

Review

Firefighter Fatalities and Injuries: A Review of Contributing Factors and Future Directions for Risk Mitigation

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Abstract

Firefighting is a high-risk occupation involving intense physical exertion and hazardous environments. Occupational exposures, including combustion byproducts, contribute to long-term cancer risk and acute burn injuries. While line-of-duty fatalities have declined, substantial morbidity remains, particularly among female and wildland firefighters who have historically been underrepresented in research. A narrative review was conducted using PubMed, Scopus, and Google Scholar to identify relevant studies published after 2010. Search terms included *firefighter, fatality, injury, cardiovascular disease, occupational exposure, cancer, wildland, and female*. Articles were synthesized using the NIOSH Hierarchy of Controls framework. Cardiovascular events and overexertion remain leading contributors to line-of-duty deaths, while non-fatal injuries are commonly musculoskeletal. Occupational exposures, related to dermal absorption of toxins and improper use of protective equipment, contribute to burn injuries and may increase long-term cancer risk. Wildland firefighters face risks in the expanding wildland-urban interface, such as prolonged smoke exposure and extended exertion, which may elevate cardiopulmonary and cancer risks. Female firefighters face challenges related to ergonomic mismatch with protective equipment primarily designed for male body dimensions. Firefighters face health risks from a variety of environmental and operational factors. Risk mitigation must transition from a reliance on PPE to higher-level engineering and administrative controls. Future research should prioritize longitudinal health tracking and standardized equipment for diverse fire service populations.

Keywords: firefighter; fire; burn; fatality; female; wildland; fire fighter



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1. Introduction

Firefighting is one of the most hazardous occupations, exposing personnel to significant physical, environmental, and psychological stressors. Although firefighter fatalities have decreased over the past two decades, 72 firefighters died on duty in 2024, with 70 fatalities reported in 2025 [1]. This review summarizes factors associated with firefighter fatalities and injuries, identifies underrepresented populations within the fire service, and outlines future directions for risk mitigation.

The fire service involves substantial physical demands, rotating shifts, and often limited recovery time, all of which contribute to cumulative physiological stress. Among approximately 1,054,800 firefighters, an estimated 63,175 sustained line-of-duty injuries in 2023 [2]. Despite gradual reductions in mortality, firefighting remains associated with significant occupational risk. Cardiovascular disease is consistently identified as the leading

cause of duty-related death and has been linked to overexertion, irregular nutrition patterns related to unpredictable schedules, sedentary time outside of emergency responses, and tobacco use [3,4]. Less attention has been directed toward non-cardiac fatal events and injuries occurring both on and off the fireground.

Most research has focused on career structural firefighters. However, the fire service includes career structural, career wildland, volunteer, and part-time personnel, suggesting potential gaps in subgroup-specific research. Recent data indicate that wildland firefighter fatalities have increased proportionally over the past decade. Female representation in the workforce has also increased, yet this group remains underrepresented in occupational health research [5,6].

Reducing firefighter fatalities and injuries requires coordinated efforts across occupational health, physiology, engineering, and organizational policy. This review examines current evidence on contributing factors and evaluates strategies aimed at improving firefighter health outcomes.

2. Materials and Methods

A narrative review was conducted to identify contributing factors to firefighter morbidity and mortality in the United States. We searched PubMed, Scopus, and Google Scholar for peer-reviewed English-language articles published between January 2010 and 2024, on firefighter fatalities and injuries, with particular emphasis on contributing factors and underrepresented populations within the fire service. The primary objective was to identify key factors related to firefighter fatalities and injuries, reveal specific populations within the firefighting service that may be suffering from increased risk, and determine future directions for risk mitigation.

2.1. Search Strategy

The search utilized combinations of Boolean operators: (firefighter* OR “fire fighter”) AND (fatality OR injury) AND (cardiovascular OR cancer OR overexertion) AND (wildland OR female). Initial screening of titles and abstracts was performed independently by two reviewers (KG, RM) to ensure inter-rater reliability. Search terms also included “firefighting,” “fatalities,” “injuries,” “firefighter,” “cardiovascular disease,” “underrepresented population,” “personal protective equipment,” “burn injuries,” “training,” “occupational exposures,” and “risk” in various combinations.

2.2. Selection Criteria

Studies were included if they provided primary data or a systematic analysis of U.S. line-of-duty deaths (LODD) or injuries. Exclusion criteria included non-peer-reviewed editorials, studies focused exclusively on non-US cohorts, and articles published prior to 2010. From an initial identification of [insert total number, e.g., 342] records, 20 high-impact manuscripts were selected for final synthesis based on their focus on emerging risk factors and underrepresented populations.

2.3. Data Extraction and Synthesis

Data were extracted into a standardized matrix focusing on three domains: (1) Physiological/Environmental Factors, (2) Equipment/Behavioral Factors, and (3) Demographic-Specific Risks. Results were synthesized using the NIOSH Hierarchy of Controls (HOC, Figure 1) to categorize mitigation strategies [7].

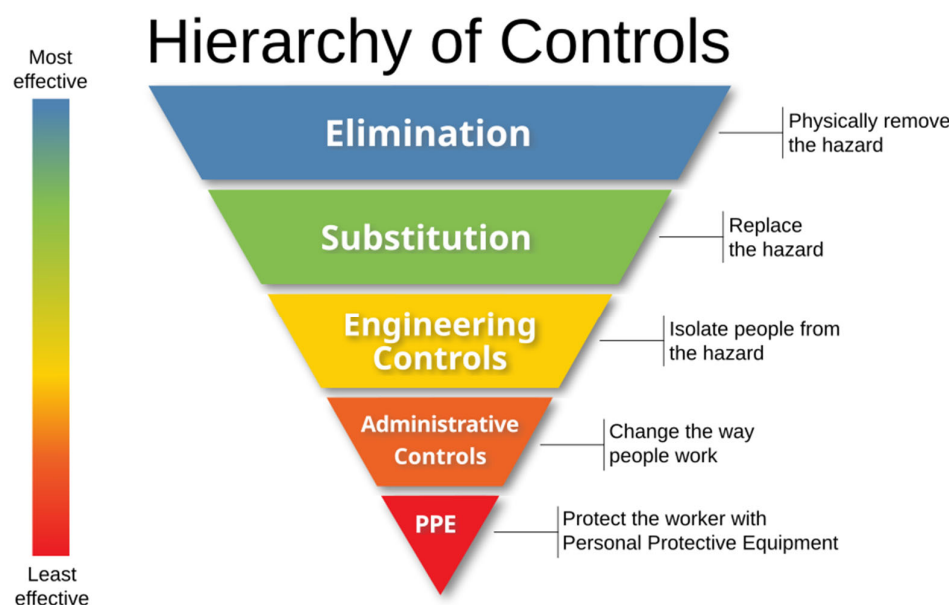


Figure 1. Schematic representation of the NIOSH framework for hazard mitigation, emphasizing the transition from individual-level protective equipment to system-level engineering and administrative elimination strategies [7].

3. Results

3.1. Contributing Factors to Fatalities and Injuries: Overexertion

The 2024 U.S. Fire Administration report documented that 58 percent of on-duty firefighter fatalities were attributed to stress or overexertion. One study reported that 98 percent of cardiac fatalities occurred during or shortly after physical exertion on duty [8]. Overexertion has also been associated with entrapment incidents and motor vehicle collisions [9].

Sprains and strains are the most common non-fatal injuries among firefighters, with overexertion accounting for 55.3 percent of cases [10]. A two-year metropolitan study found that firefighters aged 40 to 49 represented the largest injured age group at 38 percent [11]. Additional analyses reported that sprains and strains comprised 64 percent of injuries, most frequently involving the back at 32 percent [12]. Table 1 maps the risks and hazards identified in the review to specific NIOSH mitigation strategies within their Hierarchy of Controls framework, depicted in Figure 1. The HOC is a strategic framework designed to categorize and mitigate hazards based on efficacy and short-term vs. long-term expenditures. Figure 1 depicts that high-cost initial investments, such as “Elimination”, result in better returns on investment and lower expenses over time, compared to categories at the bottom of the figure [7].

Table 1. Synthesis of firefighter health risks and mitigation strategy based on the NIOSH Hierarchy of Controls.

Contributing Factor	Key Findings	Supporting Evidence	Implications for Risk Mitigation
Overexertion	Major contributor to both fatal and non-fatal events. Associated with cardiovascular incidents and musculoskeletal injuries.	58% of LODDs linked to stress/overexertion; 98% of cardiac deaths occur post-exertion [8,10,11].	Shift from individual monitoring to Engineering Controls: implement real-time biometric tracking and objective workload monitoring [13,14].

Table 1. *Cont.*

Contributing Factor	Key Findings	Supporting Evidence	Implications for Risk Mitigation
Cardiovascular Disease	Leading cause of LODD among firefighters, often linked to underlying coronary artery disease and cardiomegaly.	Sudden cardiac death accounts for ~40–50% of fatalities annually; mean age of MI cases $\approx$ 52 years. [15–18].	Administrative controls: Implement cardiovascular screening, fitness standards, nutrition programs, and targeted prevention strategies.
Occupational Exposure	Improper or incomplete use of personal protective equipment (PPE) increases the risk of burn injuries and inhalational exposure.	PPE misuse in the majority of burn cases; Fent et al. demonstrate significant VOC/PAH off-gassing and dermal infiltration [19–23].	Engineering Controls: Improve PPE design, reinforce safety training, and safety culture Universal diesel exhaust capture and development of non-fluorinated, toxic-free gear textiles [7,24].
Sleep and Shift Work	Irregular schedules and sleep deprivation impair recovery, cognition, and physical performance—a cardiac stress multiplier.	Extended shifts and overnight emergency responses linked to reduced alertness and increased injury risk [25,26].	Administrative controls: “just” shift scheduling where possible and implement fatigue management strategies.
Wildland and WUI Risks	Increasing proportion of fatalities despite small workforce representation. Risks include prolonged exertion and smoke inhalation, entrapment, and remote work environments.	Fatalities increased from ~2% to 10% of total firefighter deaths over the past decade [5,27].	Engineering/PPE: Develop lightweight, wildland-specific gear/safety protocols and expand cardiopulmonary health tracking.
Female Firefighter Female ergonomics and health	PPE designed for the male body shape leads to reduced mobility and compromised protection seal dimensions, potentially reducing protection and mobility.	Focus groups report limited mobility and inadequate seals; gear mismatch increases injury risk [6,28,29]. Limited objective data	Engineering/PPE: Establish sex-specific biomechanical standards for PPE design and procurement [29]. Administrative: expand sex-specific occupational health research.

3.2. Contributing Factors to Fatalities and Injuries: Preventable Exposure

An evaluation of firefighter burn injuries demonstrated that misuse of personal protective equipment was associated with 14 of 20 cases examined [19]. A 2020 survey of Southeastern firefighters found that 70 percent reported wearing incomplete gear, and those who reported injury were more likely to have omitted protective equipment at the time of injury: 81 percent versus 45 percent [20]. Video analyses of fireground operations similarly identified improper use of protective equipment, particularly self-contained breathing apparatus, in approximately half of observed cases [30]. Complacency and normalization of risk have also been linked to safety-related injuries and fatalities [14]. One study examining preventable workplace mortality identified an association between complacency and safety-related injuries and fatalities [31]. Recent evidence suggests that even when PPE is worn correctly, it does not provide absolute protection against toxic infiltration. Research by Fent et al. demonstrates that volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) can be absorbed dermally, particularly at areas where gear interfaces—such as the neck and wrists—are less secure. Furthermore, PPE ensembles have

been shown to ‘off-gas’ toxic substances for several hours following a fire event, presenting a secondary inhalation risk to firefighters who remain in proximity to contaminated gear or transport it in enclosed vehicle cabs.

3.3. Contributing Factors to Fatalities and Injuries: Cardiovascular Health

Analysis of NFPA and national surveillance data demonstrated that sudden cardiac death accounts for approximately 40–50% of all line-of-duty firefighter fatalities annually [15,16]. U.S. Fire Administration database analysis showed that the mean age of firefighters who suffered myocardial infarction was 52 years old, with volunteer firefighters representing the most commonly impacted group [17]. Autopsy studies of duty-related cardiac fatalities revealed that 82% of cardiac deaths in male firefighters had evidence of both coronary artery disease and cardiomegaly [18]. A cross-sectional study found an association between the frequency of occupational exposure and the development of atrial fibrillation in firefighters [32].

3.4. Increased Risk Within Underrepresented Populations in the Firefighting Service

The USFA National Fire Department Registry 2024 Annual Report documented approximately 1,210,600 firefighting personnel employed, with career firefighters representing 34.8% and volunteer firefighters constituting 52.6% [27]. The U.S. Department of Agriculture reported 11,364 wildland firefighters nationwide. Wildland firefighters represent less than 1% of the firefighting workforce; however, job-related fatalities among wildland firefighters increased from 2% to 10% of total firefighter deaths over the recent decade [5].

Female firefighters comprise approximately 9 percent of the fire service and account for roughly 3 to 4 percent of reported injuries and fatalities [33]. Overexertion and hazardous exposure remain the most common reported injury mechanisms in this group. Qualitative reports note that ill-fitting protective equipment may limit mobility and compromise protective seals, potentially increasing exposure risk [6]. Sex-disaggregated epidemiologic data remain limited.

The proportional increase in wildland firefighter fatalities over the last decade is not merely a statistical variation but reflects the lengthening of fire seasons and the increasing complexity of the Wildland–Urban Interface (WUI). This shift places traditional structural firefighters in wildland environments for which they may lack specific environmental training or appropriate lightweight PPE, increasing the risk of entrapment and heat-related illness.

This table categorizes the primary physiological and environmental hazards identified in the literature review—including overexertion, cardiovascular disease, and toxic exposure—and maps them to specific mitigation strategies within the NIOSH Hierarchy of Controls framework. It highlights the necessary transition from individual-level protective measures (PPE) to system-level engineering and administrative solutions.

4. Discussion

The findings of this review underscore a critical transition in fire service safety. While acute traumatic injuries have seen a relative decline due to improved tactics, chronic occupational diseases like cardiovascular events and cancer remain disproportionately high. To effectively mitigate these risks, the fire service must transition from a reliance on individual PPE compliance to a broader application of the NIOSH Hierarchy of Controls [7].

4.1. The Economic and Operational Hierarchy of Controls

In more detail, the HOC serves as a strategic framework for hazard mitigation, exposing the discrepancy between short-term budgetary constraints and long-term operational sustainability [7]. While the primary objective is safety, the relationship between a con-

trol's effectiveness and its implementation cost is often inversely related in the immediate term. However, this is a limited financial perspective that fails to account for the total cost of ownership.

A longitudinal analysis of safety expenditures typically reveals that the most effective interventions, Elimination and Engineering Controls, are initially expensive- yet they are the most cost-effective over a ten-year period. By removing the hazard at the source, these upstream investments significantly reduce the secondary economic burdens of workers' compensation claims, escalating insurance premiums, and the logistical exhaustion inherent in maintaining high-turnover PPE programs [5,21]. In contrast, heavy reliance on the base of the hierarchy (PPE) results in a perpetual cycle of replacement and medical surveillance costs, while offering the least systemic protection for the workforce. The well-documented failure of PPE compliance adds more weight to the argument that the lowest-cost entry point of the HOC can result in the highest cumulative financial and health/disability liability [7,20].

4.2. Cardiovascular Stress and Overexertion

Cardiovascular disease remains the leading cause of line-of-duty deaths and is typically triggered by the physiological strain of intense physical exertion coupled with extreme heat [8,16]. The current analysis suggests that current administrative controls, such as on-scene rehabilitation and mandated annual physicals, are essential but insufficient. As noted in the literature [18], there is a significant association between atrial fibrillation and occupational exposure, which highlights the underlying cardiac vulnerability of this population. The interplay between irregular shift schedules and chronic sleep deprivation exacerbates these risks [25,26,34]. While previous sections of this manuscript noted that shift modifications might offer recovery benefits, sleep debt clearly serves as a physiological multiplier for cardiac stress. Sleep disruption associated with extended shifts may further impair cognitive performance, reaction time, and recovery, potentially contributing to injury and fatal events- whether on scene or motor vehicle crashes. On-scene rehabilitation protocols, including monitoring, hydration, and cooling, are intended to reduce exertional and thermal strain [26]. However, data demonstrating reductions in mortality remain limited. Future mitigation must move beyond speculative scheduling and toward objective biometric monitoring, as suggested by the SWIFT study protocol [35], to identify signs of systemic fatigue before an event occurs on the fireground.

4.3. The Paradox of PPE

A significant finding in this review is the "PPE paradox", where gear is the firefighter's primary shield but also serves as a secondary source of exposure and physiological strain [19,20]. Research demonstrates that modern PPE ensembles continue to off-gas volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) long after the fire is suppressed [21,24]. This creates a hidden inhalation/absorption risk during gear transport and storage. Furthermore, the breathability and comfort of the gear still remain a challenge; evidence shows that while moisture-wicking materials can improve comfort, they do not fully mitigate the heat retention that drives overexertion [14,26,28,36].

Furthermore, PPE does not protect the firefighter from dermal absorption of toxins and carcinogens. Even with full encapsulation, toxins can infiltrate gear at interfaces such as the neck and wrists [21–24]. Relying solely on PPE, the least effective tier in the "NIOSH Hierarchy of Controls", is a strategy of diminishing returns [7]. True risk mitigation requires engineering controls, such as universal diesel exhaust capture in bays and the development of non-fluorinated textiles that do not contribute to the very cancer risks they are designed to prevent [21–24].

In efforts to improve the compliance of PPE use, there has been an effort to better understand why firefighters choose to disregard important safety measures. It was identified that the turnout gear, the SCBA in particular, was contributing to high rates of musculoskeletal injury and balance issues due to its weight [28]. Furthermore, it was determined that another reason for improper use of PPE was due to the heat retention associated with the gear [28]. Although PPE offers inherent protection, compliance is decreased because of the weight of the gear and its burden. As a mitigative strategy, many protective fabric manufacturers have been able to design lighter-weight protective garments that have improved wicking capacity, aiding in thermoregulation while on the job [36], but the weight of SCBA remains unmitigated. Despite some recent advancements, PPE misuse is still prevalent.

4.4. Underrepresented Populations: Wildland and Female Firefighters

The changing landscape of the fire service necessitates a shift in research focus toward underrepresented cohorts. The proportional increase in wildland fatalities is not a statistical outlier but a reflection of the expanding Wildland Urban Interface (WUI) [27]. Structural firefighters are increasingly being deployed into wildland environments without the specialized, lightweight gear or environmental training required for such high-heat and high-mobility scenarios. This mismatch directly contributes to entrapment and heat stroke fatalities.

For female firefighters, the risk is often ergonomic in nature. Much of the currently available PPE is designed based on male anthropometric data, leading to a gear mismatch that increases musculoskeletal injury risk and limits mobility during critical tasks [5]. Biomechanical modeling has shown that ill-fitting self-contained breathing apparatus (SCBA) carriage and oversized turnouts significantly alter internal forces and the center of gravity [6]. This leads to unique injury patterns that are often misclassified as general overexertion. A focus group of female firefighters reported that the turnout gear limits their mobility while also creating inadequate seals and overlap; creating potentially unnecessary exposure to environmental hazards [29]. Furthermore, there is a paucity of sex-disaggregated epidemiologic data in this population. Females are vulnerable to many different forms of cancer which do not affect men; such as endometrial or cervical cancer.

4.5. Cultural and Behavioral Factors

Finally, the culture of safety within the fire service represents a significant administrative barrier [30]. Behavioral factors, such as complacency regarding gear cleaning or the perceived prestige associated with soiled equipment, directly counteract decontamination protocols. Even evolving policies on grooming standards reflect the tension between tradition and safety requirements [14]. Mitigation must include a cultural shift where health-seeking behaviors, such as mandated cancer screenings and strict post-fire clean-up procedures, are viewed as essential components of operational readiness.

4.6. Limitations

This narrative review relies primarily on observational and surveillance-based studies, which limit the ability to establish causal relationships. Definitions of overexertion, line-of-duty death, and injury classification vary across reporting systems, complicating cross-study comparisons. The heterogeneity of the firefighting workforce and small subgroup sample sizes limit generalizability. Muddy data, heterogeneity of databases, and under-reporting may also obscure the true picture. Under-representation of wildland, volunteer, and female firefighters in the literature further restricts subgroup-specific conclusions.

5. Conclusions

This review confirms that while acute traumatic injuries are declining, the fire service faces a rising burden of chronic occupational disease and evolving risks in wildland and female cohorts [27,31]. To effectively improve risk mitigation, three specific shifts in the fire service approach are required.

First, there must be a transition from a PPE-centric safety model to a higher-level application of the Hierarchy of Controls [28]. Policy and funding should prioritize engineering controls, such as universal diesel exhaust capture and the development of toxic-free gear materials, rather than placing the burden of safety solely on individual PPE compliance [14,36].

Second, the fire service must standardize safety protocols for underrepresented groups. Future research should establish sex-specific biomechanical standards for gear to reduce injury risk for female firefighters [5,6]. Additionally, wildland safety protocols must be adapted to account for the increasing frequency and intensity of operations within the Wildland Urban Interface [27].

Third, a cultural shift in occupational health is necessary. The fire service must evolve to view administrative health interventions, such as mandated cancer screenings and biometric fatigue monitoring, as essential components of operational readiness rather than secondary concerns [13,26].

Addressing these gaps requires coordinated efforts between federal agencies, equipment manufacturers, and fire service leadership. By moving beyond behavioral compliance and focusing on systemic engineering and administrative solutions, the fire service can better protect its diverse workforce from both acute and chronic occupational hazards.

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