Medical Research Archives

ESMED
European Society of Medicine

OPEN ACCESS

Published: November 30, 2022

**Citation:** Harrison TR, Muhamad JW, et al., 2022. Firefighters and Cancer: A Review of the Current State of Cancer Incidences and Recent Trends in Risk Perception and Risk Reduction Efforts, Medical Research Archives, [online] 10(11). https://doi.org/10.18103/mra.v10i11.3320



DOI
https://doi.org/10.18103/mra.v10i11.3320

ISSN: 2375-1924

REVIEW ARTICLE

# Firefighters and Cancer: A Review of the Current State of Cancer Incidences and Recent Trends in Risk Perception and Risk Reduction Efforts

**Tyler R. Harrison[1], Jessica Wendorf Muhamad[2], Ekaterina Malova[3]**

[1]Department of Communication Studies, University of Miami, Coral Gables, Florida, USA
[2]School of Communication, Florida State University, Tallahassee, Florida, USA
[3]Simon Business School, University of Rochester, Rochester, New York, USA

*Correspondence: harrison@miami.edu

ABSTRACT

**Objective:** This paper provides a review of current knowledge and trends in research on firefighters cancer risks and risk reduction efforts and calls for future research focused on European and international firefighters to understand and reduce occupational cancer risk.

**Cancer incidence:** Firefighters face increased occupational cancer risk. Firefighting has been linked with multiple types of cancer, including bladder, colorectal, brain and central nervous system, non-Hodgkin's lymphoma, skin melanoma, and prostate and testicular cancer, with several others types of cancer being found at increased rates.

**Cancer risks:** Increased occupational cancer risk is, in part, related to carcinogenic exposures at fire events and improper use and cleaning of personal protective equipment (PPE), with role and years in service increasing risk.

**Risk Perception:** Research on efforts to reduce cancer risk are growing, and include examination of firefighter knowledge, attitudes, norms, and behaviors toward decontamination, screening, and healthy eating. Many firefighters report high perceived susceptibility and severity of cancer risk, and identify fire scene exposures, contaminated gear, diet, sleep disruption, chemical exposure from cleaning products, and barriers to medical care as contributing to increased risk.

**Risk Reduction:** Firefighters have strong desire to reduce cancer risk and report generally favorable attitudes toward decontamination practices and proper gear use, but face barriers to reducing those risks, including lack of knowledge, occupational needs, organizational culture, policy, and lack of resources. Behavioral interventions to reduce cancer risk through decontamination efforts and dietary change have demonstrated positive results, however there is a dearth of research on these efforts, especially with European and international firefighters.

**Future Directions:** Future research should focus on understanding European and international firefighters' knowledge, attitudes, and behaviors toward cancer risk reduction, the impact of the built environment on cancer risk (station layout, clean cabs), improved efforts at tracking exposures, use of new technology and virtual reality in training to reduce cancer risk, and improved understanding of firefighter cancer risk by medical professionals.

**Keywords**: Firefighters, Cancer, Risk Perception, Risk Reduction, Decontamination

## Introduction

Following decades of research, there is sufficient evidence of the elevated cancer risks among firefighters directly from occupational exposure. In fact, as recently as July 2022 the International Agency for Cancer Research changed firefighting from Group 2B (possibly carcinogenic) to Group 1 (carcinogenic) designation, meaning that a link between the occupational exposures that result from firefighting and cancer has been established. This new classification of a carcinogenic occupation elevates the threats of occupational hazard in firefighting to that of tobacco usage and benzene.[1] Differences in cancer type and biological sex have also been reported, for example male firefighters exhibit higher rates of bladder cancer and females of Hodgkin's disease when compared to the general population.[2] Independent of this variance across types of cancers, data supports increased cancer incidence and mortality rates within the fire service.[3] Yet despite this evidence and new classification, notable gaps still exist in cancer research among firefighters. Partly this has been attributed to the delay between exposure to carcinogenic agents and the onset of symptoms and/or screenings.[3] This move of firefighting from a possibly carcinogenic to carcinogenic occupation will help in advancing research and in advocating for individual, social, and public policies changes. However, as with any wicked problem, the relationship between firefighting and cancer has neither a straightforward nor single solution. Improvements in cancer screening and treatments, changes in policy and practice, and individual risk reduction behaviors all have a role to play in reducing the cancer risk of firefighters; however, many of these options require individual firefighter action that may compete with occupational culture and individual beliefs. Below we explicate current knowledge of firefighter cancer incidences, and report on firefighter knowledge, attitudes, beliefs, and behaviors on issues where individual firefighters have the most control – decontamination processes, cancer screening, and diet. Additionally, we report on efforts to help firefighters reduce exposure risks.

## Cancers and Rates of Occurrence

While some cancers (such as mesothelioma) have received considerable attention, today there is growing recognition of the dangers of multiple types of cancers among firefighters. Specifically, studies have found linkages between firefighting and numerous cancers, for example, bladder, [4,5,6] colorectal,[7,8] brain and central nervous system,[9,10] non-Hodgkin's lymphoma,[5,11,12] skin melanoma,[4,5,13] prostate and testicular,[5,13,14] with most having an increased mortality rate when compared to the general population.[4] Kidney cancer has also been found at increased rates, however, findings are less consistent for kidney cancer and certain other cancers, including Hodgkin's lymphoma, [2,11,12] leukemia, [4,15,16] lymphosarcoma and reticulosarcoma,[4] multiple myeloma,[4,17,18] and pancreatic cancer.[4,11,13] For other types of cancer (esophageal, laryngeal, oral and pharyngeal, liver and gallbladder, lung, lymphatic and hematopoietic, non-melanoma skin cancer, stomach, and urinary cancer) there is less evidence of a causal relationship as a result of occupational exposure.[4]

Among the types of cancer identified in the literature, mesothelioma and bladder cancer seem to have the highest prevalence[1] and a causal association has been established.[19] A recent meta-analysis[4] found that firefighters are at approximately 58% higher risk for mesothelioma than the general population and 16% higher risk for bladder cancer. Finding of a higher incidence of mesothelioma, an asbestos-related disease, could be due to exposure to hazardous construction materials such as adhesives, drywall, floor and ceiling tiles, insulation, paint, and countless others.[20,21,22] Similarly, bladder cancer has been found to have potential causal relationship with rate of occurrence and exposure to hazardous materials (e.g., PAHs, soot).[1]

Causal relationships with cancers such as colorectal and prostate have not been established, perhaps due to confounding behaviors such as frequent screenings. Surveillance bias could also explain the inconsistent results among other cancers such as lung, with lower incidence and mortality rates, and thyroid, with higher incidence compared to the general population.[1] Although a causal relationship has not been established, the increased incidence of these types of cancer is still significant when compared to the general population, mortality rates from rectal cancer and non-Hodgkin's lymphoma among firefighters are higher.[11] Moreover, there is still ample evidence of carcinogenic agents found in the bodies of firefighters. For example, Barros et al. and Anderson et al. found an increase in presence of PAH-DNA adduct in blood and damage to DNA,[21,23] DNA methylation (the addition of methyl groups to DNA affecting molecular activity), and genotoxicity.[20,21,23] For DNA methylation, an

epigenetic regulation altered in cancers[6] length of exposure (years in service) lead to higher rate of PFAS concentration in blood.[6,16] It is important to note that differences in DNA methylation have been found across ethnic and racial groups signaling possible epigenetic risk factors. This potential susceptibility is important given the frequent exposure to potentially carcinogenic materials by firefighters.[24] Another important finding has been the presence of acute and chronic inflammation and inflammatory markers in firefighters.[25,26,27]

It is important to note that there have been country and cancer specific studies. For example, eight out of 28 European countries surveyed in 2017 agreed melanoma was an occupational hazard of firefighting, with more recently acknowledging this, such as the Norwegian Labour and Welfare Service.[28] Recognition of these as occupational hazards allows for the development of prevention programs, something of great need within the fire service.[28]

**Presumed Causes and Exposures**

Exposure to toxic materials that result from fulfilling occupational roles and responsibilities represents a threat to personal health in any profession, but perhaps is most significant among firefighters given the dangerous and diverse nature of their work. A firefighter's occupational exposure can result from fire and non-fire events.[29] Within fire events, these can also be varied with events consisting of wildland, structural, vehicle, and hazardous material spills, for example. Non-fire events can include responder medical calls in which they can be exposed to communicable diseases,[30] as well as natural disasters and building collapses (e.g., 9/11).[31]

***Fire Events***

There are key differences between wildland fire events and those that occur in urban areas. For instance, firefighting teams dispatched to a wildfire may be on site for days at a time, thus the length of exposure to toxic materials is typically extended well beyond that of urban events. The types of hazardous materials also vary. Firefighters in urban settings may be exposed to polycyclic aromatic hydrocarbons (PAHs) from combustion products,[20] volatile organic compounds (VOCs),[32] asbestos and/or other toxic building materials (e.g., soot, adhesives) from older buildings,[1] or other harmful chemicals such as PFAs (perfluorinated and polyfluorinated substances) found in the foam used by firefighters[33] and diesel exhaust from both the fire trucks and the fire stations.[34] Exposure can result from lack, misuse, or improper decontamination of personal protective equipment (PPE), inhalation, again due to misuse of PPE or removal too early at event site, ingestion, and or dermal absorption.[20] A recent study by Clarity et al., of a cohort of female firefighters found a positive association between telomere length, the biomarker for aging, and exposure to chemicals linked to possible carcinogenesis compared to females in other occupations.[35] The production and use of new chemicals (e.g., fire retardants) in urban areas merits more research. Hwang et al.[20] found that dermal exposure was highest in the neck post fire event and that longer duration of fire event exposure led to increased concentration of PAHs via inhalation. Wildland fires also present a great threat. In Brazil, Yu et al.[36] found that wildfires compared to other fire events had an increased exposure to fine (inhalable) particulate matter, $PM_{2.5}$, which has been associated with increased rates of cancer mortality.

***Years in Service***

Studies have found that role within the fire service[20,21] as well as years in service impact exposure rates, which in turn affects the incidence of cancers. A study[37] of professional firefighters found rates of hypopharyngeal and laryngeal cancers increased per decade of service. Similarly, studies[3] have found an increase in malignancy of cancer associated with length of employment in the fire service. In their study, Daniels and colleagues[7] found significant positive correlations between occupational duties (e.g., time at fire events) and mortality rate for lung cancer and leukemia.

***Gear***

Although PPE is common throughout the fire service, all components are not equally available and/or used. Self-contained breathing apparatus (SCBAs), which currently offer the highest protection against inhalation exposure[20] are more commonly used in non-wildland fire events; the extended time of fighting wildland fires makes the use of air and SCBAs problematic given the limited capacities of air tanks and the weight of carrying enough tanks to fight fires for extended time periods. Structural and vehicle fires can omit toxic particulates, however, firefighters that receive calls for wildland fires are, on average, called upon multiple times a year and for longer periods of time per fire event[1] leading to increased exposure risks. This is further

compounded by firefighters believing that brush fires are often clean fires, and they face uncertainty over appropriate gear use and decontamination. Another issue with gear, and SCBAs in particular, is that they are often removed too quickly after a fire is extinguished, exposing firefighters to contaminants during the overhaul process.[20] A recent study in Spain[38] found that among types of cancer mortality rates, the rate from larynx and hypopharynx cancers was higher among firefighters. The authors[38] suggest that this could be due in part to underusage of protective respiratory equipment.

An often overlooked but critically important consideration with SCBAs and other gear in general (e.g., bunker gear) is fit. While maintenance and decontamination are often highlighted as salient components in risk reduction, the one-size-fits-all design of PPE can also lead to unintended exposure and dermal absorption of PAHs, PFAs, and others[1]. Additionally, the construction of bunker gear does not always provide the protection firefighters need from carcinogens. The three layers most commonly found in gear (outer shell, moisture barrier, and thermal liner) are not chemical-resistant.[20] Moreover, these fire-resistant layers can actually increase dermal absorption due to gear weight and increased temperatures, humidity and moisture from extinguishment, and air flow. Notably, there is a stronger linkage between cancer from dermal exposure than inhalation.[20]

**Firefighter knowledge, attitudes, and behaviors about cancer risks**

While there is a large body of research focused on cancer rates among firefighters, less is known about how firefighters understand and act on cancer risks related to exposure and contamination. Below we explicate the research on firefighter's knowledge and perceptions of cancer risks, attitudes, and behaviors toward decontamination behaviors to reduce risk, and perceived barriers to enacting those behaviors.

***Cancer risk perceptions and knowledge***

Research shows that firefighters have general concerns about cancer risk,[39] with both new and experienced firefighters perceiving cancer as main health risk.[40] Recent studies show that firefighters believe they are at higher risk of cancer than the general public,[9] and believe those risks are high to very high for colon, pulmonary, hematologic, breast, prostate, testicular, lung, oral, and all cancers,[9] with female firefighters expressing specific concerns about breast cancer as a result of beliefs that breast tissue is the most absorbent part of the body and that gear opens in such a way as to increase exposure.[41] Concerns about cancer risk are true both of career urban firefighters in the U.S.[39,40,42,9,43,] rural volunteer and career firefighters in the U.S.,[44] female firefighters,[41] and firefighters in the Dominican Republic.[45] Oh et al. found that South Korean firefighters who had exposure risk awareness perceived higher levels of susceptibility and severity, but that it varied by age and years in service, with older and more experienced firefighters having lower risk perceptions.[10] Indeed, many firefighters expressed fatalistic views about their cancer risk, believing that it was inevitable they would get cancer[42,43] and that cancer would have severe impacts.[44]

While studies of firefighter risk perceptions generally show high levels of concern for cancer risk, as well as specific beliefs about where those risk reside, not all firefighters are knowledgeable about exposure risk. Bautista found that knowledge and awareness of cancer risk factors varied considerably among firefighters, with some firefighters very knowledgeable of risk while others had less knowledge.[46] Additionally, only some firefighters were able to make links between immediate exposure to carcinogens to long term risk. Similarly, Popescu found that 75% of firefighters were aware of and wanted to reduce their exposure to carcinogens on fire scenes, but that 25% seemed unaware or unconcerned.[47]

***Occupational influences on cancer risk perceptions***

Firefighters view their cancer risk as coming from both direct (resulting from performing essential occupational tasks) and indirect (general occupational issues related to being a firefighter) occupational risks.[42] Firefighters describe direct cancer risks to include general exposure to carcinogens as part of routine firefighting tasks, including from toxins from entering a fire, overhaul and mop up, carcinogens on bunker gear, diesel exhaust from engines, off gassing, and transference from gear to the engine, station, and bunkers.[41,42,43,44,45,48] Oh et al. breaks down these direct cancer risks into primary (exposure at fire scenes), secondary (contaminates on gear), and tertiary (cross contamination in engines and stations) exposure risks, and firefighters in South Korea had high awareness of these risk.[10] Aside from these primary, secondary, and tertiary exposure risks, Solle et al. found that female firefighters also

viewed exposure to chemicals used for cleaning fire apparatus, disinfectants from medical calls, and from turnout gear itself, which is constructed of material with flame retardant and other chemicals, to cancer risk.[41]

For most firefighters, direct cancer risks are associated with performing key elements of their work using gear that is designed to protect them. However, not all firefighters are equally equipped with protective gear. For example, Louzado-Feliciano and colleagues found that firefighters in the Dominican Republic believe they are being exposed at fire scenes through inhalation, heat, and radiation, but that they are at even increased cancer risks from lack of availability of PPE[45] considering they often do not have a full set of gear and have to share gear, even if it is dirty.

Indirect risks included concerns about the influence of diet on cancer risks – with firefighters recognizing that many drink too much and eat unhealthy foods that have been linked to cancer.[42,43] They also voiced concerns about stress[41,43,45] sleep disruptions,[41] and lack of getting annual exams contributing to cancer risks.[43,45]

***Attitudes toward clean gear, decontamination, and protective behaviors***

There are few studies that specifically examine firefighter attitudes, norms, and beliefs toward decontamination procedures. Harrison et al. in a study of firefighters across four different fire departments in South Florida found that firefighters have overall positive attitudes toward clean gear (seeing it as a sign of professionalism, trusting others who keep their gear clean, and like having clean gear).[49] Firefighters in South Korea had similar positive attitudes, but firefighters with higher exposure risk awareness perceived more benefits from wearing SCBA, as well as higher efficacy in the use, cleaning, and storage of SCBA. In general, there are mixed findings about efficacy, with several studies reporting that both professional[44,49] and volunteer[45] firefighters believe that cleaning their gear will reduce cancer risk. Macy further reported high response efficacy for the proper storing of turnout gear for both volunteer and professional firefighters, and further found a relatively high level of self-efficacy for both behaviors (90% for cleaning, and 68% for proper storage) as well.[45] However, not all firefighters share that sense of efficacy, with only 32% of firefighters in a study by Moore and colleagues reporting confidence in gear cleaning behavior.[50] Further, firefighters in the Dominican Republic expressed a willingness to engage in decontamination, but lacked the organizational resources necessary to do so.[45] Finally, perceived norms are theoretically linked to health behaviors. In their study of firefighter attitudes, norms and behaviors toward decontamination, Harrison et al. found perceived norms of other respected firefighter's behavior toward cleaning gear were lower than individual attitudes toward clean gear, but still overall on the positive side[49] – meaning that even though there is a strong positive attitude, they did not see the behavior of other firefighters toward gear cleaning as a consistent norm.

***Behaviors toward decontamination and other protective behaviors***

While firefighters are still developing best practices, there are a number of recommendations for decontamination to reduce exposure risk, including engaging in gross decontamination at the scene (rinsing gear immediately after fire scene exit and prior to doffing SCBA and turnout gear), swapping dirty hoods for clean hoods, showering within the hour, using cleansing wipes, bagging gear before transport to the station, and using sealed containers for personal transport.[49] Overall, Harrison et al. found that firefighter decontamination behavior did not match with reported attitudes.[49] While firefighters reported positive attitudes, showering after a fire was the only decontamination process that firefighters regularly engaged in (more than 50% engaging in the behavior frequently or always after a fire), while other recommended behaviors such as gross decontamination, use of cleansing wipes, routine and professional gear cleaning, and other decontamination behaviors occurring much less frequently. While training and education seem to positively influence gross decontamination and PPE use,[46, 51] most studies report inconsistent or low rates of decontamination. For example, Moore et al. reported only 65% of firefighters had cleaned their gear within the past year[50], and Macy et al. reported between 25-38% of both volunteer and career firefighters engaged in professional cleaning, cleaning after a fire, or cleaning when visibly dirty.[45] Additionally, when they cleaned gear, most used top load washers rather than professional extractors. Similarly problematic, over a quarter of firefighters reported storing their gear in their vehicles, and almost half did not view such storage as problematic, with many not even using a container for storage. While there was no difference in storage behavior, volunteers saw the

behavior as less problematic than career firefighters.

While most studies of firefighter cancer risk reduction focus on decontamination, Solle et al. studied female firefighter behaviors toward cervical cancer screening and found that they are less likely to get routine screenings but have positive attitudes toward self-samplers.[52]

***Facilitators to risk reduction behaviors***

These are a number of factors that help facilitate firefighters' decontamination behavior. Harrison et al. found that perceived norms (the degree to which other respected firefighters engage in the behavior) were the biggest predictor of overall decontamination and gear cleaning, followed by attitudes toward clean gear, and fewer perceived barriers.[49] In contrast to findings by Oh about age influencing perceived cancer risk, age was not a factor in predicting decontamination behavior.[10] Bautista further found that peer-to-peer accountability was a strong facilitator, reinforcing the notion that the behavior of other firefighters is important to decontamination and risk reduction behaviors.[46]

Aside from personal attitudes, beliefs, and norms, organizational factors can serve as facilitators for risk reduction. These include strong leadership support and specific policies regarding PPE use, availability of clean replacement turnout gear (a second set off turnout gear or a separate turnout room where gear could be checked out), and air monitors all positively influenced risk reduction behavior,[10] and training on cleaning procedures.[49,53] Additionally, Harrison et al. found that social capital and the development of networks of expertise helped facilitate cultural changes, knowledge, and practice toward decontamination and cancer risk.[48]

***Barriers to risk reduction behaviors***

Overall, there are a number of barriers to decontamination related to beliefs and knowledge about decontamination processes, occupational practices, and logistics and budgets. Multiple studies report that lack of knowledge of decontamination procedures serve as barriers to engaging in decontamination.[44,54] Firefighters in multiple studies has concern over wet gear,[54] including fear of steam burns if they engage in decontamination and are called back to a fire scene,[46,48,49] and that wet gear from decontamination and cleaning processes will decrease mobility, making it harder to do their jobs.[48,49] Incidentally, both of these fears have been debunked in a video by Palm Beach County Fire Rescue (https://www.youtube.com/watch?v=AGwyiSAIO7M) where they expose firefighters to controlled burns, engage in gross decontamination where the gear is rinsed with water, and then they re-enter the fire scene (twice); no firefighters reported steam burns, and the wet gear only weighed an additional three pounds.

Other logistical and occupational concerns include the time it takes to clean gear[46,48,49] lack of down time from running calls,[48] pressure to get back into service, and/or not having the opportunity to be out of service.[46,48] Firefighters also express concern, often arising from budgetary limitations, about limited access to extractors, clean hood, a second set of gear, and other resources needed to engage in decontamination.[46,48] These concerns are often exacerbated with fire departments that have fewer resources overall. Macy et al. found distinct differences in barriers between career and volunteer firefighters in the U.S., with volunteer firefighters reporting issues of cost and accessibility hindering cleaning behaviors.[44] Indeed, 70% of firefighters in their study indicated they would be more likely to have their gear cleaned regularly if the department paid for cleaning , and volunteers were more likely to report cost as a barrier than career firefighters. Lack of resources create barriers for firefighters in the Dominican Republic as well, where firefighters indicated a lack of a full set of bunker gear for every firefighter, and the purchase of used bunker gear which is already partially deteriorated.[45]

In addition to barriers to decontamination, firefighters face barriers to other risk reduction behaviors such as routine medical care and cancer screening. Dominican Republic firefighters reported a lack of health promotion activities, and a lack of access to health care and screenings due to the high cost of care and low firefighter salaries.[45] Cultural barriers to medical care also exist in certain groups of firefighters, including firefighters in the Dominican Republic and Black firefighters in South Florida, who report an unwillingness to go to the doctor unless there is an immediate, obvious, and serious problem.[45,55] Female firefighters reported that nontraditional work schedules and difficulties balancing home and work schedules acted as barriers to routine cervical cancer screenings.[52]

**Effectiveness of Decontamination Behaviors**

Threats such as cross-contamination and transportation of off-gassing gear have been discussed in the literature, along with attempts to find practical solutions for reducing cancer risks among firefighters. For example, a recent intervention was conducted by Burgess and colleagues to reduce firefighters' exposure to carcinogens through skin and inhalation.[56] The intervention activities included surface contamination reduction ("wash down") of turnout gear, gear cleaning with soap and water, additional skin decontamination with sauna treatment, separate transportation of contaminated equipment, and additional gear cleaning at the station. In terms of sauna treatment, further research is needed on whether an inferred sauna will allow the body to eliminate toxins through sweating. However, the study results directly support separate transportation of contaminated gear and the use of wash down for firefighters as part of skin exposure reduction. Thus, the bagging and cleaning of gear and maintaining a "clean cab" has also proved to be effective practices in post-fire decontamination.[56] The clean cab concept prescribes the firefighting equipment to be stored in outside compartments instead of inside the cab to create a barrier between firefighters and contaminated off-gassing gear and helps prevent contamination of the fire engine's cab. Other research also shows that two minutes of brushing with soap and water removed a median of 85% of PAH chemicals from the firefighter's personal protective equipment.[57] The importance of decontamination behaviors is hard to underestimate, and effective decontamination practices exist. However, firefighters do not consistently adhere to decontamination guidelines.[49] Thus, the natural question is how to increase the uptake of protective behaviors among firefighters to reduce cancer risks.

**Increasing Decontamination Behaviors and Reducing Risks**

Research into efforts to reduce firefighter occupational cancer risk is limited. One key intervention that could serve as a model for future interventions was designed to improve change in occupational practice and culture and to improve decontamination efforts among firefighters in South Florida. Formative research[42,48,50,52] and research that shows contaminated bunker gear is a potential source of exposure to carcinogens,[58] provided the foundation toward creating a health intervention to reduce exposure risks. As reported previously,[48,52] data show professional firefighters acknowledge the dangers of cancer, are concerned with their risk for cancer as a result of their occupational exposures, have positive attitudes toward clean gear, and believe that effective decontamination can reduce cancer risks. However, individual behaviors were not in line with attitudes; firefighters reported low to moderate frequencies of decontamination after a fire. In addition, although it was found that the interpretation of dirty gear as a badge of honor became less strong, clean gear was accepted as a norm but lacked the cultural importance of dirty gear.[48] Given that the risk of carcinogenic contamination depends on the combination of occupational risks, firefighter culture, and structural barriers,[48] Harrison and colleagues developed, implemented, and evaluated an intervention aimed at changing the meanings around dirty (and clean) bunker gear and improving decontamination behaviors by firefighters.[51]

This collaborative intervention[51] was guided by scientific facts and adhered to theoretical models of behavior change and principles of communication design.[59] High-reliability organizations (HROs) are unique in their physical, social, and information structures,[59] which require health messages to be tailored to their specific characteristic.[60] Thus, the intervention[51] targeted cancer risks and fire department culture change as factors unique to this HRO. The intervention presentation was delivered face-to-face by a trained research team member in collaboration with a well-respected member of each fire department to help with credibility and trust. Intervention materials included an overview of cancer risks in the fire service, a video demonstrating exposure and contamination risk using invisible dye (such as found in bank robberies), contact with physical and material environments to demonstrate cross contamination, and interaction with colleagues and family members to demonstrate how contaminants spread beyond the fire scene, and a second video presenting decontamination processes as well as the processes of cultural change. Video materials featured firefighters demonstrating decontamination procedures while scientists delivered information on cancer risks. Based on formative research, the messages were designed using the integrative model of behavioral prediction[61] and the health belief model.[62] The intervention[51] reduced perceived barriers to decontamination among firefighters and was successful in increasing firefighters' attitudes toward decontamination,

perceived norms for gear cleaning, self-efficacy toward gear cleaning, and perceived benefits of engaging in decontamination processes. It also reduced perceived barriers to decontamination. Firefighters' intention to engage in postfire decontamination practices should decrease exposure to carcinogens and mitigate cancer risks. It is important to note that while the intervention was effective in three different fire departments, there were significant differences in outcomes (i.e., attitudes, perceived norms, and barriers) between fire departments. This finding highlights the previous point about the unique nature of HRO's characteristics and cultures, suggesting the need for interventions customized to the specific HRO.[60] A recorded version of the presentation and videos can be viewed at https://www.youtube.com/watch?v=8XYvzQiqKkU ; however, current research suggests that adding soap to the decontamination process is more effective than just rinsing with water[57] as is demonstrated in the video.

**Food and Physical Activity Interventions**

A limited number of interventions aiming to reduce health risks (including cardiac health and cancer) of firefighters is described in the literature. Frattaroli and colleagues, for example, developed an intervention with a focus on food.[63] Using a holistic approach to the health and well-being of firefighters, they applied strategies at the individual, worksite, and community levels. First, they developed a pilot intervention based on participants' perceptions of food and health to promote healthy eating. Researchers implemented physical measures (e.g., weight, waist circumference, body mass index, etc.), biological measures (glucose, cholesterol, and blood pressure), counseling sessions at baseline and after six months, along with monthly educational sessions on healthy eating. As a multi-level intervention, this study targeted the environment by several means. From the individual and workplace sides, it implemented 1) electric grills to facilitate healthy cooking in firehouse kitchens, 2) scales to promote weight awareness, 3) written food resources to promote healthy eating, and 4) healthy snack alternatives to the processed foods available in the commissaries and vending machines. On a community level, local restaurants started offering healthy items at a discount for the firefighters to address the challenges to healthy eating participants described during formative research. A similar initiative was presented by Elliot and colleagues.[64] The PHLAME (Promoting Healthy Lifestyles: Alternative Models' Effects) is an individual-centered intervention using counselors skilled in motivational interviewing techniques to promote healthy nutrition and physical activity behaviors in firefighters. A total of 599 firefighters participated in a randomized trial assessing dietary behaviors, physical activity, weight, and general well-being at baseline and long-term. As a result of this intervention applying two different behavior change strategies (team-centered curriculum and individual motivational interviewing), firefighters showed improved nutrition behaviors associated with less weight gain and improved general well-being. While these studies often focus on weight and cardiac health, diet is also linked with cancer risk.

**Areas for Improvement in Policy and Practice**

Much has been made of firefighter knowledge, attitudes, culture, and behavior toward cancer risk reduction, and several researchers have reported on the importance of policy and organizational resources. There are a number of organizational and policy features that can help contribute to cancer risk reduction behaviors.

Harrison et al.[48] show that culture change in the fire service requires both a bottom up and a top-down approach. Leadership in the fire service must believe in and provide resources to support risk reduction behaviors. This is often challenging as fire departments have limited resources and decontamination processes take additional time, money, and logistical support.[48] Ultimately, firefighting organizations are known as high reliability organizations.[60,65] One key element of HROs is that they are adaptive and innovative. As such, the types of policies and practices described below come from changes that fire departments themselves are trying as part of efforts to develop best practices.

***Time***

Arguably time is one of the biggest barriers to decontamination. Decontamination takes time both at the fire scene (washing/rinsing gear, cleansing wipes, bagging gear, hood swaps) and at the station (showering, deeper cleaning of gear, drying gear, cleaning engines and other apparatus). In order for firefighters to have time to engage in decontamination, they need to be placed out of service, often for an hour or more at a time. This means that other stations need to cover for them and potentially roll out to calls that are not in their immediate service area.

***Built environment***

Overall, dirty gear not only represents expertise and honor of firefighters but is also a result of everyday firefighting practices. Dirty gear does not require maintenance, while clean gear complicates work processes with additional regular procedures. While individual beliefs and attitudes play a big role in firefighters' intentions to decontaminate,[49] structural barriers may also impede routine or advanced gear cleaning. As such, the built environment (e.g., fire station design, engines, rescue vehicles) of HROs is an important factor affecting work routines, communication practices, and health outcomes.[60]

There have been very few attempts to address the importance of physical space and layout for firefighter departments.[49,63,66] As a part of their intervention efforts to improve organizational culture in fire departments and reinforce "clean gear" concept, Harrison and colleagues developed materials for use specifically in the built environment of firefighting, including magnets for personal lockers and compartments of fire engines and laminated posters for use in shower areas for decontamination.[49] Frattaroli and colleagues provided electric grills to facilitate healthy cooking in firehouse kitchens and scales to promote weight awareness among firefighters.[63] Zanatta and Amaral aimed to contribute to a new layout design for fire departments to improve the functionality of physical space and decision-making processes with human-centered design.[66]

One of the challenges of working with a built environment in fire departments is that solutions should be easy to implement, remain cost-effective, correspond with organizational practices, and be supported by the leadership. For example, safety culture differs from one fire department to another.[67] Thus, the company officers and battalion chiefs must lead by example and be on board with organizational culture change.[68]

Firefighters also have many different ideas about the best way to have clean gear available at all times. Typically, sending gear out for professional cleaning after a serious exposure means firefighters may not have their own gear back for several days. Many firefighters advocate for a second set of gear, however at around $2,000 dollars U.S. for a set of gear, large fire departments can be looking at costs in the millions of dollars. Some fire departments have taken more creative approaches toward clean gear where they have a rolling gear truck that can bring temporary replacements while gear is sent out, thus reducing the number of second sets needed to provide everyone with clean gear. Having professional extractors and dryers in individual stations can also minimize firefighter downtime. While some fire leadership express concerns about the overuse of professional extractors for fear of gear wearing out more quickly,[49] many firefighters would argue the benefits outweigh the risks. Additionally, improvements are being made in research to the most effective ways to decontaminate gear, although additional research is ongoing.[69]

Other resources to help support decontamination are even more resource dependent. For example, the clean cab concept[70] keeps all contaminants out of the passenger compartments on engines and rescues through the redesign of both decontamination processes and apparatus design – with gear stored in compartments and decontamination required before entering the cab. This approach often relies on the purchase of newly designed engines and ladders that provide separate compartments for gear storage. Given the high cost of new engines, not all departments can afford to implement a clean cab design – but workarounds such as bagging gear and storing in separate outside compartments can serve similar functions. Other efforts of modifying the built environment focus on the design of fire stations, as many stations layout are outdated and unsafe. Some departments are able to build or remodel to fit current best practices, including separate gear storage rooms away from exhaust, exhaust handling systems, and other elements of station design. However, the impact of these efforts needs further research of efficacy,[69] and many of these efforts still require individual effort to enact consistently, but even when these systems exist, they require consistent use by firefighters, which does not always occur.

Ultimately, interventions in HROs should target both individual and organizational levels. It is true for both message designs and built environments where interventions should address such barriers as individual intentions and behaviors, organizational cultures, accepted behavioral norms and practices, available resources, and policies.

## Implications for Medical Practice and Research

### *Tracking exposures*

Many types of carcinogens are produced in a fire, and researchers are still exploring which exposures are the most important and the specific mechanisms by which the exposures are causing cancer. Some firefighter cancers seem to be related to length of time on the job (exposure). Currently, there is little official tracking of specific exposures firefighters encounter at different fire and accident scenes. Recent research is working to improve this tracking, including the development of personal exposure reporting (PER) apps,[71,72] and the use of silicone bands to track exposures.[50] Improvement in tracking of individual firefighter exposure will further advance our knowledge of specific links between occupational risks and cancer.

### *Medical care and medical resources*

Early and comprehensive screenings and initiatives to educate firefighters about cancer risk are required. When firefighters know about a higher risk of certain cancers, they can check available sources and take necessary steps for prevention. The importance of doctor-patient interactions and their potential influence on patients' behavior (e.g., preventative measures) and well-being has been established in the literature.[73] The impact of such interactions on patient outcomes is especially important with life-threatening illnesses such as cancer. Prior research has shown a direct relationship between ineffective oncologist-patient communication and poor psychological adjustment and treatment adherence.[74] Some large fire departments have their own health and benefits clinics devoted exclusively to firefighters and their families. This has potential advantages over traditional medical care as the medical professionals are aware of specific occupational health issues firefighters face, and may be more proactive in screening for cancer. Lack of knowledge of risks firefighters face has been stated as one of the barriers that keep firefighters from seeking medical care.[75]

Dealing with long-term consequences of cancer, outcome uncertainty, and possibilities of recurrence is part of everyday concerns for cancer patients. In addition, disease recurrence and cancer survivorship also come with unique challenges. Life after cancer is rarely experienced similarly to life before cancer; many survivors feel unprepared for the post-treatment period and are not referred to appropriate services.[76] Thus, physicians should strive to equip firefighters with all the necessary resources for beginning lengthy and uncertain cancer treatment. Patients weigh the costs and benefits of accepting a particulate treatment as they perceive them within the context of the constraints of their everyday lives and needs.[77] Thus, before starting cancer treatment, providers should consider whether the patient has transportation resources, household tasks, and social support. For example, research suggests that social integration support (feeling part of a group that shares interests, attitudes, and activities) is essential for firefighters and may decrease perceived work-related stress.[78] Thus, the lack of social integration support during cancer treatment may negatively impact firefighters' mental health and treatment adherence. Overall, the treatment plan should be a product of collaborative decision-making between physicians and patients, targeting the patient's specific needs and life circumstances.

## Virtual Reality Training

Simulation environments provide an effective solution for practicing firefighting. Virtual reality (VR) environments allow for a high level of immersion during computer-assisted exercises. For example, it is extremely important for firefighters to carry only the necessary equipment during their work. Thus, Nowicki and colleagues presented a virtual simulator for the ergonomic study of the firefighter's performance at the time of removal of firefighters' equipment from fire trucks.[79] Indeed, simulation environments are beneficial for training in settings that would be dangerous or unpredictable in real life. For example, a collaboration between the Royal Military Academy and the Belgian Navy allowed future firefighters to be trained in a virtual simulation of a ship's quarters instead of a real fire using a fire pit.[80] Given that introducing VR can offer solutions to both risk reduction and training of firefighting methods, cancer mitigation benefits may be expected from the implementation of a VR training module with a focus on post-fire decontamination protocols.

## Improvements in International Research

A final area for improvement is in the scope of research on firefighters and cancer. While firefighter cancer incidences are reported at an international level, most research on firefighter risk reduction is based on U.S. firefighters, with a few notable exceptions[45,53,54]. There is little published research on European and other international

firefighters knowledge, attitudes, and behavior toward decontamination, cancer screening, and other cancer risk reduction efforts. This is a major gap in the literature that needs to be addressed.

**Conclusion**

Firefighters face increased cancer risk when compared to the general public, with those increased risks directly linked to occupational practices. Many firefighters are aware of their increased risk and have positive attitudes toward decreasing those risks through decontamination processes and healthy eating. However, those positive attitudes do not correspond to positive action, with decontamination practices and cancer screening uneven at best, and healthy eating something many firefighters strive for, but seldom accomplish. Given the complex nature of the relationship between firefighting and cancer, identifying and addressing opportunities for interventions can only be characterized as a wicked problem in that the solution is neither simple or singular. Moreover, it appears that instead of a macro wicked problem (cancer), within the fire service there are a series of micro wicked problems. Micro wicked problems among firefighters include: generational gaps that lead to cultural differences; hierarchical organizational structure, inevitable exposure in the completion of essential job functions, and the tension between individual-level responsibilities and those of the organization. The first two speak to the barriers faced in the process of promoting a culture of prevention. Given their access to information, younger firefighters may have greater knowledge regarding risks from exposure, whereas older generations may rely more on knowledge acquired through experiences (length of time in the fire service) that may not coincidence with scientific research regarding risk. This is further confounded with the introduction of a rank system. Deference to senior firefighters, the majority of which are older, creates an environment in which contradiction (such as the introduction of competing information) may not be acceptable. Exposure is a reality of firefighting. Although exposure is problematic, it is perhaps the inevitableness of it and its relationship to fatalistic attitudes that is most concerning. For firefighters, preventive behaviors are juxtaposed with the reality of cancer risk as one exists only in response to the other, and unfortunately, behaviors may never fully remove the risk. Therefore, engaging in preventive behavior might exacerbate risk to mental health by placing emphasis on risk of exposure in everyday functions of firefighters. Lastly, due to the systemic barriers (e.g., budgets, firehouse design), often the recommendations are for individual-level change. Regrettably, solutions for one issue (cancer risk) may inadvertently beget need for intervention on another health concern – mental health. Already disproportionally impacted, additional responsibilities in terms of prevention that are a direct cause of their occupation may lead to increased negative – or fatalistic – attitudes towards prevention. For this reason, more studies on attitudes towards cancer risk and prevention are warranted. Currently, literature in this area is limited as a significant portion of recent studies is focused on physiological and epidemiological evidence of cancer. This review sheds light on these issues, as well as attempts to offer possible ways of mitigating their negative impact through interventions that focus on the intersections of individual, occupational, and organizational interventions.

**Conflicts of Interest Statement**: The authors report no conflict of interest.

**Funding Statement**: NA

**References**


1. Demers PA, DeMarini DM, Fent KW, et al. Carcinogenicity of occupational exposure as a firefighter. *The Lancet Oncology*. 2022;23(8):985-986. Doi:10.1016/s1470-2045(22)00390-4
2. Lee DJ, Koru-Sengul T, Hernandez MN, et al. Cancer risk among career male and female florida firefighters: Evidence from the Florida Firefighter Cancer Registry (1981-2014). *Am J Ind Med*. 2020;63(4):285-299. Doi:10.1002/ajim.23086
3. Butry DT, Webb D, Gilbert S, Taylor J. The economics of firefighter injuries in the United States. 2019. Doi:10.6028/nist.tn.2078
4. Soteriades ES, Kim J, Christophi CA, Kales SN. Cancer incidence and mortality in firefighters: A state-of-the-art review and meta-analysis. *Asian Pac J Cancer Prev*. 2019;20(11):3221-3231. Doi:10.31557/apjcp.2019.20.11.3221
5. Jalilian H, Ziaei M, Weiderpass E, Rueegg CS, Khosravi Y, Kjaerheim K. Author's reply to: Cancer incidence and mortality among firefighters. *Int J Cancer*. 2019. Doi:10.1002/ijc.32300
6. Dolin PJ, Cook-Mozaffari P. Occupation and bladder cancer: A death-certificate study. *Br J Cancer*. 1992;66(3):568-578. Doi:10.1038/bjc.1992.316
7. Daniels RD, Bertke S, Dahm MM, et al. Exposure–response relationships for select cancer and non-cancer health outcomes in a cohort of US firefighters from San Francisco, Chicago and Philadelphia (1950–2009). *Occup Envir Med*. 2015;72(10):699-706. Doi:10.1136/oemed-2014-102671
8. Walsh JM, Potter MB, Arora M, Gildegorin G, Terdiman J. A workplace colorectal cancer screening program in Firefighters: Lessons Learned. *Occup Med*. 2014;64(4):255-258. Doi:10.1093/occmed/kqu046
9. Maloney SR, Udasin IG, Black TM, et al. Perceived health risks among firefighters; the New Jersey Firefighter Health Survey. *J Occup Envir Med*. 2020;63(4):317-321. Doi:10.1097/jom.0000000000002125
10. Oh HE, Kim SJ, Woo H, Ham S. Associations between awareness of the risk of exposure to pollutants occurring at fire scenes and health beliefs among metropolitan firefighters in the Republic of Korea. *Int J Environ Res Public Health*. 2022;19(14):8860. Doi:10.3390/ijerph19148860
11. Laroche E, L'Espérance S. Cancer incidence and mortality among firefighters: An overview of Epidemiologic Systematic Reviews. *Int J Environ Res Public Health*. 2021;18(5):2519. doi:10.3390/ijerph18052519
12. Harris MA, Kirkham TL, MacLeod JS, Tjepkema M, Peters PA, Demers PA. Surveillance of cancer risks for firefighters, police, and armed forces among men in a Canadian census cohort. *Am J Ind Med*. 2018;61(10):815-823. doi:10.1002/ajim.22891
13. Casjens S, Brüning T, Taeger D. Cancer risks of firefighters: A systematic review and meta-analysis of secular trends and region-specific differences. *Int Arch Occup Environ Health*. 2020;93(7):839-852. doi:10.1007/s00420-020-01539-0
14. Lee DJ, Koru-Sengul T, Hernandez MN, et al. Cancer risk among career male and female florida firefighters: Evidence from the Florida Firefighter Cancer Registry (1981-2014). *Am J Ind Med*. 2020;63(4):285-299. doi:10.1002/ajim.23086
15. Jung AM, Zhou J, Beitel SC, et al. Longitudinal evaluation of whole blood MIRNA expression in firefighters. *J Expos Sci Environ Epi*. 2021;31(5):900-912. doi:10.1038/s41370-021-00306-8
16. Muegge CM, Zollinger TW, Song Y, Wessel J, Monahan PO, Moffatt SM. Excess mortality among Indiana Firefighters, 1985-2013. *Am J Ind Med*. 2018;61(12):961-967. doi:10.1002/ajim.22918
17. Landgren O, Zeig-Owens R, Giricz O, et al. Multiple myeloma and its precursor disease among firefighters exposed to the World Trade Center disaster. *JAMA Oncology*. 2018;4(6):821. doi:10.1001/jamaoncol.2018.0509
18. Georgakopoulou R, Fiste O, Sergentanis TN, et al. Occupational exposure and multiple myeloma risk: An updated review of Meta-Analyses. *J Clin Med*. 2021;10(18):4179. doi:10.3390/jcm10184179
19. Gallagher A. Potential toxic mechanisms for increased cancer risks in firefighters. *Oncol Times*. 2022;44(18):17-18. doi:10.1097/01.cot.0000884692.76827.a1
20. Hwang J, Xu C, Agnew RJ, Clifton S, Malone TR. Health risks of structural firefighters from exposure to polycyclic aromatic hydrocarbons: A systematic review and meta-analysis. *Int J Environ Res Public Health*. 2021;18(8):4209. doi:10.3390/ijerph18084209
21. Barros B, Oliveira M, Morais S. Firefighters' occupational exposure: Contribution from

biomarkers of effect to assess health risks. *Environ Int*. 2021;156:106704. doi:10.1016/j.envint.2021.106704
22. Korn GP, Alvarenga EH, Dall'Oglio GP, et al. The effects in the upper airway of heat and exposure to combustion byproducts of burning materials on larynx of firefighters. *J Voice*. 2022;36(5). doi:10.1016/j.jvoice.2020.08.020
23. Andersen MH, Saber AT, Clausen PA, et al. Association between polycyclic aromatic hydrocarbon exposure and peripheral blood mononuclear cell DNA damage in human volunteers during fire extinction exercises. *Mutagenesis*. 2017;33(1):105-115. doi:10.1093/mutage/gex021
24. Goodrich JM, Furlong MA, Caban-Martinez AJ, et al. Differential DNA methylation by Hispanic ethnicity among firefighters in the United States. *Epigenet Insights*. 2021;14:251686572110061. doi:10.1177/25168657211006159
25. Smith DL, Friedman NMG, Bloom SI, et al. Firefighting induces acute inflammatory responses that are not relieved by aspirin in older firefighters. *J Occup Environ Med*. 2019;61(7):617-622. doi:10.1097/jom.0000000000001626
26. McAllister MJ, Gonzalez AE, Waldman HS. Time restricted feeding reduces inflammation and cortisol response to a firegrounds test in professional firefighters. *J Occup Environ Med*. 2021;63(5):441-447. doi:10.1097/jom.0000000000002169
27. Gaughan DM, Cox-Ganser JM, Enright PL, et al. Acute upper and lower respiratory effects in wildland firefighters. *J Occup Environ Med*. 2008;50(9):1019-1028. doi:10.1097/jom.0b013e3181754161
28. Brinchmann BC, Bugge MD, Nordby K-C, Alfonso JH. Firefighting and melanoma, epidemiological and toxicological associations: A case report. *Occup Med*. 2022;72(2):142-144. doi:10.1093/occmed/kqab183
29. Oliveira M, Slezakova K, Fernandes A, et al. Occupational exposure of firefighters to polycyclic aromatic hydrocarbons in non-fire work environments. *Sci Total Environ*. 2017;592:277-287. doi:10.1016/j.scitotenv.2017.03.081
30. Slezakova K, Esteves F, Vaz J, et al. Occupational exposure of firefighters in non-fire settings. *Studies in Systems, Decision and Control*. 2022:79-88. doi:10.1007/978-3-031-12547-8_7
31. Webber MP, Singh A, Zeig-Owens R, et al. Cancer incidence in World Trade Center-exposed and non-exposed male firefighters, as compared with the US adult male population: 2001–2016. *Occup Environ Med*. 2021;78(10):707-714. doi:10.1136/oemed-2021-107570
32. Fent KW, Mayer AC, Toennis C, et al. Firefighters' urinary concentrations of VOC metabolites after controlled-residential and Training fire responses. *Int J Hyg Environ Health*. 2022;242:113969. doi:10.1016/j.ijheh.2022.113969
33. Peaslee GF, Wilkinson JT, McGuinness SR, et al. Another pathway for firefighter exposure to per- and polyfluoroalkyl substances: Firefighter textiles. *Environmental Science & Technology Letters*. 2020;7(8):594-599. doi:10.1021/acs.estlett.0c00410
34. Bott RC, Kirk KM, Logan MB, Reid DA. Diesel particulate matter and polycyclic aromatic hydrocarbons in fire stations. *Environ Sci Processes & Impacts*. 2017;19(10):1320-1326. doi:10.1039/c7em00291b
35. Clarity C, Trowbridge J, Gerona R, et al. Associations between polyfluoroalkyl substance and organophosphate flame retardant exposures and telomere length in a cohort of women firefighters and office workers in San Francisco. *Environ Health*. 2021;20(1). doi:10.1186/s12940-021-00778-z
36. Yu P, Xu R, Li S, et al. Exposure to wildfire-related PM2.5 and site-specific cancer mortality in Brazil from 2010 to 2016: A retrospective study. *PLOS Medicine*. 2022;19(9). doi:10.1371/journal.pmed.1004103
37. Langevin SM, Eliot M, Butler RA, McClean M, Kelsey KT. Firefighter occupation is associated with increased risk for laryngeal and hypopharyngeal squamous cell carcinoma among men from the Greater Boston area. *Occup Environ Med*. 2020;77(6):381-385. doi:10.1136/oemed-2019-106271
38. Zhao G, Erazo B, Ronda E, Brocal F, Regidor E. Mortality among firefighters in Spain: 10 years of follow-up. *Ann Work Expo Health*. 2020;64(6):614-621. doi:10.1093/annweh/wxaa036
39. Jahnke SA, Poston WS, Jitnarin N, Haddock CK. Health concerns of the U.S. Fire Service: Perspectives from the Firehouse. *Am J Health Promot*. 2012;27(2):111-118. doi:10.4278/ajhp.110311-qual-109
40. Schaefer Solle N, Caban-Martinez AJ, Levy RA, et al. Perceptions of health and cancer risk

among newly recruited firefighters in South Florida. *Am J Ind Med*. 2017;61(1):77-84. doi:10.1002/ajim.22785

41. Solle NS, Santiago KM, Louzado Feliciano P, et al. Perceptions of work-related health and cancer risks among women firefighters. *J Occup Enviro Med*. 2021;63(12). doi:10.1097/jom.0000000000002386
42. Anderson DA, Harrison TR, Yang F, Wendorf Muhamad J, Morgan SE. Firefighter perceptions of cancer risk: Results of a qualitative study. *Am J Ind Med*. 2017;60(7):644-650. doi:10.1002/ajim.22726
43. Jitnarin N, Poston WSC, Jahnke SA, Haddock CK, Kelley HN. Cancer perceptions among smokeless tobacco users: A qualitative study of US firefighters. *Saf Health Work*. 2020;11(3):284-290. doi:10.1016/j.shaw.2020.04.004
44. Macy GB, Hwang J, Taylor R, Golla V, Cann C, Gates B. Examining behaviors related to retirement, cleaning, and storage of turnout gear among rural firefighters. *Workplace Health Saf*. 2019;68(3):129-138. doi:10.1177/2165079919882951
45. Louzado-Feliciano P, Santiago KM, Paule L, et al. Perceptions of occupational cancer risk and prevention among Dominican Republic Firefighters. *J Occup Enviro Med*. 2021;64(3). doi:10.1097/jom.0000000000002466
46. Bautista M, Jr. Emergency Responders' Perceptions of Environmental Health Hazards and Personal Protection in Responses. [Dissertation]. Capella University; 2020.
47. Popescu C. 363 Fire Department Cancer Risk Exposure Reduction Project. *Ann Emerg Med*. 2021;78(4). doi:10.1016/j.annemergmed.2021.09.378
48. Harrison TR, Yang F, Anderson D, et al. Resilience, culture change, and cancer risk reduction in a fire rescue organization: Clean Gear as the new badge of honor. *Journal of Contingencies and Crisis Management*. 2017;25(3):171-181. doi:10.1111/1468-5973.12182
49. Harrison TR, Muhamad JW, Yang F, et al. Firefighter attitudes, norms, beliefs, barriers, and behaviors toward post-fire decontamination processes in an era of increased cancer risk. *J Occup Enviro Hyg*. 2018;15(4):279-284. doi:10.1080/15459624.2017.1416389
50. Moore KJ, Koru-Sengul T, Alvarez A, et al. Safety gear decontamination practices among Florida firefighters: Analysis of a text-based survey methodology. *Workplace Health Saf*. 2018;66(11): 522-529. doi:10.1177/2165079918754331
51. Harrison TR, Yang F, Morgan SE, Wendorf Muhamad J, Talavera E, Eaton SA, Niemczyk N, Sheppard V, Kobetz E. The invisible danger of transferring toxins with bunker gear: a theory-based intervention to increase postfire decontamination to reduce cancer risk in firefighters. *J Health Comm*. 2018; 23(12):999-1007. doi:10.1080/10810730.2018.1535633
52. Solle NS, Harte L, Allam N, et al. Attitudes and Perceptions of Cervical Cancer Screening in Female Firefighters: Evidence from the Florida Firefighter Cancer Initiative. *APHA 2016 Annual Meeting & Expo (Oct. 29 - Nov. 2, 2016)*. APHA
53. Park HS, Ham S, Jeong JH, Kim SJ, Woo H. Examination of Factors Influencing SCBA Washing Behavior among Firefighters in Metropolitan. *Int J Environ Res Public Health*. 2022;19(4):2240. doi:10.3390/ijerph19042240
54. Moura, F.D.D., *Descontaminação grossa pós intervenção em atmosferas imediatamente perigosas à vida e à saúde: uma análise dos procedimentos atualmente exequíveis às guarnições de serviço*. Monograph. Centro de Estudos de Política, Estratégia e Doutrina, Brasil; 2021. https://biblioteca.cbm.df.gov.br/jspui/bitstream/123456789/190/1/TCC%20CAO%20-%20Cap.%20Fernando%20%20-%20versao%20entrega.pdf. Accessed September 21, 2022.
55. Ogunsina K, Solle N, Murphy LA, et al. Abstract PO-251: Examining facilitators and barriers to cancer screening among Black firefighters in South Florida. *Cancer Epidemiol Biomarkers Prev*. 2020;(12_Supplement):PO-251. doi:10.1158/1538-7755.DISP20-PO-251
56. Burgess JL, Hoppe-Jones C, Griffin SC, et al. Evaluation of Interventions to Reduce Firefighter Exposures. *J Occup Environ Med*. 2020;62(4):279-288. doi:10.1097/JOM.0000000000001815
57. Fent KW, Alexander B, Roberts J, et al. Contamination of firefighter personal protective equipment and skin and the effectiveness of decontamination procedures. *J Occup Environ Hyg*. 2017;14(10):801-814. doi:10.1080/15459624.2017.1334904
58. Abrard S, Bertrand M, De Valence T, Schaupp T. French firefighters exposure to

Benzo[a]pyrene after simulated structure fires. *Int J Hyg Environ Health*. 2019;222(1): 84-88. doi: 10.1016/j.ijheh.2018.08.010

59. Harrison TR. Enhancing Communication Interventions and Evaluations through Communication Design. *J Appl Commun Res*. 2014;42(2):135-149. doi:10.1080/00909882.2013.825047
60. Harrison TR, Williams EA, Reynolds AR. The intersections of organizations, health, and safety. *The Handbook of Applied Communication Research*. Published online April 17, 2020:279-296. doi:10.1002/9781119399926.ch17
61. Yzer M. Perceived Behavioral Control in Reasoned Action Theory: A Dual-Aspect Interpretation. *Ann Am Acad Pol Soc Sci*. 2012;640(1):101-117. doi:10.1177/0002716211423500
62. Rosenstock IM. The Health Belief Model and Preventive Health Behavior. *Health Educ Monogr*. 1974;2(4):354-386. doi:10.1177/109019817400200405
63. Frattaroli S, Pollack KM, Bailey M, Schafer H, Cheskin LJ, Holtgrave DR. Working inside the firehouse: developing a participant-driven intervention to enhance health-promoting behaviors. *Health Promot Pract*. 2013;14(3):451-458. doi:10.1177/1524839912461150
64. Elliot DL, Goldberg L, Kuehl KS, Moe EL, Breger RKR, Pickering MA. The PHLAME (Promoting Healthy Lifestyles: Alternative Models' Effects) firefighter study: outcomes of two models of behavior change. *J Occup Environ Med*. 2007;49(2):204-213. doi:10.1097/JOM.0b013e3180329a8d
65. Chewning L, Doerfel M, Ballard D, Harrison TR. From crisis response to high resilience organizing. Miller V, Poole MS, eds. *Handbook of Organizational Communication*. Walter de Gruyter. (in press)
66. Zanatta M, Amaral FG. Production layout improvement in emergency services: a participatory approach. *Work*. 2012;41 Suppl 1:1720-1726. doi:10.3233/WOR-2012-0375-1720
67. Maglio MA, Scott C, Davis AL, Allen J, Taylor JA. Situational Pressures that Influence Firefighters' Decision Making about Personal Protective Equipment: A Qualitative Analysis. *Am J Health Behav*. 2016;40(5):555-567. doi:10.5993/AJHB.40.5.2
68. Firefighter Cancer Support Network. Taking action against cancer in the fire service. 2013. Retrieved from https://firefightercancersupport.org/taking-action-against-cancer-in-the-fire-service/
69. Horn GP, Fent KW, Kerber S, Smith DL. Hierarchy of contamination control in the fire service: Review of exposure control options to reduce cancer risk. *J Occup Environ Hyg*. 2022; 28:1-20.
70. Bator CH. Collaborating for Firefighter Safety and Health. *Fire Engineering*. 2018;171(6):37-40.
71. Millet B. Designing an Occupational Exposure Report for Aircraft Rescue and Firefighting. *Proc Hum Factors Ergon Soc Ann Meet. 2020; 64*(1): 924–927. doi:10.1177/1071181320641220
72. Millet B. Integrating User-Centered Design Into the Sylvester Firefighter Cancer Initiative's Personal Exposure Reporter. *Ergon Des*. 2021; 9:10648046211051196.
73. Baile WF, Aaron J. Patient-physician communication in oncology: past, present, and future. *Curr Opin Oncol*. 2005;17(4):331-335. doi:10.1097/01.cco.0000167738.49325.2c
74. Ha JF, Longnecker N. Doctor-patient communication: a review. *Ochsner J*. 2010;10(1):38-43.
75. Ogunsina K, Solle N, Murphy LA, et al. Abstract PO-251: Examining facilitators and barriers to cancer screening among Black firefighters in South Florida. *Cancer Epidemiol Biomarkers Prev*. 2020;(12_Supplement):PO-251. doi:10.1158/1538-7755.DISP20-PO-251
76. Lubberding S, van Uden-Kraan CF, Te Velde EA, Cuijpers P, Leemans CR, Verdonck-de Leeuw IM. Improving access to supportive cancer care through an eHealth application: a qualitative needs assessment among cancer survivors. *J Clin Nurs*. 2015;24(9-10):1367-1379. doi:10.1111/jocn.12753
77. Donovan JL, Blake DR. Patient non-compliance: deviance or reasoned decision-making? *Soc Sci Med*. 1992;34(5):507-513. doi:10.1016/0277-9536(92)90206-6
78. Varvel SJ, He Y, Shannon JK, et al. Multidimensional, threshold effects of social support in firefighters: Is more support invariably better? *J Couns Psychol*. 2007;54(4):458-465. doi:10.1037/0022-0167.54.4.458
79. Nowicki T, Koszela J, Matuszelański Ł. Virtual reality environment to study the ergonomic features of firefighters' activity. *MATEC Web Conf*. 2018;210:02050. doi:10.1051/matecconf/201821002050

80. Bellemans M, Lamrnens D, De Sloover J, et al. Training Firefighters in Virtual Reality. In: *2020 International Conference on 3D Immersion (IC3D)*. ieeexplore.ieee.org; 2020:01-06. doi:10.1109/IC3D51119.2020.9376336