),[11] It is also important to note that the recovery periods allowed core temperature to decrease toward baseline values. However, even after 20 minutes of recovery, the core temperature was not back to baseline, and each successive bout of exercise resulted in a higher core temperature.

As expected, heart rate increased during exercise and decreased during recovery in all three conditions. Figure 5 shows the pronounced differences in heart

Figure 5. Heart Rate During Intermittent Exercise



Note: The photographs depict the clothing worn during the heat-stress trials.

rate (HR) between the heat stress trials and no-heat-stress trial throughout the protocol. Firefighters know that PPE adds to the work they do, but these results clearly demonstrate the magnitude of the physiological burden associated with PPE. In the hydrated trials, HR reached 105 beats per minute (bpm) in the no-heat-stress condition and 152 bpm in the heat-stress condition at the end of Exercise 3—a difference of nearly 50 bpm. Importantly, the participants carried the same amount of weight. Therefore, the 50 bpm higher HR in the two heat-stress trials (caused by wearing PPE) cannot be attributed to weight. Rather, this difference reflects the strain induced by the effect of PPE on core temperature and perhaps to some degree the increased effort of walking in bulky clothing. Furthermore, the increase in heart rate when dehydration was superimposed on heat stress is clearly evident in Figure 5. When dehydration was coupled with heat stress, the heart rate was six bpm greater compared with heat stress alone.

This study confirms what firefighters know well from experience—PPE imposes substantial cardiac strain during work. However, the magnitude of the physiological strain of PPE is likely far greater than is generally known and is not entirely attributed to the weight of the gear. Additionally, our results indicate that dehydration further exacerbates cardiac strain during work, which is likely less apparent to many firefighters.

Relevance for Firefighters

Firefighters routinely face the twin challenges of heat stress and dehydration on the fireground, and the effects of these factors on cardiac strain are often intertwined. This study showed that moderate heat stress induced by walking in PPE, consistent with that documented during live-fire training exercises, caused substantial cardiac strain (HR = 150–160 bpm). Our study also showed that moderate dehydration (three percent) exacerbated thermal strain and further contributed to cardiac strain experienced with heat stress.

On the fireground, heat stress is an unavoidable challenge that results from working in heavy, encapsulating PPE that limits heat dissipation and from environmental conditions. Dehydration is a potential consequence of firefighting and of inadequate fluid intake in general, but to a large extent dehydration is avoidable. Importantly, firefighters can take a proactive approach to combat the adverse effects of heat stress and dehydration.

Recommendations

To mitigate the detrimental consequences (early fatigue, impaired job performance, or sudden cardiac event in susceptible individuals) of cardiac strain resulting from heat stress and dehydration during strenuous firefighting activities, firefighters should do the following:

1. Receive an annual medical evaluation consistent with National Fire Protection Association (NFPA) 1582, *Standard on Comprehensive Occupational Medical Program for Fire Departments*,[12] and performed by a physician familiar with the physiological demands of firefighting. In addition to clearing a firefighter for duty, findings of this exam should be used to aggressively manage risk factors for cardiovascular disease.
2. Engage in regular physical exercise to improve work performance, enhance cardiovascular function, improve thermoregulation, and provide cardioprotection.

3. Ensure proper hydration before emergency operations and consume fluids during/following operations to rehydrate. Hydration status can be monitored using a simple urine chart.
4. Adopt NFPA 1584, *Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises,*[13] and ensure that incident rehabilitation is established for emergency operation and training drills. Rehabilitation provides an opportunity for rest, rehydration, and active cooling. Additionally, during rehabilitation, EMS should monitor vital signs and observe firefighters for signs suggestive of the need for further medical care.

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References

1. Fahy, RF, PR LeBlanc, and JL Molis. (2014) Firefighter Fatalities in the United States—2013. Quincy, MA: National Fire Protection Association, 2014. http://www.nfpa.org/newsandpublications/nfpa-journal/2014/july-august-2014/features/firefighter-fatalities.
2. Smith, DL, DA Barr, and SN Kales. (2013) "Extreme sacrifice: sudden cardiac death in the US fire service." *Extreme Physiology & Medicine,* 2013; 2:6. http://www.extremephysiolmed.com/content/2/1/6.
3. Fehling, PC, JM Haller, WK Lefferts, EM Hultquist, M Wharton, TW Rowland, and DL Smith. (2015) "Effect of exercise, heat stress and dehydration on myocardial function." *Occupational Medicine*, 2015; 65(4):317-323. http://www.ncbi.nlm.nih.gov/pubmed/25868467/
4. Lefferts, WK, KS Heffernan, EM Hultquist, PC Fehling, and DL Smith. (2015) "Vascular and central hemodynamic changes following exercise-induced heat stress." *Vascular Medicine*, 2015; 20(3):222-229. http://www.ncbi.nlm.nih.gov/pubmed/25939655.
5. Smith, DL, JP DeBlois, M Wharton, PC Fehling, and SM Ranadive. (2015) "Effect of moderate exercise-induced heat stress on carotid wave intensity." *European Journal of Applied Physiology*. 2015; 115(10):2223-30. http://www.ncbi.nlm.nih.gov/pubmed/26112919.
6. Smith, DL, SJ Petruzzello, MA Chludzinski, JJ Reed, and JA Woods. (2005) "Selected hormonal and immunological responses to strenuous live-fire firefighting drills." *Ergonomics,* 2005; 48(1):55-65. http://www.ncbi.nlm.nih.gov/pubmed/15764306.
7. Colburn, D, J Suyama, SE Reis, J Morley, FL Goss, Y-F Chen, CG Moore, and DA Hostler. (2011) "Comparison of cooling techniques in firefighters after a live burn

evolution." *Prehospital Emergency Care*, 2011; 15(2):226-232. http://www.ncbi.nlm.nih.gov/pubmed/21294631.

8. Brown, J, A. Derchak, A Bennett, M Lepore, and S Edwards. (2007) "Impact of pre-participation hydration status on structural firefighter cardio-respiratory response to standard training activities." *Medicine & Science in Sports & Exercise,* 2007; 39(5):S153. http://www.researchgate.net/publication/246623010_Impact_of_Pre-Participation_Hydration_Status_on_Structural_Firefighter_CardioRespiratory_Response_to_Standard_Training_Activities_1195.
9. Espinoza, CA and M Contreras. (2007). Safety and performance implications of hydration, core body temperature and post rehabilitation Orange County Fire Authority, Wellness and Fitness Program. Irvine, CA. http://www.mcftoa.org/wp-content/uploads/2008/12/hydrationstudy.pdf.
10. Horn, GP, J Deblois, I Shalmyeva, and DL Smith. (2012) "Quantifying dehydration in the fire service using field methods and novel devices." *Prehospital Emergency Care,* 2012; 16(3): 347-355. http://www.tandfonline.com/doi/abs/10.3109/10903127.2012.664243?journalCode=ipec20.
11. Fernhall, B, CA Fahs, G Horn, T Rowland, and D Smith. (2012) "Acute effects of firefighting on cardiac performance." *European Journal of Applied Physiology,* 2012; 112(2):735-741. http://www.ncbi.nlm.nih.gov/pubmed/21660460.
12. National Fire Protection Association. NFPA 1582, *Standard on Comprehensive Occupational Medical Program for Fire Departments*. Quincy, MA: National Fire Protection Association, 2013. http://www.nfpa.org/.
13. National Fire Protection Association. NFPA 1584, *Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises*. Quincy, MA: National Fire Protection Association, 2015. http://www.nfpa.org/.

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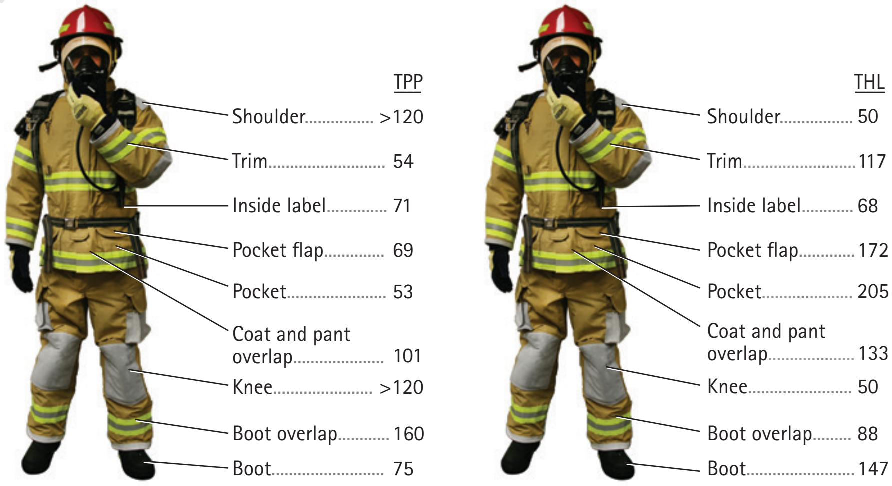
The Cost of a Pocket: the Impact of Reinforcements on the TPP and THL

By **MEREDITH McQUERRY, ROGER BARKER, ALEXANDER HUMMEL**, and **SHAWN DEATON**

RECENT RESEARCH AT North Carolina State University (NCSU) aims to determine the direct impact of additional layers and thickness or bulk on the thermal protection and heat loss qualities of structural firefighter turnout suits. The "Revolutionary Modern Turnout Suit" project, sponsored by the United States Department of Homeland Security/Federal Emergency Management Agency through the Assistance to Firefighters Grant program, is exploring new design features and material innovations to reduce the incidence of heat stress among firefighters. Currently, more firefighters are experiencing injury and even death from exhaustion and heat stress than from burn injuries.

National Fire Protection Association (NFPA) 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Firefighting* (2013 ed.), requires thermal protective performance (TPP) and total heat loss (THL) evaluations for new, unused turnout materials. The TPP is an evaluation of the material's thermal protection,

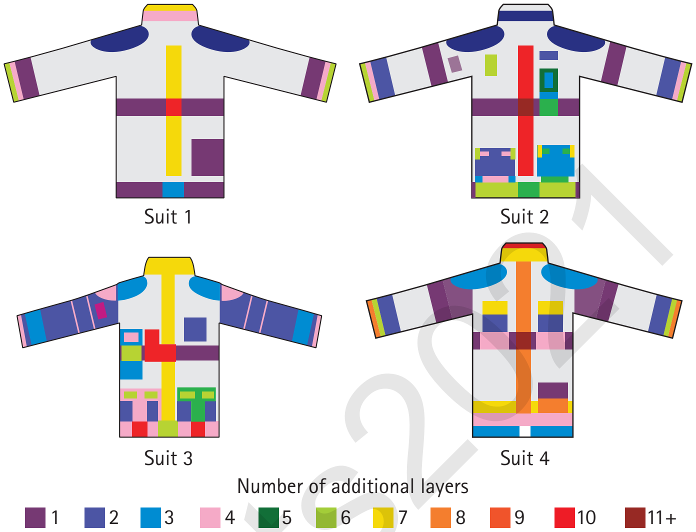
Figure 1. Effect of Reinforcements on TPP and THL



Base composite TPP = 38 cal/cm²
NFPA minimum requirement = 35 cal/cm²

Base composite THL = 263 W/m²
NFPA minimum requirement = 205 W/m²

Figure 2. Base Composite Turnout Suit Comparisons



whereas THL is a measure of the fabric's breathability or comfort. These two measures are inversely proportional to one another; thicker, heavier materials provide better TPP results, but lighter, thinner materials are ideal for THL.

The NFPA requires a TPP rating of at least 35 calories per square centimeter (cal/cm^2), whereas the minimum THL requirement is at least 205 watts per square meter (W/m^2). The limitation with these two measures as specified in NFPA 1971-2013 is that they evaluate the three-layer base composite only, which includes only the outer shell, the moisture barrier, and thermal liner layers. When the fabric is produced as a three-dimensional garment and worn with a full turnout ensemble [boots, gloves, thermal hood, helmet, self-contained breathing apparatus (SCBA), and so on], the clothing system's level of thermal protection and heat-loss capabilities changes drastically. Added reinforcements at the knee, the shoulder, the pockets, the trim, and elsewhere are not factored into current TPP and THL evaluations.

Impact of Additional Layers

As part of our research in the Textile Protection and Comfort Center (TPACC) at NCSU, we evaluated the impact of these additional reinforcements in terms of TPP and THL. We selected as a benchmark a standard (the control) turnout suit typical of what departments would purchase on the market today. We made TPP and THL measurements on the base composite and on the garment overlaps (coat and pant, boot and pant) and on the additional reinforcements (pocket, pocket flap, knee and shoulder padding, trim, NFPA label).

Figure 1 demonstrates that most of the turnout suits had much higher TPP ratings than required and, as a result, much lower THL values that do not meet the minimum NFPA requirement. The base composite, used as a control, had a TPP rating of 38 cal/cm^2 and a THL of 263 W/m^2, which is greater than the minimum requirements. By adding a single layer of outer shell material to represent a pocket, the TPP was increased to 53 cal/cm^2 and the THL was reduced to the minimum requirement (205 W/m^2). The pocket composite was the only reinforcement evaluated that would pass the minimum THL requirement. The reflective trim increased the TPP to more than 50 cal/cm^2 but reduced the THL by 146 W/m^2. Among portions with the lowest THL were the NFPA label (identifying the garment's size, specifications, and so forth), which covers a significant area of the garment and which reduced the THL to 68 W/m^2, and the knee and shoulder reinforcements, which further reduced the THL to 50 W/m^2. The area with the highest level of thermal protection (160 cal/cm^2) in the turnout ensemble is where the boot and pant overlap. This overlap covers a significant amount of the lower leg and reduces the THL to 88 W/m^2.

Base Composite Percentages

Although these results demonstrate the impact of standard reinforcements found in many turnout suits on the market today, some departments add even more material to provide additional levels of thermal protection. We analyzed the base composite area on four different turnout suits. The base composite percentage was found by determining the number of reinforcements added to the three-layer base composite. Suit 1 included only the reinforcements required by NFPA 1971, Suit 2 was typical of what a number of departments purchase, and Suits 3 and 4 are unique suits from two American fire departments.

Overall, a typical turnout suit, identical to the one evaluated above, had a base composite (outer shell, moisture barrier, and thermal liner) percentage of just 50 percent. Suits from other areas of the country had as little as a 33-percent base composite area, meaning almost 70 percent of their turnout suit consisted of additional reinforcements, not including the coverage the SCBA provided.

Most of the additional layers and reinforcements were in the front of the coat (Figure 2). The additional layers ranged from one to more than 11 extra layers. The front coat of Suit 1 had a base composite percentage of 52.5 percent; Suit 2, 45.9 percent. Suits 3 and 4, however, were bulked up for even greater protection, with base composite percentages in the front of the turnout coat of just 35.2 percent (Suit 3) and 22.5 percent (Suit 4). These two suits also had the highest number of additional layers throughout the suit.

Findings

Overall, these results illustrate the limitations of fabric level TPP and THL measurements for structural firefighter turnouts. This research found that structural turnout suits provide a level of thermal protection that greatly exceeds the minimum 35 cal/cm^2 indicated by fabric level TPP testing. Also, because of increased layering effects, the TPP can exceed 150 cal/cm^2 in some locations within the turnout ensemble. Such a drastic increase in TPP leads to a significantly detrimental decrease in heat loss to as low as 50 W/m^2 in some areas.

Thus far into the study, the research conclusions demonstrate the imbalance between the garment's protection and its comfort and the limitations of using fabric level methods for measuring the TPP and the THL. These data illustrate the unintended negative consequences of overspecification and the impact of additional layers on thermal protection. To achieve a more successful balance between thermal protection and comfort, the need for each additional reinforcement and layer should be evaluated to help provide meaningful improvement to the THL in the garment.

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Off-Gassing Contaminants from Firefighters' Personal Protective Equipment

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FIREFIGHTER PERSONAL PROTECTIVE equipment (PPE) provides excellent protection from environmental hazards during firefighting, but the protective ensembles often become contaminated with combustion by-products while serving this purpose. Few scientific research studies have attempted to quantify this contamination, which may consist of nonvolatile, semi-volatile, and volatile compounds. At normal environmental conditions, nonvolatile compounds exist primarily as solids; semi-volatile compounds are found as both condensed (liquid or solid) and gas phase; and volatile compounds readily generate vapors that can be inhaled because of their high vapor pressure. As examples, flame retardants are generally nonvolatile, whereas low molecular weight polycyclic aromatic hydrocarbons (PAHs) are semi-volatile and single-ring aromatic hydrocarbons (like benzene and toluene) are volatile organic compounds (VOCs).

During firefighting, nonvolatile contaminants present an exposure hazard mainly through firefighters coming in physical contact with the substances and subsequent dermal absorption and hand-to-mouth ingestion. Volatile and semi-volatile contaminants may also present an exposure hazard through the inhalation route, whereby the PPE acts as a temporary adsorptive material for airborne contaminants (gases and particles) that may then be released into the air during postfire activities. These evaporating contaminants may be inhaled after a firefighter doffs his self-contained breathing apparatus (SCBA).

This potential inhalation route of exposure has not been previously investigated. Hence, investigators from the National Institute for Occupational Safety and

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(1) Enclosure used by NIOSH to sample off-gassing PPE ensembles. After closing the lid, the metal canister collected VOCs for analysis. *(Photo courtesy of the National Institute for Occupational Safety and Health.)*

Health (NIOSH) in the United States and Queensland Fire and Emergency Services (QFES) in Australia separately set out to study the accumulation and off-gassing of combustion by-products on firefighters' PPE ensembles. Results from these two independent studies were recently published in the same issue of the peer-reviewed *Journal of Occupational and Environmental Hygiene* (June 2015).

Table 1 describes the similarities and differences of these two studies. The basic premise of both studies was the same-to test PPE ensembles for off-gassing contaminants before and after being worn while fighting fires in structures with typical room-and-contents furnishings (NIOSH) or common training fuels (QFES). QFES investigators also tested PPE ensembles after laundering per manufacturer's recommendations to determine whether off-gas concentrations returned to normal background levels.

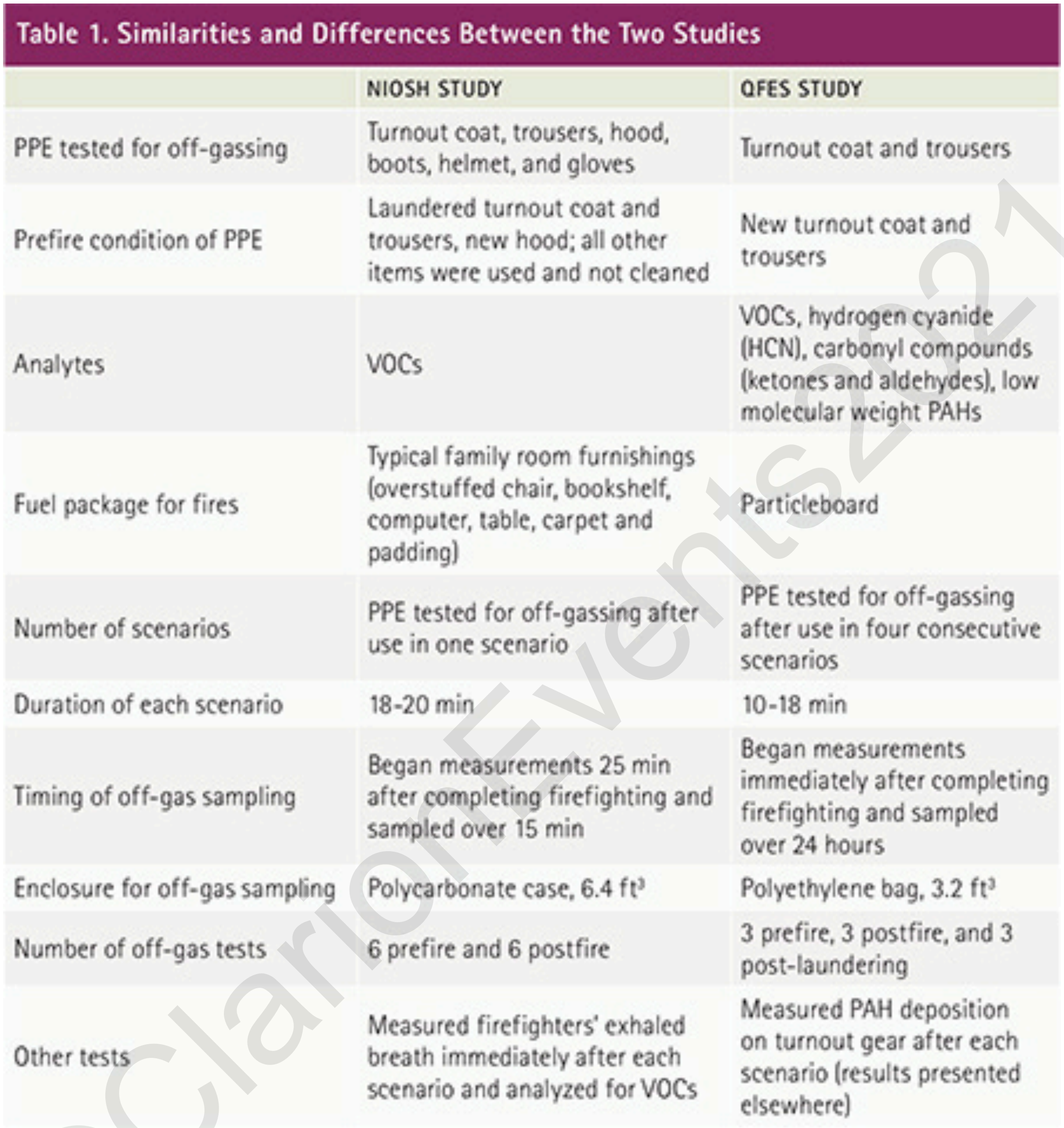

Table 1. Similarities and Differences Between the Two Studies

	NIOSH STUDY	QFES STUDY
PPE tested for off-gassing	Turnout coat, trousers, hood, boots, helmet, and gloves	Turnout coat and trousers
Prefire condition of PPE	Laundered turnout coat and trousers, new hood; all other items were used and not cleaned	New turnout coat and trousers
Analytes	VOCs	VOCs, hydrogen cyanide (HCN), carbonyl compounds (ketones and aldehydes), low molecular weight PAHs
Fuel package for fires	Typical family room furnishings (overstuffed chair, bookshelf, computer, table, carpet and padding)	Particleboard
Number of scenarios	PPE tested for off-gassing after use in one scenario	PPE tested for off-gassing after use in four consecutive scenarios
Duration of each scenario	18-20 min	10-18 min
Timing of off-gas sampling	Began measurements 25 min after completing firefighting and sampled over 15 min	Began measurements immediately after completing firefighting and sampled over 24 hours
Enclosure for off-gas sampling	Polycarbonate case, 6.4 ft³	Polyethylene bag, 3.2 ft³
Number of off-gas tests	6 prefire and 6 postfire	3 prefire, 3 postfire, and 3 post-laundering
Other tests	Measured firefighters' exhaled breath immediately after each scenario and analyzed for VOCs	Measured PAH deposition on turnout gear after each scenario (results presented elsewhere)

Results

Investigators in both studies measured elevated levels of a variety of VOCs off-gassing from PPE ensembles postfirefighting (compared to prefirefighting levels), with similar findings for benzene, toluene, ethyl benzene, xylenes, and styrene (Table 2). QFES investigators also measured elevated levels of methyl isobutyl ketone, acetaldehyde, crotonaldehyde, benzaldehyde, and hydrogen cyanide (HCN). HCN was measured at concentrations up to 10× higher than any other compound. NIOSH investigators found a relationship between off-gas concentrations and exhaled breath concentrations of benzene, toluene,

(2-3) The enclosure used by QFES to sample off-gassing structural firefighting ensembles. The ensembles shown are post-laundering. After sealing the enclosure, sampling pumps were operated through the plastic enclosure (photo 3) to commence sampling. *(Photos courtesy of Queensland Fire and Emergency Services.)*

ethyl benzene, xylenes, and styrene. QFES investigators found that most off-gas concentrations returned to normal background levels after laundering.

Discussion

Inhalation exposures are likely to occur when firefighters are not wearing SCBA or alternative forms of respiratory protection and they do the following:

- Continue to wear a turnout coat and trousers when packing up and loading the apparatus.

- Rehab near used PPE ensembles or, if PPE is not fully doffed, in the rehab area.
- Change air cylinders between work cycles on the fireground.
- Wear or store PPE ensembles in the cab of the apparatus or personal vehicle.
- Spend time in a location at the firehouse where unlaundered PPE ensembles are stored.

Off-gas exposures are likely to be highest immediately following use of PPE in a fire, when firefighters are in close proximity to PPE, and especially if firefighters and their PPE are in an enclosed space.

The findings from these studies are important because they demonstrate *that off-gassing from contaminated PPE can extend exposure time beyond the fireground and, therefore, represents another source of exposure for firefighters that should be managed.* Off-gassing air concentrations in both studies were below applicable occupational exposure limits, although higher concentrations may have been measured if testing occurred immediately after firefighting and culminated within 15 minutes thereafter.

Potential exposures from off-gassing PPE, albeit typically brief, consist of multiple compounds, including known irritants (e.g., aldehydes), chemical asphyxiants (e.g., HCN), and carcinogens (e.g., benzene). The potential additive or synergistic effects of these multiple exposures are largely unknown. Irritants can cause inflammation in the lungs, and chemical asphyxiants reduce the oxygen-carrying capacity of the blood. In addition to the effects on the respiratory system, both irritants and chemical asphyxiants can place added stress on the cardiovascular system.

Firefighters appear to have a higher risk of various types of cancer and, therefore, should minimize their exposures to potential carcinogens as much as possible. *Appropriate storage and timely laundering of PPE could substantially reduce cumulative exposures to these compounds over the duration of a firefighting career.*

The significant relationship between off-gas concentrations and exhaled breath concentrations found by NIOSH suggests that contaminated PPE contributes to firefighters' absorbed dose even during the short time (few minutes) firefighters

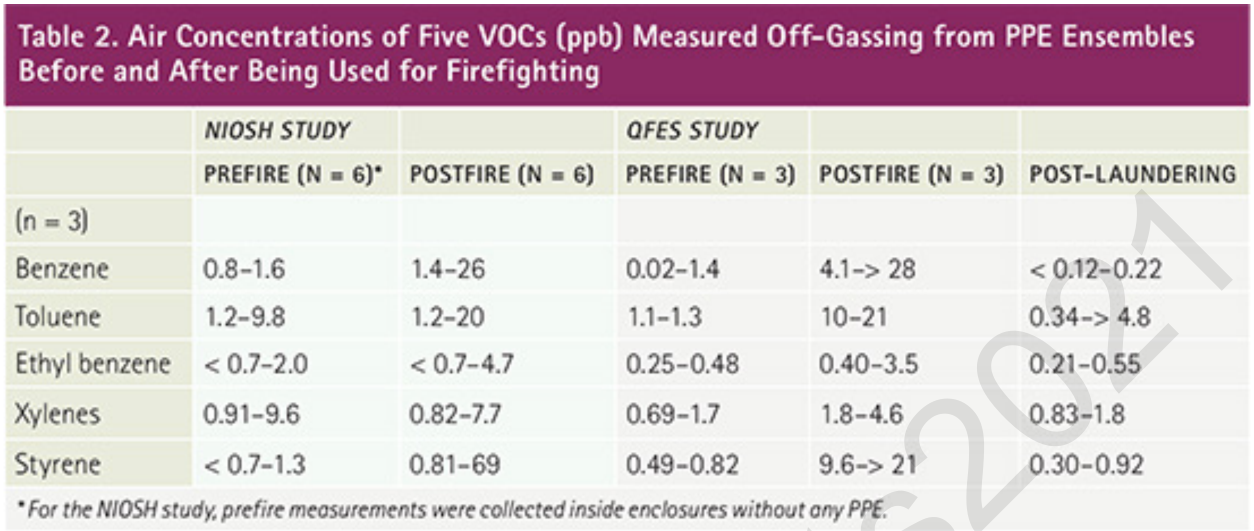

Table 2. Air Concentrations of Five VOCs (ppb) Measured Off-Gassing from PPE Ensembles Before and After Being Used for Firefighting

	NIOSH STUDY		QFES STUDY		
	PREFIRE (N = 6)*	POSTFIRE (N = 6)	PREFIRE (N = 3)	POSTFIRE (N = 3)	POST-LAUNDERING
(n = 3)					
Benzene	0.8–1.6	1.4–26	0.02–1.4	4.1–> 28	< 0.12–0.22
Toluene	1.2–9.8	1.2–20	1.1–1.3	10–21	0.34–> 4.8
Ethyl benzene	< 0.7–2.0	< 0.7–4.7	0.25–0.48	0.40–3.5	0.21–0.55
Xylenes	0.91–9.6	0.82–7.7	0.69–1.7	1.8–4.6	0.83–1.8
Styrene	< 0.7–1.3	0.81–69	0.49–0.82	9.6–> 21	0.30–0.92

**For the NIOSH study, prefire measurements were collected inside enclosures without any PPE.*

doff gear. However, the exhaled breath concentrations measured by NIOSH could also be partially attributed to direct uptake of VOCs through the skin during firefighting. Further research is required to determine the relative effects contributed by each of these exposure pathways.

Both studies focused primarily on measuring volatile substances. Semi-volatile and nonvolatile compounds could also contaminate firefighters' PPE ensembles and potentially transfer to the skin of firefighters where they could be absorbed dermally or ingested. Unlike VOCs, which will mostly evaporate from surfaces within a few hours, semi-volatile compounds could evaporate over much longer periods of time and pose a longer duration inhalation hazard. Furthermore, PAHs and other carbonaceous substances that contaminate PPE may act like activated carbon, adsorbing VOCs in the fire atmosphere and then slowly releasing them over time.

Research aimed at a greater understanding of where and why the highest firefighter exposures occur during fire response activities may assist in lowering PPE contamination levels. Further research is needed to fully characterize the magnitude and composition of contamination on firefighters' PPE ensembles, with an emphasis on highly persistent compounds like flame retardants, dioxins, and phthalates. An assessment of the effectiveness of decontamination and laundering at removing such contamination is also needed.

The following resources contain additional information on this topic:

- Kirk KM and Logan MB. (2015) "Structural Fire Fighting Ensembles: Accumulation and Off-gassing of Combustion Products," *J Occup Environ Hyg*, 12:6, 376-383.
- Fent KW, Evans DE, Booher D, Pleil JD, Stiegel MA, Horn GP, and Dalton J. (2015) "Volatile Organic Compounds Off-gassing from Firefighters' Personal Protective Equipment Ensembles after Use," *J Occup Environ Hyg,* 12:6, 404-414.
- NIOSH (2013) "Health Hazard Evaluation Report: Assessment of Dermal Exposure to Polycyclic Aromatic Hydrocarbons in Fire Fighters." http://www.cdc.gov/niosh/hhe/reports/pdfs/2010-0156-3196.pdf.

The two independent studies by NIOSH and QFES clearly demonstrate that a variety of volatile substances can accumulate and subsequently off-gas from firefighters' PPE ensembles. The off-gassing compounds could result in inhalation exposure for firefighters if they remove SCBA and remain in close proximity to their PPE postfirefighting, particularly if this occurs within an enclosed space. Firefighters and fireground support personnel should take measures to minimize these exposures. These measures include rehabbing away from their used ensembles; storing their ensembles in dedicated, well-ventilated areas; and, if possible, transporting ensembles outside the apparatus cab or personal vehicle after responding to a structure fire. Prompt laundering of ensembles after use in structural firefighting operations is an additional effective measure in reducing postfirefighting exposures to volatile products of combustion.

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FireDex®

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Fire-Dex, located in Medina, Ohio, is a leading manufacturer of head-to-toe protection for 1st responders. Fire-Dex was formed after A Best Products Co. purchased Morgan Protection Apparel in Rome, GA in 1983; manufacturing welding and firefighting gloves with good dexterity, the name "Fire-Dex" was an obvious choice. Fire-Dex strategically grew by adding more accessory items such as fire hoods and suspenders and then began manufacturing structural turnout gear in 1987. Expansion continued in the following years, adding ParaDex EMS and USAR Gear, and then in September of 2008 Fire-Dex acquired the Chieftain brand, bringing with it a long history in the fire industry, dating back to 1927. Fire-Dex entered the footwear market in 2010 when they launched their first structural firefighting boot, the FDXL-100 Red Leather Boot. Recognizing the health benefits of wearing lighter gear when structural turnouts aren't necessary, Fire-Dex proudly acquired TECGEN PPE in September of 2015 as its latest addition to the Fire-Dex family of brands.

Fire-Dex's commitment to customer satisfaction, production excellence and product innovations has paved the path for continued rapid growth and the ability to consistently develop and acquire new life-saving technologies in the fire protection market.

LINKS:

- Fire-Dex Products
- Fire-Dex's NFPA 1851 Inspection, Cleaning, and Repair Trainings
- Gear Tracker; The NFPA 1851 Gear Tracking Solution
- FireWriter2 Custom Gear Configurator