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Management of Firefighters' Chemical & Cardiovascular Exposure Risks on the Fireground

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Abstract

The fire service research community around the world has focused substantial resources on reducing firefighter risk for sudden cardiac events and chemical exposures that may lead to cancer. Research presented here summarizes important lessons learned from a full-scale residential Fire Study that allowed quantification of the risks as well as the effectiveness of interventions to reduce those risks. To address fireground exposure concerns, personal protective equipment (PPE) and administrative controls exist. But, these controls are not always straightforward to apply. Leadership and management concerns with ongoing implementation of these controls are introduced and opportunities for change management are discussed. While research provides a solid basis upon which to institute policy and practice, fireground leadership and management is critical to ensure appropriate implementation.

Keywords

fire fighting; firefighter chemical exposures; sudden cardiac events; fireground risk mitigation; contamination control

Introduction

Leaders in the fire service are faced with an evolving landscape of local hazards to which they respond as well as the challenges that they need to manage on the fireground. To support fire departments, meaningful investments have been made in fire service research.

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Research on health and safety of firefighters has been driven by the evolving fireground, the fire service's deeper appreciation for individual health risks, and the availability of funding —including the notable efforts of the Federal Emergency Management Agency's Fire Prevention and Safety (FP&S) Grant program. Through these research efforts, important advances have been made in our understanding of the hazards associated with structural fire fighting (Kerber, 2012). As a result, the fire service has been provided with important tactical guidance to increase firefighter effectiveness while decreasing risk. At the same time, substantial evidence suggests that fire fighting leads to cardiovascular strain, and it is widely reported that firefighters also have an increased risk of developing certain job-related cancers. Through FP&S funding, efforts have been focused on studying these topics. However, these efforts will not result in improved health and safety without effective leadership and management to implement these findings.

To begin, take a quick look at some statistics. Based on reporting from the National Fire Protection Association (NFPA) and the United States Fire Administration (USFA), it is well established that sudden cardiac events are one of the leading causes of duty-related deaths among firefighters (Fahy & Molis, 2019). Kales, Soteriades, Christophi, and Christiani (2007) estimated a 10–100 times increased risk for firefighters suffering sudden cardiac death after fire suppression compared to the risk associated with non-emergency duties. In 2019, Smith et al. (2019a) confirmed these estimations using autopsy data. These findings suggest that fire suppression activities may trigger sudden cardiac events in individuals with underlying heart disease.

During this same time frame, an increasing number of epidemiology studies have been conducted to determine the risk of cancer in the fire service. In a seminal effort, LeMasters et al. (2006) conducted a meta-analysis of several epidemiology studies from 1975–2003 and found an elevated risk for multiple types of cancer. In one of the largest cohort mortality studies ever conducted in firefighters, the National Institute for Occupational Safety and Health (NIOSH) found statistically significant mortality and incidence rates of all cancers and cancers of the esophagus, intestine, lung, kidney, and oral cavity, as well as mesothelioma for firefighters compared with the general population (Daniels et al., 2014; Pinkerton et al., 2020). The NIOSH team also found an exposure-response relationship for lung cancer as well as leukemia (Daniels et al., 2015). Studies conducted throughout the world have identified increased risks among firefighters for multiple types of cancer (Glass et al., 2014; Pukkala et al., 2009; Tsai et al., 2015).

There are a number of factors that can increase the risk of cancer. Some modifiable lifestyle risk factors include smoking, alcohol consumption, diet, obesity, and sun exposure as reviewed by Jahnke, Poston, Haddock, and Jitnarin (2017). Additionally, firefighters may be exposed to numerous carcinogenic compounds on the fireground, including benzene, certain polycyclic aromatic hydrocarbons (PAHs), formaldehyde, vinyl chloride, and other halogenated compounds. The three primary routes of exposure on the fireground include inhalation, ingestion, and dermal absorption. As products of combustion are emitted into the air from the fire source, one of the most direct routes for exposure of the firefighter is to breathe them in, which will allow absorption into the body through the respiratory system. Not only is this a direct route of exposure, but contaminants that make it to the lung are readily absorbed through the pulmonary capillaries directly into the bloodstream. Products of combustion may also end up on a firefighters' skin and be available for transdermal absorption. While the skin provides an excellent barrier to many chemicals, it is not impervious. The longer a chemical is present on the skin, the more time is available for transdermal absorption. Several important products of combustion can be absorbed through the skin directly in vapor or particulate form (Franz, 1984; VanRooij De Roos, Bodelier-Bade, & Jongeneelen, 1993). Finally, ingestion is possible by swallowing contaminants captured by mucous or the mucociliary ladder of the lungs or while ingesting food in a manner that allows transfer of contaminants from personal protective equipment (PPE) or hands onto food and into the digestive system.

NIOSH plays a leading role in identifying risks and protecting workers across all industrial sectors. The Hierarchy of Controls model shown in Figure 1 defines five broad methods of protecting occupations from the hazards in the workplace, in order from most effective (top) to the least effective (bottom). The fire service relies heavily on PPE due to the variability and often unknown conditions in the emergency response. As such, modern PPE is expected to protect the firefighter against environmental heat, water, and abrasion hazards; and now requirements are being added for protection against smoke ingress. It is important to remember that in addition to the protection it must provide, the PPE must still permit the firefighter to operate, conducting physically strenuous activities that require a high level of strength, muscle coordination, and/or endurance. Performing strenuous work in PPE results in metabolic heat generation that increases core body temperature and exacerbating cardiovascular strain.

The purpose of this review is to provide fire service leaders with updated scientific information so they can be better informed on how to balance protection and risk that must be managed on the fireground.

Cardiovascular & Chemical Exposure Risks in Today's Fire Service

There has been great energy in the research community around the world focused on reducing firefighter risk for sudden cardiac events as well as risks for chemical exposures that may lead to cancer (Austin Wang, Ecobichon, & Dussault, 2001; Bolstad-Johnson et al., 2000; Burgess et al., 2012; Fent et al., 2014; Hostler, et al., 2014; Jankovic, Jones, Burkhart, & Noonan, 1991; Kales et al., 2007; Keir et al., 2017, 2020; Laitinen, Makela, Mikkola, & Huttu, 2012; Oliveira et al., 2020; Sjöström, Julander, Strandberg, Lewne, & Bigert, 2019; Smith et al., 2019a; Stec et al., 2018; Wingfors, Nyholm, Magnusson, & Wijkmark, 2018). This article will largely focus on lessons learned from a series of studies led by the Illinois Fire Service Institute (IFSI), the UL Firefighter Safety Research Institute (FSRI), and NIOSH, with funding support from the FP&S Grant program. As the following information will focus on managing risk on the fireground, the bulk of this review will come from our Fireground Study, where teams of twelve firefighters responded to a ventilation limited fire involving 2 rooms in a full-scale residential-style test structure. Our work has resulted in many peer-reviewed scientific papers (Fent et al., 2017, 2018, 2020; Gainey et al., 2018; Horn et al., 2018; Kerber, Regan, Horn, Fent, & Smith, 2019; Smith et al., 2019b), which will be summarized in this review with a focus on leadership

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lessons. For this study, firefighters were assigned to fire attack, search and rescue, outside vent, overhaul and command/pump operations and their job specific thermal and chemical exposures were quantified. The goal of this study was to better understand how operating in an environment typical of the early 21st century fireground impacts cardiovascular strain and chemical exposures related to carcinogenic risk. Additional insights have been gathered from subsequent studies, which have elucidated the contaminant pathways from the fire environment to the human body and the attenuation from the turnout gear.

Potential Respiratory Exposure on the Fireground

There are many risks for respiratory exposure while working at a residential structure fire. The most obvious threat is within the burning structure, which is why the fire service has expectations of SCBA usage for work in this location. However, risks are also present on the fireground outside of the structure and potentially from PPE **after** the firefight has ended, and too often we have failed to adequately protect firefighters when they are not in an *immediately dangerous to life and health* (IDLH) environment. Some major findings from our study include:

- ***Polycyclic Aromatic Hydrocarbons (PAH), Particulate, and Benzene During the Firefight.*** The concentration of contaminants available for inhalation depends on the job assignment most closely associated with proximity to the fire itself. Firefighters assigned to attack and search job assignments are likely to have the highest median airborne PAH (17,800–23,800 μg/m^3) and benzene (37.9–40.3 ppm) exposures followed by overhaul (PAH: 512 μg/m^3, benzene: 0.9 ppm), outside vent (PAH: 96 μg/m^3, benzene: 0.2 ppm), then incident command/pump operator (PAH: <30 μg/m^3, benzene: <0.01 ppm) job assignments (Fent et al., 2018). However, the usage of SCBA trends in the opposite direction, reducing risk for the attack and search firefighters—but not protecting those who do not wear appropriate respiratory protection on the fireground.

- ***Airborne Measurements of Hydrogen Cyanide (HCN).*** The highest concentrations of hydrogen cyanide were measured in the area where the attack firefighters operated (median 33.5 ppm). However, as these firefighters were wearing SCBA during their activity, inhalation exposure was likely low. The next highest concentrations were measured at the outside vent position (Fent et al., 2018), where SCBA usage is not as consistent. The median personal air concentration of HCN for the outside vent firefighters (14 ppm) was well above the NIOSH short-term exposure limit (4.7 ppm), and occasionally exceeded IDLH limits (50 ppm).

- ***Gas Exposure During Overhaul.*** Anecdotally, firefighters may choose to doff their SCBA during overhaul. In our Fireground study, we characterized the impact of unprotected overhaul exposure using a mouse model without airway protection while firefighters were conducting overhaul to assess risk to the lungs in the form of gene expression (Gainey et al., 2018). Although gas metering showed that the levels of gasses that are commonly monitored during overhaul were well below NIOSH ceiling limits, 3,852 lung genes were differentially expressed in the mice exposed to overhaul environment compared with mice on the fireground, indicating increased risk for those who conduct overhaul without airway protection.

- ***Particulate on the Fireground.*** Concentrations of particulate were by far the highest inside the structure during fire attack (median >1,000,000/cm^3). However, significant elevations of particulate concentrations were also measured outside of the structure near the attack engine (median >20,000/cm^3). Concentrations were the highest on the fireground when downwind of the structure with heavy ground-level smoke, but were also measurable when downwind of the structure with minimal ground-level smoke. It is important to note that diesel exhaust from the nearby apparatus also contributed particulate, gases, and vapors to the samples measured. (Fent et al., 2018).
- ***Off-gassing Following Fire Fighting Activity.*** Even after the firefight has ended and the visual signs of inhalation risk have subsided, inhalation hazards may remain if contaminated PPE is not properly handled. During the firefight, PPE may absorb volatile compounds (e.g., benzene, HCN) that can then be released back to the air in areas that may not have originally been contaminated. One component of our Fireground study investigated off-gas concentrations in a compartment the approximate size of an apparatus cab and found that levels were well below applicable short-term exposure limits (e.g. benzene: 3,200 μg/m^3) (Fent et al., 2017). However, off gassing provides another potential route of exposure for those who may have already been exposed during the firefight.

Respiratory Exposure Control Measures

Fortunately, respiratory protection control measures are well known and in place in many fire departments. Positive-pressure self-contained breathing apparatus (SCBA) can essentially eliminate inhalation of these toxicants (Occupational Safety and Health Administration, 2011). Unfortunately, however, firefighters do not always wear SCBA, for example, when sizing up the fire, when working as the engineer or incident commander, or when conducting overhaul operations. Results of this study highlight the need for SCBA protection throughout the firefight as well as the importance of enforcing these policies during overhaul and outside vent operations. Furthermore, pump operators and incident commanders should consider respiratory protection when working in smoky conditions or when they may be exposed to diesel exhaust.

Additionally, secondary exposure to off-gassing may be reduced by allowing the PPE to air out outside of enclosures. The off-gas levels returned to near background concentrations after 17–36 minutes after our initial measurements for the majority of the volatile organic compounds (VOCs) (Fent et al., 2017). However, semi-volatile compounds would likely take much longer to volatilize and is an area of continuing research.

Potential Dermal Absorption Risks from the Fireground

While protecting the airway may be the most important control measure to implement on the fireground, it has become increasingly apparent that dermal absorption plays a key role in systemic exposure for firefighters. Skin exposure can occur during fire fighting by way of permeation or penetration of contaminants through the hood, turnout jacket and trousers, in between interface regions of this ensemble, or through the cross-transfer of contaminants on gear to skin.

- In our Fireground study, higher PAH biomarkers and benzene concentrations were found among firefighters assigned to fire attack and search operations than any other job assignment (Fent et al., 2020). This is a particularly important finding because the attack and search firefighters protected their airways during the fire response by using SCBA and were not allowed inside the structure without airway protection. Overhaul firefighters had significantly lower biomarkers of PAHs despite operating inside the structure (with SCBA) for longer periods of time than did the attack and search firefighters. Thus, the concentration of contaminants, and potentially elevated temperatures and increased pressure within the structure during the active firefight, may have resulted in increased concentrations of contaminants being absorbed by the skin. These findings reinforce previous reports that dermal absorption contributed to firefighters' systemic levels (Baxter, Hoffman, Knipp, Reponen, & Haynes, 2014; Fent et al., 2014; Keir et al., 2017).
- In several scenarios, contamination was found on the neck even when hoods designed to block particulate penetration were worn. In some cases, these qualitative patterns of contamination appeared to be related, in part, to the hood doffing process.

Dermal Absorption Control Measures

Current PPE designs have important, yet limited ability to fully protect against fireground products of combustion reaching the skin. Research and development activities are currently taking place to redesign PPE to further reduce chemical ingress through particle blocking hoods and tightening down PPE interfaces. The benefit of the changes still must be quantified. It is also important to study opportunities to implement administrative controls to reduce these absorption risks. By managing these administrative controls, the fire service may be able to affect a reduction in exposure even using current PPE.

- ***On Scene PPE Cleaning.*** Three types of decontamination methods were evaluated during the Fireground study: 1) dry-brush decontamination with a stiff-bristled brush; 2) experimental air-based decontamination with modified leaf-blower; and 3) wet-soap decontamination with water and dish soap applied to the turnout gear, scrubbed with a brush and then rinsed. The wet-soap method removed an average of 85% of surface PAH contamination (Fent et al., 2017). Dry brush decontamination removed about 25% of the contamination and the air-based decontamination had minimal impact. In a separate study, Calvillo et al. (2019) found that water only decontamination also had limited effectiveness, though important limitations are identified in their manuscript. We suspect that the surfactant in dish soap, which is designed to liberate fat-soluble compounds from surfaces, was important for removing PAHs.

- ***On Scene Skin Cleaning.*** Cleansing wipes were found to reduce PAH contamination on neck skin by a median of 54% (Fent et al., 2017). Not all cleansing wipes may have equal efficacy and further study is warranted into all means of on scene skin cleansing. However, because ~50% of the contamination may remain on the skin after using cleansing wipes, showering, hand washing and other means of more thorough cleaning of the skin should be conducted as soon as feasible.

- ***Implementing Contaminated Doffing Techniques.*** While firefighter PPE continues to improve, doffing PPE can result in secondary exposures to the same contaminants from which the firefighter was initially protected. Traditionally, firefighters are trained to doff their PPE by pulling their hood down around the neck to allow access to the facepiece straps. This approach results in exposing the neck to the contamination on the outside of the hood. Similarly, fire fighting gloves are often doffed in a manner that results in transfer of contaminants from the outside of the glove to the skin of the hand. By performing gear removal in a manner similar to hazmat or EMS PPE doffing where contact with the outer layer of the PPE is avoided, it may be possible to more carefully control where the contamination can contact the skin (Illinois Fire Service Institute, 2017, 2018). While not always feasible on the fireground, firefighters may consider this approach, particularly in the case where the firefight has ended, and a firefighter is reporting to rehab. These techniques for contamination control can be integrated with a standardized process for cleaning the neck skin once the hood has been doffed.

- ***Suppression Technique.*** The process for selecting which suppression technique to employ on the fireground must first consider occupants of the structure—how to rapidly search and rescue those at risk with respect to the tenability for trapped occupants (Kerber et al., 2019). Secondary considerations may include how tactical choice impacts risk for compromising fire fighting PPE and how fireground operations may impact firefighter's chemical exposures. In our Fireground study, the transitional attack (applying water to a fire from the exterior prior to entry) scenarios resulted in significantly lower ambient temperatures throughout the structure while firefighters were operating compared to the interior attack, but this did not translate to a significant reduction in firefighter's heat stress (Horn et al., 2018). However, urine measurements from these firefighters indicate that transitional attack resulted in 20% to 50% lower metabolite levels of certain PAHs compared to interior attack (Fent et al., 2020). Overall, our findings indicate that, while there was no significant impact of tactic on heat stress, transitional attack could be implemented as an administrative control to reduce firefighters' exposures to PAHs ***when it is appropriate. It must be stressed that selection of fire attack tactics must consider a broad range of factors in addition to firefighters' exposures.***

Cardiovascular and Thermal Risks from the Fireground

Fire fighting increases thermal and cardiovascular strain. In fact, the increase in body temperature exacerbates the increase in cardiovascular strain. We have documented significant increases in heart rate (near age-predicted maximum for fire attack, search, overhaul, and outside vent job assignment) and core temperature (mean increases of 1.8 F for fire attack and search and ~3.1 F for overhaul and outside vent activities) even during this short experiment in which firefighters worked with a 30 minute SCBA air cylinder.

Additionally, firefighters were assigned to unique responsibilities, (i.e. overhaul was done by a different crew than fire attack) such that each firefighter was fresh prior to their job assignment and core temperatures could increase to even higher levels if multiple bouts of activity are required. Furthermore, earlier studies that have shown convincingly that some of the cardiovascular changes, such as increased coagulatory markers or a decrease on cardiac blood flow could be mechanistically linked to sudden cardiac events. In this study, we found that five firefighters who had normal ECGs in a 12-hour control period developed indicators of myocardial ischemia following fire fighting (Smith et al., 2019b).

Cardiovascular and Thermal Risk Control Measures

Medical evaluations performed by a physician serve as the most important steps to ensure firefighters can endure the cardiovascular and thermal strains of the job. Those tests must be performed by a physician who understands the job's physiological and psychological stresses. Firefighters also need access to a wellness and fitness program to ensure they are fit enough to safely do the job.

On scene, leaders should consider the physical stress of the job and consider rotating crews or providing relief when possible. This may include having a fresh group of firefighters perform overhaul or repack the hosebed. In places where personnel are severely limited, it may mean having extended rehab time before performing overhaul, or even putting firefighters in lighter-weight protective clothing to perform overhaul.

One of the great balancing acts that leaders face is providing adequate protection against burn injuries and smoke exposure on one hand, and the increased cardiovascular and thermal strain that comes from using heavy, encapsulating gear on the other hand. Rehabilitation also provides an opportunity to make sure that firefighters are evaluated to make sure they are recovering as expected.

Leadership & Management in Fireground Exposure Risk Reduction

Protecting the Airway

Many fire departments have policies for wearing SCBA during fire fighting operations, and it is a common expectation during interior fire fighting activities. However, more widespread challenges remain when firefighters are operating in other job assignments. In recent years, anecdotal evidence suggests an increase in SCBA usage during overhaul. While this decreases exposure risks, this use comes with a cost, namely, an increase in the metabolic cost of the work and a resulting increase in temperature and cardiovascular strain. Fireground leaders should account for the increased metabolic work necessary when conducting overhaul with SCBA compared with the same task without an SCBA. In the Fireground study, we measured a mean increase in core temperature of ~3 °F while working through a single 30-minute SCBA cylinder in overhaul (Horn et al., 2018). Such an increase in core temperature may not be overly concerning for a rested firefighter. However, if that firefighter had just completed fire attack or outside vent, their core temperatures would already be elevated, and this additional work may result in core temperatures that increase to dangerous levels. To support extended use of SCBA throughout overhaul, leadership should consider bringing additional personnel to the scene in order to reduce the thermal and cardiac strain on firefighters. Additional personnel on scene will allow fire attack firefighters (who may be heavily exposed to fireground contaminants) to more rapidly conduct decontamination/rehabilitation. Another approach that has been implemented in some jurisdictions is to conduct overhaul after rehabilitation in lighter weight wildland/hybrid PPE in an attempt to mitigate the thermal and cardiovascular exposure risks while providing the highest level of airway protection.

Enforcing airway protection for other job assignments will, in many places, require a change in culture and expectations. Outside vent firefighters will often wear SCBA when in heavy smoke, but gasses such as HCN may not be visible and may partition to upper levels differently than heavier products of combustion such as particulate and benzene. Additionally, while it is good practice to establish command and pump operations at locations upwind from the smoke plume, such locations are not always available. In such cases, airway protection can provide an increase in contamination control (Burgess et al., 2020) if policies and procedures are implemented to support this control measure. While these fireground concentrations are found to be much lower than inside the structure, they are an increase over background levels and another source of exposure near the fire building.

Relatively recent understanding of risks posed by PPE off gassing after the firefight has led to some changes in policy and in some cases updates in apparatus and station design. But in its simplest case, because of the potential off-gassing route of exposure, turnout gear should be left outdoors to off-gas and/or separated and isolated from occupied compartments of an apparatus (e.g. bagged and/or transported in an unoccupied compartment on the apparatus or other vehicle). Some departments have assigned gear transfer totes to their members to reduce this risk in personal and fire department vehicles.

Cleaning PPE

The Fireground study provided the first quantification of the effectiveness of gross on-scene decontamination techniques (Fent et al., 2017). While the evidence of effectiveness is clear, implementation of the practice has sometimes been met with challenges, resistance, and questions. Some of this resistance may be attributed to varying beliefs and behaviors related to wet decontamination techniques, such as concerns over time limitations and the safety impacts of wet gear (Harrison et al., 2018a). Such barriers to implementing post fire decontamination may be overcome through targeted messaging (Harrison et al., 2018b); but can also be reduced through managing iterative enhancements in processes as this relatively new fireground function is tested, evaluated, and improved.

As with any fireground function, training is important to learn technique. It is suggested that, if adopted at a fire department, wet soap decontamination be included during live-fire training evolutions so it can be more efficiently and effectively implemented on the fireground. This practice will help firefighters know how to best apply water to minimize soaking the gear and the firefighter. Water application will depend on contamination level but should mostly be used to pre-wet the gear, then rinse off the soap solution. Anecdotally, excessive water has been used to remove large pieces of debris from the turnout gear, which can result in soaking the gear and increase possibility for wetting interfaces and skin. Consider balancing wet and dry methods when large pieces of debris are present. However, if dry methods are used, it is important to manage the potential exposures from contamination that becomes airborne. Those being deconned as well as those doing the decontamination, and anyone downwind of that location, should consider appropriate PPE from this airborne particulate.

Fireground officers will also need to manage the process of handling PPE after it is deconned on scene, particularly if it is wet. The 2020 Edition of the NFPA 1851 standard (National Fire Protection Association, 2020) contains a decision support tool that should be consulted. In addition, fire departments should consider department policies for handling gear wetted by environmental conditions or hose overspray and enforce similar precautions that would be taken if the outer shell has been wetted these sources.

Environmental extremes can present important challenges while conducting fireground decontamination, and leaders need to make appropriate decisions to balance the risks from contaminated gear with other environmental hazards. It is important to remember that on a hot summer day the firefighter inside their PPE waiting to be deconned may have just completed a long, intense bout (or bouts) of fire fighting activity and cannot cool down or recover from the thermal and cardiovascular stress of fire fighting as easily as if his or her PPE were removed. Similarly, a firefighter conducting decontamination in freezing conditions may be at increased risk for hypothermia and frostbite. Thus, it is important to balance the risk of heat stress or cold stress for the member with the risk for additional chemical exposure. One way to manage this balance is to address environmental stressors as part of integrated rehabilitation. The flow of personnel through decontamination should be managed by prioritizing firefighters based on availability of air and their physical and psychological stress levels. Establish multiple decontamination lines/stations to move firefighters through more rapidly when feasible. Provide hydration where feasible. In the cold, manage cold stress by provide warming stations for all those being decontaminated and those working in decontamination lines as quickly as possible. Manage risk for slips and falls by making ice melt available where decontamination is taking place. Deconning fire fighting PPE is an important risk reduction process but should be managed with the other risks that may be present on each fireground.

Cleaning Firefighter Skin

Leadership in the fire service should also consider implementing a skin cleansing program for every response or training scenario where products of combustion are present. By including skin cleaning as part of training, firefighters can develop the expectation that they are responsible for cleaning themselves after a bout of fire fighting activity. Similar to decontaminating PPE after training, this process can begin to build muscle memory in controlled conditions prior to deployment on the fireground. Wipes can be made available as soon as firefighters exit a burn structure and begin debrief as well as during bottle changes, air fill stations, and before getting back on the apparatus. Making the wipes visible and company/command officers reminding firefighters to use them will reinforce this habit.

On the fireground, wipes should be made available near the command vehicle, staging areas, on forward located apparatus, and transition to rehabilitation. It may also be useful to provide a mirror at a few locations to help firefighters self-identify the presence of contamination. A small investment can go a long way in assisting firefighters to be efficient in their use of wipes and to be cognizant of the need to do so. Fireground leadership can support this awareness and implementation in best practices.

Contaminated PPE Doffing

Implementing contaminated doffing techniques on the fireground may appear a foreign and challenging proposition in many departments. While a great deal of time and effort has historically been spent teaching firefighters to quickly and effectively don their turnout gear, relatively little time is typically spent on the doffing process. On the other hand, training for medical responses (EMS) will often focus on donning PPE appropriately for body substance isolation, but also highlights the importance of doffing PPE, particularly gloves, appropriately. Likewise, hazmat responses require specialized PPE and a controlled and institutionalized decontamination and doffing process to ensure these hazardous materials are not transferred to the responder. Thus, many firefighters are familiar with the need for contaminated doffing methods, and the fire service has adopted these processes for specific responses.

Now is the time for leadership to consider implementing similar approaches for contaminated equipment doffing after fireground activities. An opportune time to develop, test, and implement these techniques is during training scenarios, either live-fire training at an academy or station-based training. The more these approaches are practiced, the more likely they will be performed correctly on the fireground.

Integrating Decontamination and Rehabilitation on the Fireground

Incident scene rehabilitation has evolved in the fire service and has become a common fireground activity in many departments. Thanks in part to the evolution of NFPA 1584, processes have become standardized and expected. With the increasing concerns related to firefighter hygiene and cleanliness, there is an opportunity to evolve rehabilitation to integrate decontamination – f*rom hygiene to hydration*. In this way, the on-scene decontamination, contaminated doffing, and skin cleaning processes become part of an established fireground tactic.

It is important that these hygiene steps take place prior to entering rehab where feasible. If contaminated gear is not cleaned and doffed, then contamination can easily spread to firefighters' skin as well as the equipment and personnel working in the rehab sector and then other firefighters. The potential for PPE off-gassing can further expose firefighters and support personnel as airway protection is not commonly worn in rehabilitation. Additionally, if hygiene practices are not appropriately managed, risk for ingestion of fireground contaminants can increase while eating finger foods where transfer from hand-to-food-to-mouth is possible. To reduce this risk, skin cleaning wipes or sinks can be provided along with mirrors at the entry to rehab as a reminder to clean skin in order to reduce risk to the firefighter and rehab personnel.

Finally, rehab provides an important opportunity to reflect on the incident actions as an individual and group. This process is important for tactical debriefing, but also to immediately report exposures from the incident and assess if personnel are recovering appropriately. Exposure tracking—both chemical and emotional—has become an important component of a firefighter's personal activities after a fire. Several apps, such as National Fire Operations Reporting System (NFORS), have been developed to ease the reporting process. Leaders should consider encouraging personal responsibility in collecting this information, particularly during the initial recovery period allowed by incident scene rehabilitation. Furthermore, the time spent in rehabilitation can be used to ensure firefighters are appropriately recovering from the event. Those managing rehabilitation should be made aware of a firefighter not feeling well after strenuous activity in order to keep a close eye on the individual, in rehabilitation and after return to the station. Similarly, conversations within rehabilitattion may provide the opportunity to identify personnel who are emotionally struggling with the events of the incident so that peers may be able to provide support and assistance.

Summary

As risks continue to evolve on the fireground, so too will research to assist the fire service in responding. We know more now about the type and magnitude of the risks that are faced than at any time in fire service history. However, we are still working to quantify how effective interventions might be as well as how to support fireground leaders and managers to implement these interventions. We have provided a summary of lessons learned from fireground studies as well as begun the discussion of challenges that must be overcome to implement effective interventions. For more resources related to this project, science, translation and teaching tools can be downloaded free of charge from the on-line project toolkit (https://www.fsi.illinois.edu/CardioChemRisks/#!/) and throughout the UL FSRI Fire Safety Academy (https://training.ulfirefightersafety.org/) and website (https://ulfirefightersafety.org/). More will be learned and shared as the fire service and research community work through his process together.

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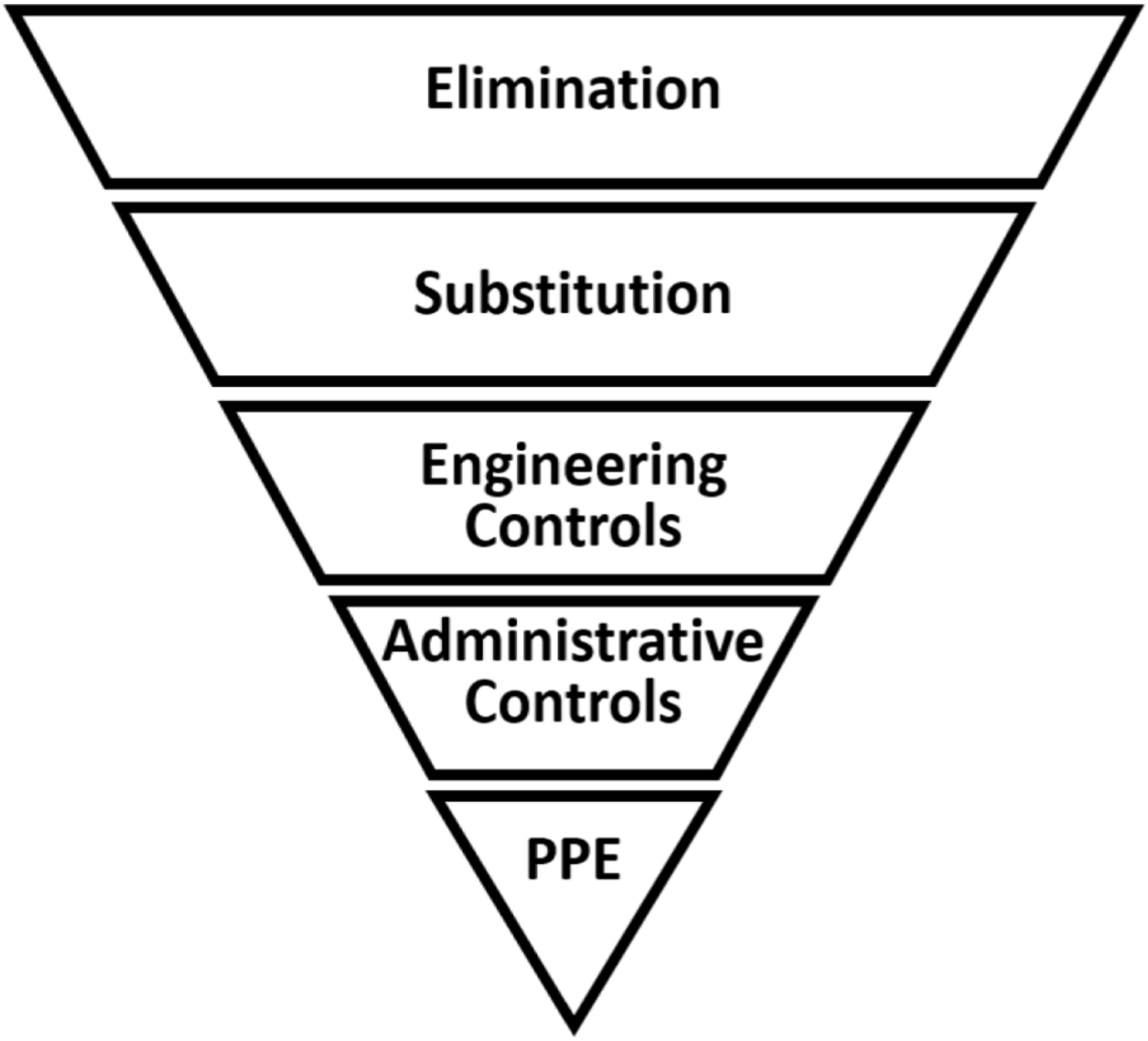

Figure 1:
Hierarchy of Controls