PPE REIMAGINED

RETHINKING FIRE SERVICE PPE: TOWARD A SMARTER, MORE RESPONSIVE PROTECTION PARADIGM

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INTRODUCTION

The modern fire service faces evolving hazards, shifting mission profiles, and increasing scrutiny over long-term health outcomes. Yet much of its personal protective equipment (PPE) and standards architecture remain rooted in legacy assumptions that prioritize structural fire suppression above all. As the nature of risk evolves — from chemical exposures and carcinogenic contaminants, to lithium-ion battery fires and all-hazards responder tasks — the fire service and PPE industry must confront hard questions: **Is current PPE still "fit for purpose"? Are standards development processes agile enough? And can we reimagine PPE design and procurement to better align with real-world risk, performance tradeoffs, and health outcomes?**

This report explores those questions — reviewing what can be improved in standard development, how risk assessment and PPE needs should be revisited, where standards may hinder innovation, what new designs may be possible, and how procurement/field evaluation practices should evolve. Background is provided below that explains the how the project was organized to answer a series of questions design to more efficiently and effectively evolve PPE to align with modern fire service needs.

THE PROCESS FOR REALIGNING FIRE SERVICE PPE WITH MODERN FIRE FIGHTER NEEDS

The IAFF PPE Reimagined project began by looking back at the major points where fire fighter PPE changed because the fire service, researchers, and manufacturers were willing to rethink assumptions. The first national fire fighter clothing standard in the 1970s established minimum design and performance criteria. Project FIRES then moved turnout clothing into a modern two-piece configuration, introduced Thermal Protective Performance (TPP) as a more meaningful measure of insulation, and helped shift vapor barriers toward breathable moisture barriers. Later, SCBA standards made positive-pressure SCBA the expected respiratory protection for structural firefighting, and the heat and flame test fire-hardened SCBA while also revealing clothing design issues that needed correction.

Other advances followed the same pattern. Third-party certification improved consistency by requiring independent testing, product labeling, quality-system review, follow-up evaluation, and safety investigations when needed. Heat-stress research then showed that simply increasing thermal insulation was not enough; fire fighter physiology had to be considered. Total Heat Loss (THL), supported by field research with the Indianapolis Fire Department, gave standards a way to account for breathability and helped balance burn protection with heat-stress reduction. Electronic safety equipment, beginning with PASS devices and later thermal imagers, radios, and related technology, showed that PPE standards also had to address durability, alarm reliability, and function under severe fireground conditions. WMD-era concerns further expanded PPE thinking by encouraging design flexibility, liquid integrity, particulate protection, and improved interface control--concepts that later became important for reducing exposure to fireground contaminants and carcinogens.

These historical examples show that the most meaningful PPE improvements occurred when standards were driven by fire fighter needs, emerging hazards, and measurable performance rather than by simply adding more requirements to existing products. The project advisory panel therefore concluded that fire service PPE has evolved by accumulation. Requirements have been added over time, but the overall system has rarely been realigned with today's missions, hazards, costs, health concerns, and operational tradeoffs. Modern PPE remains highly optimized for structural fire suppression, but it may not be equally appropriate for every fire fighter, every response, or every region. It has also become more complex and expensive without always delivering a proportional increase in protection value.

- Does every fire fighter need the same minimum level of protection?
- Should geography, climate, call profile, and mission assignment influence PPE selection?
- Can overprotection in some areas create excessive physiological burden or a false sense of invulnerability?
- If PPE cannot be adequately cleaned, should some products be redesigned for limited-use or lower-cost applications?
- If the fire service reassessed modern firefighting from the ground up, would it choose the same PPE system?

The panel ultimately reframed those issues into a more basic decision process: define the mission; identify the hazards and priority risks; establish the expected level of protection; determine how successful protection should be measured; and then identify the technologies capable of providing that protection. The important sequence is that the fire service and hazard experts should answer the mission, hazard, and protection-expectation questions first. Researchers, test laboratories, standards organizations, and technology providers are essential for developing metrics and practical solutions, but they should not define the problem too early by limiting the discussion to products that already exist.

The PPE Reimagined approach therefore starts and ends with fire fighters. It begins with fire service judgment about missions and acceptable risk, uses science and standards to translate those expectations into measurable performance, and returns to fire fighters through field evaluation to determine whether new solutions are protective, usable, maintainable, and worth adopting.

(1) WHAT CAN BE IMPROVED IN THE CURRENT FIRE-SERVICE/STANDARD-DEVELOPMENT PROCESS?

The structure and pace of standards revisions often lags real-world hazards. Standards for structural and proximity firefighting PPE in the U.S. (e.g., National Fire Protection Association — NFPA) are generally updated on a fixed cycle. But the hazards fire fighters face — from chemical exposures, battery-fire risks, to emerging vehicle and building fire types — evolve more quickly than standards cycles can respond.

This structural lag can result in a disconnect between what PPE is certified to handle and what fire fighters actually encounter in the field. For example, recently the Fire Safety Research Institute (FSRI) highlighted emerging thermal and chemical hazards — including battery-fire events — that challenge traditional PPE assumptions [1].

Moreover, the standards development process itself — committee-based, consensus-driven, conservative — tends to favor incremental changes rather than disruptive innovation. As one industry article put it, "getting the standard 'correct' can significantly change the provided protection," but achieving consensus requires balancing widely disparate stakeholder interests.

Given the growing complexity of hazards — and the stakes for fire fighter health — the current cadence and structure of standards development may no longer be sufficient. Principal additional factors include:

There are limited feedback loops linking field data, epidemiology and PPE design. While some efforts exist to monitor fire fighter health and exposures (e.g., chemical monitoring, cancer registries), the feedback into PPE design and standard requirements remains weak. For instance, the U.S. National Fire fighter Registry for Cancer (NFR) was established in 2018 to help identify occupational cancer risk factors in fire fighters — including exposures from fires, gear, and station environments. Yet the registry's long-term viability is uncertain and uptake remains voluntary. There is certain hope that this approach becomes well adopted and sustainable.

Meanwhile, researchers at FSRI and elsewhere have documented PFAS chemicals in turnout gear and noted that PFAS content increases with wear, laundering, and aging — raising cancer concerns. Without a robust, sustained, and standardized mechanism to feed epidemiology, exposure science, and field data back into standard revisions and procurement, PPE design risks falling behind both operational needs and health science.

There is still a lack of flexibility for mission-specific PPE strategies. The current standard-driven model implicitly promotes a "one-size-fits-all" structural-ensemble mindset. Departments often purchase and issue full turnout gear for all fire fighters—even if the majority of responses are medical, rescue, or non-structural incidents. This "blanket issuance" strategy discourages tailored PPE choices.

Although some consolidation of standards has occurred (e.g., merging multiple PPE-related standards into a more integrated framework) to facilitate a "systems approach" to PPE and other protective technologies supply chain resilience [2]. But there remains limited formal recognition — in either standards or procurement practices — of modular or layered PPE approaches that reflect the variety of modern fire-service missions.

The integration of new health-related hazard research into standard criteria has been slow. Although research on contaminants (PAHs, VOCs, PFAS), decontamination efficacy, and long-term health risks have gained momentum, many of the findings are still not embedded into standard testing criteria. For example, PFAS contamination of turnout gear and associated cancer risk is now well documented [3].

Yet there is no standard yet requiring testing of PPE for PFAS or other restricted substances release over wear cycles, chemical permeability, or cumulative contamination loads. Similarly, vapor-phase and ultrafine particle infiltration (from modern fires, vehicle fires, EV/battery fires) remain insufficiently addressed. Emerging projects (e.g., FSRI's "Emerging Issues Related to PPE") are trying to close these gaps. But the process remains reactive rather than proactive.

Thus, it is the recommend that the standard-development process should be augmented by a **living-risk feedback framework** – combining field incident data, chemical exposure monitoring, epidemiologic studies, and predictive hazard modeling – to trigger more frequent "hazards-driven" standard reviews outside the fixed revision cycle.

(2) HOW CAN THE PPE NEEDS AND RISK ASSESSMENT BE REVISITED?

To better align PPE with real-world risk, fire departments and standard bodies must rethink the process through which they define needs, evaluate hazards, and prioritize PPE investments.

(A) WHAT DO STATISTICS SHOW ABOUT PPE EFFECTIVENESS AND ALIGNMENT WITH NEEDS?

Physiological burden and performance tradeoffs. Multiple peer-reviewed studies show that wearing full structural PPE (coat, pants, hood, gloves) with SCBA significantly reduces physical performance, increases heat strain, and impairs work capacity. For instance, one study found VO_2max — a measure of aerobic capacity — dropped by 17–20% when wearing PPE and SCBA [4]. Another study simulating a "smoke dive" in a high-heat environment (110–272 °C) observed fire fighters' core temperatures (gastrointestinal) climb from ~37.5 °C at start to ~38.4 °C post-exposure, then further up to 39.6 °C after recovery — clearly demonstrating the thermoregulatory load imposed by PPE under strenuous fireground tasks [5]. Additionally, heat stress correlates to impaired balance, increased slips/trips/falls, overexertion injuries, and even cardiac risks [6]. These physiological burdens are not trivial — they affect task execution, safety margins, and long-term health.

Contamination and carcinogen exposure. Contaminant exposure remains a systemic issue. A 2022 study showed that protective clothing worn during live-fire suppression had significantly elevated levels of polycyclic aromatic hydrocarbons (PAHs), especially in the moisture barrier and outer shell [7]. Moreover, conventional decontamination (washing) is insufficient: a study comparing aqueous laundering to advanced methods found that water wash alone left high-molecular-weight PAHs largely intact, while advanced liquid CO_2 cleaning improved removal substantially [8]. Meanwhile, research continues to mount on PFAS — encountered in during structural fires and also historically widely used in turnout gear moisture barriers and outer shells. A recent toxicology study even linked PFAS exposure from fire fighter occupational exposures to changes in microRNA — early indicators of altered gene regulation associated with cancer risk [9]. These data indicate that, while structural PPE remains effective at preventing acute burn and thermal injuries under many scenarios, it is less effective at mitigating long-term chemical exposures — particularly under modern fire conditions where smoke, vapors, ultrafine particles, and toxic combustion by-products are pervasive.

Alignment gaps between PPE issued and mission profiles. Another alignment problem emerges when considering how often full structural PPE is truly necessary. Many firefighting responses are non-structural — medical emergencies, rescue, vehicle accidents, false alarms, inspection code enforcement, station standby, etc. Yet departments frequently issue structural gear to all fire fighters. This "default full-ensemble policy" stresses turnout gear with unnecessary exposure to contaminants (PFAS, PAHs), wear and tear, and laundering cycles — without providing additional safety for those lower-risk calls. Thus, statistics on performance burdens, chemical exposures, and duty cycles point to a misalignment between PPE protection, hazards encountered, and actual mission needs.

(B) WHAT ARE THE PRIORITY NEEDS AND HAZARDS THE FIRE SERVICE WANTS ADDRESSED?

Based on emerging research, field experience, and fire fighter health concerns, several priority PPE needs and hazards deserve attention:

- **Chemical and carcinogen exposure reduction** — PAHs, VOCs, ultrafine particles, toxic vapors from modern combustion (plastics, e-waste, battery fires), PFAS in turnout gear, and absorption through skin or inhalation during overhaul.
- **Thermal stress mitigation** — heat strain, cardiovascular load, reduced performance, fatigue, slips/trips/falls, and heat-related illness.
- **Contamination control and effective decontamination** — better barrier technologies, improved gear interfaces (hoods, glove/coat interfaces), effective laundering or cleaning methods, and wash-cycle performance.
- **Flexibility for all-hazards mission profiles** — lighter, more breathable, more comfortable PPE for non-structural calls, overhaul, rescue, EMS, wildland engagement, and extended-duration incidents.
- **Long-term health and occupational disease risk reduction** — minimizing exposure to PFAS, carcinogens, toxins, and establishing PPE lifecycles that consider contamination, degradation, and replacement.
- **Compatibility with emerging hazards** — lithium-ion battery fires, electric-vehicle fires, energy-storage-system fires, novel building materials, foam/chemical fires, etc.

As part of its PPE Reimagined project funded by the Department of Homeland Security, the overarching theme of this PPE Supplement, the IAFF is engaged in a strategy related to viewing PPE requirements through the lens of an updated hazard and risk assessment. A separate effort to identify protection priorities and identify key tradeoffs was undertaken by the Wildfire Conservancy. The key findings in that report are described in the following pages.

UNDERSTANDING PPE TRADEOFFS, PRIORITIES, AND FIRE FIGHTER IMPACT

SUMMARY OF SEPARATE REPORT PROVIDED BY THE WILDFIRE CONSERVANCY (SACRAMENTO, CA, USA)

Modern firefighting bears little resemblance to the world in which today's structural firefighting PPE was conceived. Although turnout gear has been steadily refined to provide exceptional thermal protection, the work fire fighters now perform is more diverse, more physiologically demanding, and more mobility-intensive than at any other time in the profession's history. Structural fires still happen—and when they do, they are hotter, faster, and more hazardous—but they represent only a fraction of the calls a typical fire fighter responds to. Yet the same heavy, multilayer thermal ensemble built for those uncommon, high-heat scenarios is worn during many responses.

The result is a growing mismatch between what PPE protects against best and what fire fighters experience most often. Data from IAFF surveys and nationwide interviews as part of the IAFF Department of Homeland Security "PPE Reimagined" project make that reality clear: fire fighters overwhelmingly describe turnouts as hot, heavy, bulky, and restrictive. They respect the protection the ensemble provides, but they also recognize that the insulation and moisture barriers designed for extreme thermal resistance impose a significant physiological burden on ordinary responses—where intense heat is rarely present, but the gear is still worn.

This tension sits at the heart of today's PPE conversation.

A PROFESSION ANCHORED IN TRADITION, OPERATING IN A CHANGING ENVIRONMENT

Fire fighters do not make PPE decisions in a vacuum. Like other high-stakes professions—military, law enforcement, emergency medicine—the fire service is a High Reliability Organization where long-standing practice is often seen as synonymous with safety. Tradition is a stabilizing force, especially in dangerous work. But it also creates resistance to change, especially when new gear looks or feels unfamiliar, or when it challenges established norms of what "real" firefighting should look like.

The perception of risk also shapes PPE expectations. Fire fighters tend to emphasize **immediate, high-consequence threats**—flashover, collapse, direct flame — as opposed to **long-term health risks** such as cancer, cardiovascular strain, and chronic toxic exposures. Even when fire fighters fully support cancer-prevention efforts, they may not understand the specific substances they are exposed to or the role PPE plays in mitigating that exposure. Decisions made on the fireground prioritize short-term survival and operational effectiveness; long-term harm is less considered.

These cultural realities must be part of any effort to modernize PPE. New ensembles must not only perform better—they must be acceptable to fire fighters, intuitive to use, and endorsed by leadership.

WHAT FIRE FIGHTERS ENCOUNTER VS. WHAT THEIR GEAR IS BUILT FOR

One of the most significant insights from national survey results is how little high-heat exposure most fire fighters actually encounter while wearing structural PPE. Nearly three-quarters of respondents reported experiencing elevated thermal conditions in 10% or fewer of their turnout-gear incidents. Only a small minority encountered such heat in more than a quarter of their calls. Figure X1 shows just how common elevated heat exposures are.

Yet thermal protection remains the top priority fire fighters identify for PPE design. This paradox reflects the dual pressures of the job: extremely high-risk events may be rare, but they are catastrophic when they happen. Fire fighters need gear that protects them during those moments. But wearing that same gear during low-risk, mobility-centric responses creates its own dangers.

At the same time, fire fighters can be exposed to a range of hazardous liquids—fuels, oils, hydraulic fluids, contaminated water, and blood. These exposures may happen more frequently than serious thermal events, but they receive less design emphasis in turnout development and are managed inconsistently across fire departments. Some fire fighters rinse gear on scene; others send it to a professional cleaner; still others simply continue operating until the shift ends. Such variation underscores the need for more intuitive fabric technologies and clearer departmental guidance.

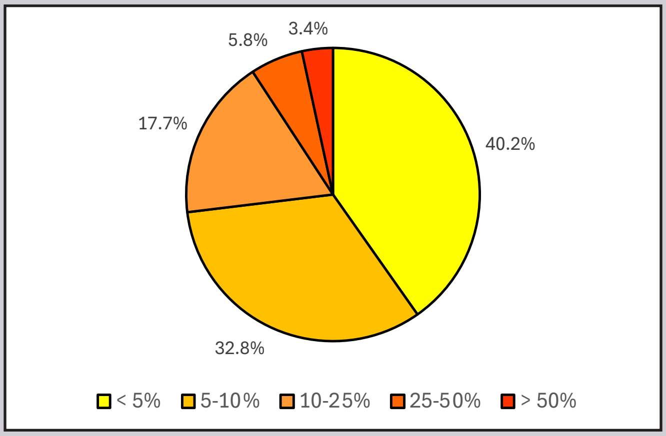

Figure X1. Frequency of Encountering Elevated Temperature or High Radiant Heat During Structural Fires or Other Emergency Calls When Wearing Turnout Gear

THE TOLL OF HEAT STRESS AND MOBILITY RESTRICTIONS

What fire fighters feel most strongly in structural PPE is heat—not necessarily from the fire, but from their own gear. Nearly half reported experiencing heat stress during at least a quarter of their turnout-gear responses. Physiologically, this matters: heat stress is a major contributor to cardiac strain, still the leading cause of fire fighter line-of-duty death.

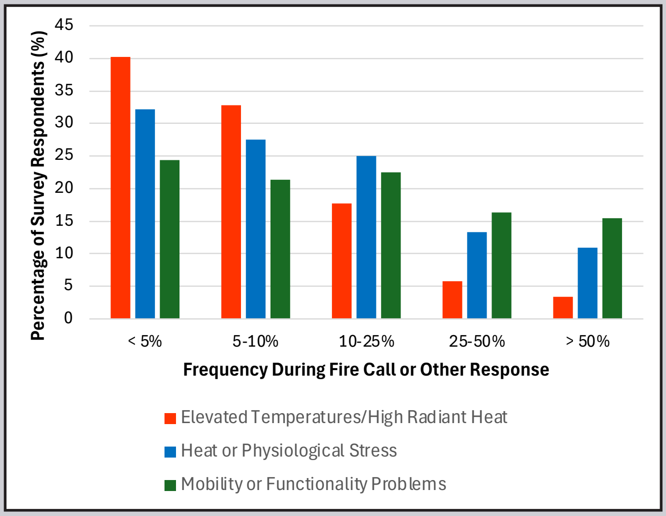

Figure X2. Comparison of Frequencies When Wearing Turnout Clothing During Emergency Responses.

This internal heat load, combined with the weight and rigidity of the ensemble, impairs mobility as well. About one-third of fire fighters experience movement restrictions in a significant portion of their calls. Interview participants repeatedly emphasized how turnout gear becomes heavier and more unwieldy as the call progresses—soaked with sweat or hose water, weighed down by tools, and stiff until fully broken in. New gear was described by several as feeling like an "iron suit." Figure X2 puts the frequency of these hazards into perspective by combining the results from Figure X1.

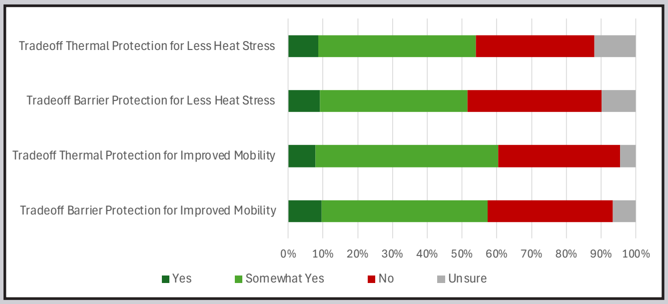

Figure X3. Survey Respondent Willingness to Make Tradeoffs Between Thermal Protection or Barrier Production for Better Heat Stress Relief or Improved Mobility

These experiences directly influence the tradeoffs fire fighters say they are willing to accept. In the IAFF survey, strong majorities indicated they would accept **some loss of thermal or liquid-barrier protection** if it meant better mobility or reduced heat stress. They were not rejecting safety—they were redefining it. Mobility, comfort, and physiological safety are not luxuries; they are operational requirements. Findings from the project survey are shown in Figure X3 based on different possible tradeoffs for gear performance attributes.

FIT, FORM, AND THE HUMAN VARIATION CHALLENGE

Fit emerged as one of the most powerful themes in the interviews—affecting comfort, mobility, safety, and willingness to wear gear properly.

Female fire fighters reported consistent, universal challenges with turnout fit:

- Excessive pant rise requiring constant adjustment
- Tightness through hips and thighs leading to chafing
- Chest and torso mismatches that forced oversized coats
- Overlong sleeves restricting glove dexterity

Men with atypical proportions—very tall, short, slender, or broad—encountered similar issues. Poorly fitting pants cut circulation or caused skin injuries. Boots that didn't match foot shape created blisters or altered gait. Gloves that were too stiff or oversized led to early doffing during tool work.

When gear doesn't fit, fire fighters often alter it—sometimes themselves, sometimes through unofficial tailors—creating unseen weaknesses in thermal insulation or seam integrity. These modifications may void certifications, yet fire fighters pursue them because the discomfort and mobility limitations of ill-fitting gear feel like more immediate threats.

A future PPE system must embrace the full diversity of fire fighter body shapes, including cost-effective custom sizing and gender-specific patterning.

LIQUIDS, CONTAMINATION, AND FABRIC PERFORMANCE

Structural fire fighters regularly encounter hazardous liquids—even on non-fire calls. Fuels and hydraulic fluids can soak into outer shells or penetrate clothing layers if the fabric is worn or becomes saturated over the course of an incident. Some fire fighters described burns caused by fuel that traveled through wildland clothing or through worn portions of turnouts. Others mentioned how fuels left on gloves or coat sleeves caused lingering irritation or odor.

Concerns about **non-fluorinated finishes** also surfaced. As more jurisdictions require PFAS-free outer shells, some fire fighters are noticing increased liquid absorption and reduced durability.

While the health rationale for PFAS elimination is compelling, the transition requires new fabric technologies to ensure that PPE remains resistive to common chemicals encountered on the fireground.

The broader issue is that fire fighters typically clean gear inconsistently. Without reliable indicators of contamination or clear departmental expectations, they may continue using gear with absorbed fuels or biologically hazardous fluids—raising both ignition risk and long-term health issues.

MISUNDERSTANDINGS, MYTHS, AND THE NEED FOR BETTER HAZARD COMMUNICATION

Interviews revealed several beliefs that shape PPE expectations—some accurate, some less so. A few fire fighters expressed skepticism that steam burns remain a real hazard, arguing that water application cools the environment rather than increases steam generation. Others questioned whether certain PPE elements, such as helmets, truly meet their stated certification levels. Some worried that high-performance turnouts give fire fighters a false sense of security, encouraging them to push deeper into hazardous environments.

Regardless of their technical accuracy, these perceptions influence gear acceptance. They reinforce the need for clear, evidence-based education on how modern fire environments behave and how PPE is designed to respond under expected use conditions.

WHAT FIRE FIGHTERS WANT: TOWARD A MORE ADAPTIVE PPE SYSTEM

Across hundreds of survey responses and extensive interviews, fire fighters expressed a coherent vision for what structural PPE should become. They want a system that:

- **Matches the incident**, rather than using the same gear for all responses
- **Reduces heat stress**, both through better materials and optional lighter configurations
- **Allows natural movement**, with articulation that mirrors how fire fighters climb, crouch, drag hose, and break through obstacles
- **Fits correctly**, including gender-specific and body-type-specific variations
- **Is easier to clean**, with materials that resist common liquids and maintain performance after repeated laundering
- **Supports situational awareness**, through improved communication systems or hazard-recognition cues integrated into the ensemble

Figure X4 captures findings from the survey for fire fighter opinions regarding how protective clothing use and expectations.

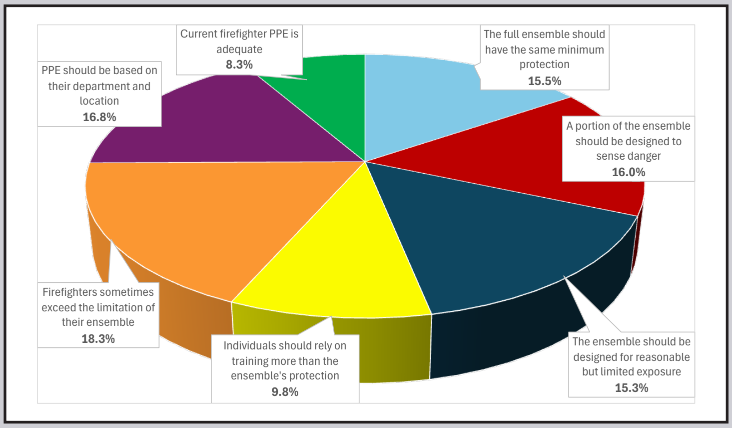

Figure X4. Fire fighter Perspectives Relative to Addressing PPE

Fire fighters were consistent: safety is not solely about insulation or protection against catastrophic events. It is also about mobility, endurance, and awareness—factors that determine whether a fire fighter can perform tasks effectively without fatigue, error, or overexertion.

THE ROLE OF LEADERSHIP AND POLICY

For any PPE innovation to succeed, leadership must champion it. Fire fighters in both surveys and interviews emphasized that when officers model good practices—cleaning gear, wearing proper PPE, embracing new equipment—others follow. When leadership is indifferent or skeptical, change stalls.

Departments will need to develop policies that guide when lighter or modular PPE should be worn, under what conditions full structural ensembles are required, and how contaminated gear should be managed. Just as importantly, they must actively communicate the "why" behind these policies to counter misunderstandings and reinforce buy-in.

A NEW PATH FORWARD

The structural firefighting PPE system of the future cannot simply be a more breathable version of the current turnout ensemble. Instead, it must be a **modular, scalable system** in which each component aligns with the hazard profile of the incident. A fire fighter responding to an EMS call or a low-intensity outdoor fire should not be saddled with the same weight and insulation needed for interior attack. A fire fighter performing technical rescue in summer heat should have an option that prioritizes mobility and heat dissipation without sacrificing critical basic protection. And during interior structural firefighting, turnout gear must still provide robust, compliant protection—but ideally with materials that reduce internal heat load and improve ergonomic movement.

This does not mean lowering safety standards. It means **rethinking what safety means** in an era where the majority of fire fighter injuries stem from heat stress, cardiac strain, slips/falls, and toxic exposures—not thermal burns.

By embracing modularity, inclusive design, new fabric technologies, integrated sensing, and consistent training, the fire service can evolve its PPE to meet modern operational realities. Fire fighters have been clear about what they need: comfort that does not compromise safety; mobility that enhances performance; and protection that reflects the actual hazards they face on the fireground and beyond.

(C) WHAT PPE TRADEOFFS ARE FIRE FIGHTERS WILLING TO ACCEPT?

Based on interviews, emerging research, and early adoption of hybrid PPE approaches in some departments, the following tradeoffs appear acceptable — especially when mitigated with training, policy, and procedural controls:

- **Reduced thermal protection in favor of improved mobility and breathability** for calls where structural flame exposure is unlikely (e.g., medical, rescue, overhaul, inspection). Fire fighters often prefer comfort and functionality for routine tasks. Some departments already maintain lighter "rescue/wildland" garments for non-structural missions.
- **Layered PPE strategy:** base layers for station/work uniforms; a "light" all-hazards ensemble (e.g., for EMS, rescue, overhaul, wildland); full structural turnout only when risk demands. This approach balances protection, wear life, contamination exposure, and physiological burden.
- **Willingness to accept "good enough" chemical protection (vs. maximal flame protection) for many calls** — especially when using respirators or SCBA, combined with decontamination protocols and contamination-reduction policies.
- **Acceptance of more modular PPE (hoods, gloves, boots, interface seals, particulate-blocking liners)** if these innovations translate into lower contamination risk, easier laundering, and improved ergonomics — even if they fall slightly short of full structural flame performance.

As part of its PPE Reimagined project funded by the Department of Homeland Security, the overarching theme of this PPE Supplement, the IAFF is engaged in a strategy related to viewing PPE requirements through the lens of an updated hazard and risk assessment. A separate effort to identify protection priorities and identify key tradeoffs was undertaken by the Wildfire Conservancy. The key findings in that report are described in the following pages.

(3) ARE SOME REQUIREMENTS POTENTIALLY PROBLEMATIC, CUMBERSOME OR OUT-OF-DATE?

While PPE standards have historically saved lives and reduced acute injuries, several requirements, test methods, or criteria now appear to hinder rather than advance fire fighter protection — particularly in light of new health risks and operational realities.

(A) WHERE DO TEST METHODS AND CRITERIA INTERFERE WITH NEEDED INNOVATION?

Some of the specific areas include:

1. **Focus on thermal protection over chemical exposure or contamination.** Traditional test methods emphasize flame resistance, thermal insulation, heat flux, char length, structural integrity, and breathability (to a degree), among other tests [10]. But there has been no widely adopted standard for chemical-permeation resistance, contaminant retention, or long-term chemical exposure under realistic fire scenarios — even though real fires increasingly involve plastics, electronics, e-waste, foams, and other materials that release VOCs, ultrafine particles, PFAS-laced aerosol, etc.
2. **Lack of standardized protocols for modern hazards (battery fires, ESS, EV fires, synthetic-fuel fires).** Emerging hazards like lithium-ion battery fires are not addressed explicitly in existing PPE standards. Research by FSRI and others has begun to characterize these risks, but standard test suites remain focused on structural building fires.
3. **Inadequate requirements for interface integrity and persistent protection under wear/wash cycles.** While hood, glove, coat, and pant interfaces have been studied (e.g., by FSRI/IFSI), most of the testing remains limited to new gear and ideal conditions. Real-world use — repeated heat exposure, smoke contamination, laundering, UV, abrasion — likely degrades performance over time. Standards seldom require periodic re-testing of used gear, or define degradation thresholds for chemical permeation, PFAS release, or barrier failures.
4. **Potential overemphasis on worst-case structural scenarios.** By centering standards around structural fire suppression, many test criteria may mandate safety margins (bulkiness, moisture barriers, heavy insulation) that are unnecessary — even counterproductive — for the large share of non-structural calls. This design conservatism may inhibit development of lighter, more ergonomic, and contamination-conscious "all hazards" garments.

MOISTURE BARRIER TRADEOFF ANALYSIS

SEPARATE EVALUATION OF PROVIDED DATA TO SHOW HOW PRODUCT AVAILABILITY IS AFFECTED BY SELECTED TEST METRICS

A central finding from the PPE Reimagined project is that current fire fighter moisture barrier requirements may unintentionally constrain the development of more breathable, lower-burden protective clothing. Historically, moisture barriers were shaped around ePTFE-based constructions and the progressive addition of liquid chemical, viral penetration, durability, and ultraviolet light degradation requirements. While these criteria were intended to improve protection and durability, they also created a design environment in which manufacturers must meet demanding liquid and seam performance requirements that can limit the use of alternative materials. The result is that current moisture barriers may provide more liquid barrier protection than is needed for many common fire service missions, while imposing avoidable penalties in breathability, flexibility, and physiological burden.

The barrier tradeoff study examined four non-PFAS moisture barrier candidates that were not certified products but were selected to explore how different material constructions perform across competing protection and comfort attributes. The evaluated properties included weight, thickness, stiffness, flame resistance, viral penetration resistance, liquid penetration resistance, liquid runoff behavior, total heat loss, and evaporative resistance. This approach was intended to determine whether modifications to flame and liquid barrier test expectations could permit the use of more breathable materials without creating unacceptable reductions in protection. Figure X, as an example of different flame resistance test approaches, illustrates the overall tradeoff concept and its impact on product outcomes: as liquid barrier stringency increases, breathability and comfort may be reduced; conversely, allowing runoff-based or risk-based liquid performance criteria may create opportunities for lighter, more breathable barrier systems.

Characteristic	ASTM D6413	ISO 15025, Method A
Sample contact & orientation	Cut edge; vertical; placed in inverted U-shaped holder	Surface (30°); vertical; placed on board with pins
Burner type & fuel	Bunsen, 38 mm, methane, 0.3 cal/cm²	EN burner, 20 mm, propane, 0.24 cal/cm²
Contact time	12 seconds	10 seconds
Metrics	• Afterflame time • After glow time • Char length • Observations of burning behavior	• Afterflame time • After glow time • Hole formation • Flame spread classification

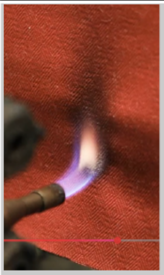

Figure X: An Example of How Tests can Affect Product Compliance. *In the two pictured flame resistance tests, the ASTM D6413 test method used in NFPA 1970 can provide strikingly different results for measuring the ease of ignition and continued burning of a material when contacted y flame because flame is applied to a cut edge of a vertically suspended fabric sample. In contrast, the ISO 15025 test uses a surface flame exposure, where some individuals may argue is more representative for how material are exposed in the field when part of garments.*

The broader implication is not that liquid or viral barrier requirements should be eliminated, but that they should be better aligned with actual fire service hazards and mission-specific needs. Survey findings indicate that hazardous liquid exposures are relatively infrequent for many fire fighters, while heat stress, mobility limitations, contamination control, and cleaning concerns are more commonly reported. Therefore, a single worst-case moisture barrier requirement may not represent the best balance for every protective clothing application. A risk-based approach could permit different barrier categories for structural firefighting, overhaul, rescue, wildland interface, or routine all-hazards response, provided that the limitations of each category are clearly defined and supported by training and operational policy.

This tradeoff analysis supports the need for future standards and procurement specifications to move beyond simple pass/fail compliance and toward transparent performance mapping. Fire departments should be able to see how a moisture barrier performs across flame resistance, liquid protection, viral resistance, repellency, breathability, stiffness, and durability. Such information would allow departments to make more informed decisions about whether a specific barrier system is appropriate for their hazards, climate, call mix, and operational practices. In this way, the moisture barrier tradeoff study provides an important example of how PPE requirements can be reimagined to preserve essential protection while creating room for lower-burden, non-PFAS, mission-adaptive protective clothing.

5. **Slow bureaucratic process and high barriers to change.** Consensus-based standards development tends to resist disruptive change. Innovations such as PFAS-free moisture barriers, breathable particulate-blocking membranes, modular PPE layering, sensor-integrated SCBA or gear, and mission-specific ensembles may struggle to gain traction under existing test regimes.

(B) WHAT ARE SOME EASY WINS TO ADDRESS IN THE NEXT VERSION OF STANDARDS?

Given the evolving hazards and documented health concerns, several relatively straightforward actions could improve PPE safety and alignment without waiting decades for comprehensive overhaul:

- **Add chemical exposure and permeation testing to standard criteria** — require gear to be evaluated for resistance to typical combustion by-products (PAHs, VOCs, ultrafine particles), and assess how much penetrates to inner layers or underlying clothing.
- **Define wash-cycle and aging criteria** — require that gear maintain barrier integrity, chemical retention performance, and heat/thermal protection after repeated laundering, UV exposure, abrasion, and wear cycles.

- **Encourage modular PPE selection and layered ensembles** — formally recognize a "light/all-hazards/non-structural" PPE category with separate certification pathway, and allow departments to issue such ensembles for calls that don't require structural turnout.
- **Integrate PFAS-free materials and sustainable barrier technologies** into standard options — while giving credit (certification pathways) for moisture barriers that meet performance without PFAS content.
- **Require interface-seal performance for hoods, gloves, SCBA facepieces, and coat/ pant junctions under smoke and particulate conditions,** not just flame or thermal test conditions.
- **Include ergonomic and physiological performance metrics (e.g., THL, Ret, bulk/body mobility metrics, weight limits) as part of comfort/performance evaluation,** especially for non-structural PPE ensembles.

These improvements could be relatively low-cost to implement (testing labs already exist, many research efforts are underway) and would immediately improve alignment of PPE protection with modern risks.

PHYSIOLOGICAL MANIKIN EVALUATION AND THE NEED FOR SYSTEM-LEVEL PPE ASSESSMENT

SEPARATE INVESTIGATION IN CONJUNCTION WITH FLORIDA STATE UNIVERSITY

A recurring limitation in the evaluation of structural firefighting PPE is that the principal thermal performance measures used in standards, including Thermal Protective Performance (TPP) and Total Heat Loss (THL), are primarily fabric-level measurements. These measurements remain important because they provide standardized indicators of insulation and heat dissipation for material composites. However, they do not fully describe how a complete turnout ensemble performs when worn by a fire fighter under realistic operational conditions. The actual garment includes reinforcements, pockets, trim, labels, closures, overlap areas, SCBA coverage, and other design features that can substantially change both thermal protection and heat loss across the body.

This distinction is important because the fire fighter does not wear a fabric composite; the fire fighter wears a complex protective system. Prior work has shown that only a portion of a typical turnout garment may consist of the base composite of outer shell, moisture barrier, and thermal liner. Other areas can include multiple additional layers, particularly at the front closure, knees, shoulders, pockets, labels, and boot/pant interface. These areas may provide very high localized thermal protection but can also reduce heat loss, increase bulk, and contribute to physiological burden. As a result, a garment can meet fabric-level TPP and THL requirements while still creating uneven heat transfer, reduced evaporative cooling, and increased heat strain in actual use.

The physiological consequences of this limitation are significant. Heat stroke, cardiovascular strain, and other heat-related effects remain central acute hazards in the fire service. Therefore, the goal of PPE design should not be to maximize thermal protection alone, but to achieve an optimized functional balance between protection, heat dissipation, mobility, and fire fighter endurance. This balance is especially important because the highest thermal exposures may occur only during a limited portion of fireground operations, while the physiological burden of PPE is present throughout donning, staging, suppression, overhaul, rescue, and recovery.

A more complete evaluation approach is the use of sweating thermal manikins and integrated physiological modeling. Unlike isolated fabric tests, a physiological manikin permits assessment of the full ensemble as worn, including the effects of garment design, layering, closures, reinforcements, air gaps, and body coverage. Dynamic sweating thermal manikins can be operated under controlled environmental conditions and, in some cases, with movement protocols that better approximate fireground work. The resulting data can be used to estimate system-level heat loss and to model predicted physiological outcomes, including core temperature, skin temperature, sweating rate, cardiac strain, heat sensation, and comfort perception. Figure X may be used to show the physiological manikin used for this type of ensemble-level evaluation.

Figure X. "Andi" Physiological Manikin at Florida State University Equipment (left) and with Turnout Gear During Test (right)

Preliminary work indicates that manikin-based measurements can provide a stronger connection between PPE design and predicted fire fighter heat strain than fabric-level measurements alone. Prior research has identified a relationship between manikin THL and predicted core temperature, including the potential use of a manikin THL benchmark to help prevent core temperature from rising above selected safety thresholds. This suggests that system-level manikin testing could support future standards development by providing a more realistic basis for comparing different turnout ensembles and design approaches.

At present, however, there is no single standardized test method for integrated real-time physiological manikin modeling of fire fighter protective clothing. Existing protocols have been developed for individual manufacturers and research programs, but differences in environmental conditions, work/rest cycles, metabolic assumptions, garment configurations, and modeling approaches can affect results. For example, different protocols may use different ambient temperature and relative humidity conditions, different work durations, different rest periods, different metabolic rates, or different garment configurations such as whether the coat is open or closed. These differences make it difficult for fire departments to compare products on an "apples-to-apples" basis.

The principal implication for the PPE Reimagined effort is that future evaluation of fire fighter protective clothing should include system-level assessment, not simply material-level compliance. Standardized physiological manikin protocols could provide a more meaningful way to compare ensembles for heat stress potential, comfort, and operational burden. Such testing would not replace TPP, THL, or other established material tests, but would supplement them by showing how the complete ensemble performs as a worn system. This approach would also support risk-based PPE selection, allowing departments to evaluate whether specific ensembles provide the appropriate balance of thermal protection and physiological performance for their climate, call mix, and operational needs.

Incorporating physiological manikin testing into future PPE standards or procurement specifications would help move the fire service toward more informed decision-making. It would provide a clearer technical basis for comparing traditional turnout gear, lighter-weight configurations, alternative moisture barriers, and mission-adaptive ensembles. More importantly, it would recognize that fire fighter protection includes not only preventing burn injury, but also reducing the physiological stress imposed by the PPE itself.

(4) IS THERE THE POSSIBILITY OF NEW PPE DESIGNS?

Yes — and several factors suggest both that some aspects of gear are "hard to change," and that other aspects are ripe for disruptive redesign.

(A) WHAT FORCES TEND TO KEEP GEAR MOSTLY THE SAME — AND WHAT IS CHANGING?

Forces maintaining the status quo:

- The high-stakes nature of structural firefighting (flashover, rapid flame spread, radiant heat, collapse, falling debris) — requiring robust, proven, heavy duty protection. Structural turnout gear has saved countless lives. Departing from proven designs entails risk.
- Existing supply chains and manufacturing processes, which are optimized around traditional materials (thermal barriers, moisture barriers, outer shells), designs, layering, and certification pathways aligned with legacy standards.
- Departmental procurement inertia and budgeting cycles — replacing entire PPE inventories (coats, pants, helmets, gloves, boots, SCBA) is expensive and logistically challenging. Many departments adopt a "buy once, use until end-of-service-life" paradigm.
- Cultural factors and fire fighter expectations: structural PPE is seen as "the uniform." Changing to lighter or modular gear may be resisted, especially without clear performance data and rigorous testing under realistic hazards.

Forces driving change:

- Awareness and concern over chronic health risks due to chemical exposures, PFAS, carcinogens, and long-term disease outcomes. Recent research (e.g., by FSRI, university epidemiology) has created demand for cleaner, safer gear.
- Rising incidence of non-structural response profiles (EMS, rescue, battery fires, wildland-urban interface, vehicle and EV incidents, hazmat, mixed-use occupancies), which require different protective properties.
- Advances in materials science: PFAS-free moisture barriers, breathable particulate-blocking membranes, washable barrier liners, improved glove/hood designs, and more ergonomic ensemble designs.
- Research into interface control, contamination reduction, improved decontamination methods (e.g., liquid CO_2 cleaning), and performance under wear cycles.
- Growing regulatory, legislative, and insurer pressure to reduce long-term health liabilities (e.g., occupational cancer), and increasing scrutiny of fire-service exposures by public health authorities.

(B) ARE THERE OPPORTUNITIES FOR DRAMATIC DESIGN CHANGES?

There are some of the most promising directions include:

- Layered PPE systems ("mission-adaptive ensembles"): base uniform → light all-hazards ensemble → full structural turnout. Such a system allows departments to outfit personnel based on call type, reduce unnecessary exposures, lessen physiological burden, and extend gear life.
- Modular PPE components with customizable protection levels: detachable hoods/hood liners, modular glove systems, particulate-blocking liners, optional moisture barriers, scalable layering, etc., that allow fire fighters to "dial up or down" protection as needed.
- PFAS-free barrier technologies and gear materials — leveraging new fabrics, coatings, or laminate technologies that achieve water, oil, chemical resistance without PFAS, reducing long-term chemical exposure risks.
- Integration of sensing, monitoring, and "smart PPE" — e.g., SCBA or helmet-mounted sensors for gas/vapor detection, heat sensors, telemetry for physiological monitoring (core temperature, heart rate),

exposure logging, and gear-use tracking. Early academic work has proposed sensor-augmented SCBA or gear interfaces for hazard detection and situational awareness.
- Comfort-optimized designs that improve mobility, reduce heat strain, and increase field adoption — using lighter, more breathable fabrics, ergonomic cuts, modern liners, flexible gloves, lower-bulk boots, and interface seals optimized for both safety and mobility.

In sum, there is real potential for a transformative redesign of PPE — but only if standards, procurement, and culture evolve in tandem with materials science and risk-awareness. In the IAFF PPE Reimagined project described above, a first attempt in radical PPE redesign was examined by Cornell University.

REIMAGINING FIRE FIGHTER TURNOUT GEAR: DESIGN CHALLENGES, FIELD REALITIES, AND NEW DIRECTIONS

SUMMARY OF CORNELL PROJECT REPORT

Fire fighters today work in a world that is far more complex than the one for which traditional turnout gear was designed. The modern fire service responds not only to structure fires but also to medical calls, vehicle accidents, severe-weather incidents, and the ever-expanding wildland–urban interface. Their duties span from high-heat interior attack to patient lifting, roadside extrication, and prolonged outdoor work. Yet the protective ensemble they wear—still anchored in a decades-old structural firefighting paradigm—has not evolved at the pace of these changing responsibilities.

Cornell University's *PPE Reimagined* project sought to confront this mismatch. Their progress report highlights the friction between real-world needs and legacy design, bringing together research, field observations, and iterative prototyping to explore what fire fighter PPE could become. The result is a compelling story of constraints, cultural habits, and opportunities for reinvention.

A SYSTEM DESIGNED FOR YESTERDAY'S FIRES

One of the core insights from Cornell's work is that today's turnout gear performs its structural firefighting mission exceptionally well—sometimes too well. Standards such as NFPA 1971 demand high levels of thermal resistance, moisture barrier performance, tear strength, and durability. Those requirements have steadily pushed materials toward heavier, more insulating, less permeable constructions.

The paradox is striking: the gear protects fire fighters from acute heat but exposes them to chronic physiological stress. Fire fighters report feeling overheated long before reaching a fire scene, burdened by weight, limited by stiffness, and soaked with trapped sweat.

And this is not just a comfort complaint. Heat strain has been linked to:
- Earlier fatigue
- Increased cardiovascular burden
- Slower decision-making
- Reduced cognitive and physical performance

The more the gear protects, the more it impedes. And beyond structure fires—where the majority of calls no longer fall—the gear's protection often exceeds the hazards.

Cornell's project underscores that overdesign, when misaligned with mission, becomes its own form of risk.

WHAT FIRE FIGHTERS SAY: A REALISTIC VIEW FROM THE FIELD

Cornell's team visited the New York State Academy of Fire Science and several departments in upstate New York. Those conversations and observations provided some of the clearest insights into how turnout gear actually functions on the fireground—not in standards documents, lab tests, or idealized response models.

Instructors and line fire fighters voiced many of the same themes:

Heat, Wetness, and Layering – Many described a sense of constant dampness, whether from sweat or water intrusion. Moisture barriers do little to help evaporative cooling, and during crawling or kneeling the thermal and moisture layers compress, pushing stored heat and moisture closer to the skin.

Some fire fighters even believed that a wet T-shirt under gear could cause "steam burns"—a sign of how uncomfortable and confusing moisture management becomes under high insulation and poor ventilation.

Mobility Challenges – Watching fire fighters duckwalk, crawl, and climb revealed how much the gear fights the body:

- Pant legs rode up during crawling.
- Baggy cuts and large overlaps created unnecessary bulk.
- Shoulder mobility was visibly restricted under SCBA straps.
- Collars, cuffs, and hoods interfered with head and wrist movement.

Fire fighters confirmed these issues. The gear works, but it does not work with them.

Pocket and Tool Limitations – Tools are stored wherever space can be found—but that space is often compromised by other gear. SCBA waist straps cover coat pockets; radios shift; tools punch through pocket linings. Fire fighters often resort to personal arrangements—right glove in right pocket, left glove in left—to reduce fumbling under stress.

Cleaning and Contamination – Despite rising awareness of PFAS, soot, and persistent contaminants, cleaning routines remain inconsistent. Hoods are notoriously difficult to wash and dry, often stretched out and degraded after repeated donning. Helmets rarely receive thorough internal cleaning. Velcro traps debris. Complex assemblies deter proper maintenance.

One fire fighter summed it up well: "If a cleaning step is hard, it just won't get done."

Cultural Factors Matter Just as Much – Gear acceptance is not solely about performance. Fire fighters want gear that:

- Looks like what fire fighters wear
- Feels familiar
- Works fast with gloved hands
- Allows rapid donning and doffing
- Withstands rough handling
- Doesn't require constant configuration changes

The cultural expectation of "wear everything for everything"—whether necessary or not—makes flexible systems difficult to introduce, even if logically appealing. Fire fighters are open to innovation, but it must feel intuitive, durable, and field-proven.

WHY THE CURRENT SYSTEM STRUGGLES: INTERFACES, OVERLAPS, AND COMPROMISES

A recurring theme in the project has been that interfaces—where one component meets another—are often the weakest links in protection, comfort, and practicality.

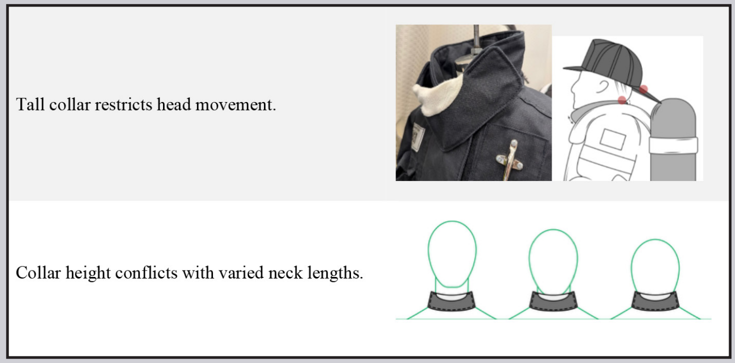

Figure Y1. Impact of NFPA Restrictive Criteria on Fire fighter Coat Collars

Consider a few examples:

- The coat–pant interface introduces bulk, reduces mobility, and creates entry points for contaminants.
- The collar interacts unpredictably with the hood and helmet, frequently hindering head movement.
- Pockets clash with SCBA straps and tool belts.
- Storm flaps snag on trim.
- DRDs exist because the coat's design requires them—yet fire fighters nearly universally ignore them and rely instead on grabbing the SCBA.

The more components you add, the more potential conflicts arise. Cornell's insight is that reducing the number of interfaces—by rethinking the system as a whole rather than as a collection of parts—may unlock dramatic design improvement.

A DIFFERENT WAY FORWARD: CORNELL'S MODULAR COVERALL CONCEPT

Rather than reinventing turnout gear from scratch, Cornell's design exploration looks at how to reorganize the system into something more adaptable, more breathable, and less dependent on rigid layer requirements.

Their emerging concept revolves around a three-part structure:

1. A high-performance station-wear layer designed for cooling, not just modest flame resistance. Most station wear today is cotton or cotton blends—comfortable but sweat-soaked—and rarely engineered for thermophysiological performance. Cornell proposes a Nomex-knit base with 3D spacer structures positioned in areas where fire fighters experience the most compression from SCBA straps and gear.

These spacer structures create micro-air channels that help:

- Reduce cling
- Enhance evaporative cooling
- Prevent moisture buildup under pressure points
- Improve thermal comfort during long responses

Manikin testing and human evaluations will explore how well this system reduces heat load when worn under a full turnout ensemble.

2. A removable thermal-barrier top for adaptable protection. Rather than committing to a permanently integrated three-layer configuration, Cornell introduces a removable thermal barrier that can be added or removed depending on conditions.

Benefits include:

- Lighter configurations for non-structural tasks
- Reduced heat stress during extended operations
- Better customization for body shape and movement
- Easier laundering and replacement of the most sweat-exposed regions

This approach challenges some NFPA restrictions on layer attachment—but the concept shows how innovative thinking can illuminate future standard revisions.

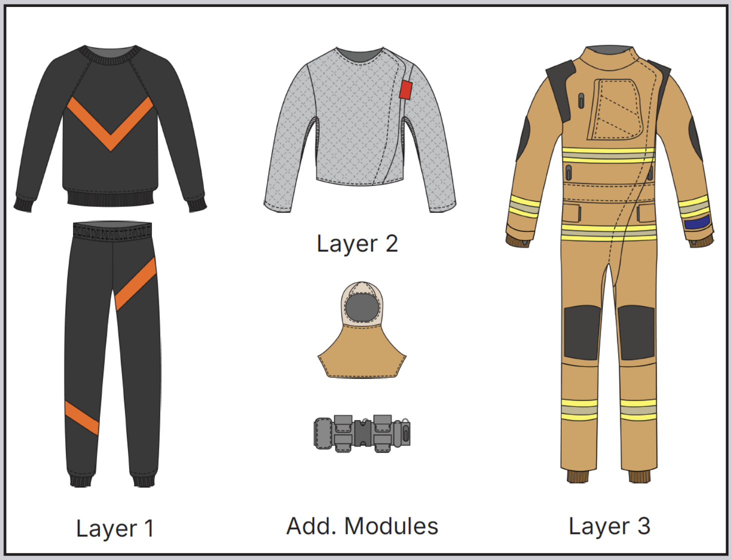

Figure Y2. Preliminary Convertible Coverall Design. *A 3-layer convertible garment system can be configured depending on thermal protection needs: they are 3, outer shell; layer 2, additional thermal barrier top; and layer 1, Station wear base layer.*

3. A coverall outer shell that simplifies interfaces and improves contamination control. By shifting from separate coat and pants to a coverall, the system eliminates one of the most awkward and problematic interfaces.

A coverall:

- Reduces bulk at the waist
- Prevents coat hem/SCBA strap conflicts
- Minimizes contamination gaps
- Allows a cleaner integration of storage modules
- Supports better movement through unified patterning

Early reactions from fire fighters were skeptical—particularly around waist mobility and the difficulty of tying the upper half around the waist when doffed. Cornell's iterative redesigns focus on addressing these concerns through refined patterning, better hinge points, and lightweight structures.

A REDESIGNED HOOD FOR BETTER PROTECTION AND MOBILITY

The hood emerged as one of the least-liked but most essential components of turnout gear. Hoods stretch out, trap moisture, and often fail to interface cleanly with the facepiece and coat collar.

Cornell proposes relocating the collar from the coat to the hood itself—creating a bib that sits on top of the coverall and simplifies the interface around the neck and SCBA mask.

This configuration could:

- Improve donning and doffing speed
- Reduce bulk at the coat collar
- Offer better particulate-blocking potential
- Eliminate one of the more frustrating closures for fire fighters
- Provide improved neck mobility

The shift is subtle but potentially transformative, especially for comfort and contamination control.

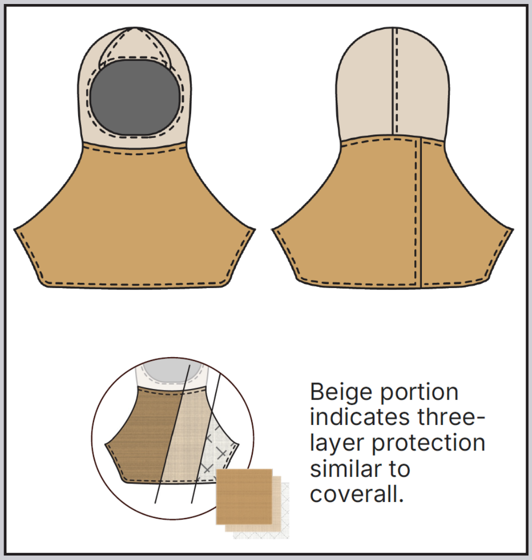

Figure Y3. Preliminary Hood Module Design. *A non-attached, pullover hood allows for familiarity and flexible usage. One totally outside the coat and potentially eliminates the need for collar.*

SMARTER STORAGE THROUGH A WAIST STRAP SYSTEM

Pocket placement is one of the most contentious issues in turnout gear. Fire fighters want fast access to radios, wedges, cutters, and gloves, but coat pockets are often blocked by SCBA straps or overloaded.

Cornell's proposed waist storage strap separates pockets from the coat, functioning more like a tool belt. With configurable pocket modules, fire fighters can adjust their loadout for different missions.

Advantages include:

- Reduced coat bulk
- Preserved access even with SCBA
- Better weight distribution
- A possible home for bailout systems
- Simpler cleaning and replacement of heavily contaminated components

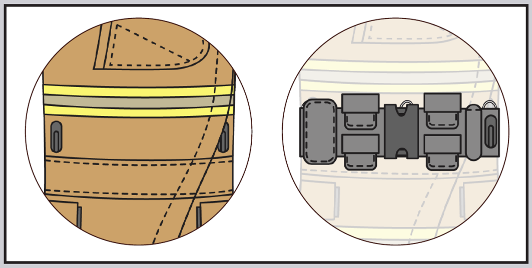

Figure Y4. Preliminary Hood Module Design. *Anchored to garment with front hooks and dees, storage can be customized to specific mission needs.*

This feature aligns fire fighter behavior with the design, rather than forcing behavior to adapt to gear.

DESIGNING FOR REALITY, NOT IDEAL CONDITIONS

Throughout the progress report, a consistent message emerges: fire fighters don't use gear the way standards imagine they do. They adapt, improvise, push limitations, and sometimes bypass intended features entirely.

A successful gear redesign must therefore:

- Accommodate rapid donning and doffing
- Be compatible with SCBA in all positions
- Minimize components that can be forgotten, misaligned, or ignored
- Anticipate rough handling
- Avoid "fiddly" adjustments under stress
- Provide intuitive comfort feedback

The Cornell approach deliberately watches how fire fighters actually move—climbing ladders, crawling, carrying irons, staging, rehabilitating—and aligns design choices to those movements rather than to theoretical fireground postures.

TOWARD THE FUTURE OF TURNOUT GEAR

The *PPE Reimagined* project surfaces a series of promising directions for future development:

- **Modular ensembles** that adapt to mission profile
- **Simplified interfaces** that eliminate problematic overlaps
- **High-performance station wear** that addresses heat stress where it begins
- **Coverall-based outer shells** that reduce contamination pathways
- **Better hood designs** that improve neck protection and mobility
- **Smarter storage systems** separated from the coat
- **Testing protocols** that focus on physiological outcomes, not just thermal resistance

Cornell's team isn't finished—their next stages involve manikin testing, human trials, and prototype construction—but their progress already shows that meaningful change is possible, even within the constraints of stringent standards.

A PATH TOWARD SMARTER PROTECTION

Fire service culture, practical realities, and historical design assumptions have shaped turnout gear into what it is today. But as the nature of the job evolves—and as health and safety priorities shift toward long-term physiological and contamination risks—the gear must evolve as well.

Cornell's project offers a thoughtful, collaborative, and evidence-based model for how that shift can occur.

Not by discarding what works.

Not by reinventing the wheel.

But by reorganizing the system, rebalancing tradeoffs, and re-centering the fire fighter's lived experience.

In doing so, it paints a picture of what turnout gear might look like in the next decade: lighter, cooler, less complex, more adaptable, and better aligned with the full spectrum of modern fire service missions.

(5) WHAT TYPE OF INFORMATION BEST IMPROVES FIRE SERVICE AWARENESS FOR PROCURING APPROPRIATE PPE?

Even before dramatic redesigns or standards overhaul, fire departments can make smarter PPE purchasing decisions — provided they ask the right questions and structure their procurement specifications and field tests accordingly.

(A) WHAT FOUNDATIONAL QUESTIONS SHOULD DEPARTMENTS ASK VENDORS?

- **What contaminants, chemical species, and particle sizes was the gear tested to resist or block (e.g., PAHs, VOCs, PFAS, ultrafine particles, battery-fire by-products)?** And what were the test conditions:

full-scale fire, smoke only, overhaul, wear cycles, laundering?

- **What is the performance of the gear after repeated laundering, heat cycles, abrasion, UV exposure — both in terms of thermal protection and chemical/particulate barrier integrity?** In other words: how does gear performance degrade with real-world use?
- **What is the Total Heat Loss (THL) and Evaporative Resistance (Ret) of the ensemble?** This yields insight into breathability, physiological burden, and suitability for long-duration or non-structural operations.
- **Does the gear use PFAS-based coatings or moisture barriers?** Has the vendor developed PFAS-free alternatives, and if so, what data supports equivalent protection? Given emerging health research and regulatory pressure, this question is no longer optional.
- **What is the design philosophy regarding modularity or layering?** Can the gear be configured for different mission types (structural, EMS, overhaul, wildland, rescue)? Are components (hoods, gloves, liners) interchangeable or replaceable?
- **What interface sealing strategy is used (coat/hood, glove/coat, pants/boots, SCBA-facepiece)?** Is there data on particulate or vapor infiltration at interfaces under smoke/heat conditions?
- **What laundering/decontamination protocols are recommended?** Are there third-party studies verifying the effectiveness of those procedures at removing PAHs, soot, and other contaminants?
- **What is the expected service life of the gear under typical wear/clean cycles — including performance retention, barrier integrity, and potential chemical release?**

Asking — and demanding data-based answers to — these questions enables departments to move procurement beyond price and brand, toward evidence-based risk mitigation.

(B) HOW DOES AN ORGANIZATION BUILD A COMPREHENSIVE PPE SPECIFICATION ADDRESSING FIRE DEPARTMENT NEEDS?

A comprehensive PPE specification should include:

1. Risk-based use categories — define PPE ensembles according to mission type (structural fire, overhaul/cleanup, EMS/medical, rescue, wildland, hazmat, battery/vehicle fire, training). For each category, define expected hazards (thermal, chemical, particulate, moisture, physical trauma) and required level of protection.
2. Performance criteria for each hazard type — not just thermal performance, but chemical-permeation thresholds, particulate infiltration limits, vapor/gas barrier performance, particulate-blocking efficiency, interface integrity, wash-cycle resilience, and ergonomic/breathability metrics (THL, Ret, weight, mobility).
3. Material and chemical-content disclosure requirements — require vendors to declare whether PFAS or other high-concern chemicals are used, what alternative barrier technologies may be, and provide data from objective testing (third-party labs, preferably under realistic fire/smoke conditions).
4. Testing regimen requirements — require testing under various conditions: new gear; aged gear (after heat, wash, abrasion, UV cycles); full-scale fire simulations; smoke-only conditions; overhaul-phase exposure; chemical exposure (PAHs, VOCs, battery fire by-products); particulate infiltration; and field wear simulations.
5. Field-evaluation and acceptance protocol — before full procurement, departments should execute a “trial deployment” (e.g., with a small number of fire fighters), collect qualitative feedback (mobility, comfort, usability) and quantitative data (core temperature, heart rate, exposure data, contamination levels after calls, laundering results, interface performance, degradation after repeated use).
6. Lifecycle and maintenance policy — specify decontamination protocol (laundering, advanced cleaning), frequency, criteria for retirement or replacement (e.g., after X wash cycles, exposure events, or performance degradation), and storage/transportation policy to minimize cross-contamination (e.g., sealed bags, storage outside living quarters, training for PPE hygiene).

By adopting such a specification framework, fire departments can better align PPE procurement with real-world hazards and long-term health outcomes — not just minimum compliance or lowest cost.

(C) HOW DOES AN ORGANIZATION CARRY OUT A PROPER FIELD TEST?

A proper field test (before wide-scale PPE adoption) should include:

- **Selection of representative users** — a cross section of personnel (different roles, ages, sexes, physical fitness levels). Female and minority fire fighters must be included — given known fit and sizing issues.
- **Diverse mission types** — deploy the gear on a variety of calls: structural fire, overhaul, EMS, rescue, training, wildland interface, vehicle/battery fire, etc.
- **Baseline and ongoing monitoring** — measure physiological parameters (heart rate, core temperature, hydration, exertion), mobility/performance (speed, agility, footing/stability), contamination exposure (surface sampling, air monitoring), and user feedback (comfort, ease of donning/doffing, interface issues, mobility, heat stress, usability).
- **Post-use forensic testing** — after a set number of uses or specific exposures, test the gear for barrier integrity, chemical penetration, moisture barrier degradation, thermal protection retention, and decontamination effectiveness.
- **Laundering and maintenance cycles** — include scheduled cleaning per department protocols; after each laundry cycle, re-evaluate performance (thermal, barrier, contamination).
- **Documentation and data logging** — maintain a detailed record of calls, exposures, use conditions, environmental hazards, gear configuration, user feedback, and test results. Use this data to inform procurement decisions, standard compliance, and long-term PPE lifecycle planning.

Such a field trial — if properly designed and executed — will yield actionable data far more relevant than standard lab-only testing or vendor claims.

IAFF PROCUREMENT GUIDANCE

As part of the project, the IAFF has created a checklist approach that can be used by departments to help guide departments in their procurement of PPE. Elements of the guidance include:

- Setting up a selection team
- Needs assessment and prioritization of risks
- Determining current gear limitations
- Understanding existing industry requirements (key NFPA tests)
- Interacting with manufacturers
- Conducting field evaluations
- Documenting the selection

(6) SHOULDN’T THE FIRE SERVICE HAVE BETTER FIELD SURVEILLANCE?

The absence of robust, systematic field surveillance of exposures, gear performance, health outcomes, and near-misses represents one of the biggest vulnerabilities facing the fire service today. Key gaps include:

- **Limited participation in registries or long-term health tracking** — although programs like the NFR exist, participation is voluntary, funding unstable, and linking exposures to outcomes remains challenging.

- **Insufficient routine environmental and PPE contamination monitoring** — many departments lack protocols for regular surface sampling, air monitoring, or PPE testing post-incident (especially for overhaul, chemical fires, battery fires, EV fires).
- **Lack of data integration** — incident data (type, hazards, duration), PPE configuration, cleaning cycles, user feedback, and health outcomes are rarely tracked in a unified or accessible database to inform departmental policy or standard development.
- **No mandated "exposure incident reporting" tied to PPE performance or failure** — e.g., when a gear ensemble fails, or when a fire fighter experiences exposure due to interface leakage, or suspect fast-degrading gear, these events rarely get systematically recorded or fed back to procurement or standard committees.

To address these gaps, fire departments — individually or collectively (e.g., via state/provincial fire marshals, national associations) — should establish **surveillance systems** that include:

- Routine gear and station environmental sampling (air, surfaces) after significant incidents (e.g., structure fires, battery/vehicle fires, hazmat calls).
- Long-term health outcome tracking (cancer incidence, respiratory issues, skin disorders, reproductive effects), ideally via a national or regional registry with mandatory participation for career fire fighters.
- Gear performance logs (hours of wear, number of exposures, cleaning cycles, usage conditions, retirements) to monitor gear life and degradation trends.
- Post-event debriefs including PPE performance evaluation (fit, comfort, interface integrity, contamination, mobility, heat stress).

Such data would supply the evidence base needed to support risk-based PPE procurement, standard improvements, and health-protective policy decisions.

(7) IS THERE A PATHWAY TOWARD A SMARTER, HEALTH-AWARE, HAZARDS-RESPONSIVE PPE PARADIGM?

The demands on fire-service PPE are no longer static — they are evolving rapidly as mission profiles diversify and hazards shift from traditional flame/thermal risk toward chronic chemical exposure, aging gear hazards, and novel threats such as combustion of modern construction materials.

Yet much of the PPE and standards ecosystem remains rooted in legacy thinking: heavy turnout gear, structural-fire-only test criteria, periodic (3–5 year) standard revision cycles, and limited field feedback loops.

This disconnect has real consequences: reduced mobility, heat strain, chemical exposure, insufficient decontamination, long-term health risk, unnecessary contamination due to overuse of structural gear on routine calls, and lack of data to guide procurement or retirement decisions.

To bridge the gap, the fire service — in cooperation with standard bodies, researchers, manufacturers, and public-health agencies — must embrace a **living-risk, data-driven PPE paradigm**. Specific steps to advance include:

1. Embedding chemical exposure, contamination, permeation, and aged-gear degradation criteria into standard test regimes.
2. Establishing layered, mission-adaptive PPE categories and certification pathways.
3. Prioritizing PFAS-free and sustainable barrier technologies.
4. Implementing rigorous procurement specifications that demand objective data from vendors (thermal, chemical, cleanup, ergonomic, interface sealing).

5. Running comprehensive field trials before wide-scale procurement.
6. Launching systematic field surveillance — environmental sampling, exposure logging, health outcome tracking, gear performance tracking.
7. Feeding surveillance data, epidemiology, and hazard research back into standards review — more frequently than existing cycles.

If these steps are taken, the PPE of the future could look very different — lighter, more flexible, tailored to mission type, protective not just against flame but against chronic chemical exposure, resilient over time, and optimized for fire fighter health, performance, and safety.

STANDARDS STRATEGY FOR REIMAGINED PPE

As part of the project, the IAFF Project Team established a separate report: A Blueprint for Evolving Structural Firefighting PPE.

The PPE Reimagined Blueprint treats NFPA 1970 as an essential baseline for catastrophic structural fire risk, but not as the endpoint for modern fire fighter protection. The recommended strategy is to use NFPA 1970 as the safety floor while creating a faster, more adaptive pathway for requirements that address mission-specific protection, heat stress, contamination control, chemical content, and lifecycle performance.

Near term, the project should be advanced through a PPE Reimagined Supplemental Specification that can be used in procurement, field trials, and candidate NFPA annex/TIA language. This overlay would not replace NFPA 1970 certification; instead, it would require departments and manufacturers to report additional performance information in areas that current minimum compliance does not fully resolve.

- Mission-adaptive ensemble categories that distinguish structural firefighting, routine/all-hazards response, and overhaul/contamination-control operations.
- System-level physiological performance, including thermophysiological burden, heat-storage potential, evaporative cooling capacity, and mobility/function outcomes.
- Contamination-control metrics, including cleanability ratings, smoke/particulate interface performance, service-life chemical stability, and verified restricted-substance/PFAS disclosures.
- Whole-ensemble and lifecycle transparency, including dynamic interface testing, fit and sizing inclusivity, modular component replacement, machine-readable traceability, and field-trial validation.

Longer term, the Blueprint recommends development of an Advanced Protective Clothing Standard that would remain compatible with NFPA 1970 while providing separate pathways for routine/all-hazards and overhaul/contamination-forward garments. That standard should be governed through a balanced structure involving labor, operations, manufacturers, certification bodies, exposure scientists, occupational-health specialists, and participating fire departments. Its development should use round-robin test validation, pilot deployments across varied climates and call profiles, and post-market surveillance so that standards evolve from field evidence rather than periodic revision cycles alone.

This standards strategy shifts the fire service from a single compliance model to a living, data-driven protection system: one that preserves structural-fire survivability, but also measures and manages the chronic risks, physiological burdens, contamination pathways, fit limitations, and operational tradeoffs that now define fire fighter PPE performance.

(8) WHAT IS THE CONCLUSION OF THIS PPE APPROACH?

There should be a call for innovation, data, and adaptive protection. We owe it to fire fighters — past, present, and future — not only to protect them from immediate dangers of flame, heat, and collapse, but also to shield them from the silent, cumulative risks of chemical exposure, cancer, and long-term disease.

The path forward is not simply more of the same turnout gear — but **smarter gear, designed with real-world hazard diversity in mind; backed by research, measurable data, and hazard-driven risk assessment; evaluated under real-world conditions; and periodically re-assessed as hazards, building-scape, materials, and mission profiles evolve.**

Standards, procurement practices, operational tactics, and fire-service culture must evolve accordingly. The result — a PPE paradigm built not just for the fires of yesterday, but for the complex risks of tomorrow — is possible. But only if the fire-service community, standard-setting bodies, researchers, manufacturers, and policymakers commit to change.

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