PPE REIMAGINED

INSIGHTS AND RECOMMENDATIONS FOR A NATIONAL CHANGE IN PERSPECTIVE

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EXECUTIVE SUMMARY

The IAFF's research into PPE use, attitudes, and barriers underscores the urgent need to modernize fire fighter protective equipment in line with today's evolving hazards and fireground demands. Fire fighters face significant physiological, chemical, and operational risks, often exacerbated by legacy equipment, cultural resistance, and inconsistent safety protocols.

The path forward must prioritize fire fighter health, address behavioral barriers, and leverage fire fighter input to guide the development of next-generation PPE. Through a combination of technical innovation, cultural transformation, and policy reform, departments can significantly reduce long-term health risks while improving performance and compliance on the fireground.

Most fire fighters feel that their PPE is at least somewhat protective of their health and safety but that it is too hot, difficult to move in and can impede their ability to do their job effectively. Current PPE is often designed for maximum protection—for example, structural turnouts must meet NFPA standards for direct flame impingement—but many calls and responses that fire fighters attend to do not involve direct flame impingement. Fire fighters must be protected on the job, but the need for a more modular approach to PPE is apparent.

Fire fighters feel that greater comfort in PPE, through better fit, more flexibility, greater breathability, and better liquid resistance would allow them to be more effective on the job, especially during longer responses and work hours. They indicated they are willing to have less protective gear to increase comfort and believe that hazards can be avoided through better training.

Lighter and more mobile ensembles that are appropriately protective for the majority of responses fire fighters are attending can result in less physiological and heat stress, greater mobility and dexterity, greater situational awareness and communication on the fireground, and ultimately greater comfort for the fire fighter. Choosing the right PPE for the job is as essential as choosing the right tool for the job.

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PROJECT SUMMARY

The profession of fire fighter has evolved to become more than just someone who puts out a structure fire or a wildfire. Most firefighting agencies and departments are now "all risk all response" requiring fire fighters to perform fire suppression, emergency medical response, technical rescue, hazardous materials, and prevention. Yet PPE has remained largely the same with the options of turnouts/structural firefighting PPE or pants and jacket/station uniform. PPE needs to change to support the modern fire fighter. As hazards and responses and the fireground have changed, PPE should change to meet those challenges.

This project has complied background information, performed novel survey and interviews with fire fighters, and provided recommendations for how the fire service can "re-imagine PPE." This report is intended to provide guidance to manufacturers, agencies, and departments at a national level. Therefore, our approach in gathering information was national in scope.

In approaching this project, we had two potential solutions: Option 1: "Novel PPE" using multiple types of gear that are incident specific, Option 2: "Universal protection" or a "one-PPE-protects-all" approach. Ultimately, we believe that a modular PPE systems approach, or "Option 1" is best solution. As the data support, not only is the profession of firefighting diverse, but there are regional needs and challenges. Ambient temperatures affect fire fighters tolerance and heat stress, different climates and situations impact the type of calls fire fighters respond to, different agencies or job specializations require different levels of mobility and protection.

In analyzing the data, we also understand that fire fighters have a unique approach to risk and risk assessment that is inherent to the profession. This is considered when we ask fire fighters what functional trade-offs they are willing to live with in their PPE, and what their priorities for physical, chemical and biological protections are. When we look to recommend protection standards now and into the future, we also need to understand the frequency of encounter and relative risk of various hazards such as direct flame impingement, hazardous liquids and chemicals, molten metals, hot steam or vapor, etc.

These data, the relative exposure frequency of hazards and the needs of the fire fighters surveyed, will be influenced by the bulk of the work they do at their respective agency/station. Therefore, we have also collected data on their respective locations (e.g. IAFF Local) to better understand regional needs such as metropolitan versus rural stations.

Our focus areas for the survey and interviews included: Experience and PPE Effectiveness, Maintenance Challenges, Respiratory Challenges, Training and Education, and Reimagining PPE. The preliminary surveys, final surveys, and interviews were illuminating and had a high level of data agreement and robust sample sizes suggesting that the core themes and needs identified by fire fighters are the true challenges we are facing.

PILOT SURVEY AND PRELIMINARY RESEARCH

When working with fire fighters on their PPE needs and perceptions, it's important to understand their perspective. The strong culture of tradition and the dangers that the job brings colors their perception of risk and their acceptance of risk (Harrison et al. 2018). This in turn will affect their willingness to adopt health promoting behaviors and to comply with safety protocols and PPE standards.

Firefighting as an occupation is a type of High Reliability Organization (HRO) which includes other professions like military, police, and emergency room personnel. Resistance to change is common in (HROs) like police and military. Jobs are often life and death; the consequences of inexperience or error are very high. As a result, individuals in HROs are more likely to adhere to "how it's always been done" rather than try new systems or procedures (Harrison et al. 2018). Firefighting also has a culture of tradition and an ethic of "service before self" that "glorifies the acceptance of extreme personal risk far ahead of the thoughtful analysis and management of risk factors." (Davis et al. 2020). Fire fighters are likely to resist change and to downplay or forgo risk, especially if mitigating risk interferes with their job duties or job readiness.

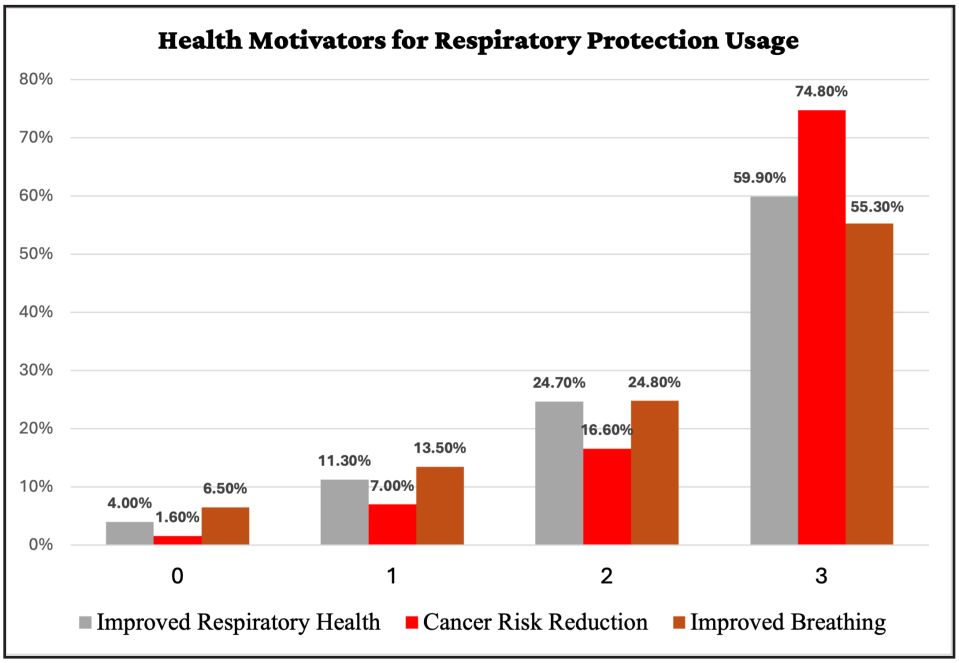
In reimagining PPE, we need to understand: 1. What are the functional trade-offs fire fighters are willing to live with, 2. What are fire fighter's priorities for physical, chemical, and biological protection, 3. What are the protection standards needed now and into the future. The research team used models and ethos from public health to develop an appropriate survey and data collection methods (Miles, et al. 2019). These models consider fire fighter attitude and norms. A general approach of surveys and interviews can often help fully understand challenges with PPE in the fire service.

For this report, we used information gained from earlier research specific to wildland firefighting to understand the incentives or lack of incentives for changes to the status quo for fire fighters in general. These included both wildland fire fighter use of respirators and their attitudes towards decontamination of protective clothing.

RESPIRATORY DEVICE USAGE IN WILDLAND FIRE FIGHTERS

Recent work on that used a similar approach of surveys and interviews with fire fighters looked at respiratory usage among wildland and urban interface fire fighters. The project worked to understand why usage and compliance of respiratory protective devices was so low in wildland and urban interface fire fighters.

Figure 1. Health Motivators Among Fire fighters for Respiratory Protection Device Usage



Rodriguez 2024 found that while fire fighters were highly motivated by health concerns with cancer risk reduction (74.8%) and improved respiratory health (60%) being considered extremely important, they were also very concerned about impaired breathing

(64.2%), impaired communications (38.9%) and comfort and fit of devices (39.2%) (Figure 1). This speaks to the assessment of long term versus short term risk and consequences in fire fighters. Decisions made on the fireground are based on immediate needs and threats, not necessarily cumulative exposures and long-term health. When surveying fire fighters about their PPE trade offs—protection and risk versus comfort and mobility, for example—these attitudes and norms related to risk must be taken into account.

These initial survey results were coupled with interviews (n=29) to further understand the issues. There were 81.5% male (n=22) and 18.5% female (n=5) participants of which 11 held leadership roles and 16 held non-leadership roles in the fire service.

The interviews covered in-depth conversations on risk and preferred trade offs with respiratory PPE devices. The assessment of knowledge and experience in risk assessment related to respiratory exposures was illuminating with 100% of those in leadership agreeing that chemical risk associated with firefighting can lead to disease (86.7% of those in non-leadership positions said the same) but demonstrating limited knowledge of what those threats are with 63.6% unfamiliar with polycyclic aromatic hydrocarbons (PAHs) and 72.8% unfamiliar with volatile organic compounds (VOCs). Of those in non-leadership positions, 100% were unfamiliar with PAHs and 93.3% were unfamiliar with VOCs.

This again gives insight into fire fighter decision making and risk assessment. They generally understand that smoke exposure and respiratory occupational exposures are bad and lead to disease, but they do not know exactly what they are being exposed to. In the absence of full information, imperfect decision making is taking place with respect to PPE usage.

PPE DECONTAMINATION PRACTICES IN WILDLAND FIRE FIGHTERS

As the fire service has become all encompassing, with many departments now considered "all risk all response," occupational exposures have become highly varied. Research is still trying to determine the scope of the problem and understand and explore pathways of exposure (e.g. respiratory, dermal, oral). Again, most wildland fire fighters are generally aware that occupational exposures on the job are dangerous and lead to disease, yet their actions would suggest otherwise. Current PPE decontamination practices are low.

Stricker 2023 explored the barriers and facilitators to health promoting practices—specifically decontamination of PPE in wildland fire fighters—through in-depth interviews and a survey of PPE practices. Significant themes in the data included: a lack of training on how to decontaminate PPE and how frequently it should be performed, and a culture that supported and encouraged the wearing of visibly dirty PPE. The importance of the visual appearance of PPE in fire fighters cannot be overstated.

In an HRO organization, like the fire service, decisions on the job have high consequences including death, injury, and loss of property. On many large incidents, fire fighters may be working with others they may not already know; visible signals of experience and hard work are important to ensure that they can be trusted on the fireground (Stricker 2023). Similarly, new or lower ranking fire fighters may need visual cues to signal they are hard-working and reliable. As a result, dirty PPE—such as the burned and worn helmets common in the east coast—has a value that can make implementation of cleaning practices difficult.

However, Stricker 2023 also found that attitudes towards risk and the subsequent cleaning practices among fire fighters did change over time. Those who were older, with more years of experience were more likely to take cleaning practices seriously. Their health motivators were typically wanting to be present for family and children and wanting to enjoy retirement. Younger and less experienced fire fighters were typically more focused on the immediate consequences of the job and felt that consequences like cancer would be something to deal with later in the job; occupational exposure

reduction was not a priority for them.

Leadership also had an outsized role in how wildland fire fighters approached PPE decontamination. If leadership both modeled and implemented decontamination practices, such as laundering or changing dirty turnouts regularly, washing and brushing boots, and establishing clean zones in the fire station, all fire fighters would participate. If leadership did not model or enforce these behaviors or if they downplayed their importance, other fire fighters would do the same regardless of their personal knowledge or beliefs. Fire fighters would often go against what they thought was appropriate or safe if leadership did not support these actions.

In reimagining PPE, how a garment or protective device wears over time should be considered very important culturally to fire fighters. And as change is implemented, the influence of leadership should be an integral part of the rollout and adoption of new PPE and PPE practices. The strong culture of tradition in firefighting should be embraced and used to implement new PPE practices, with leadership playing their role in forging new traditions.

PRELIMINARY SURVEY

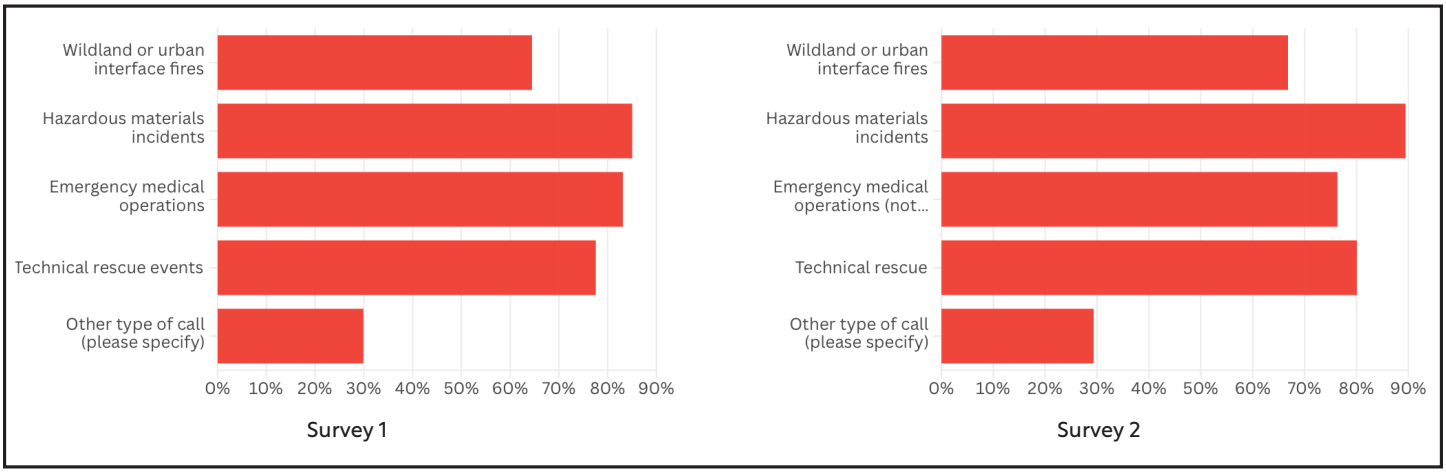
Insights from previous research, such as themes of resistance to change, downplaying of risk, focus on short-term risk versus long-term risk, visual cues in PPE, and the influence of leadership, age, and experience on decision-making were used to inform the questions for two preliminary surveys for this project. The purpose of the preliminary surveys was to test the question types and response rates as well as gain insights into consistency in responses, and other data quality questions. These initial survey results were then used to build the much larger survey that informs this project. The initial survey demographics are summarized in the table below.

Table 1. Demographic Summary of Two Preliminary Surveys

	# OF PARTICIPANTS	# OF LOCALS	CALL VOLUME (AVERAGE)	% OF CALLS RELATED TO FIRE
SURVEY 1	105	98	12,000/year (+/- 25,000)	26% (+/-18.7)
SURVEY 2	115	65	50,000	23% (+/- 12.1)

These initial data reflect what we saw later in the much larger survey—that the majority of calls that fire fighters are responding to do not, in fact, involve fire. Initial survey data collected showed a diversity of calls including: WUI/Wildfires, Haz Mat, Emergency Medical, and Technical Rescue, with many fire fighters reporting they wore their structural gear to these calls (Figure 2).

Figure 2. Q5/6 For which of the other types of calls listed above, do you wear the same protective clothing as for structure fires?



In addition, the preliminary surveys allowed for an understanding of fire fighter risk assessment. For example, they were asked how frequently they encountered different types of heat and flame hazards. The research team then determined the relative risk of these encounters and rated hazards by frequency of exposure and relative risk (Figure 3). Encounters with molten metals were reported as infrequent but identified as high risk. Other high risk, high encounter hazards included heat/flame exposure, contact with steam or hot vapors, and contact with hot surfaces. These are important insights when reimagining PPE; to understand what the frequent encounters and high hazards are on the modern fireground. It's also important to design and plan for encounters that may be infrequent, but also pose a high hazard, such as molten metals.

Similarly, exterior fireground flame/heat exposures, interior fireground flame/heat exposures, and smoke/soot/particles were considered to be high hazard, high frequency encounters. While hazardous liquids (chemicals) and high voltage electrical were considered high hazard they were rated with a low frequency of encounter (Figure 4).

When the survey asked fire fighters how they would rate their PPE for protectiveness, fire fighters rated protection from molten metals as relatively low in importance (Figure 5). This is likely due to its low encounter rate on the fireground. However, if encountered, it is a very high hazard. When reimagining PPE, high hazard, low encounter rates are part of the consideration. All PPE requires trade offs (e.g. comfort, mobility, communications, etc.) and determining how protective PPE should be for all hazards is an important consideration.

Figure 3. Initial Survey Results Regarding Frequency of Encounter and Research Team's Assessment.

Most Common Response

	Never	<5%	5-10%	10-25%	25-50%	>50%
Exterior fireground exposures	7.89% 9	46.49% 53	16.67% 19	18.42% 21	4.39% 5	6.14% 7
Ordinary (interior) fireground heat/flame exposures	1.75% 2	35.96% 41	23.68% 27	16.67% 19	13.16% 15	8.77% 10
Emergency (interior) fireground exposures	10.53% 12	43.86% 50	21.93% 25	14.91% 17	4.39% 5	4.39% 5
Direct flame impingement	16.67% 19	54.39% 62	14.04% 16	9.65% 11	2.63% 3	2.63% 3
Contact with steam or hot vapors	2.63% 3	42.11% 48	20.18% 23	16.67% 19	9.65% 11	8.77% 10
Contact with hot water or other liquids	8.77% 10	43.86% 50	21.05% 24	15.79% 18	5.26% 6	5.26% 6
Contact with molten metals	31.58% 36	56.14% 64	7.89% 9	1.75% 2	1.75% 2	0.88% 1
Contact with hot solids	15.79% 18	44.74% 51	18.42% 21	11.40% 13	3.51% 4	6.14% 7
Contact with hot surfaces	5.26% 6	36.84% 42	21.93% 25	15.79% 18	7.89% 9	12.28% 14

Limited Concern – High Risk

High Risk – High Encounter

Figure 4. Q6 Indicate how often you encounter the following types of heat and flame hazards

	NEVER	LESS THAN 5% OF THE TIME	5 TO 25% OF THE TIME	OVER HALF OF THE CALLS	NEARLY EVERY CALL
		Most Common Response			
Exterior fireground heat exposures	1.87% 2	29.91% 32	35.51% 38	14.02% 15	17.76% 19
Ordinary (interior) fireground heat/flame exposures	0.00% 0	19.63% 21	45.79% 49	12.15% 13	21.50% 23
Emergency (interior) fireground heat/flame exposures	2.83% 3	34.91% 37	30.19% 32	11.32% 12	19.81% 21
			High Risk – High Encounters		
Significant fireground smoke/soot/particulates	0.00% 0	18.69% 20	40.19% 43	18.69% 20	21.50% 23
Steam or hot liquids	3.77% 4	43.40% 46	26.42% 28	12.26% 13	12.26% 13
Hazardous fireground liquids (chemicals) Limited Concern – High Risk	8.57% 9	63.81% 67	7.62% 8	7.62% 8	11.43% 12
Blood, body fluids, or infectious liquids (including sewage)	3.74% 4	36.45% 39	30.84% 33	22.43% 24	5.61% 6
High voltage, electrical arc, or other electrical hazards	5.61% 6	57.01% 61	15.89% 17	9.35% 10	11.21% 12
Hazardous physical environments	1.87% 2	32.71% 35	31.78% 34	17.76% 19	14.95% 16

Figure 5. Survey 2 Q9 How would you rate these hazards for how PPE is designed to protect you from each hazard?

	LOW IMPORTANCE	MODERATE IMPORTANCE	HIGH IMPORTANCE
Exterior fireground exposures	24.56% 28	38.60% 44	36.84% 42
Ordinary (interior) fireground heat/flame exposures	0.87% 1	11.30% 13	87.83% 101
Emergency (interior) fireground exposures	1.77% 2	12.39% 14	85.84% 97
Direct flame impingement	2.65% 3	14.16% 16	83.19% 94
Contact with steam or hot vapors	1.75% 2	26.32% 30	71.93% 82
Contact with hot water or other liquids	5.26% 6	40.35% 46	54.39% 62
Contact with molten metals	24.56% 28	24.56% 28	50.88% 58
Contact with hot solids	9.65% 11	38.60% 44	51.75% 59
Contact with hot surfaces	4.39% 5	30.70% 35	64.91% 74

Initial survey results also helped inform targeted questions for the larger survey this project conducted. For example, in the initial survey, questions about liquid protection indicated that coat, pants, gloves, and footwear (not hood or helmet) were most likely to be exposed to liquids. Notably, 85% of fire fighters reported seeing or experiencing PPE being contaminated from an incident and occasionally catching on fire later. Because this was such a large number, a specific question related to flammability was included in the larger survey. These data were not replicated (see Survey section below) in the larger survey. This discrepancy could be due to the relatively small number of locals/departments represented; though it is possible the flammability concern was an overrepresentation based on one or a few small incidents being widely discussed.

Finally, the initial survey asked questions related to fire fighter beliefs around PPE, specifically, what it is supposed to be providing on the fireground. Fire fighters felt they should have more options for PPE insulation related to their geographic location, typical operations, or tactical procedures (69%). They felt some portions of the ensemble should be designed to permit the fire fighter to "sense" when conditions on the fireground were escalating (64%). That the full ensemble (garments, helmet, hood, gloves, footwear) should have the equivalent minimum protection (62%). And ensemble elements should be designed to provide protection for a reasonable, but limited amount of time of exposure to emergency fireground conditions (63%). There was also a general belief that fire fighters sometimes exceeded the limitations of their ensembles by going into fireground situations and staying longer than is consistent with the protective capabilities of their ensemble (75%).

SURVEY

The purpose of the data collected in this survey was to identify fire fighter needs and priorities with respect to PPE at a national level. Fire fighters were asked a series of questions based on key focal areas including: experience and PPE effectiveness, maintenance challenges, respiratory challenges, and training and education (Appendix A).

The survey was distributed via email to an IAFF list and other agency and department contacts. It was left open for a month and received 576 responses representing 294 fire departments across the United States (including Alaska and Hawaii). The average career length of fire fighters who responded to the survey was 18 years (median: 20 years). The participants estimated that they responded to structure fires on average 29% of the time (median: 25% of the time).

The full suite of questions that were included in the survey can be found in Attachment A. Data were fully analyzed using both standard summary statistics as well as more in-depth analysis to fully understand any potential correlations or areas of interest. A summary of key findings is included in this section.

KEY FINDINGS

1. EXPOSURE TO HEAT AND FIREGROUND CONDITIONS

Fire fighters generally reported experiencing low to moderate heat exposure during their incident responses where they wore turnout gear. A large percentage (73%) of survey participants reported that high heat exposure was 10% or fewer of their incident responses. Only 9% reported that "elevated temperatures" or "high radiant heat" was 25% or more of their incident responses (Figure 6).

Despite low occurrence, fire fighters reported that thermal protection were of "high importance" for PPE design (Figure 7).

The areas of PPE most frequently cited for added thermal protection are: pant knees (18.5%), coat sleeves (13%), coat shoulders/upper back and hood (23.4%), and back of gloves (12.5%) (Figure 8).

Conclusion: Situations of high heat, direct flame contact, and other thermal threats are not common, everyday occurrences for most fire fighters, but are a priority for protection. Improvement in thermal protection of PPE could include reinforcing areas like the knees of pants, sleeves, and shoulders and upper back of coats. These areas are also the part of the garments where movement causes the fabric to stretch or fit tightly against skin and undergarments while being worn, reducing the air pockets that often support the thermal protectiveness of PPE. Other areas like back of gloves are likely in need of greater thermal protection due to their proximity to the thermal hazard and the use of tools, which may increase exposure to high heat.

Figure 6. Survey Q6: During what percentage of responses where you wear turnout gear do you encounter fireground conditions where you are exposed to some form of elevated temperatures or high radiant heat?

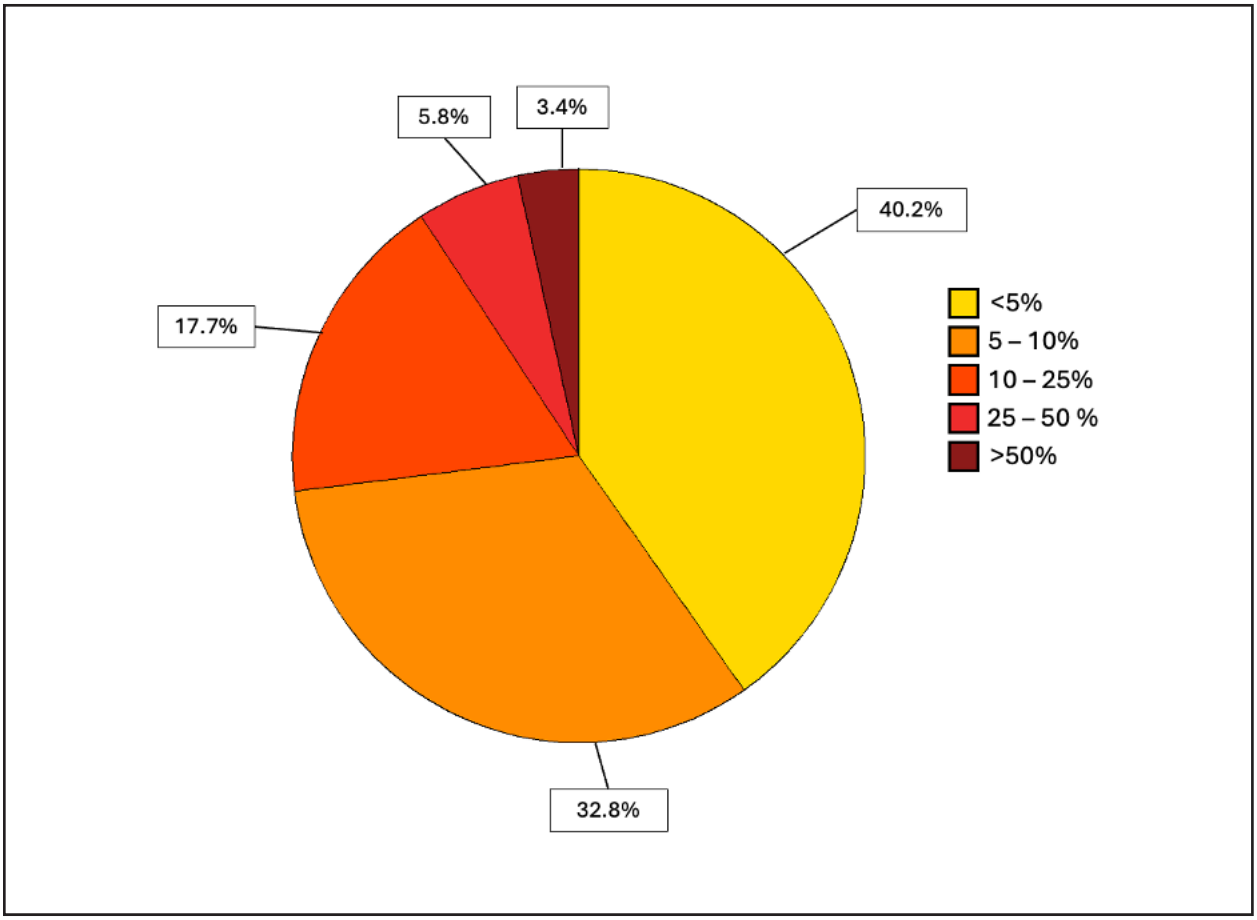


Figure 7. How would you rate these hazards in importance for how PPE is designed to protect you from exposure to each hazard?

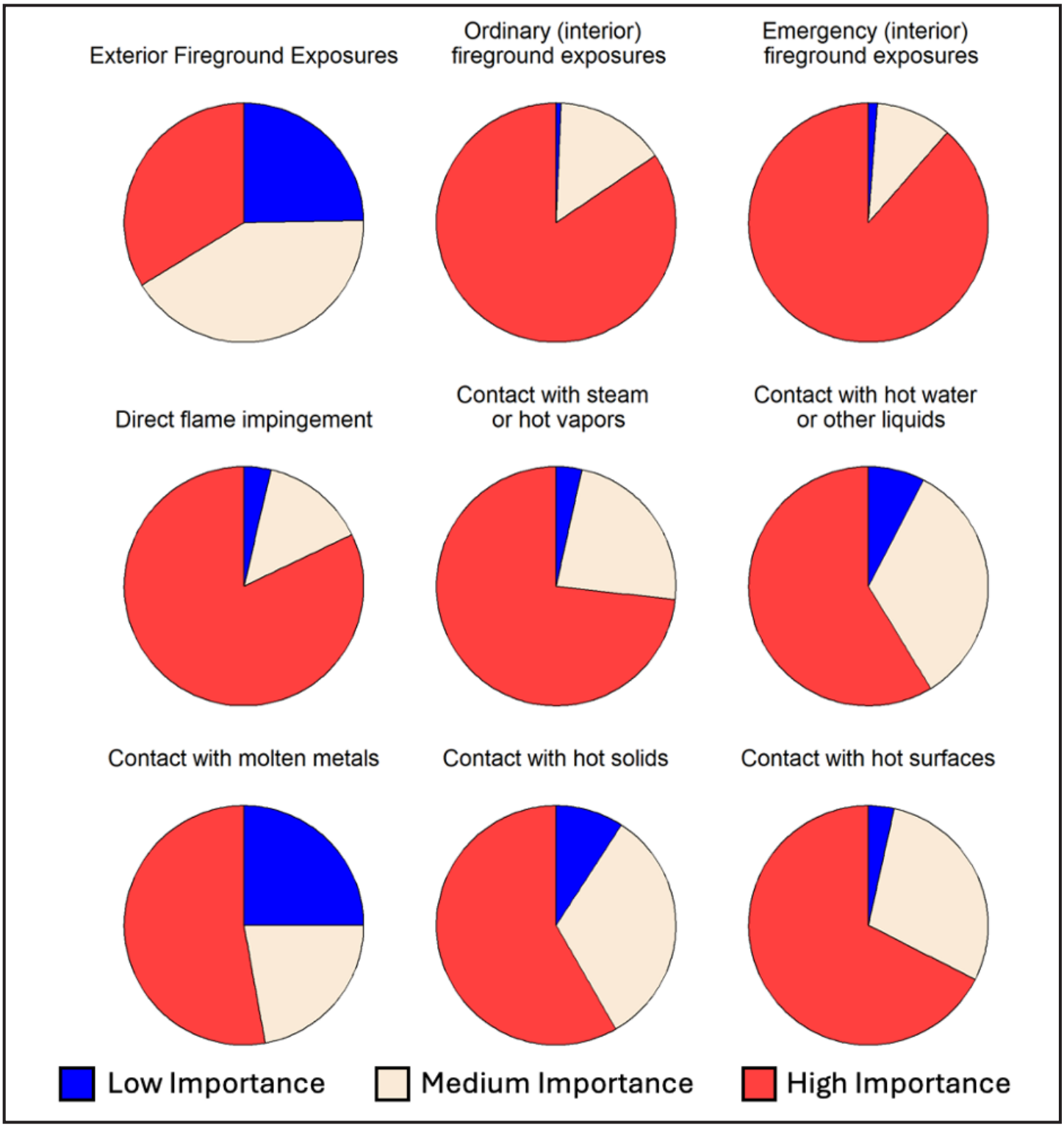
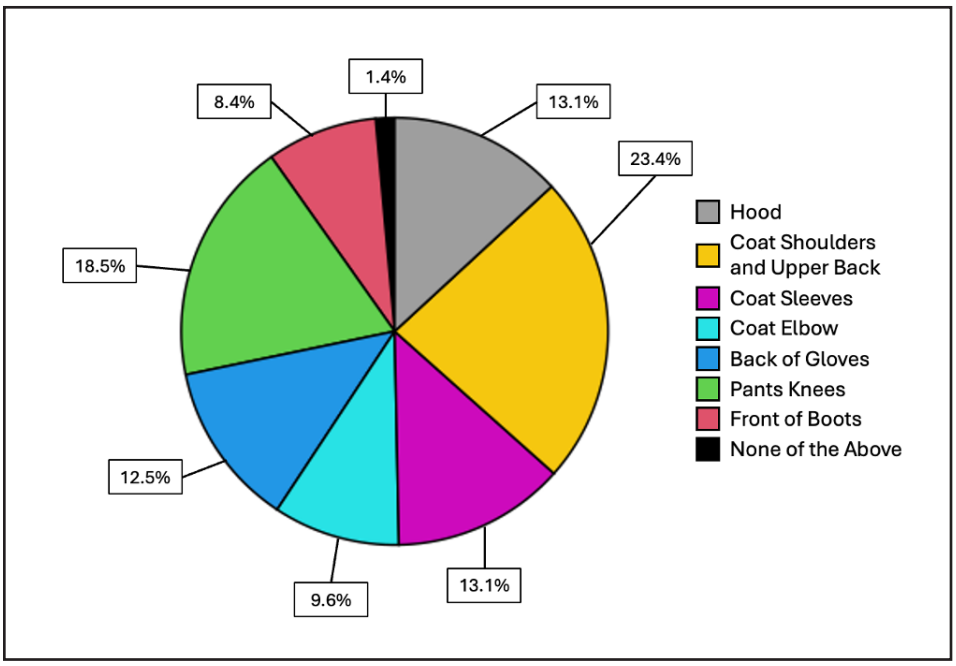


Figure 8. Which areas of your ensemble warrant the greatest insulation form high heat for protection purposes?



2. EXPOSURE TO HAZARDOUS LIQUIDS

The most frequently encountered hazardous liquids are fuels, oils, greases, and lubricants (67.6%). Blood and body fluids were the second most commonly encountered hazardous liquids (10%) (Figure 9).

One of the concerns that has been raised by some fire fighters and their departments/agencies recently was related to flammability concerns around PPE regarding liquids contamination. A total of 15.6% of participants reported that their PPE had caught fire after contamination with a flammable liquid (Figure 10).

There does not seem to be a universally accepted method of addressing PPE that has been exposed to hazardous liquids. This may be a reflection of the diversity of hazardous liquids (fuels, blood/body fluids, acids and chemicals, molten metals, etc.). It may also address a lack of consensus on how to safely clean and return gear to service (or isolate and remove from service, if necessary). Responses were nearly equally split between rinsing gear at the scene (24.2%), use of washing machine (26.2%), a third-party cleaning service (22.6%), and to isolate and remove from service (21.7%) (Figure 11).

Conclusion: While fuels and greases are the most commonly encountered hazardous liquids on incident, risk of flammability due to contamination of PPE is a relatively low, but still significant concern. The lack of consistency in cleaning of PPE contaminated by liquids reflects a real need for guidelines and standards for addressing these concerns. The modern fireground can include risk of exposure to contaminated water, corrosives, pesticides, chemicals, battery acids, non-water extinguishing agents (e.g. foams) in addition to the more commonly encountered blood and fuels/greases. Fabrics and garments that resist hazardous liquids exposures and/or are easily laundered or cleaned would reduce secondary exposure to fire fighters from contaminated gear and reduce the possibility of flammability of gear.

Figure 9. Q15 Which potentially hazardous liquid would you most likely encounter (be exposed to) during an emergency response?

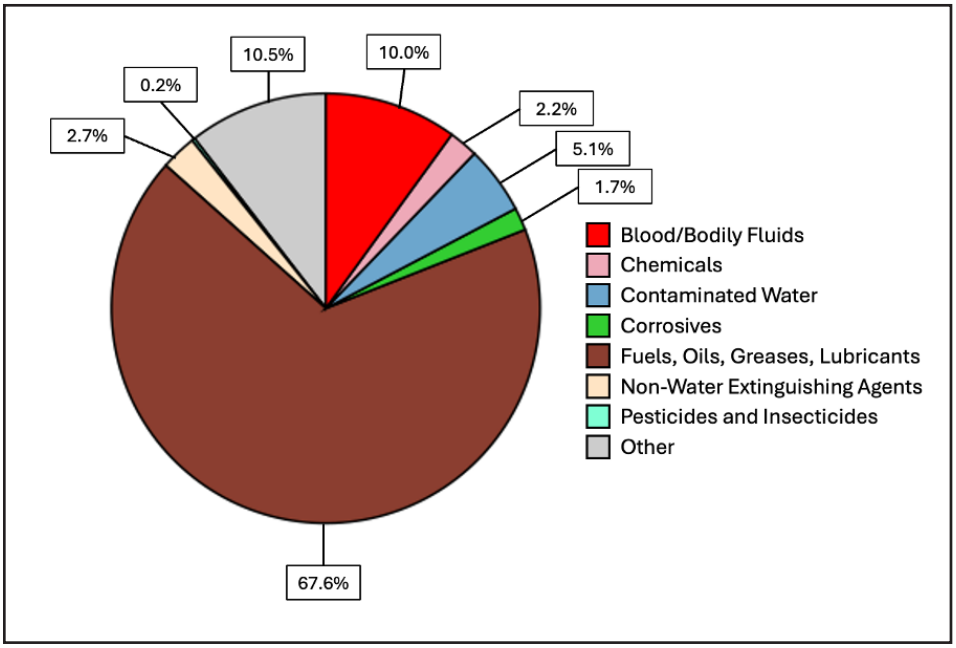


Figure 10. Q19. Have you ever had a situation or know of an event when your PPE or someone else's PPE has been contaminated on scene with a hazardous liquid and caught on fire in the current or subsequent shift?

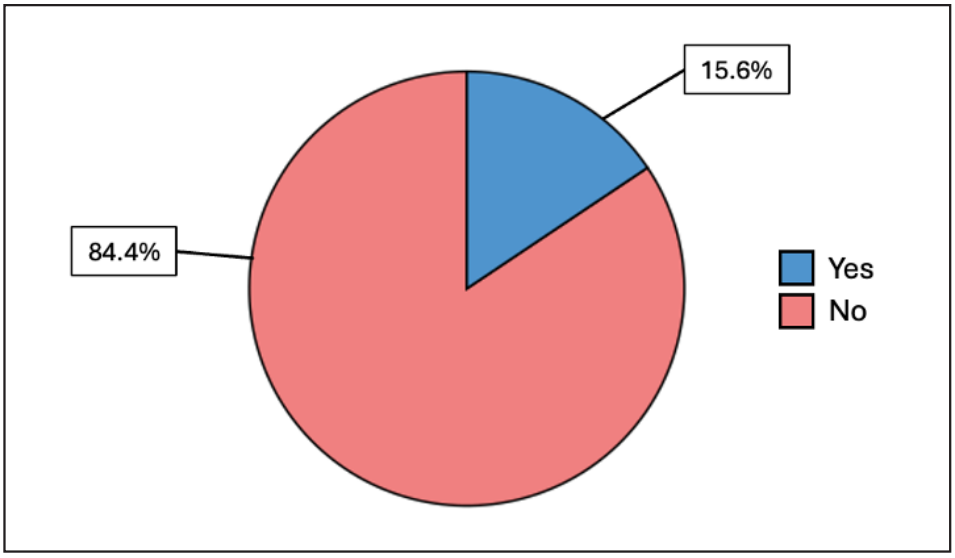
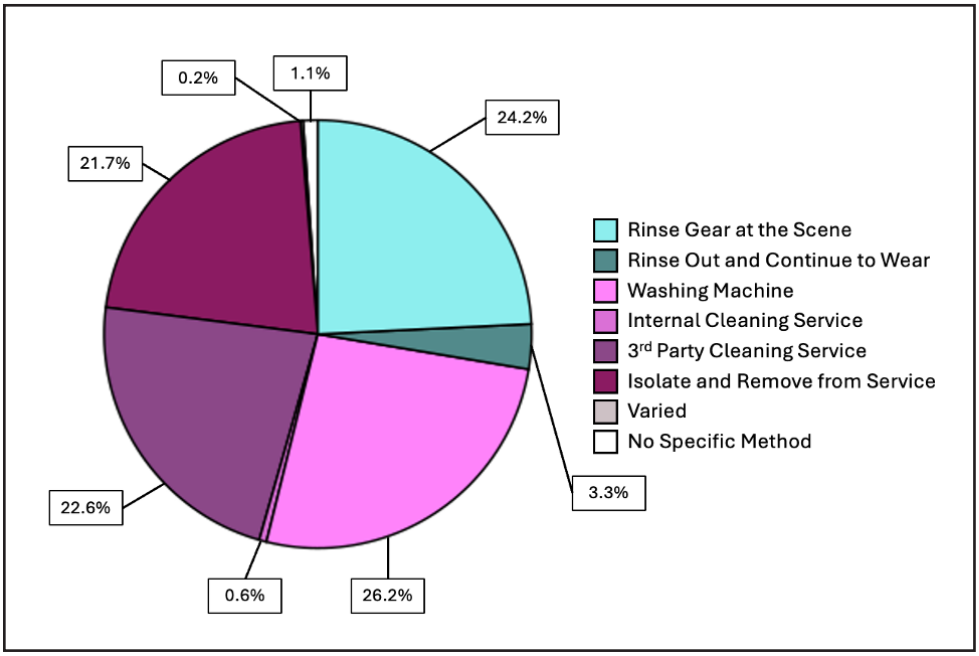


Figure 11. Q20. How does your department handle clothing and gear that has been exposed to hazardous liquids?



3. PHYSIOLOGICAL STRESS AND MOBILITY

Heat stress and the physiological strain of heat stress is a common concern with respect to turnouts. Approximately half (49.2%) of all participants reported heat stress on 25% or more of their responses where they wear turnout gear (Figure 12). In addition, 53.9% were willing or somewhat willing to trade off thermal protectiveness for lower physiological stress on the fireground (Figure 13). Protection of hazardous liquids was also a reduced priority compared to heat stress with 51.7% of participants willing or somewhat willing to accept reduced liquids protection in exchange for gear that was less heavy and hot (Figure 14).

To further understand the heat stress question, the approximate location of the fire fighter responding to the question was determined based on the IAFF local they belonged to. Their answers regarding heat stress were then compared to their physical location (latitude/longitude) using a chi-squared analysis. Not surprisingly, the further south a fire fighter was located, the more likely they were to report feeling heat and physiological stress from turnouts. However, there were no significant differences in heat stress based on east/west locations (Figure 15).

Mobility in turnouts is also a problem. A total of 15.4% of respondents reported challenges with mobility on 50% or more of their calls. And 16.4% reported mobility challenges in 25–50% of their calls. A total of 31.8% of fire fighters are reporting mobility challenges on a significant number of their calls that involve turnout gear (Figure 16). And 60.4% are willing or somewhat willing to accept reduced protection against liquids in exchange for more mobility (Figure 16). The same percentage (60.4%) are willing to accept reduced thermal protection in exchange for more mobility.

To better understand if the challenges of mobility in turnout gear was related to experience on the job, a correlation was performed that compared self-reported years on the job with reported mobility challenges. Challenges with mobility in turnout gear were found to be unrelated to the firefighter's years of experience on the job based on an ANOVA statistical analysis (F statistic = 0.75 with a probability of 0.5582).

Conclusion: The majority of fire fighters reported feeling hot or physiologically stressed wearing turnout gear on most of their calls for service and are willing to accept reduced thermal protection for gear with less heat and physiological stress. The discomfort of hot and heavy gear is balanced by the thermal protectiveness of the turnout gear, which is important when needed. However, given that the majority of calls do not involve direct flame impingement or thermal hazards, it may be prudent to consider a lighter version of turnouts that can be worn to most calls that require less than full thermal protection.

Fire fighters also are willing to accept reduced liquids protection in exchange for less heat stress. Given that most of their hazardous liquids encounters are fuels/greases and blood and body fluids, again, a lighter version of turnouts that can be worn to the majority of calls that require less than full thermal protection would be a significant improvement in comfort and reduced strain on the body.

Mobility in turnouts is also a huge priority for fire fighters. The majority are willing to trade off protections from heat and liquid hazards in exchange for more mobility. This highlights the need for movement and the ability to do the job. Fire fighters still rate thermal danger and hazards as a high priority, so the willingness to trade off is not necessarily an error in risk assessment but instead speaks to the real need for increased mobility.

Figure 12. Q21. During what percentage of responses where you wear turnout gear do you experience heat stress or other physiological stress conditions?

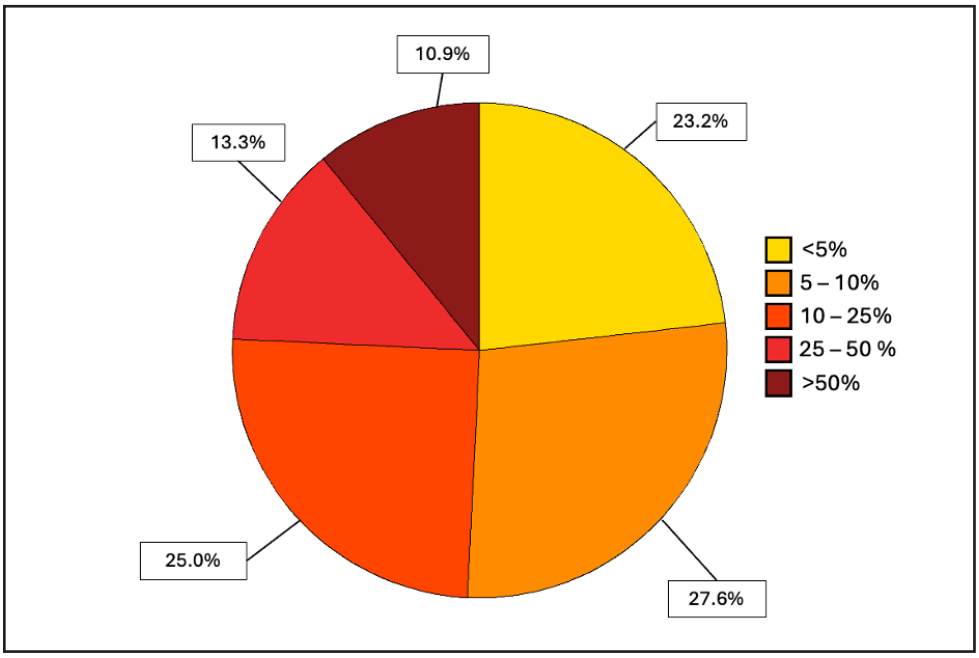


Figure 13. Q22. Are you willing to trade off thermal protection for lowering physiological stress on the fireground?

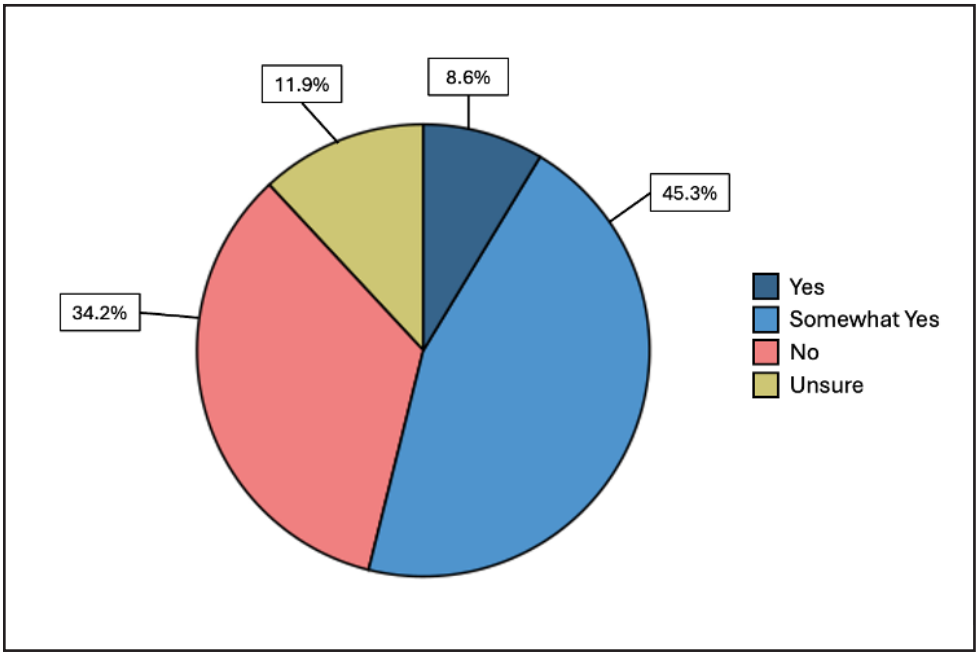


Figure 14. Q23. Are you willing to trade off barrier protection (against liquids) for lowering physiological stress on the fireground?

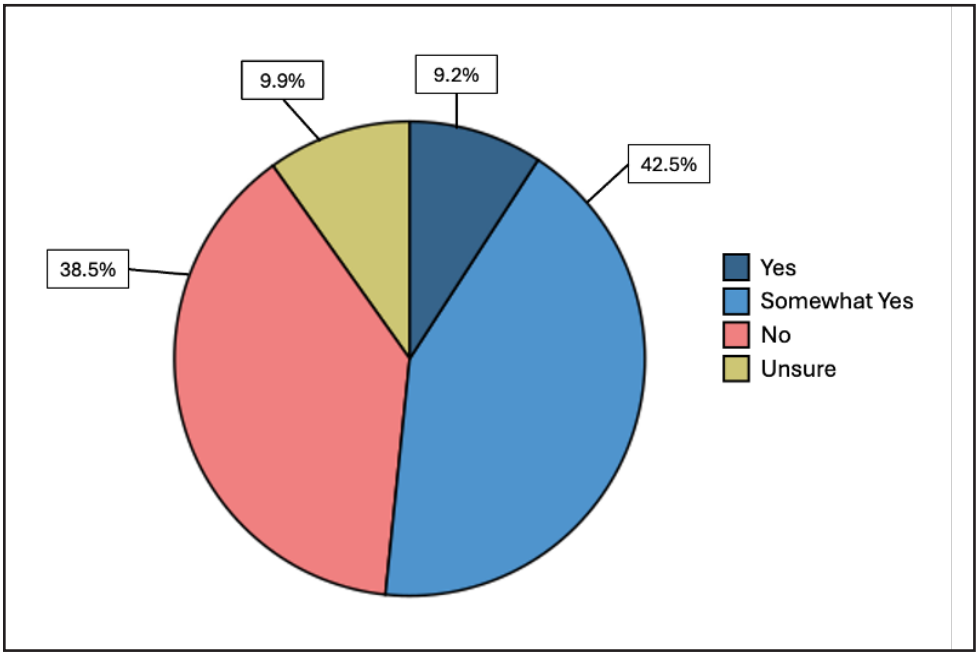
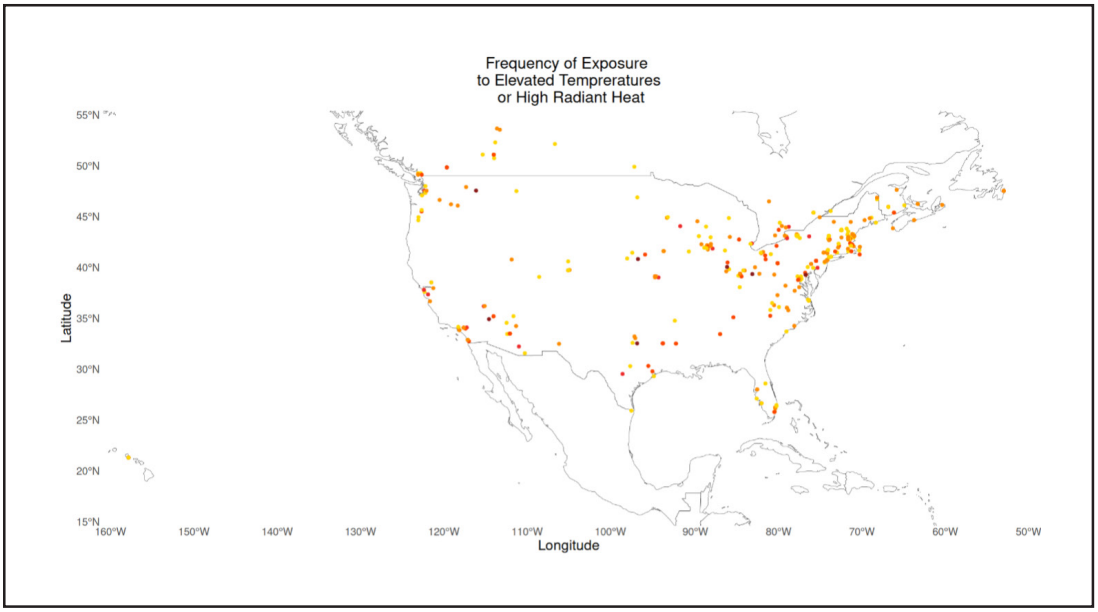


Figure 15. Q21. During what percentage of responses where you wear turnout gear do you experience heat stress or other physiological stress conditions?



	LATITUDE	LONGITUDE
25 TO 50%	-0.01089326	0.009448945
10 TO <25%	0.04015421	0.013638992
5 TO <10%	0.10268122	0.020844236

	CHISQ.	DF. P
LATITUDE	19.8956 4	0.0005237*
LONGITUDE	6.9494 4	0.1385842

Figure 16. Q24. During what percentage of responses where you wear turnout clothing do you experience problems with mobility or other?

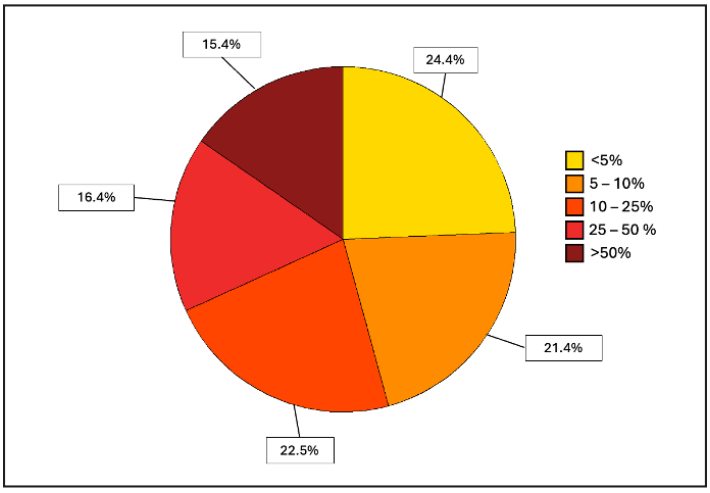
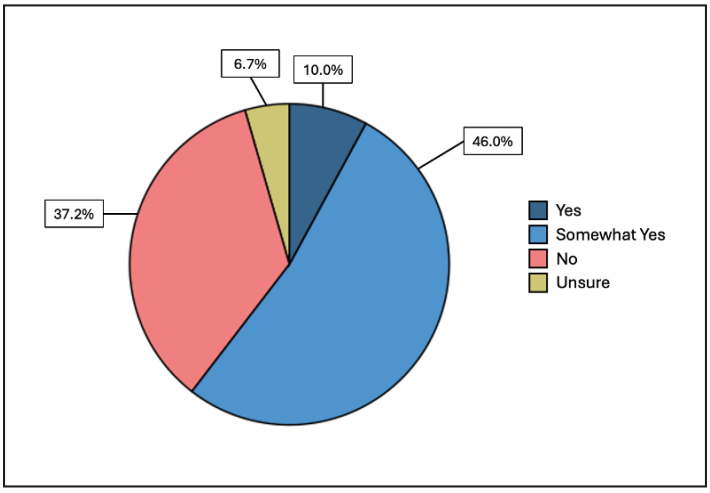


Figure 17. Q26. Are you willing to trade off barrier protection (against liquids) for improving your mobility and functional performance on the fireground?



4. PPE PRIORITIZATION AND DESIGN CHARACTERISTICS

Fire fighters want PPE that is easy to decontaminate, does not contain hazardous substances, is adjustable (for size and fit), high mobility and comfort. Their biggest concerns are heat and flame protection, followed by protection from hazardous liquids and low physiological stress (Figure 18).

Conclusion: This prioritization by fire fighters demonstrates the clear demarcation between traditional PPE design and approaches that focus on maximum protection for the potentially greatest threats on the fireground with the operational priorities of fire fighters which include mobility, heat and physiological stress reduction, and comfort (Table 2)

Table 2. Comparison of hazards and related insights based on survey data

ASPECT	KEY COMPARISON	INSIGHT
THERMAL VS. LIQUID EXPOSURE	Heat exposure is more frequent, but liquid contamination is more hazardous and insidious	Liquid risks often go unrecognized until after contamination; gear may not be adequately cleaned or retired
PROTECTION VS. PERFORMANCE TRADE-OFFS	Large majority of fire fighters prefer mobility and reduced stress over full protection	Suggests a disconnect between current PPE standards and operational needs; becomes even more paramount when metrics for functionality are not included in gear standards
CLEANING METHODS	Wide variability, including rinsing and reuse without decontamination; though improving based on guidance provided by emerging standards on care and maintenance	Indicates a lack of consistent protocols and training; practices are improving but clothing not always designed for ease of cleaning and decontamination
RISK RECOGNITION VS. HAZARD FREQUENCY	Even when frequency is low, hazards like heat, flame, and blood are still rated as critical for PPE design	Implies need for gear that accounts for infrequent but high-risk exposures and the need for gear that accounts for frequent lower-risk exposures

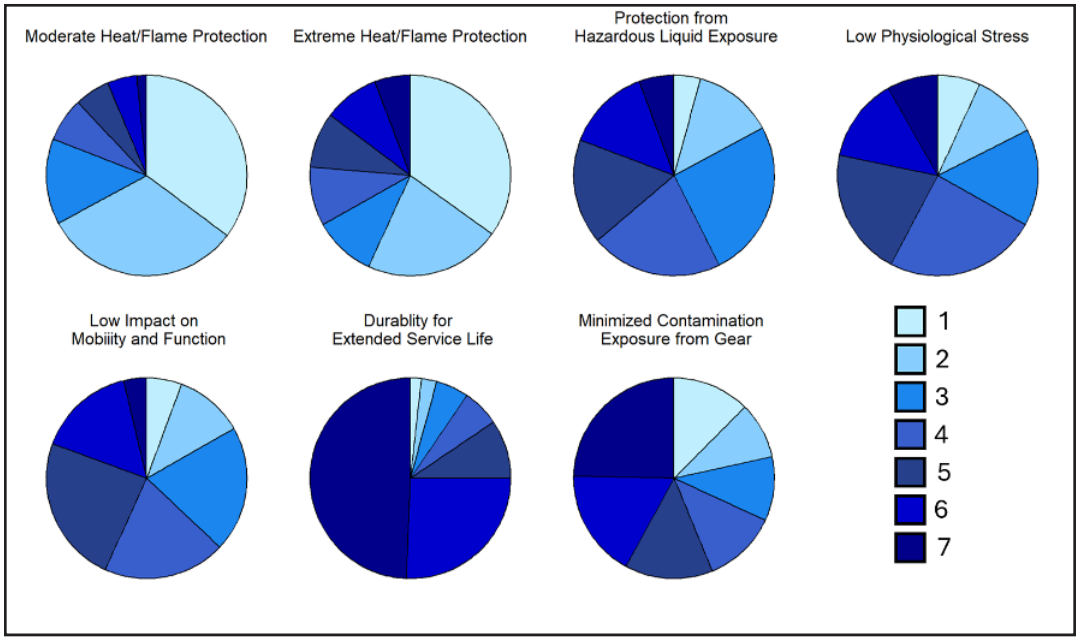


Figure 18. Q28 Rank desirable performance attributes and impacts of PPE

5. USE OF STRUCTURAL PPE ACROSS INCIDENT TYPES

Many fire fighters report wearing structural PPE for non-structure responses including medical aid (20.1%), hazardous materials response (30.3%), technical rescue (23%), and interface fires (18%) (Figure 19).

Conclusion: Fire fighters are wearing structural turnouts to calls that may not require full thermal and flame protection. This use of PPE in other responses may be part of the reason why fire fighters are willing to trade off thermal and flame protection for more mobility. If a large number of their responses requiring high mobility (e.g. medical aid) are when they are wearing heavy and bulky turnouts, they may be less satisfied with the performance of their gear and/or may be limited in their job due to the PPE they are wearing.

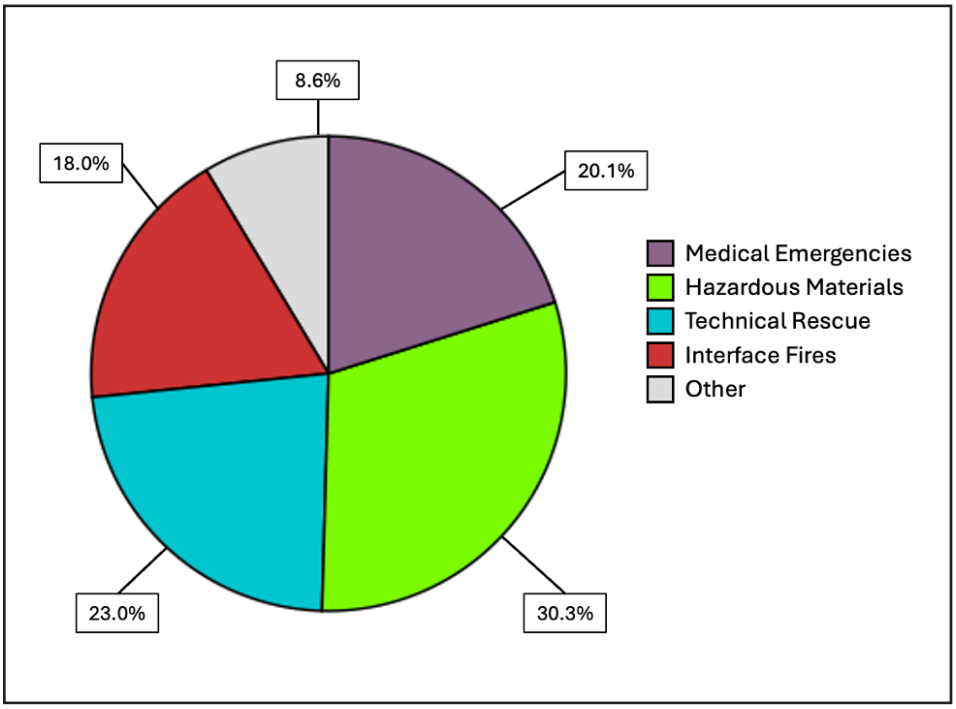


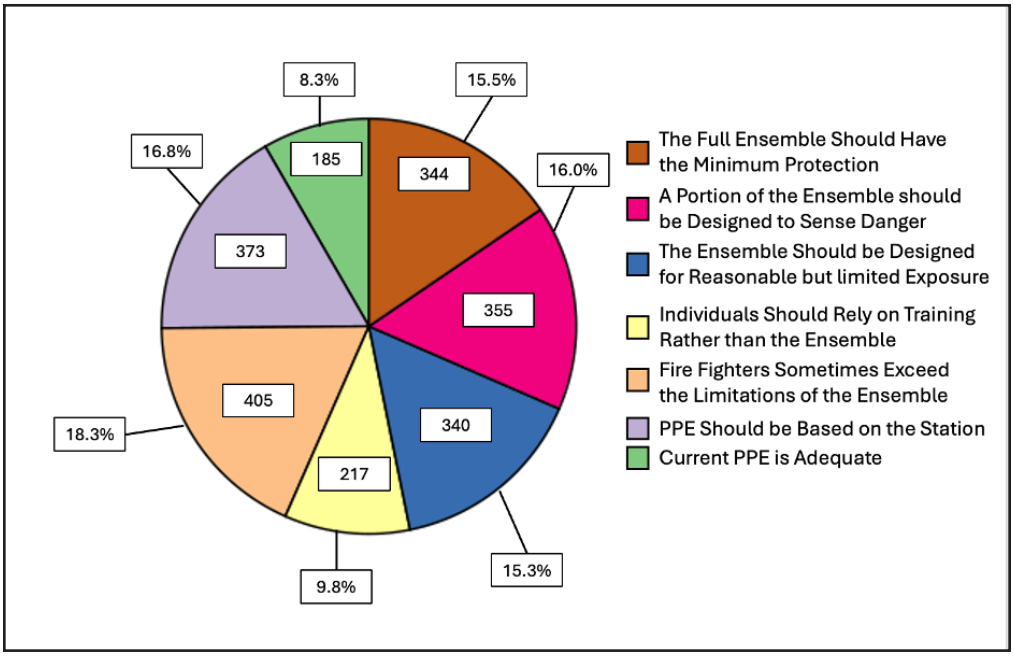
Figure 19 Q5. For which of the other types of calls listed above, do you wear the same protective clothing as for structure fires?

6. PERCEPTIONS OF PPE FUNCTIONALITY AND LIMITATIONS

Fire fighters were asked about their perceptions of the safety of their PPE, and what changes they might be interested in seeing. Only 8.3% of participants felt that current PPE is adequate. Preferences included a desire for greater situational awareness (e.g. sensing danger) (16%) and a more modular approach (PPE should be based on the station's geographic location and most frequently encountered responses) (16.8%). Perceptions included thinking that fire fighters sometimes exceeded the limitations of their PPE ensemble (18.3%). Fire fighters generally believed that the ensemble should be designed for reasonable but limited exposure (15.3%) and that the full ensemble should have minimum protection (15.5%) (Figure 20).

Conclusion: That so few fire fighters felt that current PPE is adequate reflects some of the challenges that are being identified throughout this survey data. Preferences for more situational awareness and a modular approach to PPE along with a desire for minimum protection in a full ensemble speak to the challenges of the modern fireground. Firefighting is a diverse occupation and the current binary model of turnouts or station uniforms do not reflect the myriad hazards or job types in the fire profession.

Figure 20. Fire fighter preferences and perceptions on functionality and limitations of PPE



INTERVIEWS

Key informant interviews were conducted in addition to the survey data. The purpose of the interviews was to gather more in-depth information to better understand survey results and to provide a more detailed picture of fire fighters' experiences with their PPE. A total of 9 interviews were conducted with fire fighters; the purpose was to gather experiences from across the United States, different geographical locations, different duty assignments, and different levels of experience. Both men and women were interviewed and subjects represented fire fighters who worked primarily in structural response, wildland/forestry response, or a mix of both from California, Washington, Idaho, Massachusetts, Colorado, and Virginia.

A list of questions was organized by theme to be explored and standardized across interviews (Appendix B). Themes targeted and questions targeted in these interviews were informed by survey data and the purpose of this project. They included: Experience and PPE Effectiveness, Maintenance Challenges, Respiratory, Training and Education, and Reimagining PPE.

In understanding these themes, it is important to note that these are qualitative data based on fire fighters' personal experiences and beliefs. They may not be reflective of every department, situation, or fire fighter experience. However, thematic saturation was reached relatively quickly in this interview effort. The consistency of responses across interview subjects lends weight to the evidence presented here. Experiences with comfort, mobility, and safety are somewhat uniform and universal in this data set.

THEMES

The interview transcripts were parsed and analyzed for themes. Key themes from interviews subjects included concerns regarding comfort and safety, fuels and fabrics, non-fluorinated finishes, and safety fallacies and training. An overall concern consistent across interview subjects is that a majority of responses did not require the level of PPE that was worn. In other words, PPE is generally overly protective. Many fire fighters, for example, are responding to medical calls or even brush and wildland fires in structural response gear. While highly protective PPE can be important to protect from unusual or catastrophic fire events, the downside is that fire fighters are often burdened by gear that is hot, heavy, and can limit mobility and situational awareness; these issues come with their own safety concerns. The larger question then becomes, what are the trade offs that fire fighters are willing to make in their gear?

COMFORT AND SAFETY

Comfort is not often associated with PPE or the profession of firefighting and is often thought of as a state of ease or relaxation. In this context, comfort is referred to as PPE that does not cause undue burden to the wearer. PPE that is not comfortable, that may be ill-fitting or causes thermal burden, chafing, or other discomfort will often result in early doffing, or improper wear which compromises the protective values of the ensemble.

In the interviews, themes of comfort and safety had three subthemes: Uncomfortable or ill-fitting PPE, temperature extremes and breathability of fabrics, comfort changes over duration of the incident.

A. UNCOMFORTABLE OR ILL-FITTING PPE

While fire fighters generally tend to be taller and heavier, they come in a multitude of different sizes, similar to the general public. Often coats, pants and other aspects of PPE are cut to a certain standard sizing. Ill-fitting or uncomfortable PPE resulted in early doffing (a potential safety hazard and/or increased occupational exposures), improperly worn PPE, PPE altered (either by the fire fighter or a dry cleaner/seamstress) in a way that damages the integrity of the garment, reduced mobility and situational awareness

Women: Women, in particular, experience challenges with sizing of garments that are often cut for male proportions and do not take into account sex-specific ratios of hips, butt, chest, and crotch areas. Specifically, all female interview subjects mentioned the crotch (e.g. zipper) portion of the pants was much too long and required them to "hitch up" their pants during hikes, when clearing large hazards, or any other "high step" type activity. This meant only having one free hand for tools or other equipment. Pants that were too tight around the thighs (due to waist to hip ratios) impaired mobility and caused significant chafing and bleeding. Coats that were not wide enough across the chest were sized up which resulted in sleeves that were too long and had to be rolled, impacting dexterity with tools and mobility. Experiences with custom fit or "made to measure" turnouts and gear were positive. Some vendors make female specific cuts for PPE but they were often costly and did not always solve all issues.

Unusual Sizes: Similar to women, men who were an unusual size—very short, very tall, especially broad or slim) experienced challenges with ill-fitting PPE. Pants that were sinched with belts resulted in chafing and bleeding. Improper fitting boots resulted in physical injuries to feet. Experiences with custom fit turnouts and gear were highly positive with multiple interview subjects recommending it but also noting that it was often cost-prohibitive, especially for small departments.

Alterations: When PPE does not fit properly, often fire fighters will have it altered. This can include professional alteration by a seamstress, dry cleaners or other service, or alterations done by the fire fighter. When these garments are cut, re-sewn or otherwise altered outside the manufacturer or their

authorized facility, it can impact the integrity of the garment, potentially making it less safe. In addition, details such as using Nomex thread instead of cotton thread are often overlooked.

Dexterity: Poor fitting gloves can significantly reduce dexterity when using tools. This often results in early glove removal which can increase occupational exposures and reduce safety/protection of hands.

Comms: SCBA that does not have good comms or unreliable comms results in removal of mouthpieces or other protective parts of SCBA to talk or communicate. At least one fire fighter reported challenges with a wireless (e.g. Bluetooth) communication system; after one experienced failure during an active incident, they did not choose to use this system again and simply partially doffs the SCBA facepiece to communicate if needed. Unreliable comms and difficulty communicating can also result in early doffing of SCBA during mop-up/overhaul.

Recommendations: Whenever possible, measure the fire fighter to assure custom fit gear; increase glove size variety; a full range of motion in gear will increase comfort which will increase safety. Communications options that are reliable to reduce early doffing of respiratory protection should be explored.

B. TEMPERATURE EXTREMES AND BREATHABILITY OF FABRICS

Many regions of the United States experience significant temperature extremes. Fires occur at any time of year and in every region. Some fire departments operate in regions that can have temperature differences of 30–40 degrees in a single day; or their response area can have wildly different climates. This can make having a "one size fits all" approach to PPE difficult. Los Angeles County Fire Department, for example, can respond to beach locations in ~70 degree weather or to desert areas which can have extremes of 120+ degrees in the summer. In addition, Washington and Colorado can experience burns in the winter that are extremely cold. For wildland fire fighters who work on controlled burns or respond to fires in the winter, subzero temperatures are not uncommon.

Thermal comfort: Fire fighters interviewed do not expect their PPE to be fully comfortable and understand that protection from thermal and direct flame hazards and liquids will result in heavy and less breathable fabrics. Most interview subjects had 10+ years of experience in the fire service and had experienced at least one significant change in PPE ensembles. Overall, fire fighters wanted more breathable fabrics and PPE that felt less "hot" and were willing to address potential reductions in flame and heat resistance through training. There was significant concern about thermal burden on fire fighters and overall health as well as occupational injuries (e.g. heat injuries, cardiac stress, etc.).

When a structural firefighting department on the east coast transitioned to a modern firefighting ensemble (as opposed to older rubber coats and boots), "the immediate second and third effects …[was] a number of cardiac related events with some of our older members." -Subject H

There was a concern that overprotection from flame/burns will result in greater heat stress injuries (e.g. hyperthermia) for fire fighters and that burn injuries from lighter and more breathable gear can be solved through training. Most fire fighters interviewed were very knowledgeable about NFPA standards and that PPE must meet certain requirements. At least one fire fighter suggested that testing standards should be evaluated to ensure they are reflective of what is needed and encountered regularly on the fireground.

"Is the standard overdoing it? Is the testing process overdoing it? I don't know. Those are concerns that I definitely have." -Subject E

Recommendations: Evaluate the testing standards and ensure they are reflective of what is needed and encountered regularly on the fireground. Provide breathable/modular options for fire fighters working in regions with temperature extremes (hot or cold).

C. COMFORT CHANGES OVER DURATION OF THE INCIDENT

Many fires and incidents that fire fighters respond to can be relatively brief, but there are also incidents that can last much longer. Extended attack, "mega fires," conflagrations, and even medical aid calls can last hours or extend over several days. Fire fighters interviewed universally reported that the longer they wore their PPE, the more uncomfortable it became. Shoulder straps dig in, turnouts can become wet and heavy from hose water and sweat, or they can become unbearably hot. Newer fabrics are stiff and take time to break in. New gear is more difficult to wear with one fire fighter likening new gear to "wearing an iron suit." New gear is most likely the most protective with intact fabrics and seams, but it can reduce the mobility of a fire fighter, making them more likely to prefer older or more worn gear (which may be less protective).

"I've never been in gear that got more comfortable as the incident progressed" -Subject H

Moisture: One interview subject reported that the moisture barrier is internal to the turnouts they wore. This resulted in the outer shell absorbing water and fluids during an incident (e.g. hose water), making the PPE heavier and less mobile over the duration of the incident. Previously worn gear (east coast, older options) included a rubber coat with a removable quilted linter; these options for PPE were removed when a catastrophic incident in 1995 caused multiple fire fighters to lose their lives to burn injuries.

Recommendations: Explore fabric options for turnouts that are more flexible while retaining their moisture resistance.

FUELS AND FABRICS

While experiences will vary depending on the department and assignment, many fire fighters reported that the fabrics of their PPE (both turnouts and wildland coat/pants) were regularly soaked with fuels, diesel, and hydraulic fluids. Contamination with these products can result in an ignition/flammability risk, dermal exposure risk, and a fabric integrity risk. Some departments may be more likely to encounter blood/biological hazards than fuels, but recommendations for improvements to PPE would be similar.

Ignition/Flammability: While the survey data indicated that some fire fighters experienced ignitions (on gear/PPE) as a result of contamination of PPE with fuels, interviewed subjects did not report a similar issue; this may simply be due to small sample size of interview subjects. Ignition and flammability risk remains a low to moderate but persistent concern.

Dermal Exposure: Depending on the PPE worn—turnouts versus a station pants or wildland coat/pants—penetration of fuels to the skin may vary. Fuels are carcinogenic and extended exposure can result in skin burns. Repeated exposure from gear that is not regularly cleaned can also be a problem. Two interview subjects reported regular contamination of gloves with fuels; in one case the gloves were regularly replaced, in the other case they were not.

"...he had...fuel burns on his shoulders and down his back that were extreme." -Subject D

Fabric integrity: Prolonged exposure to fuels and hydraulic fluid may impact the integrity of the fabric in garments, causing them to prematurely breakdown. In addition, certain components of the ensemble, like gloves and boots, may be more absorbent and not easily cleaned.

Example 1: Use of drip torch or chainsaw which soaks through the jacket/shirt and caused fuel burns on the skin after several hours of exposure

Example 2: Fuel soaked through top layer of turnout and later caught on fire during an incident

Recommendations: PPE fabrics should provide liquid resistance appropriate to expected exposure hazards, and be able to be easily laundered. Departments and fire fighters should regularly clean and switch out PPE, not just when they think they have had an exposure. Some exposures may be small or undetected but still need to be addressed.

NON-FLUORINATED FINISHES

The presence of per- and polyfluoroalkyl substances (PFAS) in fabrics and PPE has become a topic of conversation in both the firefighting and research and scientific communities. PFAS are a suite of man-made chemicals present in numerous manufactured goods, including those that combust during a structure fire, present in drinking water in some locations, and in sources as diverse as surfboard wax. These are persistent (e.g. they do not break down easily and are not readily metabolized or excreted from the body) and have been associated with negative health outcomes. While the scientific community works to understand the cause-and-effect relationships between PFAS exposure and related negative health outcomes, some jurisdictions have already set bans to phase out intentionally added PFAS gear for their fire departments.

In the interviews, fire fighters were not specifically asked about PFAS or non-fluorinated finishes on gear. Instead, they were asked general questions about longevity of gear, maintenance concerns, and performance of gear. Independently, two interview subjects mentioned challenges with non-PFAS gear (e.g. gear with non-fluorinated finishes on outer shell materials).

Concerns expressed included that their experience was showing gear with non-fluorinated finishes to seemingly be less liquid resistant and not as durable.

"The concerns I have for the outer shells? Non-fluorinated finishes are not holding up well. The non-fluorinated finishes are allowing absorption." -Subject E

Recommendations: Fluorinated finishes are banned in some departments and there seems to be a general push to remove these fabrics due to concern regarding PFAS. An appropriate alternative finish technology should be pursued. A better understanding of the impacts of fabrics used in PPE on fire fighter health and safety, and overall PPE performance is needed.

SAFETY FALLACIES

Some interview subjects felt that PPE was overprotective or was addressing hazards not often encountered on the fireground. One interview subject felt that steam burns were not an issue and were a holdover from a training manual in the 1970's. They felt that water used in extinguishing fires did not create steam. Specifically, the fire environment prior to extinguishment was wetter than during extinguishment. Therefore, steam burns were not a big risk and that burn injuries on the job were being miscategorized.

An interview subject felt that independent third party testing of certain portions of the ensemble should be increased. For example, helmets may not be meeting the standards they are certified for.

REIMAGINING PPE

At the conclusion of the interview, subjects were asked a series of open-ended questions intended to solicit their opinions on how to improve current PPE available in the fire service. A summary of notable suggestions and comments are provided in this section.

- Current allowable helmets are not as protective or as comfortable as European models or other options. The visual perception of the helmet and type of helmet is large. This interview participant switched back to a "traditional" helmet after using the European style for several months. They

admitted that the European style was significantly more comfortable and felt more protective to wear but a traditional helmet fit in better with the culture of their fire department.

- The military has a women's cut for their uniforms that appear to fit better and be more comfortable. They also have a "curvy" cut and a "straight" fit.
- More options and clearer policies around purchasing and acquiring PPE that fits. In addition, if PPE needs to be altered for size or better fit, current guidelines specified for proper alterations must be emphasized (e.g. use Nomex thread, use an authorized tailor, etc.)
- The Air Force has suits that are flame retardant, zip on and off easily, and are flexible and breathable (from an interview subject with flight/airplane experience); a flight suit is much more comfortable than heavy coat and pants-based clothing configurations.
- Particulate blocking hoods should be easier to clean; some experiences include reduced mobility, increased noise due to "crinkly" fabric and associated reduced situational awareness. The idea of a particulate blocking hood is good, but integrity of the fabric and ability to effectively clean is a concern.
- People in alpine sports like skiers and snowboarders seem to have bulky gear and insulating gear that is still flexible and mobile.

NOTABLE INSIGHTS

Notable insights included stand out ideas or statements that did not necessarily fit into an overarching theme but were significant to understanding the landscape of PPE in the fire service.

Protectiveness: Fire fighters were asked if there were specific aspects of their PPE that stood out to them or if there were improvements they would like to see made. Many felt that the overall protectiveness of their gear was good but that the protectiveness and encapsulation of the gear made their job difficult.

"...the coat, the pants, the bulk of the tank, uh, certainly. Decreases overall mobility, flexibility, and ability to move comfortably on the fireground through. It reduces profile openings, doors, uh, windows when a hallway gets kind of crowded with a number of people." -Subject H

Fire fighters generally felt that breathable fabrics were less thermally protective from flames, but most were willing to accept this compromise for more comfort and mobility.

"I think that the thermal protectiveness is good. But the trade-off with that is the breathability." -Subject D

RECOMMENDATIONS

Firefighting as a profession has evolved to encompass a diverse array of first responder duties and responsibilities as well as wildland and urban interface responses. Fire fighters respond to burning structures and auto accidents, hazardous material and battery fires, grassland and timber fires, and medical aid calls. They fly and jump from helicopters, climb ladders and perform swift water and technical rescues. This requires PPE that has thermal protection, liquid protection, and allows for mobility and comfort as well as effective communication.

Firefighting is also a high-risk occupation. A variety of polices, procedures, and recommendations, including those for PPE usage and application have been created to reduce risk and ensure these individuals are protected on the job. However, the data collected in this report demonstrate that fire fighters would like to have higher rates of thermal comfort, mobility, dexterity, and situational awareness

and they are willing to accept lower levels of protection in their PPE to achieve this. The reasoning is that mobility, comfort, and situational awareness are an integral part of safety on the fireground. The approach of fully encapsulating an individual will reduce risk of catastrophic incidents; at the same time, the majority of responses from fire fighters do not require the highest level of protection. It is important to find a balance between protection and form/fit/function of PPE.

- A "one-size-fits-all" approach to PPE does not reflect the modern fireground. Only giving the choices of turnouts or station uniform for work wear (or pants/jackets for wildland responses) imparts a thermal and mobility burden on the fire fighter when it is not necessary. Allowing departments and stations to have more options to reflect the needs of their service areas will provide safety by allowing for comfort and the "right tool for the right job."
- Comfort and mobility: These can and should be increased, even at the cost of reduced protection from hazards where some small reductions in thermal and liquid protections may provide a reasonable trade off for improved ergonomic features that impose less physiological stress on the fire fighter. With a modular approach to PPE systems this can be obtained as a significant majority of fire fighter calls/responses do not require full protection from all hazards in PPE.
- An ill-fitting garment reduces mobility, increases physiological stress and injury, and reduces safety compliance. Providing a wider range of sizes and cuts is a priority for safety and fire readiness.
- Better protocols and implementation of PPE decontamination with respect to liquid and other fireground hazards is needed. The fire service may not appreciate the hazards of liquid exposures, and more education is needed in this area. On the other hand, some aspects of liquid protection may be leading to more encumbrances from gear impacting mobility and comfort.
- Fabrics that are breathable and can be cleaned and laundered easily will reduce occupational exposures and reduce the risk of ignition of gear. Contamination of gear with fuels, greases, and lubricants is common; fabrics and laundering practices must effectively address this hazard to reduce ignition risk and occupational exposure risk from these hazardous liquids.
- Any changes to PPE design, performance, or other compliance must be implemented top-down with strong support from leadership. Leadership must both model appropriate PPE usage and care practices as well as enforce it among other fire fighters. A strong resistance to change and willingness to accept more risk—hallmarks of the firefighting profession—will be a barrier to any changes in PPE that lack leadership support.

PPE DESIGN AND INNOVATIONS

There is a distinct need for a modular and scalable PPE system that is tailored to specific incident types, while supporting universal use when possible. While the fire service includes diversity of job types and incident responses and responsibilities, PPE is still largely homogenous. A PPE system that includes specialized pieces of the ensemble and prioritizes ergonomic and physiological performance (comfort, breathability, weight) would better meet the needs of the modern fire fighter.

Integration of early warning systems and features in gear—such as sensors indicating escalating physiological or fireground conditions—would greatly improve the health and safety of fire fighters and allow for better situational awareness on incidents. There is a vast pool of technological advancements in monitoring and data collection on ambient conditions and human health and safety that could be applied to the fire service to the benefit of the individual fire fighter as well as the coordinated emergency response to the incident.

One of the concerns regarding updating or increasing the protectiveness of PPE (e.g. thermal) is that fire fighters will feel more comfortable advancing into dangerous conditions on the fireground and/or rely too heavily on the protectiveness of their PPE, resulting in greater injuries and death. A PPE system that understands the needs for recognizing the limitations of gear while permitting effective communications and situational awareness and also includes early warning systems would address these concerns.

PPE must also be easier to clean. Cleaning of PPE through preliminary exposure reduction (gross decon), washer/extractor (machine) laundering, or other methods is one of the best common-sense methods for reducing primary and secondary exposure to known and suspected carcinogens. PPE that is easier to clean is also important for reducing flammability concerns from exposure to fuels and hydraulic fluid.

Fabrics should be more flexible and "breathable" to allow for greater functionality and reduced thermal burden on the fire fighter. In addition, challenges with liquid protection remain. While non-fluorinated finishes on fabrics have created changes in some areas of performance, with both positive and negative outcomes, fire fighter expectations for these fabrics along with the metrics by which they are judged as having acceptable performance should be aligned to changes in available material technologies that are replacing PFAS finishes and other uses in fire fighter PPE.

POLICY AND OPERATIONAL STANDARDS

Most fire fighters now have a clear understanding that their occupational exposures are resulting in a higher risk of cancer and other diseases. Yet, there continues to be challenges in implementing health promoting practices such as regular decontamination of PPE.

Ensuring that standardized cleaning and decontamination practices are properly established across departments and providing multiple sets of PPE for rotation and cleaning, particularly when contamination risks are high.

Departments and agencies should develop guidance documents for trade-off decisions in PPE. Leadership must make decisions on when to prioritize thermal protection versus mobility, for example. This will likely be guided by the department or fire station and depend on what kinds of job duties they are most actively engaged in (e.g. EMT/medical, structural fires, vehicle fires, WUI fires, etc.).

In addition, it is recommended the agencies and departments prioritize the fit and comfort of PPE. Offering a better way to assess correct sizing at the fire fighter level along with a greater range of sizes, investing in custom or tailored PPE, providing a better range of fabrics or gear will significantly improve fire fighter health and safety. If fire fighters are uncomfortable in their gear, if their gear causes injuries or movement problems, or is easily damaged, it will be worn improperly or not at all. Alternatively, fire fighters may make modifications to their ensemble to improve the fit in a way that compromises the integrity of the garments.

CULTURE AND CHANGE

Changes and innovation to PPE can vastly improve working conditions and safety for fire fighters. But change in the fire service can be hard. A culture of what the "traditional" fire fighter should look and act like can impede efforts to improve safety. The most effective way to implement change within the fire service is to ensure that new PPE and operational policies are accepted and implemented from the top (leadership) down and include support from informal leaders within the fire service. A piece of PPE as iconic as the helmet, for example, will not be easily changed, regardless of the potential increase in safety and comfort.

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APPENDIX A: SURVEY QUESTIONS

Questions included in the table below represent those in the Survey Monkey survey distributed for this project. Question formatting appeared slightly different in the online survey format.

Which Local do you belong to?
Approximately what is your department's total call volume in a given year?
Of the total calls in a year, what percentage of these calls are structural or related fire responses?
How many years have you been a fire fighter?
What other types of calls do you respond to where you wear some form of protective garment (check all types that apply)?
For which of the other types of calls listed above, do you wear the same protective clothing as for structure fires (check all types that apply)?
During what percentage of responses where you wear turnout gear do you encounter fireground conditions where you are exposed to some form of elevated temperatures or high radiant heat?
Indicate how often you encounter the following types of heat and flame hazards (using the frequencies indicated below). NOTE: Emergency fireground conditions include hostile events such as a flashover or backdraft.
For the same hazards above, how would you rate these hazards in importance for how PPE is designed to protect you from exposure to each hazard? NOTE: Emergency fireground conditions include hostile events such as a flashover or backdraft.
In terms of PPE heat and flame resistance capabilities, indicate which of the statements you believe to be true (check all that apply)? NOTE: Emergency fireground conditions include hostile events such as a flashover or backdraft.
Which areas of your ensemble warrant the greatest insulation from high heat for protection purposes?
During what percentage of responses where you wear turnout gear are you exposed to liquids that include contaminated water, chemicals, blood/body fluids, non-water extinguishing agents, fuels, oils, greases, or any other potentially hazardous liquids?
Indicate how often you encounter the following types of liquids from the previous question on the fireground (using the frequencies indicated below).
Have you or your gear been exposed to any of the following liquids during an emergency response?
If your department uses hydraulic tools such as cutters and spreaders, do you handle hydraulic fluid?
Which potentially hazardous liquid would you most likely encounter (be exposed to) during an emergency response?
Are there any other liquids that you encounter but have not been identified in this survey?
What additional liquids have you previously encountered that are not identified in this survey?
Rank the portions of your turnout clothing that are most likely to be exposed to the liquids covered in this survey (a ranking of 1 represents the item most likely to be exposed; a ranking of 6 the least likely item to be exposed).
Have you ever had a situation or know of an event when your PPE or someone else's PPE has been contaminated on scene with a hazardous liquid and caught on fire in the current or a subseqent shift?
How does your department handle clothing and gear that has been exposed to hazardous liquids (check all that apply)?
During what percentage of responses where you wear turnout gear do you experience heat stress or other physiological stress conditions?
Are you willing to trade off thermal protection for lowering physiological stress on the fireground?

Are you willing to trade off barrier protection (against liquids) for lowering physiological stress on the fireground?
During what percentage of responses where you wear turnout clothing do you experience problems with mobility or other functions (e.g., hand dexterity)?
Are you willing to trade off thermal protection for improving your mobility and functional performance on the fireground?
Are you willing to trade off barrier protection (against liquids) for improving your mobility and functional performance on the fireground?
How would you rate these PPE characteristics in importance for how PPE is designed to protect you from exposure to different hazards.
Rank desirable performance attributes and impacts of PPE on a scale of 1 to 7, where you can assign only one rank per performance attribute or impact (1 is the most important; 7 is the least important)
Are there any specific questions that that we should ask that have not been covered in any of the topics addressed above

APPENDIX B: INTERVIEW QUESTIONS

Participants were provided these questions in advance. When interviewed, they were asked these questions with few alterations. Occasional follow up questions to explore an emerging theme were included (but not listed here). In addition, some questions were omitted if they became redundant or were not relevant to the person being interviewed.

Questions asked may include the following. These are intended to provide examples of questions that might be asked. Additional follow up questions that are not listed may be asked during the interviews to provide more depth and clarity as needed. Interviews typically last 30–45 minutes depending on the discussion.

Experience and PPE Effectiveness:

- What are your primary duties and how does your current PPE support or hinder those responsibilities?
- In your opinion, how effective is your current PPE in terms of protection on the job? For example, from heat, flame, hazardous materials, smoke and soot, cuts and abrasions?
- In your experience, how does your PPE affect your comfort and mobility on the job? Are there specific aspects of your PPE such as materials/fabrics, features, that stand out to you?
- Tell us your opinions on the weight, thermal protectiveness, and breathability of your current PPE? Breathability is how the fabric "feels" and how well it allows for heat loss from the individual.

Maintenance Challenges

- Which part of your ensemble needs to be replaced most frequently?
- What are the most time consuming and costly parts of PPE maintenance? What are the easiest?
- In your opinion, what are some improvements that can be made to the longevity and maintenance of your PPE?
- What is the lifespan of your PPE (turnouts)?

Respiratory (this can be altered to reflect flame and heat, hazardous materials, etc.)

- What are some of the biggest challenges with respiratory protection? Challenges could include with the fit/comfort, visibility/situational awareness, weight/bulkiness, airflow/ability to breathe easily, availability.

Training and Education

- Where did you learn about how to clean and maintain your PPE?
- In your experience, how do training programs address cleaning and maintenance of PPE?

Reimagining PPE (ask these questions last)

- Which part of your ensemble are you least satisfied with?
- If you could change anything about your PPE, what would it be?
- If PPE were to be modular, (e.g. customizable to the station, department, or call), how do you see that affecting your job and duties? Modular could include different turnouts, respiratory protection, tools, or other materials with the intent of protection from biological, hazardous, flame, or other hazards.
- Have you seen gear or PPE used in other industries that you wish was available to fire fighters?
- Is there anything important regarding PPE we haven't discussed yet?

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