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TECHNICAL NOTES

Evaluation of the Performance of Station Wear Worn under a NFPA 1971 Structural Fire Fighter Protective Ensemble

FINAL REPORT BY:

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FOREWORD

There has not been robust validated research conducted on the effects of station wear while worn under a NFPA 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting* protective ensemble (aka “bunker gear”) in a fire and heat environment. The fire service is generally unaware of the risk that is associated with the use of non-certified NFPA garments, including synthetic fabrics, while worn as station wear garments under bunker gear. The second leading cause of fire fighter injuries in the United States is exposure to heat and smoke. The scope of NFPA 1975, *Standard on Emergency Services Work Clothing Elements* specifies the requirements for the design, performance, testing, and certification of non-primary protective work apparel and the individual garments comprising work apparel. The standard also specifies the requirements for the thermal stability of textiles used in the construction of work apparel.

The project goal is to establish a baseline understanding of burn protection provided by garments worn under bunker gear based on their thermal stability. This project is comprised of the following tasks:

- Review the requirements of NFPA 1975 for thermal stability.
- Identify available reports, articles, or other documents related to the risks associated with garments while worn as station wear under bunker gear.
- Identify the gaps in the literature on the system’s level effect of non-thermally stable garments worn under bunker gear.
- Conduct a targeted information gathering of end-user (fire fighters) to understand the selection process of station wear.
- Design a test program to evaluate NFPA 1975 station wear with a NFPA 1971 compliant protective ensemble.
- Compile and submit a final written report based on the findings from all above tasks.

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About the National Fire Protection Association (NFPA)

Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy, and by partnering with others who share an interest in furthering the NFPA mission.



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NFPA's [membership](#) totals more than 65,000 individuals around the world.

Keywords: firefighting, fire fighter, station wear, garment, NFPA 1975, NFPA 1971

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EXECUTIVE SUMMARY

Structural turnout gear is essential for the safety of fire fighters as they rely on the material and garment properties to protect them from multiple thermal hazards and potential injuries. The station wear, or clothing worn under the structural turnout suit, also contributes to the thermal protection of the overall ensemble. However, depending upon the station wear's fiber content and material fabrication, it may also contribute to possible burn injuries. The purpose of this study was to evaluate the impact that National Fire Protection Association (NFPA) 1975 certified, certified flame resistant, and non-certified station wear garments have in relation to fire fighter burns and heat injuries while worn under a NFPA 1971 structural fire fighter ensemble. A comprehensive literature review was conducted to identify gaps in the current body of knowledge and to identify the contributing factors that lead to burn injuries including: material type (fiber content), garment certification, base layer burn protection, and thermal stability. An information gathering questionnaire was distributed nationwide with over 1,800 current active-duty United States firefighting personnel responding to questions regarding their selection and use of station wear. Through the questionnaire responses it was determined that 72% of participants were aware of NFPA 1975, Standard on Emergency Services Work Clothing Elements, and 80% were aware of the overall risk of wearing non-certified station wear garments (i.e., synthetics that will melt or drip). However, even though a high percentage of awareness was indicated, 45% of career fire fighters responded that they were not required to wear certified or flame resistant station wear per NFPA 1975. The findings of this study from the literature review and comprehensive nationwide questionnaire will be useful for educating the fire service, informing the NFPA 1975 and NFPA 1971 technical committees, and assisting the design of future research.

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**Evaluation of the Performance of Station Wear Worn under
A NFPA 1971 Structural Fire Fighter Protective Ensemble**

Sponsored by: NFPA Fire Protection Research Foundation (FPRF)

Final report: June 22nd, 2018

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Abstract

Structural turnout gear is essential for the safety of fire fighters as they rely on the material and garment properties to protect them from multiple thermal hazards and potential injuries. The station wear, or clothing worn under the structural turnout suit, also contributes to the thermal protection of the overall ensemble. However, depending upon the station wear's fiber content and material fabrication, it may also contribute to possible burn injuries. The purpose of this study was to evaluate the impact that National Fire Protection Association (NFPA) 1975 certified, certified flame resistant, and non-certified station wear garments have in relation to fire fighter burns and heat injuries while worn under a NFPA 1971 structural fire fighter ensemble. A comprehensive literature review was conducted to identify gaps in the current body of knowledge and to identify the contributing factors that lead to burn injuries including: material type (fiber content), garment certification, base layer burn protection, and thermal stability. An information gathering questionnaire was distributed nationwide with over 1,800 current active-duty United States firefighting personnel responding to questions regarding their selection and use of station wear. Through the questionnaire responses it was determined that 72% of participants were aware of NFPA 1975, *Standard on Emergency Services Work Clothing Elements*, and 80% were aware of the overall risk of wearing non-certified station wear garments (i.e., synthetics that will melt or drip). However, even though a high percentage of awareness was indicated, 45% of career fire fighters responded that they were not required to wear certified or flame resistant station wear per NFPA 1975. The findings of this study from the literature review and comprehensive nationwide questionnaire will be useful for educating the fire service, informing the NFPA 1975 and NFPA 1971 technical committees, and assisting the design of future research.

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Introduction

The second leading cause of fire fighter injuries in the United States is exposure to heat and smoke. Unfortunately, there has been a lack of coordinated effort to report severity, type, and specific contributing factors, such as the clothing worn underneath the structural firefighting ensemble. As fire fighters face multiple thermal hazards, they rely on the protective properties of their uniform to keep them safe. However, most individuals in the firefighting profession are likely not aware of the associated risks of wearing non-certified National Fire Protection Association (NFPA) base layers, including synthetic fabrics, as station wear under their protective ensemble. Station wear is the uniform worn around the fire station, usually consisting of a variation of a T-shirt or long sleeve shirt and shorts or pants. There has been extensive research conducted on fire fighter personal protective equipment (PPE), including the NFPA 1971 certified structural turnout suit, worn to minimize exposure to hazards that cause serious workplace injuries and illnesses (United States Department of Labour n.d.). Studies have shown that the structural fire fighter turnout suit, also known as bunker gear, consists of multiple fabric layers for protection against puncture, chemical, heat and flame, and steam hazards (McQuerry, DenHartog, & Barker 2016a). However, there has not been robust validated research conducted on the effects of station wear when worn separately or while worn under a NFPA 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting* protective ensemble (aka "bunker gear"), especially in a high heat environment under thermally stressful conditions.

NFPA 1975, *Standard on Emergency Services Work Clothing Elements* specifies the requirements for the design, performance, testing, and certification of non-primary protective work apparel and the individual garments comprising work apparel. The standard also specifies the requirements for the thermal stability of textiles used in the construction of work apparel. There

remains a lack of clear understanding of the impact that both certified NFPA 1975 and non-certified station wear garments have in relation to fire fighter burns and heat injuries while worn under a certified NFPA 1971 garment.

Research Objectives

The purpose of this research project was to evaluate the impact of wearing certified NFPA 1975 station wear versus non-certified station wear and its relation to burns and heat injuries while worn under a certified NFPA 1971 turnout suit. The primary goal of this study was to identify the factors that have led to excessive burn injuries and assess the balance between burn protection and station wear thermal stability. Review of previous studies focusing on the impact of base layers on the thermal protection of fire fighters will potentially determine the factors that contribute to burn injury, the impact of wearing non-certified versus certified station wear garments, and identify gaps in the literature concerning the balance of thermal stability and burn protection. This research will also include the design and distribution of an information-gathering questionnaire about fire fighter station wear selection and use by department type, region, experience, etc. Of specific interest were differences in material type (i.e., thermoplastic or thermally stable), primary factors of importance for selection, prominence of certified versus non-certified station wear, as well as, inclusion of the scope of wildland fire fighter base layers.

To accomplish the purpose of this study, the following research objectives were established:

1. To conduct a comprehensive review of literature regarding the influence of station wear on burn injuries while worn under a certified NFPA 1971 turnout suit.

- a. To identify gaps in the literature regarding burn injuries due to station wear when worn under a certified NFPA 1971 turnout suit in order to develop an experimental test plan for future research.
2. To design, administer, and analyze an information gathering questionnaire in order to determine the most common practices regarding fire fighter station wear selection, use, design, material type (fiber content), and its perceived performance.
3. To formulate an experimental test plan to assess the performance and thermal stability of various base layer materials and identify the factors that contribute to burn injuries.

Literature Review

Structural Turnout Ensemble

A certified NFPA 1971 structural fire fighter turnout suit ensemble includes a turnout coat, pants, thermal hood, helmet, gloves, boots, self-contained breathing apparatus (SCBA), and SCBA mask. An additional piece of the ensemble, which is sometimes forgotten about due to its invisibility, is the station wear worn underneath the turnout suit. Currently, this station wear is not considered a “part of the ensemble” from the NFPA 1971 standard’s point of view. Therefore, its contribution to thermal protection and potential risks for burn injuries (i.e., wearing a thermoplastic synthetic fiber) are not included in the design, selection, and protection requirements within NFPA 1971. The standard only states “garments shall consist of a composite of an outer shell, moisture barrier, and thermal barrier” (NFPA 2018), referring to the turnout suit only.

The structural turnout suit is the first layer of protection for fire fighters. The turnout suit is comprised of various layers which further protect the wearer from heat-related thermal hazards,

liquids, sharp objects, and low-level chemicals. The outer shell, moisture barrier, and thermal liner are essential elements of the structural turnout suit.

Outer Shell. The outer shell is the first line of defense for the fire fighter against thermal hazards and sharp objects. The outer shell is defined as, “the outermost component of an element or item not including trim, hardware, reinforcing material, pockets, wristlet material, accessories, fittings, or suspension systems” (NFPA 2018). It only contributes a minor amount of thermal protection to the overall garment; however, it serves to protect the inner components and layers that provide the majority of the thermal protection (i.e., the thermal liner and moisture barrier). The outer shell protects fire fighters from cuts and abrasions while they are on scene, whether it be a structure fire or a brush fire. Most importantly, it is the outer shell that maintains the function and effectiveness of the thermal liner and the moisture barrier (Young 2010).

Moisture Barrier. The moisture barrier is, “the component of an element or item that principally prevents the transfer of liquids” (NFPA 2018). “In order to serve these functions, the moisture barrier is constructed with an expanded PTFE (Polytetrafluoroethylene) permeable film barrier laminated to a woven or nonwoven flame-resistant substrate material” (Young 2010). It is important to routinely examine the moisture barrier as it is the layer most likely to be damaged due to the combination of the woven and nonwoven materials.

Thermal Liner. The thermal liner or barrier is, “the component of an element or item that principally provides thermal protection” (NFPA, 2018). Thus, this layer is the most important layer of the turnout gear. The thermal liner grants the majority of the thermal protection within the ensemble. “Thermal liners trap air in or between layers of nonwoven material that is quilted to a face cloth material. More so than the other layers, the material makeup of the thermal liner is critical to the comfort and safety of firefighters” (Young 2010).

Station Wear

The structural turnout suit is arguably the most important part of the fire fighter uniform. The National Fire Protection Association has set NFPA 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting* to regulate the manufacturing and use of the fire fighter turnout suit to ensure maximum safety in an active fire emergency. Yet, the layer of clothing that separates the wearer from their turnout suit has not been standardized or enforced by NFPA and has undergone very little testing and research. The station wear ensemble includes the short or long sleeve shirt, as well as shorts or long pants, worn underneath the structural turnout suit. The station uniform is the last barrier between a fire fighter and potentially deadly burns; it is of the highest importance to ensure that this base layer does not add to thermal injuries, exacerbate heat strain, hinder mobility, or negatively impact the wearer in any way.

In the first edition of NFPA 1975, which standardizes station/work uniforms and other elements of PPE, the use of flame-resistant fabric for station T-shirts and pants was mandated. It was assumed that fire fighters would be regularly exposed to flame and should always be equipped with fire resistant clothing. In a 1999 update to NFPA 1975, the standard was revised to include 100% cotton, 100% wool, or certified flame-resistant materials (Stull 2011). This change was made because it was decided that the non-melting characteristics of the base layer garment were deemed more important than the overall flame-resistance of the material; and that the interior layer should not, at least, *contribute* to burn injuries.

Today, NFPA 1975 includes a thermal stability test that ensures that the materials used in station uniform manufacturing do not melt, drip, or ignite when exposed to high heat (NFPA 2014). The main point of this requirement is that the fire fighters should not wear anything that contains thermoplastic materials, such as polyester and nylon, which can melt onto the wearer's skin.

While these standards and precautions have been set, the organizations or fire authorities having jurisdiction do not always adhere to these mandates and not all regulate the use of certified NFPA 1975 station wear garments. When it comes to selecting what station wear ensemble is to be worn underneath the structural turnout suit, many authorities leave the choice up to the fire fighters themselves, especially in volunteer organizations. The problem with this approach is the lack of knowledge about the risks of wearing non-certified garments, such as synthetics, and the lack of literature focusing on factors that contribute to burn injuries.

Little research has been done regarding what material is best suited for station wear garments worn under turnout suits. Therefore, the purpose of this literature review is to evaluate the impact of certified versus non-certified garments under turnout suits and their relation to burns and heat injuries. Within this study, the researchers will also gather feedback from fire fighters about which materials they prefer, as it will be up to them to adhere to the recommendations.

Studies on station wear thus far have mainly focused on the physiological and perceptual comfort responses of station wear worn under a certified protective ensemble in relation to different fabric material types and their comfort sensations (Smith et al., 2014; Smith, Haller, Hultquist, Lefferts, & Fehling 2013a, 2013b, 2013c). Smith (2014) focused on the effects of different base layer fabrics on skin temperature and comfort when worn under protective fire fighter equipment, concluding that there was no significant difference in heart rate, core temperature, perceived exertion, or thermal discomfort between the various base layers (Smith et al., 2014). However, skin comfort and humidity sensations were slightly more favorable for the wool base layer than cotton. A similar study conducted by Yoo and Barker (2005) investigated the thermophysiological and sensorial impacts as well as end-use conditions of heat-resistant

protective garments on wearer comfort (Yoo & Barker 2005). They found that the influence of perceived comfort is dependent on the specific conditions under which the clothing is worn.

Previous studies have also examined how fabric materials contribute to the thermal comfort of fire fighters in various conditions. Flame-resistant and “wicking” properties have been evaluated for their effect on thermal comfort and heat stress related injuries and both were found to have no advantage for physiological improvement (Dorton 2015; Wickwire et al., 2007). A study by Kalyani and Jamshidi (2009) recommended station wear configuration types and when they should be worn. They suggested replacing pants with shorts under PPE to reduce heat stress (Kalyani & Jamshidi 2009). McLellan and Selkirk (2004) also found that replacing long pants with shorts reduced thermal strain during activity (McLellan & Selkirk 2004).

These studies have focused on the heat stress relief and comfort benefits; however, little to no research has been conducted regarding the repercussions of these changes such as, wearing shorts versus long pants or wearing synthetics, which will melt versus flame resistant rated materials.

NFPA 1975 & NFPA 1971

NFPA 1975 is the *Standard on Emergency Services Work Clothing Elements* and NFPA 1971 is the *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*. These standards provide an in-depth identification of emergency work clothing and the specifications required of each ensemble and garment element. Each standard lays out specific design, selection, and performance requirements.

NFPA 1975, *Standard on Emergency Services Work Clothing Elements*. NFPA 1975 outlines the specific thermal stability standards which must be applied in the construction of fire

fighter work apparel. The purpose of this standard is to provide emergency services personnel with work apparel that will not contribute to burn injury severity. It aims to establish minimum requirements for thermally stable textiles that will not rapidly deteriorate, melt, shrink, or adhere to the wearer's skin, causing greater or more severe burn injuries. The standard states that garments such as socks, dress uniforms, and specific types of undergarments including briefs, boxer shorts, boxer briefs, and bras are not considered part of the fire fighter ensemble and are not required to meet the standards of NFPA 1975. According to the standard, flame resistance is defined as the property of a material that prevents combustion following the application of a flaming or non-flaming source of ignition without subsequent removal.

The basic design requirements of the NFPA 1975 standard are as follows: garments that are constructed from flame resistant fabrics must be stitched with thread of a flame resistant fiber. Metal hardware needs to be smooth and must not contact the body during wear. The standard includes the following articles as part of the upper body protective ensemble: shirt with collar, full front opening, either long or short sleeve; or T-shirt pullover without front opening and without collar in either long sleeve or short sleeve. All elements of the PPE must pass thermal stability (no melt or drip) requirements in order to be certified according to the NFPA 1975 standard.

There is an additional option for flame resistance (FR) certification that includes passing the vertical flammability char length test requirement. "Materials should be tested individually for flame resistance and have an average char length of no more than 150 mm (6 in.), they should have an average afterflame of less than 2 seconds and shall not melt or drip" (NFPA 2014). ASTM D 6413 Flame Resistance of Textiles (Vertical Test) should be used to assess melting, dripping, and char length. "Pass or fail performance shall be based on any observed melting or dripping, the

average afterflame time, and average char length," per the requirements previously stated (NFPA 2014).

"Textile fabrics, excluding interlinings, shall be tested individually for thermal stability and shall not melt, ignite, or stick to the glass plates and shall have a rating of resistance to blocking of 1 or 2" and "all thread utilized in work apparel shall be tested for heat resistance and shall not melt at or below 260 C (500 F)" (NFPA 2014). The test method that should be used is ASTM F 2894, *Standard Test Method for the Evaluation of Materials, Protective Clothing and Equipment for Heat Resistance Using a Hot Air Circulating Oven*. The specimens are placed in the oven on a stretching frame at 260 C (500 F). The rating of resistance to blocking is determined and any sticking to the glass plate, melting, or ignition for any specimen is observed and recorded. Any evidence besides "no damage" and/or a rating of resistance to blocking of 1 or 2 constitutes in a failure (NFPA 2014).

NFPA 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*. NFPA 1971 sets requirements for PPE including the outer shell, moisture barrier, and thermal barrier. This standard focuses on setting minimum levels of protection from thermal, physical, and environmental hazards. The standard mandates specific garment testing to assess material melting, dripping, and igniting characteristics. The standard states that the elements of the PPE shall be tested for insulation and thermal protective performance (TPP). Protective apparel must undergo extensive flame resistance testing and cannot have an afterflame of more than 2 seconds and cannot melt when exposed to flame. The outer shell, moisture barrier, and thermal barrier must be tested for shrinkage and cannot shrink by more than 10% in any direction after laundering. All elements of the PPE must not melt, separate, or ignite—and seams shall not drip

or ignite. All of these requirements are set to ensure maximum protection in the construction of the fire fighter turnout suit and its various components (NFPA 2018).

Thermal Stability of Fibers & Fabrics

The fire authorities having jurisdiction should be informed of the important factors when selecting station wear. Factors including thermal stability, heat and thermal shrinkage, thread heat resistance, seam strength, label durability, and optional flame resistance can predict whether garments are suitable for burn protection (Varner 2008). It is also important to be informed of the fiber properties and characteristics of the garments worn as station wear. Fiber properties tend to spark the biggest debate when it comes to balancing thermal stability and comfort in station wear.

"[...] man-made synthetic fibers are produced by reactions of oil-based products that produce polymer pellets (plastic)" (Bernhardt Purified Cotton 2015). Thus, synthetic fabrics are made out of thermoplastic materials, meaning they are "more sensitive to heat" and will "burn and melt more easily." It seems logical, therefore, to use cotton fabric for fire fighter station wear, since synthetics are susceptible to melting. However, it becomes more complicated when blends and other properties needed to enhance other characteristics (i.e., comfort, breathability, moisture management, mobility, and durability) and material properties are considered.

Fabric properties also influence the thermal stability of station wear garments. The "structure of knitted fabrics and weave type of woven fabrics play a crucial role in the protective as well as comfort performance of the coverall" (Udayraj, Talukdar, Das, & Alagirusamy 2016). Udayraj et al., (2016) found that a high density woven fabric as the outer layer and a bulky knitted fabric as the inner layer offered better thermal protection in coveralls (Udayraj et al., 2016).

Every aspect of the fiber and fabric have some effect on the thermal properties, including the coloring of the fabric. While color and dyeing of the fabrics does not have as significant an impact as fabric thickness and construction, it cannot be completely ignored. "Significantly lower absorption and higher reflectance were observed for the dyed fabric as compared to fabric with dyed fiber in the infrared region" (Udayraj et al., 2016). Even though it is a small aspect, wearing lighter versus darker colors can matter and should be taken into consideration when trying to create the most protective yet comfortable station wear possible.

Going further than the basic construction properties, fabrics and fibers can also be treated with finishes such as aerogel and aluminum coatings. Aerogels can be used as a finish or made into an actual material. Aerogel has amazing properties that make it perfect for thermal insulation. It has low thermal conductivity, low density, high porosity, high shock absorbency, and other attractive qualities. The mix of qualities are perfect for uses like fire fighter suits. An experiment by Jin et al., and Qi et al., on the effectiveness of aerogel in thermal protective clothing (Udayraj et al., 2016) demonstrated an increase in protection and a decrease in burn injury. Aerogels in the use of protective wear, however, are still being developed.

Currently, some companies employ aluminum coatings in their protective wear. While aluminum coatings have been shown to provide lower temperature and protect radiant heat exposure, they do not perform well with flame exposure, which is a huge drawback for firefighting protective ensembles. Thus, there has been a rise in the invention of new fibers and fabrics themselves to try to combat thermal risk, instead of just changing the properties of natural fibers or traditional synthetics.

The development and application of phase change materials must also be considered as they are commonly found in synthetic, athletic apparel garments, which fire fighters often choose

to substitute their station wear with. “Phase change materials are materials with high latent heat of melting (fusion) and therefore can release or store large amounts of heat during phase change from solid to liquid or vice versa” (Udayraj et al., 2016). The material stores heat from the external environment, draws it away from the skin, and offers more protection. PCM may sound like the perfect solution but it does have some limitations. Currently, only PCM with low phase transition temperature is available, but for high heat exposure, such as firefighting applications, a high phase transition temperature would be needed. Like any other fabric, the effectiveness also depends on the fabric thickness. PCMs are most effective when used closest to the skin. PCMs could potentially be beneficial for improving comfort when implemented into station wear, but further research still needs to be done.

The major gap in thermal stability research for fibers and fabrics is not due to a lack of information, but a lack of research period, as little to no studies on the effect of burn injuries with synthetics versus natural or high heat resistance manufactured fibers has been conducted. It appears the information is evident; it just needs to be applied and tested for station wear.

Station Wear Selection

“Firefighters depend on turnout systems to protect them from burn injury, but firefighters can also help themselves by choosing what they wear under their turnout gear carefully” (Young 2010). Station wear base layers can have a positive, negative, or neutral impact on thermal protection depending on what type is chosen. It is known that synthetic, thermoplastic materials will melt and can have a negative impact on wearer burn injury in certain contexts, such as military applications; whereas cotton materials are neutral. Choosing a base layer that contains heat-and flame-resistant fibers could be very beneficial. “Although the conditions in which they work are often radically different, all fire fighters, regardless of their specific jobs, can aid their fire

protective gear by choosing base layers that are additive and offer increased thermal protection” (Young 2010).

When left to choose a station uniform for themselves, most stations select 100% cotton materials because of their natural melt-resistant properties. Requiring members to wear 100% cotton bypasses the issue of discerning the safety between fiber blends and synthetics. When it comes to experimenting with general clothing materials and fabrics for turnout suit manufacturing, some fire authorities and individual fire fighters are intrigued by new material technologies which promote good moisture management. Their assumption is that excessive moisture within a garment could possibly contribute to burn injuries since wet gear can be more conductive than dry gear (Stull 2011).

According to the article “Selecting a Station/Work Uniform” the best way to select station wear is to check the testing results of different options then "conduct a wear trial, and involve department members and the labor organization in the process" (Varner 2008). Station representatives can go to trade shows to ask questions and find materials that comply with NFPA 1975. There are many options to choose from, but selection really comes from doing extensive research. In addition, the impact of cost, durability, and replacement life cannot be ignored when considering fire organizations’ selection choices.

Burn Injury Studies and Statistics

Between 2012 and 2014, 12.8% of reported fire fighter injuries were burn injuries, and 9% of fire fighters indicated that their protective gear was at fault for their injury (Administration 2014). Injury can result from various gear failures, ranging from a gap between the gloves and the cuffs of the turnout suit to fabric that does not perform at the level necessary for fire protection. A study by Onofrei et al., (2015) developed a predictive model for time to first and second degree

burns while wearing a modern protective ensemble. Based on this model, she recommends that a “typical three-layer thermal protective clothing system” be worn in order to maximize the protective nature of the equipment (Onofrei et al., 2015). This study’s findings also indicate that the heat capacity of the fabric layers also play a significant role in the case of short duration, high intensity heat exposures.

It is also well established that as the thermal conductivity of the fiber or fabric increases, the heat transfer rate increases and the time to second-degree burn decreases. Fabric thickness greatly impacts the overall thermal resistance and burn time. As layers get thicker, the second-degree burn time increases (Udayraj et al., 2016). However, fire fighters still feel the effects of heat strain and physical stress, even if their layers are sufficiently protecting them from a second-degree burn.

Stored energy burns are also a concern “caused by energy stored within the fabric after the exposure ends rather than the heat transferred during the exposure, especially at lower heat exposure conditions” (Udayraj et al., 2016). Data shows that of the burn injuries that fire fighters have experienced in routine or hazardous conditions, most of them occur due to prolonged exposure to heat (Onofrei et al., 2015). “Specific heat capacity is the measure of heat storage in the fabrics. As fiber specific heat capacity increases, stored energy within the fabric increases resulting in less heat transfer through fabric to skin. Hence, second degree burn time increases” (Udayraj et al., 2016). This research expresses that fabrics with a higher specific heat capacity can protect fire fighters from burn injuries for a longer period of time. Coupled with burn injury data, it becomes clear that using thick fabric with high specific heat capacities is crucial to the safety of fire fighters.

A retrospective study of 20 fire fighters that had been treated for burn injuries shows that 70% of the fire fighters experienced burns underneath or due to either misuse or noncontiguous areas of their protective clothing and of that, 5% experienced steam burns (Kahn, Patel, Lentz, & Bell, 2012). Fire fighters run the risk of experiencing steam burn when protective garments do not allow perspiration to evaporate and cool the body. This increases a need for protective clothing to have optimal heat and moisture transfer abilities (Onofrei et al., 2015).

While the studies mentioned above are in relation to the turnout suit ensemble, the impact of station wear base layers must not be ignored. Unfortunately, there have not been any studies conducted, to the researchers' knowledge, that address the stored energy burn potential or thermal stability risks of wearing non-certified (synthetic) versus certified station wear materials underneath an NFPA 1971 certified turnout suit in various operating conditions.

Identification of Gaps in the Literature

After a thorough review of the available literature on structural fire fighter station wear and base layers, the researchers have found several gaps in the available body of knowledge. While some research has been done on the relationship between station wear, turnout suits, and heat stress, there is a lack of information regarding burns sustained by fire fighters as a result of wearing non-certified station wear underneath their turnout gear. Reporting services have offered statistics on the causes of fire fighter deaths and injuries, but these studies fail to provide specific statistics or case studies that link burns directly back to station wear and/or base layers. While NFPA 1975 does specify requirements for non-primary protective work apparel and the individual garments comprising work apparel, there is again no research on the burn and heat injury of station wear used under a protective ensemble. In fact, most studies done on station wear are related to thermal comfort instead of thermal stability.

There remains a gap in the literature on the impact of station wear materials (i.e., natural fibers versus synthetics versus manufactured flame resistant fibers) and garment designs (i.e., short versus long sleeves and shorts versus pants) on potential burn injury when worn underneath a turnout ensemble. Although the design, material, and protective qualities that enhance thermal protective clothing are important, and ensuring fire fighters receive the maximum protection possible is of high priority, there remains a lack of research that understands how these factors influence burn injuries and/or burn protection, specifically when worn in conjunction with a structural turnout suit.

Methods

To better understand the needs of end users within the fire service, an information gathering questionnaire was designed and distributed nationwide, across the United States, to current active duty, career and volunteer, structural and wildland fire fighters. The results gathered from this questionnaire will inform the experimental design of future studies in order to assess the thermal stability and performance needs of station wear. This feedback will also be shared with relevant NFPA standards committees, such as NFPA 1975 and 1971, to inform revisions within the standards.

Questionnaire Design

A 55-question, qualitative and quantitative, information gathering questionnaire was designed and administered to fire fighter end users. Data was gathered from over 1,800 current active-duty, career and volunteer, structural and wildland fire fighters across the United States. Sections in the questionnaire included: demographics, station wear selection, station wear use,

station wear materials, station wear design, base layers and wildland firefighting (if applicable to the respondent), and a final section of open ended, free response questions.

The information gathered from the questionnaire will allow the NFPA to better develop standards for fire fighter uniforms. Results will help evaluate the impact that both certified NFPA 1975 and non-certified station wear garments have in relation to fire fighter burns and heat injuries while worn under a certified NFPA 1971 garment in a real world environment. The results will be useful for the fire service, academic research, and NFPA 1975 and NFPA 1971 technical committees.

Questionnaire Analysis

Descriptive statistics of respondents' selection, use, and satisfaction with their station wear were calculated to determine the awareness, performance needs, and potential improvements of base layer garments currently being worn in the fire service. Fire fighters' comments from the open-ended and text input questions were coded by three independent researchers using the interpretive thematic analysis method. This method allows grouping of the responses into overarching themes with related issues.

Results and Discussion

Participant Demographics

The first section of the questionnaire gathered data on the demographics of the participants. It determined that 96% of participants were male with 73 female respondents in total. Ninety-three percent (93%) of participants identified themselves as white/Caucasian; 2% as black/African American; 2% identified as Hispanic/Latino; and the final 3% identified as American Indian,

Alaskan Native, Asian, Native Hawaiian, or Pacific Islander. Eighty percent (80%) of participants were career fire fighters, while 20% were volunteer or paid-on-call fire fighters. Of these participants, 88% worked full-time while the other 12% worked part-time.

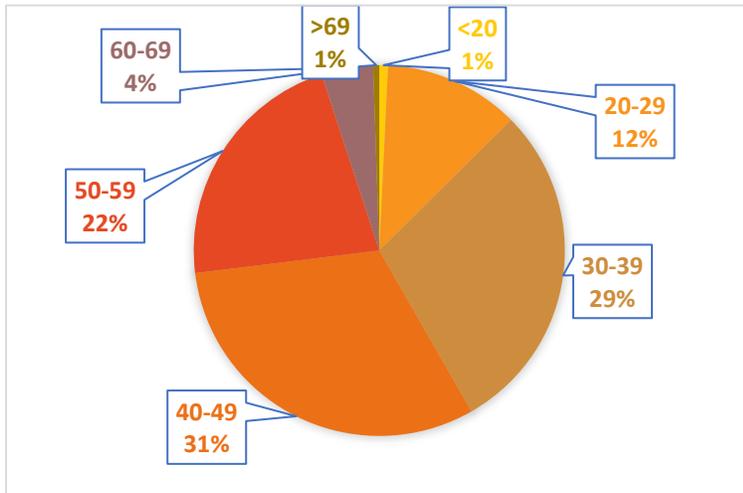


Figure 1. Age range distribution of participants.

Figure 1 illustrates the age distribution of the respondents. Most of the participants fell into the 30-39 (29%) and 40-49 (31%) age ranges. Less than 1% of participants were under 20 years of age. Only 5% of participants were 60 years of age or older. Participants were also asked

about their years of experience (Fig. 2). Most participants had between 10-19 years of experience (33%), with 20-29 years of experience closely following (29%). Nineteen percent (19%) of participants had less than 10 years of experience, and only 4% had more than 40. Participants' city of service was assigned to a region of the United States (Northeast, 21.4%; Midwest, 24.3%, South, 35.6%, and West, 18.8%) for geographical analysis of station wear use and selection.

Station Wear Selection

The station wear selection portion of the questionnaire gauged participants' familiarity with and awareness of NFPA 1975 and gathered information regarding how and why fire fighters selected their current station uniform. This section also asked questions

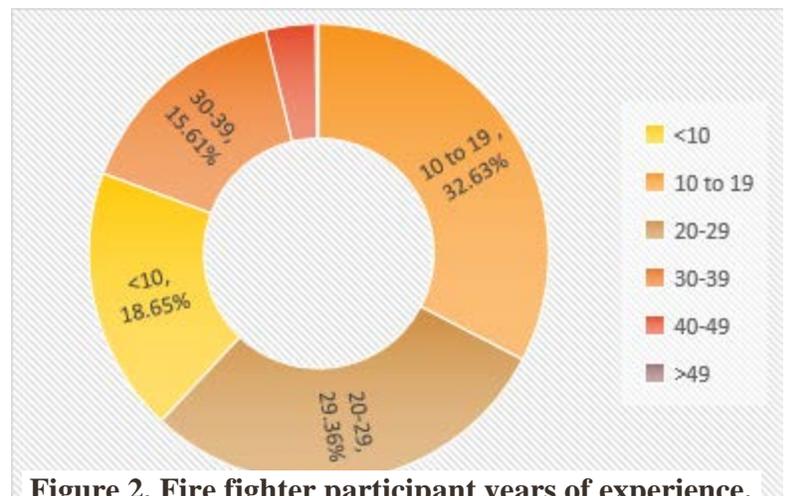


Figure 2. Fire fighter participant years of experience.

pertaining to whether participants' station uniforms are NFPA 1975 certified (including FR) or not. Several responses were broken down in terms of department type (career vs volunteer) and region of the United States (Northeast, Midwest, South, or West).

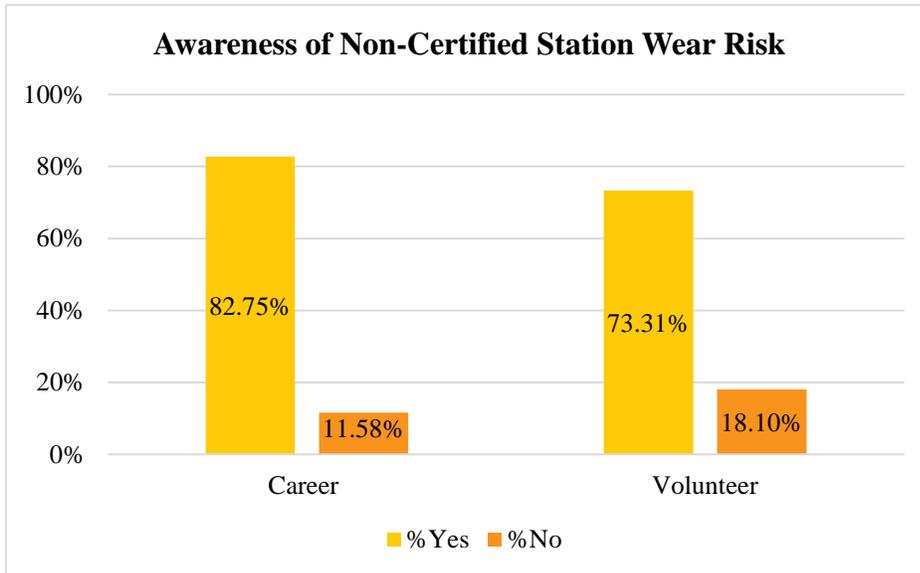


Figure 3. Risk awareness of non-certified station wear by department type (career versus volunteer).

Seventy-two percent (72%) of participants indicated that they were familiar with NFPA 1975. Seventy-three percent (73%) of career fire fighters were familiar with the standard compared to just 66% of volunteers.

Eighteen percent (18%) of volunteer fire fighters also indicated that they were not aware of the risk associated with wearing non-certified station wear, while less than 12% of career fire fighters were unaware. Overall, 80% of respondents were aware of the risk of wearing synthetics, or station wear that does not meet the “no melt, no drip” thermal stability requirements specified in NFPA 1975 (Figure 3). Many of the respondents who selected “other” expressed in the comments that they were only somewhat familiar with the standard, or were aware of its existence but not its specifics. Almost 20% of participants were not aware or unsure of the risks associated with wearing non-certified station wear underneath their turnout suit ensemble.

The majority of participants (49%) indicated that they do not work in a department where everyone wears the same base layer garments. Forty-five percent (45%), however, do wear the

same base layer as their coworkers. When broken down by commitment level, the difference is drastic. Fifty-three percent (53%) of career fire fighters wear the same base layers as their coworkers, compared to only 11% of volunteer fire fighters. Overall, 72% of participants indicated that their organization either provides or requires a specific type of station wear. A quarter of the respondents work in a department/organization that does not provide or specify the work clothing worn underneath their turnout suit. Similar to the previous question, there is a noticeable difference between career and volunteer departments. Eighty-five percent (85%) of career fire fighters that work in a department where everyone wears the same base layer also receive station wear or specific requirements from their fire authority having jurisdiction. Meanwhile, only 22% of volunteer fire fighters who wore the same base layers had a uniform provided or required by their fire organization.

Of the participants who answered that their fire organization provides or requires specific station wear, only 38% of these fire fighters (career and volunteer) were required by their department to wear NFPA certified garments. Forty-five percent (45%) of participants who were provided station wear, or given station wear requirements, were not required to wear NFPA 1975 certified uniforms, while 15% were unsure. When comparing career and volunteer fire fighters, 44% of career fire fighters indicated they were not required to wear certified or flame resistance station wear, whereas over 55% of volunteer fire fighters, that were provided or required to wear a specific base layer, indicated that these garments were not required to be thermally stable per NFPA 1975 certification.

Regardless of whether or not their organization provided their station wear or specified particular garments, only 28% of all respondents (n=1614) indicated that they were required to wear NFPA 1975 certified flame resistant (FR) station wear (Figure 4). The majority, at 63%, were NOT required to wear FR certified station wear. 34% of career fire fighters and 7% of volunteer fire fighters indicated that they WERE required to wear NFPA 1975 FR certified station wear.

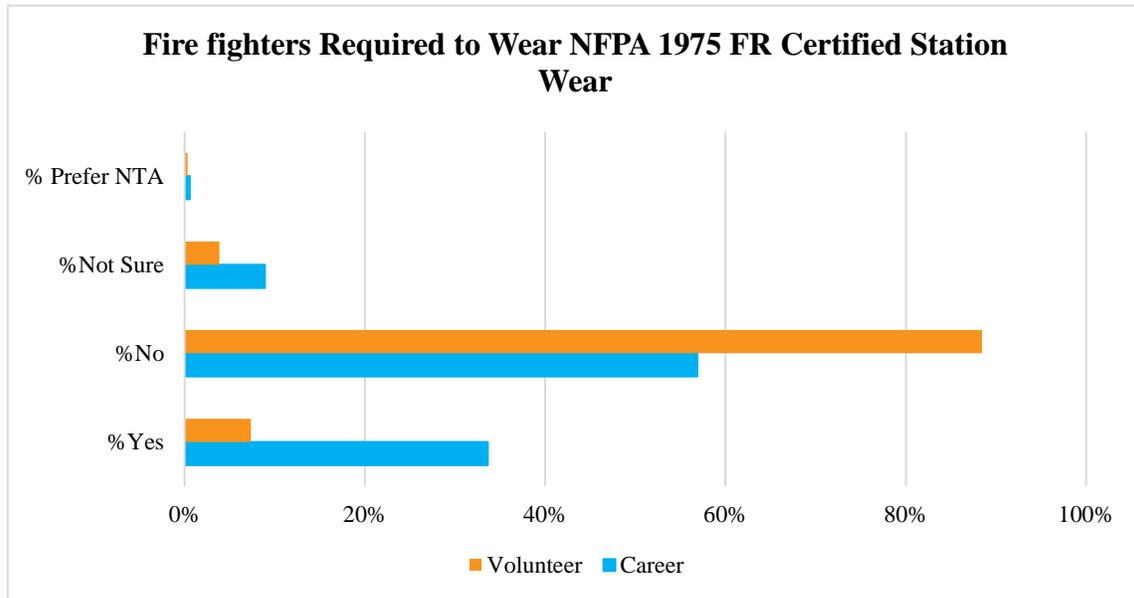


Figure 4. Percentage of fire fighters who indicated they are required by their department (career or volunteer) to wear NFPA 1975 Flame Resistant Certified station wear.

While significantly more career firefighting departments uphold these requirements, the majority of both career (57%) and volunteer (88%) fire fighters say that their department does not require FR certification. Those who indicated that they are required to wear certified FR station wear were asked to describe their garments. Many of the responses indicated 100% cotton and FR meta-aramid garments.

Those who answered that they were not given any requirements by their fire authority were asked if their departments have considered or wear-tested certified station wear. Of the 25% of fire fighters who do not have any requirements from their organization, the majority do not work in a department that has considered or wear tested certified station wear. However, 33% have

conducted wear testing and discussed why their organization chose not to adopt NFPA 1975 certified station wear. The majority of respondents mentioned that the cost of certified station wear was not feasible. Several others explained it was due to a lack of comfort.

Fifty-six percent (56%) of participants had their current station wear chosen for them (Figure 5). Fifteen percent (15%) chose their own and 13.6% purchased their own. Fourteen point eight percent (14.8%) had their current station wear given to them. When comparing career and volunteer fire fighters, 65% of career fire fighters indicated their station wear was chosen for them while that percentage was less than 20% for volunteer fire fighters. Forty-two percent (42%) of volunteer fire fighters indicated that they were left to choose their own base layers, compared to only 9% of career fire fighters. Twenty-six percent (26%) of volunteer fire fighters and 11% of career fire fighters purchased their own station wear, while 15% of career fire fighters and 12% of volunteer fire fighters had theirs given to them.

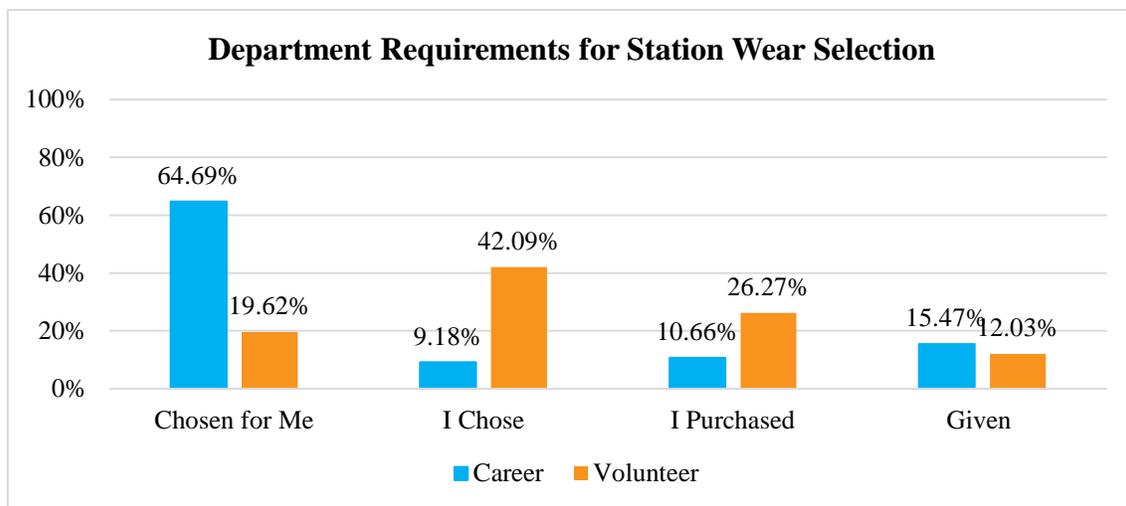


Figure 5. Station wear selection by department type (career versus volunteer).

The final question in the “Station Wear Selection” section of the questionnaire asked participants to indicate the level of importance they place on comfort, mobility, and protection when selecting their station wear. Overall results (Figure 6) indicate that mobility (74%) and comfort (70%) are more important when selecting station wear compared to thermal protection,

with only 50% of fire fighters indicating safety/protection was “very important.” More participants were “neutral” when considering the thermal protection (19%) of their station wear versus when considering the comfort and mobility (4.7% and 4.4%, respectively). The mean value of fire fighters’ responses about the selection of their station wear indicated higher importance was placed on comfort (mean: 4.48 ± 0.93) and mobility (mean: 4.57 ± 0.86) compared to protection (mean: 4.11 ± 1.06).

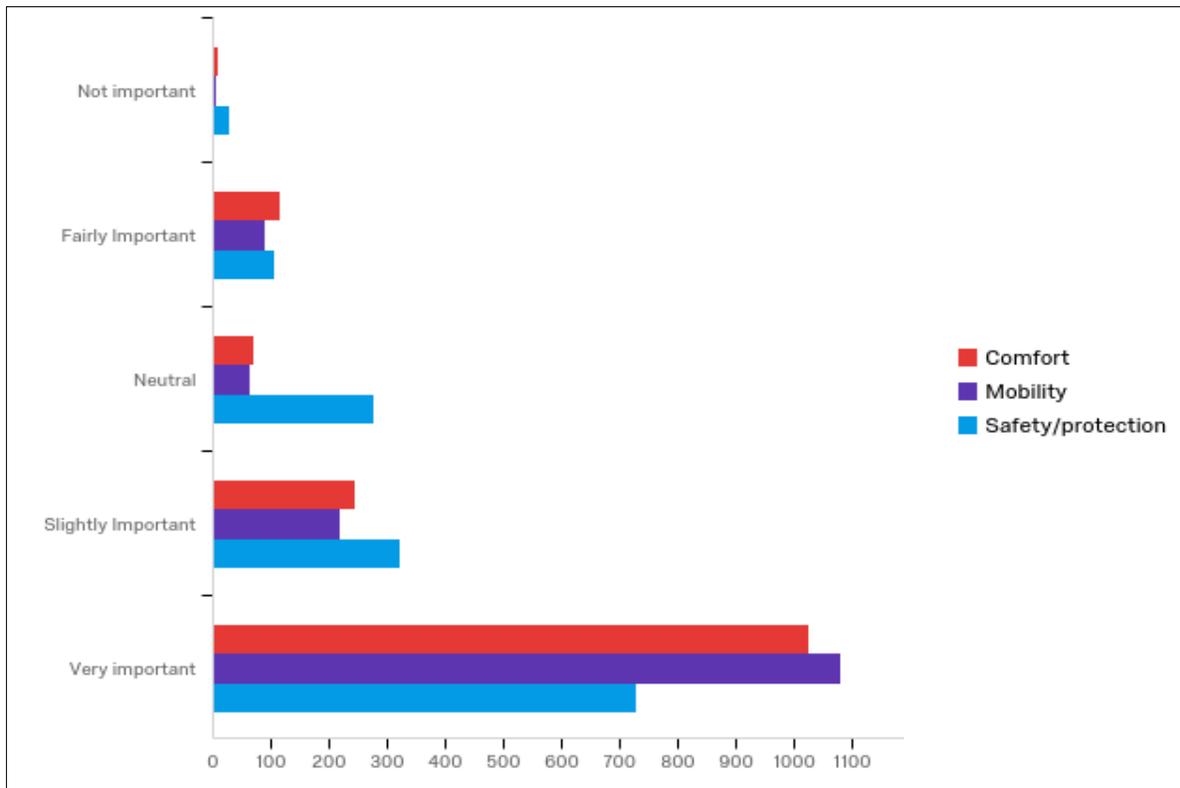


Figure 6. Importance of comfort, mobility, and protection when selecting station wear.

When broken down by region, comfort was rated “very important” by 73% and 72% of fire fighters in the South and West, respectively; only 67% of fire fighters in the Midwest and Northeast indicated comfort was “very important” when selecting their station wear (Figure 7). Mobility was rated as “slightly important” by 13-15% of fire fighters in all regions; and as “very important” by 70-77% of fire fighters in all regions. Fifty-two to fifty-five percent (52-55%) of fire fighters in

the South and West regions rated protection as “very important” whereas only 43-48% of fire fighters in the Northeast and Midwest felt it was a very important factor when choosing their base layers. Overall, there were no statistically significant differences ($p < 0.05$) in importance factor selection between fire fighters in the Northeast, Midwest, South, or West (Figure 7).

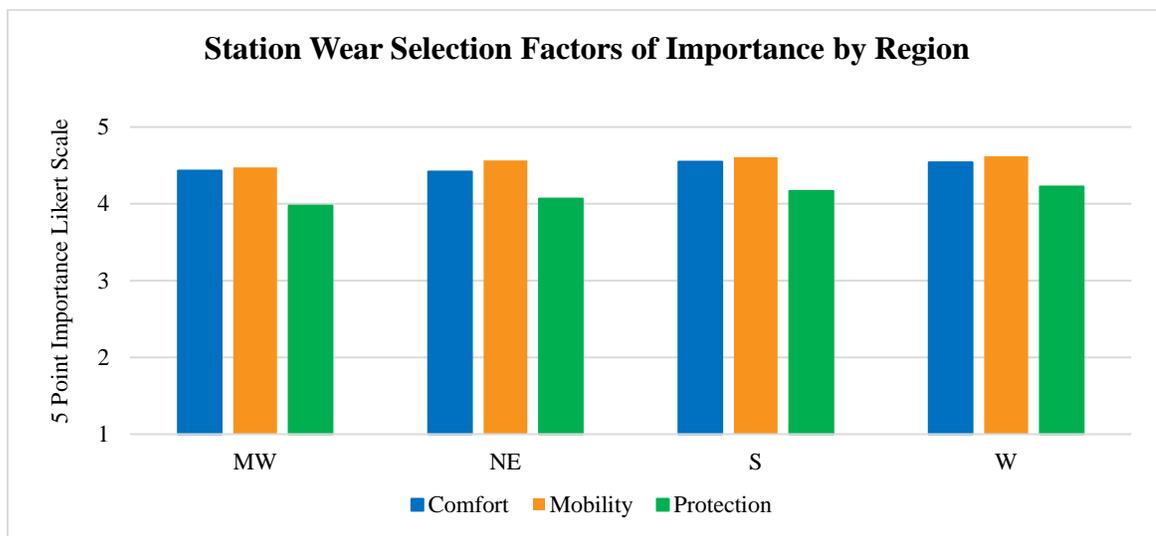


Figure 7. Station wear selection importance by region.

Station Wear Use

The questionnaire continued by asking participants to describe the garment configurations of their station uniforms (i.e., short sleeve versus long sleeve; single layer versus multi-layer, etc.). For improved analysis, the responses of participants who indicated they were wildland fire fighters or participated in wildfire suppression activities were removed from the overall response analysis to prevent bias in the data.

The frequency and timeline of wearing shorts was asked of each participant. Thirty-five percent (35%) of fire fighters (the majority) indicated that they sometimes wear shorts underneath their turnout suit, followed by 22% that never wear them, 16% that rarely wear them, 12% that very frequently wear them, and 3% that always wear them. Participants indicated that the peak

months for wearing shorts are between May and September. The frequency of wearing shorts was normalized by region and results indicated that fire fighters in the West are more likely to “sometimes” wear shorts (42%), followed by fire fighters in the Northeast and South (39%), and Midwest (35%) regions. Only 11% of fire fighters in the West report that they “never” wear shorts, followed by 22% in the Northeast, 25% in the South, and 30% in the Midwest.

Similar questions were asked regarding short versus long sleeve shirts. Forty-eight point four percent (48.4%) of participants indicated that they wear short sleeves under their turnout suit, but many of the free responses described that it is largely dependent on the weather (Figure 8).

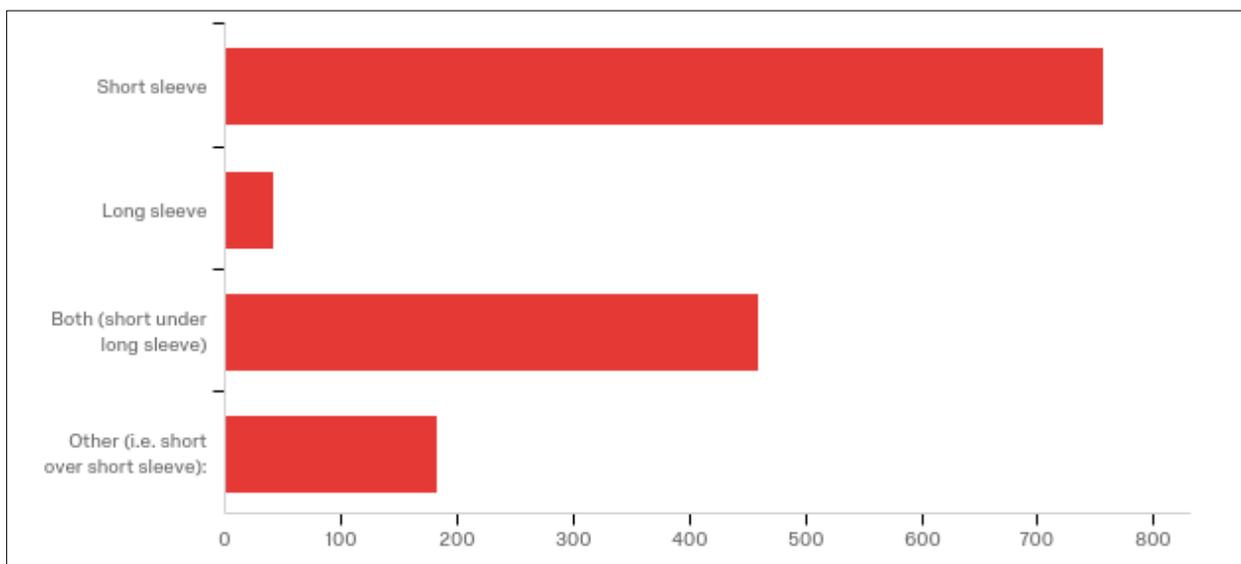


Figure 8. Fire fighters who wear short sleeves, long sleeves, or a combination of both.

Likewise, 39% of participants stated that they sometimes wear long sleeves under their turnout suit, but that they only do so when the temperature is cooler. Fire fighters were then asked to describe which months they wore short sleeves. Unlike the shorts versus pants question, the differences between months were minimal, indicating that the amount of fire fighters who wear a short sleeve shirt from month to month remains more even. Alternatively, the responses when asked which months one wears long sleeves varied dramatically. Responses indicated a spike

between November and March, during the winter months, for wearing long sleeves. When analyzed by region, fire fighters in the Northeast and Midwest were more likely (44%) to wear long sleeves than their counterparts in the South (40%) and West (39%). Twenty-eight percent (28%) of fire fighters in the West indicated they “never” wear long sleeves, followed by 18% of fire fighters in the South, 14% in the Midwest, and 12% in the Northeast.

At 44%, the majority of fire fighters indicated that they do not wear a short sleeve T-shirt underneath a long sleeve station shirt, while 39% responded that they do wear two layers—a base layer t-shirt and a long sleeve station wear shirt. By region, this data varied: 45% of fire fighters in the Northeast indicated they wear a long sleeve shirt on top of a short sleeve T-shirt while only 16% in the Western region indicated such a double-layer shirt configuration. Sixty-eight percent (68%) of fire fighters in the West and 55% in the South responded that they do not wear a long sleeve shirt over a T-shirt. Overall, only 15% of respondents “sometimes” wear a long sleeve shirt over a short sleeve shirt.

When asked which shirt configurations the fire fighters wear most often at the fire station, 38% indicated that they only wear a T-shirt, while 51% indicated that they wear both a T-shirt and a station wear shirt. Very few chose other responses. The regional analysis followed a similar trend as previous questions with fire fighters in the West indicating they wear a T-shirt at the station more often (55%) than their counterparts in other regions (37-45%). Fire fighters wearing both a T-shirt and station wear shirt at the fire station were most likely to work in the Midwest (57.5%) followed by the Northeast (49%), South (44%) and then the West (39%).

Fire fighters were then asked what shirt configurations they most often wear underneath their turnout suit (Figure 9). Sixty-one percent (61%) said that they wear only a T-shirt, while 30% wear their station shirt and a T-shirt (two layers). Eighty-eight percent (88%) of fire fighters in the Western part of the U.S. indicated they only wear a T-shirt underneath their turnout suit followed by 67% in the Midwest, 66% in the South, and 60% in the Northeast. Only 8% of fire fighters in the West wear both a short sleeve T-shirt and a station wear shirt underneath their bunker gear with the majority of fire fighters adopting this configuration in the colder, Northeastern part of the U.S. (35%). Of the wildland fire fighters who participated in the study, 38% indicated that they wear only a T-shirt underneath their gear, while 53% did not find that the question was applicable.

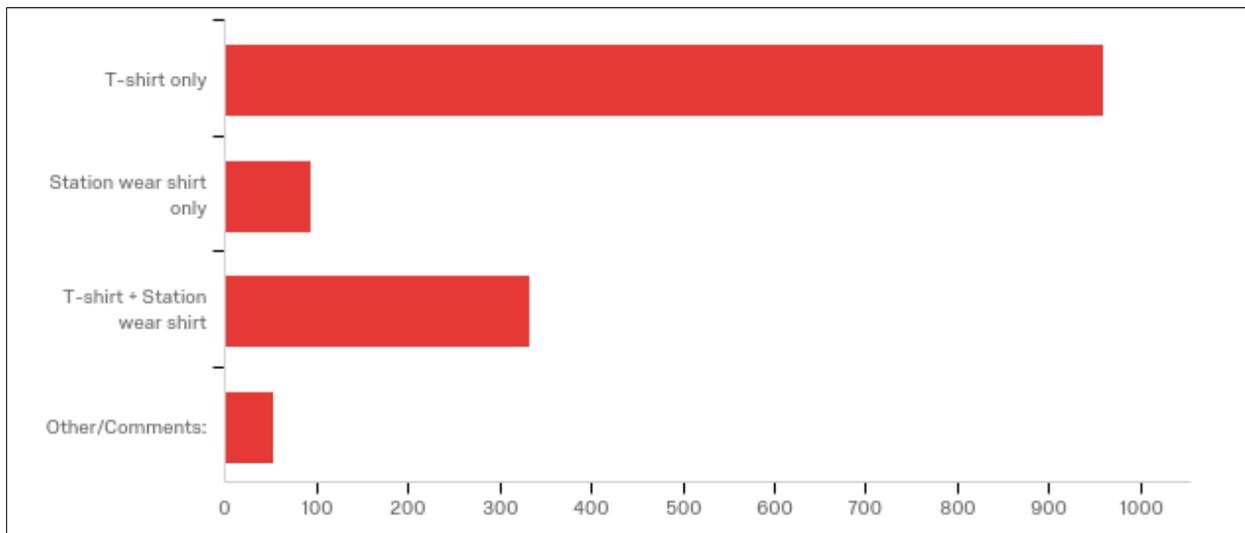


Figure 9. Fire fighters who wear short sleeve, long sleeve, or a combination of both underneath their turnout suit.

Station Wear Material

In the fourth section of the questionnaire, participants were asked questions regarding the materials that they wear and/or prefer to wear underneath their turnout suit or as station wear. At 48%, the majority of fire fighters do not wear a station uniform that is certified flame resistant (FR) according to NFPA 1975. Twenty-nine percent (29%) (406/1406) did indicate wearing a

certified FR uniform while 23% were unsure and 1% preferred not to answer. This data varied greatly by region (Figure 10) with 65% of fire fighters in the West indicating they wear NFPA 1975 certified FR station wear, followed by 27% in the South, 17% in the Northeast, and 14% in the Midwest.

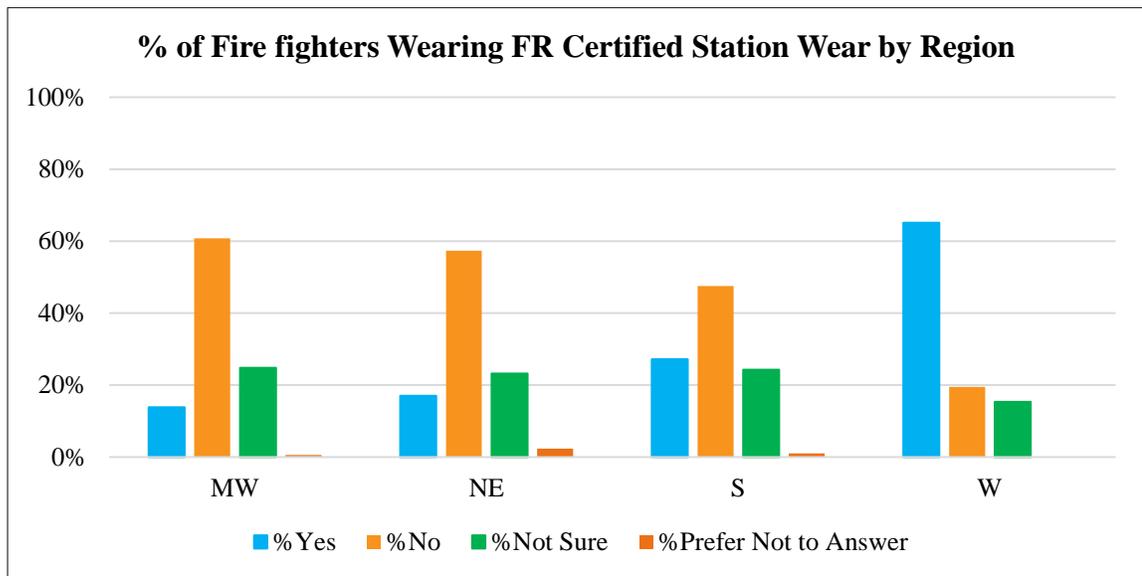


Figure 10. Percentage of fire fighters wearing NFPA 1975 flame resistant (FR) certified station wear by region (Midwest, Northeast, South, and West).

Participants were asked to describe the fiber content of their station wear. Thirty-one percent (31%) of participants responded that at least one of their garments was 100% cotton. At 43%, the majority of participants answered that at least one of their garments was a cotton/polyester blend and of those, 60% said they wear a 50% cotton/50% polyester blend. Overall, 26% of all responses mentioned a 50% cotton/50% polyester blend. Meanwhile, only 4% of participants reported wearing a 100% polyester garment. Eleven percent (11%) of responses mentioned wearing a flame resistant meta-aramid material, and only 3% described wearing an aramid fiber blend. Less than 1% of participants wear wool garments, while 5% wear a different fiber or blend. Nine percent (9%) of participants either did not know or did not find this question to be applicable.

When asked if they prefer synthetics over natural fibers, 55% of fire fighters answered that they do not, while 26% answered that they do. Those that answered “yes” were asked to elaborate on why they prefer synthetics. Sixty-one percent (61%) of participants indicated that they value synthetics for their comfort properties, such as fabric weight and hand. Forty-nine percent (49%) elaborated that they value the thermal comfort (coolness) of synthetic shirts. Twenty percent (20%) of participants explained that they value the mobility of synthetics; while 17% listed the moisture, management capabilities of synthetics for why they prefer to wear them as their station wear. Sixteen percent (16%) of participants indicated that they value the durability properties of synthetics, such as colorfastness and longer wear life, compared to certified uniform materials. Four percent (4%) of participants mentioned the design of synthetic apparel and 4% mentioned the breathability. Two percent (2%) of participants mentioned the fit of synthetic apparel, while less than 2% mentioned cost or wrinkle resistance. When broken down by region, there were no significant differences in preferences between fire fighters in different parts of the United States, with 24-29% indicating they prefer synthetics and between 51-60% indicating they prefer cotton or wool (natural fiber) station wear.

Participants were then asked if their station uniform had a printed graphic located somewhere on the surface. Seventy-five percent (75%) of participants answered that their uniform does have a printed graphic. Those that answered “yes” were asked to describe where the graphic was located. Eighty-seven percent (87%) of participants answered that a graphic was located somewhere on the chest. Of those, 56% specified that the graphic was located on the left breast of the shirt, while 7% specified that the graphic was located on the right. Many of these participants noted that there was a graphic on both the left and the right sides of the chest. Seventy-one percent (71%) of participants indicated that there is a graphic located on the back of their station wear. A

common configuration was a graphic on both the left breast and the back of the shirt. Four percent (4%) of participants had a graphic on the pants of their station wear, while 13% had a graphic on the sleeve(s) of their shirt. Some participants described different locations on different garments, such as pullovers and sweatpants.

Station Wear Design

The design portion of the questionnaire asked fire fighters about their satisfaction with their current station wear and to indicate which features were most important to them for their station uniforms (i.e., protection, comfort, moisture management, mobility, aesthetics, etc.). Participants were first asked to rank their satisfaction with their current station wear according to the following features: comfort, mobility, and safety/protection (Figure 11). Seventy-three percent (73%) of fire fighters indicated that they were “satisfied” or “very satisfied” with the comfort of their station wear. Similarly, 76% indicated that they were “satisfied” or “very satisfied” with the mobility of

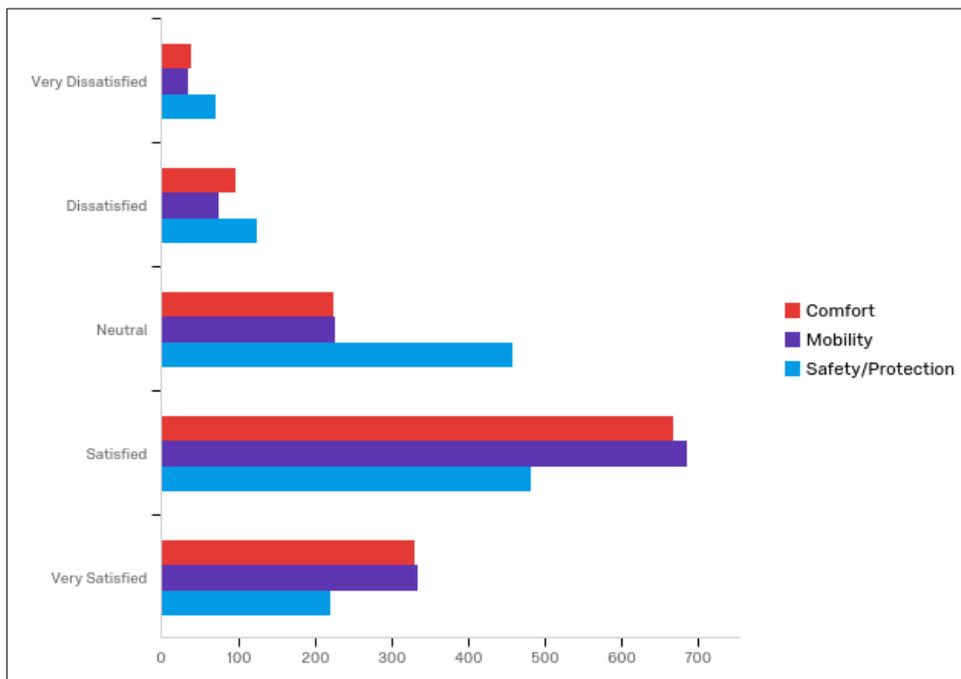


Figure 11. Fire fighters’ satisfaction of current station wear pertaining to comfort, mobility, and protection.

their current station wear. However, only 52% indicated that they were “satisfied” or “very satisfied” with the safety/protection aspects of their station wear.

These results are interesting in comparison with the results of the importance fire fighters place on these same three factors—comfort, mobility, and protection—when selecting their gear. Overall, participants indicated that they place greater amounts of importance on comfort and mobility during selection and are more satisfied with these factors compared to the safety and protection they feel they are currently being provided. However, they did not place as large of a value of importance on protection when selecting their station wear.

When station wear satisfaction results were broken down by region, differences were negligible for comfort and mobility. For thermal protection, however, more fire fighters in the Western region (47%) were “satisfied” with the safety of their station wear compared to fire fighters in other regions of the U.S. (30-34%). In fact, 25% of fire fighters in the West indicated they were “very satisfied” with the protection of their station wear compared to only 11% in the Northeast and 14%-15% in the Midwest and South, respectively. The results did not indicate, however, that fire fighters in other regions were more dissatisfied with the thermal protection of their station wear, but instead, that they were more “neutral” regarding this performance aspect of the garments.

When analyzed by department type, career fire fighters were more “dissatisfied” (8.4%) and more “satisfied” (50.4%) with the comfort of their station wear than their volunteer counterparts who were found to be more “neutral” (26%). The comparison of the comfort satisfaction of station wear between department types may be skewed by the fact that more career fire fighters are required to wear the same base layers; these garments are more likely to be NFPA 1975 certified or specified by the fire authority having jurisdiction. Volunteer fire fighters often

respond in their street clothes, which are likely to be more comfortable than department issued or required clothing, as volunteers have more of a choice in what they are wearing as base layers.

Volunteer fire fighters tended to be more “neutral” when rating the satisfaction of the mobility of their station wear as well, with career fire fighters having a stronger opinion one way or the other (dissatisfied or satisfied). In relation to previous results which indicate career fire fighters are more likely to be provided flame resistant and thermal protective station wear, volunteer fire fighters were less satisfied (38%) with the safety and protection of their station wear compared to their career fire fighter colleagues (55%).

Fire fighters were then asked to choose the top three features they felt were important in a station wear uniform (Figure 12). The features to select from included: thermal protection, liquid protection, chemical/biological contaminant protection, comfort (breathability), moisture management, mobility and range of motion, design and aesthetic appeal, and other/comments.

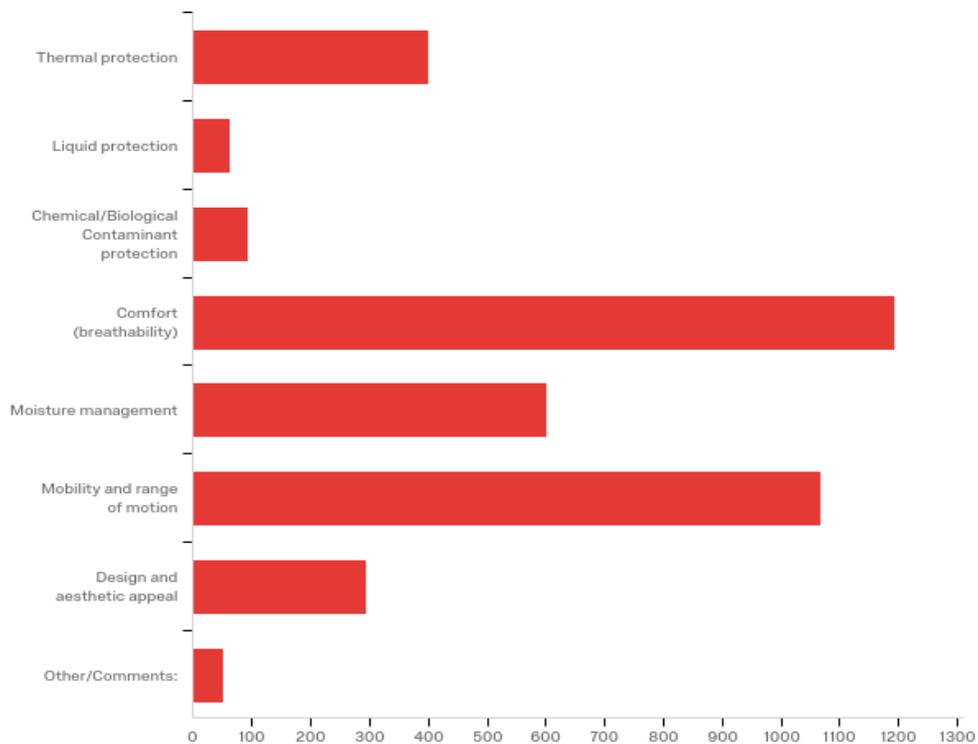


Figure 12. Most important features identified by fire fighters when selecting station wear.

The most common top three choices from all participants were #1) comfort/breathability (31.7%; 1193/3769), #2) mobility/range of motion (28.3%; 1068/3769) and #3) moisture management (16%; 603/3769); these were followed by #4) thermal protection (10.6%; 401/3769) and #5) design/aesthetic appeal (7.8%; 295/3769). Fewer participants indicated that chemical/biological contaminant (2.5%; 93/3769) and liquid (1.7%; 63/3769) protection were most important. The order of importance of these features did not differ by department or commitment type.

Analysis of the most important feature by region of the U.S. indicated that fire fighters in the Midwest value “comfort (breathability)” (64.6%) as the top feature for station wear performance, more so than fire fighters in other regions (South, 59.2%; West, 56.7%; Northeast, 53.6%). The second most important feature listed first, if not “comfort,” was “thermal protection.” Fire fighters in the Northeast (34.1%) selected “thermal protection” as the number one most important feature for their station wear more often than fire fighters in the other regions (West, 31.2%; South, 29.8%; Midwest, 24.5%). Overall, no matter the region, participants of the questionnaire valued comfort (58.9%), as the number one most important feature.

Participants were also given the option to write in their own comments. Many fire fighters mentioned that an important feature to them is the durability of the product. Some wrote that compliance to their uniform policy is their main concern. Two participants mentioned cost, and two mentioned that they value wearing something that is not carcinogenic.

When asked if their current station wear provides sufficient thermal protection, 40% of participants answered no, while only 36% answered yes. The remaining 24% responded “not sure” and “prefer not to answer.” Volunteer fire fighters were much more likely to respond that their

station wear does not provide adequate thermal protection (53.2%) compared to career fire fighter respondents (36.3%). By region, participants from the West felt their station wear provided sufficient thermal protection at a rate (55.3%) significantly higher than participants from other regions (South, 36.9%; Northeast, 29.1%; Midwest, 25.9%). Only 23.7% of fire fighters in the Western region of the U.S. felt their station wear does not provide sufficient thermal protection with the overall average of all participants who answered “No” being 40%.

Additional analysis was conducted to determine if fire fighters who did NOT perceive their current station wear as providing sufficient thermal protection (40% of all respondents) were a) aware of the risk of wearing non-certified garments, b) if their department provided or specified their station wear, c) if they wore NFPA 1975 certified station wear, and d) how their station wear was selected. Fire fighters who did NOT perceive their current station wear as providing sufficient thermal protection were found to be primarily aware (76.9%; 409/532) of the risks associated with wearing non-certified station wear. The majority of these participants (57.5%) were also provided or instructed to wear specific station wear while 36.3% were not. Of those who were dissatisfied with their station wear’s thermal protection, 71.6% did NOT wear a NFPA 1975 certified station uniform; less than 20% who were dissatisfied with their current station wear’s thermal protection were wearing NFPA 1975 certified garments. Of those 532 fire fighters dissatisfied with their station wear’s thermal protection, only 27% (144) chose and/or purchased their own; 65.8% (350) indicated their station wear was chosen for them or given to them.

Overall, these results indicate fire fighters are not as confident or aware of whether or not their station wear provides sufficient thermal protection. Those who elaborated on their answer within the comments often explained that they are not sure how they feel regarding the thermal protection of their garment. Many mentioned that they do not know whether their station wear is

flame resistant, what standards it has been tested to, or simply have not had to wear it in a fire emergency situation. Others expressed that they do not expect their station wear to provide thermal protection. Those that were satisfied explained that they have not had any poor experiences with their station wear or that they are satisfied with it because they know that it is certified according to NFPA 1975 requirements. Participants mentioned synthetics in both a negative and positive manner. Some felt like their station wear could harm them if the synthetic material melts, while others were confident that their synthetic garments would protect them appropriately.

When asked the same question in regards to comfort, 78.6% of respondents indicated their current station wear provided sufficient comfort while 16.5% responded that it does not. Differences in responses by department type (career versus volunteer) were negligible. By region, differences were also minimal, with fire fighters from the South (20.2%) more likely to report the comfort of their station wear was not sufficient (17.8%, Northeast; 16.3% West, 10.7%, Midwest).

Participants were invited to elaborate on why they were or were not satisfied with the comfort of their station wear. Those who were satisfied listed features such as mobility, breathability, softness, water resistance, and lighter weight. Some mentioned that they use shirts with “moisture management abilities,” although the measurement of such properties has not been well defined or standardized in the textile testing industry, and those garments that are “well-suited for daily weather and heat.” Others specified that they like the feel of cotton. It should be noted that the statements made above by participants completing the survey may support the selection of non-certified station wear uniforms that pose a potential risk for burn injuries. Those who were not satisfied mentioned that their station wear is irritating to the skin, stiff, heavy, and fits poorly. A few explained that while their station wear is sufficiently comfortable now, it takes a while to break it in. This statement was applied particularly to flame resistant meta-aramid materials. Others

mentioned that poor durability and shrinkage compromise the comfort of the garment. Many participants referred to their station wear's poor ability to transfer heat and cool down the body.

Similar additional analysis was also conducted for this question to determine if fire fighters who did NOT perceive their current station wear as providing sufficient comfort were a) aware of the risk of wearing non-certified garments, b) if their department provided or specified their station wear, c) if they wore NFPA 1975 certified station wear, and d) how their station wear was selected. Fire fighters who did NOT perceive their current station wear as providing sufficient comfort were found to be primarily aware (75.6%; 170/225) of the risks associated with wearing non-certified station wear. The majority of these participants (77.8%) were also provided or instructed to wear specific station wear while 17.8% were not. Of those who were dissatisfied with their station wear's comfort, the majority (54%) WERE wearing NFPA 1975 certified garments. Of those 225 fire fighters dissatisfied with their station wear's comfort, only 17% (38) chose and/or purchased their own. Seventy-eight percent (78%) (176) indicated their station wear was chosen for them or given to them.

Finally, participants were asked if they would sacrifice the heat resistance of their station wear in order to improve their comfort. The majority of respondents (43%; 586/1361) indicated that they would make this sacrifice, while 35% would not and 21% were not sure. Career fire fighters were more likely to be willing to make this sacrifice in thermal protection for improved comfort (45.8%) than volunteer fire fighters (31.8%). Fire fighters in the West were less willing ("No": 43.1%) to sacrifice heat resistance for improved comfort than fire fighters in other regions of the U.S. (Northeast, 34.4%; South, 33.8%; Midwest, 30%). Similar to the previous questions, participants were asked to elaborate on whether or not they would sacrifice the heat resistance of their station wear in order to improve their comfort. Those who would not sacrifice the heat

resistance of their garments explained that they do not want to risk wearing something that might melt and cause further injury. Many mentioned that they would be able to adapt to slightly less comfort so that they can prioritize their own safety. However, those who would readily sacrifice heat resistance often felt that if the fire was hot enough to the point of affecting the station wear, then they would likely already be seriously injured or possibly deceased. Many fire fighters feel as though it is the job of the turnout suit to provide the majority, or all of the thermal protection, and that station wear will not make a difference.

Base Layers and Wildland Firefighting

The next section of the questionnaire, “Base Layers and Wildland Firefighting,” was completed only by those fire fighters who indicated that they engage in wildfire suppression activities. Participants were asked in this section about their involvement in wildfire emergencies and the base layers that they wear underneath their wildland fire gear. Thirty-nine percent (39%) (530/1355) of questionnaire participants responded that they engage in wildland firefighting activities and were asked to answer several questions relevant to that type of work. These participants were asked to describe the frequency at which their department responds to wildfire emergencies. The responses were highly varied. Few participants answered that they encountered wildfire emergencies “very infrequently,” only engaging in this sort of activity a few times per year. Many indicated that they respond to wildfire emergencies very often during high-risk seasons, while others answered that they respond to wildfires on a daily or weekly basis year-round. Responses ranged from once or twice per year to hundreds of times per year.

Participants were then asked to describe the base layers that they wear underneath their wildland firefighting ensemble by checking all options that applied or by adding a comment (Figure 13). Forty-one percent (41%) of wildland fire fighters wear a short sleeve shirt while 12%

wear a long sleeve shirt. Only 2% (23 participants) indicated that they wear more than one shirt layer. When comparing base layer pant configurations, only 8% of wildland fire fighters wear shorts, compared to 31% that wear long pants. Only 2% indicated that they wear more than one pant layer. The open-ended comments indicated that many fire organizations have their fire fighters wear structural firefighting gear while responding to wildfire emergencies, as they do not have wildland gear. Other responses explained that many fire fighters prefer to wear undergarments only underneath their wildland pants.

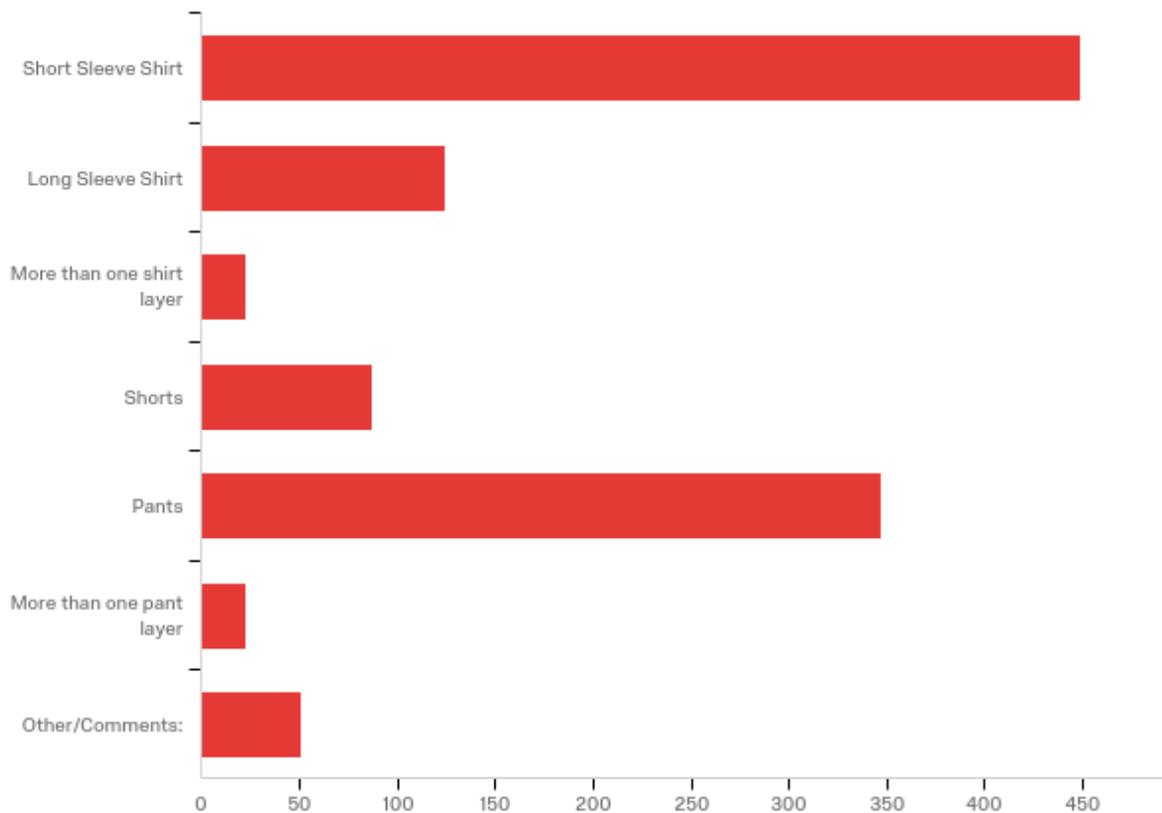


Figure 13. Base layer configurations worn underneath wildland firefighting ensemble.

When asked to indicate whether or not the station wear worn under their wildland ensemble is NFPA 1975 certified, 64% of wildland fire fighters indicated that their station wear is not certified. Only 20% (106/523) answered that they wear certified station wear underneath their wildland firefighting ensemble, while 10% were unsure. Many of the open-ended comments

explained that only one garment, such as either the shirt or pants, is certified while the other is not. Those who answered “yes” to this question were asked to indicate whether or not their certified station wear was also certified flame resistant. At 67% (70/104) the majority answered that the certified station wear they wear underneath their wildland firefighting ensemble is also certified flame resistant. Only 13% answered that their certified station wear is not also certified flame resistant, while 14% were unsure.

Fire fighters who participated in wildfire suppression activities were also asked if they wore different base layers for wildland fire responses compared to structural fire responses. The majority (79%; 407/515) of participants indicated that they do not wear different station wear or base layers for different response types (wildland versus structural). This did not differ between department types (career versus volunteer). For those participants who indicated they did wear different base layers for different response types, they were asked to describe in detail the differences between them. Several participants explained that they do not wear an extra layer of pants for wildland fire responses, but that long pants are required. Many participants indicated that they wear long sleeved shirts for wildland fire responses, but can choose another option for structural responses. More fire fighters indicated that they use garments made from a flame resistant meta-aramid material for wildland responses than for structural responses. Participants described T-shirts underneath their structural gear, along with the option of wearing pants, shorts, or undergarments.

Those who answered “no” when asked if they wore different base layers for different responses were asked to explain whether or not they felt they would benefit from having different garments for different operating situation. Some indicated that they would like to have base layers with improved features such as flame resistance, moisture management, and comfort. Several

participants explained that they would like to see these changes in base layers for wildland responses, as they wear their structural base layers for wildland calls. Those who answered “yes” felt that the base layers should match the level of protection and physical expectation required by the activity. The majority answered that they see no need to change. Several elaborated on this and explained that with correct outerwear and situational awareness, there would be no additional benefit to having different base layers.

Open-Ended Questions

The final section of the questionnaire consisted of five open-ended response questions. Each question was individually coded by three separate researchers per the interpretive thematic analysis method. Coding categories, or themes, were established with underlying subcategories to identify specific issues. Coding categories were mostly similar for all open-ended questions with few differences depending on the specific context of the question. Main coding categories (themes) for all questions were identified as: cost, comfort, durability, mobility, protection, cleaning, design, fit, materials, education, and awareness. Within these main themes, subcategories were identified. For comfort, these subcategories included specific issues related to breathability, moisture management, wicking, lightweight, and heat stress. Durability was broken down by colorfastness and abrasion. Issues were separated between thermal, chemical, and liquid for protection. Within cleaning, differences between laundering and repair issues were identified and coded separately. Within design, a specific issue pertaining to aesthetics was identified by participant comments. Sizing was included as an issue under the main theme of fit. Within materials, mention of specific fibers was broken down by: cotton, wool, FR fibers/aramids, synthetics, and blends. An additional subcategory under “Materials” of “screen print/embroidery” was added during coding of the responses.

Some questions demanded unique codes such as: NFPA (certified versus certified FR) and fire authority issuance/mandate were added for the first two questions, which pertained to changes in station, wear materials/design and reasons behind not wearing NFPA 1975 certified station uniforms. The question regarding awareness of burn injury incidents due to wearing synthetic station wear was primarily coded by awareness (those that were either aware or not aware) and broken down by participants being aware due to first-hand experience or witnessing such events versus awareness via publications, news articles, or second hand word of mouth. The awareness of incidents was also coded by their specific context: burns, wildland, and military, if provided by the participant. The open response questions asking for additional comments pertaining to station wear worn underneath structural and wildland firefighting ensembles, respectively, utilized the same initial code with additional categories relating to relevance, situational awareness (within education), and selection.

A synthesis of the overall responses for each open-ended question is provided below. Where appropriate, responses by theme and issue were quantified to provide a clearer understanding of the prevalence of such responses. Also, where appropriate, individual participant comments are given in quotations to highlight unique points or prevalent ideas identified by the majority of the comments.

Material and Design Changes: The first question asked participants, “If you could change the materials and/or design of your station wear, what would you change and why?” There were 792 relevant and appropriate responses to this question. Figure 14 illustrates the primary response code (meaning the most appropriate theme assigned if multiple codes were given to a single comment) percentages for all comments.

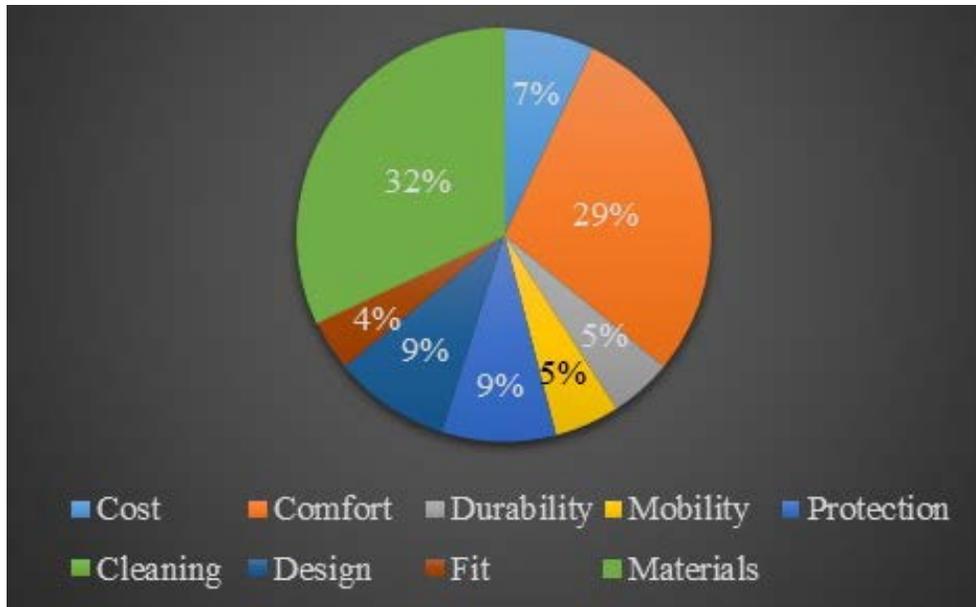


Figure 14. Percentage of primary response codes for station wear material/design changes.

From Figure 14, it can easily be identified that the majority of responses referred to material changes (32%) followed by improvements in comfort (29%). Forty (40) responses cited concerns over the cost of station wear, specifically the cost of purchasing NFPA certified garments. One participant explained, *“If the prices were the same, I would opt for fire resistant station wear. (...) The benefits do not justify the cost and the compliant uniforms have a reputation for being hot.”*

Comfort was identified as a primary issue that needed to be changed in over 165 responses (>32%). Breathability was identified *“as a must,”* and mentioned the most for improving comfort, followed by wicking, lightweight, moisture management, and heat relief issues. One participant even requested, *“The addition of vents and gussets to allow for more breathability and motion,”* which has recently been explored in structural turnout suits and demonstrated significant heat strain relief (McQuerry, Barker, & DenHartog 2018a, 2018b; McQuerry, Den Hartog, Barker, & Ross 2016; McQuerry, DenHartog, & Barker 2016b).

Durability is also very important: *“Station wear should be as comfortable and as durable as possible. This uniform is worn during apparatus and station maintenance and should be as durable as a good pair of jeans or work pants.”* Within the durability category, better colorfastness was cited frequently as the current materials (cotton and FR) tend to fade fast per the participants’ experience. As one participant explained durability and wear life directly relate to cost: *“I really want a material that is more durable than cotton. I spend a lot of money on 1975 uniforms, and they rip, tear, [and] fade way t[o]o fast.”*

Mobility was identified as a critical component of the materials and design of station uniforms; as one participant described, *“I think mobility is critical. I would like stretch material incorporated into station wear. Ergonomics is critical to mobility and efficiency. Restricted movement equates to body stress and energy loss.”* Other responses related to mobility requested more flexibility in the trousers; more elasticity, movement, and comfort; less stiffness of the fabric; gussets in the design for increased range of motion; and overall reduced bulk with a flexible fit.

Fifty-one (51) responses mentioned protection as being a primary factor that fire fighters would like to see changed or improved for their station wear. Overall, fire fighters were most concerned with the thermal protection of their station wear followed by the potential cancer causing contaminants in the flame retardant finishes applied to base layers that are worn against the skin. Liquid protection was mentioned minimally. Even when citing protection, fire fighters were still concerned with the impact that station wear has on their comfort, as one respondent described, *“I would prefer the greatest available heat and flame resistance while maintaining comfort.”* Others expressed a desire for greater heat resistance and increased thermal protection but that they are hindered by their fire organization’s selection of alternative materials for their

station wear: *“I would change them to something more heat resistant to provide better protection. We have tried in the past and were told that is what turnout gear is for.”*

Similar to protection, design specific changes were primarily mentioned in 52 responses (9%). Requested design changes included adding cargo style and more pockets to the pants, wearing shorts in the warmer months, changing the color to be either lighter or darker than their current uniforms, and moving towards more functional, less formal apparel for increased performance on the job. One participant explained, *“The fire service appears to be getting more and more formal for station wear. We have a button up Nomex® shirt we have to wear almost all day.”* Many responses contradicted one another with some fire fighters wanting to eliminate formal button-up station wear shirts while others desired them but requested a different material (100% cotton).

Fewer comments focused on fit and sizing with the majority of those pertaining to improved fit for female fire fighters. Participants also expressed wanting station pants that fit more like *“reasonably well fitted blue jeans - something that sits just slightly below the waist and that is somewhat form fitting but not tight.”* Others expressed a need for tall sizes.

The majority of all comments focused specifically on changing station wear materials. Preferences for materials were as varied as the participants themselves. Some fire fighters wanted to *“remove all synthetics,”* change to an *“all cotton uniform,”* or wear *“more polyester with moisture wicking capabilities.”* Forty-one percent (41%) (75/182) of comments were primarily coded as desiring 100% cotton station wear materials followed by 19% preferring a synthetic or synthetic blend, 18% requesting a flame resistant meta-aramid material or another FR material, and 2.7% mentioning wool. Other comments coded as “Materials” referred to changes in general and not by specific fiber content or material type.

One hundred percent (100%) cotton was the material that was mentioned most frequently. Fire fighters perceived cotton to have a better balance between protection and comfort than other material options. Most participants requested their station wear be changed to 100% cotton with improved mobility/flexibility in the form of a T-shirt design. These participants also expressed that station wear made with a flame resistant meta-aramid material was “*way too hot,*” whereas cotton provided better breathability and was perceived as being lighter weight. Those who desired 100% wool garments (only five comments) preferred it for cold weather/winter wear.

Fire fighters who requested FR meta-aramids or other FR materials did so for their enhanced protection, durability, and comfort. One participant described his experience with and preference for FR meta-aramid materials in detail: “*I had good experience in flame resistant Nomex®. It wore well with limited fading, shrinkage, etc. I would prefer to wear certified Nomex® over a cotton t-shirt or a certified base layer with wicking ability. The limiter is always cost. Nomex® lasts longer and would be more economical over a multi-year period, but the City, union, and line firefighters do not think that way.*” Another fire fighter described FR meta-aramids as the most favorable material for the following reasons, “*It's safer providing another layer of protection, it wicks well, breathes well, provides mobility and it looks more professional.*”

Others expressed a desire for synthetics and synthetic blends due to improved mobility and comfort. These respondents felt that, “*The thermal protection of the newer turnouts are sufficient enough to protect the firefighter. If that material starts to break down, we are in an environment that is too hot and dangerous already.*” One participant described his preference for synthetics justified by the need for improved thermal comfort and heat relief/retention: “*I do wear a lot of Under Armor and other wicking gear to help with moisture control and comfort. I think the trade-off can keep me safer from overheating or becoming hypothermic.*” Another participant faulted

the “over protection” currently provided in turnout suits for the reason behind burn injuries, *“Our garments are not the weak link. If anything the increase in thermal protection has caused firefighters to go farther and further than is reasonably safe, resulting in death or injury.”*

Within the materials section, comments pertaining to screen-printing, embroidery, and metal badges, pins, and name plates were individually coded. A total of ten comments mentioned the need to *“remove all screen printing,”* *“get rid of all metal nameplates and have them embroidered,”* and *“embroidery instead of silk screening.”* These desires to eliminate screen printing and metal were due to screen prints being melted by heat and metal heating up when near thermal exposure.

Additional comments for this question were primarily coded according to “No Change,” “NFPA,” “Fire Organization Issued/Mandated,” and “Education/Awareness.” One hundred thirty-nine (139) comments supported no change with current station wear, with some participants indicating station wear is, *“not a concern under bunker gear.”* One participant mentioned the desire to maintain his or her cotton station uniform because, *“over my 40 years the only time that I ended up in the hospital with 2nd and 3rd degree burns was while wearing a Nomex® uniform.”* Forty-eight (48) comments referred to the NFPA, and specifically to certified or certified FR uniforms, with most of these comments indicating a preference for 1975 compliant uniforms. Less than twenty (20) participants mentioned limitations due to the fire organization’s issuance/mandate of their station wear. Some cited being a volunteer department, affordability issues, city administration, and policy changes for reasons why they were not wearing certified station wear. A total of only three comments were related to lack of awareness and the need for more education on the standard’s requirements.

Reasons for Wearing a Non-Certified Station Uniform: The second open-ended question pertained to participants who choose to wear a non-certified station uniform. Fire fighters who indicated that they did not wear certified station garments were asked to explain why. The frequency of the most common cited reasons is displayed in Figure 15. Cost was the number one reason for not wearing NFPA 1975 certified station wear followed by comfort, materials, protection, design, durability, and mobility.

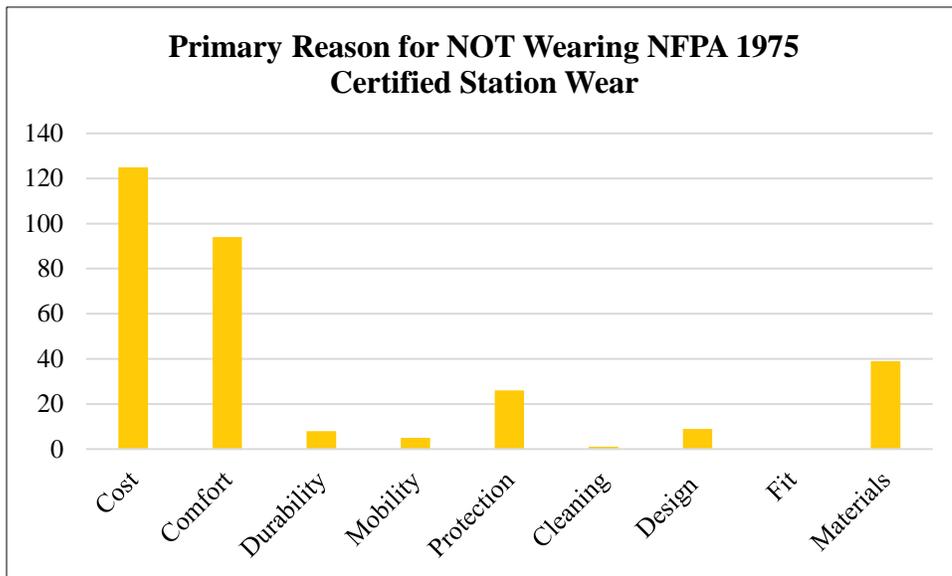


Figure 15. Frequency of responses by theme for not wearing a NFPA 1975 certified station uniform underneath NFPA 1971 turnout gear.

While many participants cited “cost” as the most frequent and primary reason for not wearing a certified station uniform or base layers, they also cited comfort, durability, and mobility as secondary reasons. Within durability, specific comments most frequently pertained to the lack of fade resistance of the color of the garments after repeated washings. As one participant described, “*Certified garments cost too much for which our budget cannot maintain when a pair of pants will not last 3-6 months in appearance. The washed out chalky look takes over so quickly with certified garments.*” Given the higher cost of certified uniforms and their perceived lower

durability (colorfastness), mobility (due to stiffness of the fabric), and comfort (heavier, less breathable) many participants choose not to wear an NFPA 1975 compliant station uniform. For example, some participants explained: *“Too expensive, may not be comfortable, not provided by department and if it was it wouldn’t be women’s size and style,”* and *“There are several reasons: cost of the garments, care and cleaning standards to ensure the garments maintain their protection, and unknown increased risk of cancers associated with chemicals associated with NFPA certified garments.”*

Fire fighters justified comfort over potential burn injury due to the low risk versus high reward relationship between the two, *“It’s risk vs reward, the chance that I’ll become involved in an incident where the importance of the thermal protection of my uniform comes into play is low. Uniform clothing that provides protection from chemicals, body fluids or thermal injuries is horribly uncomfortable.”* Similarly, participants felt their turnout suits were sufficient for providing adequate thermal protection: *“I feel that my primary thermal protection comes from my turnout gear. If I’m in a situation where I’m relying on my base layer to protect me, there is a bigger problem at hand,”* and *“I believe flame resistant clothing under bunker gear is redundant. If you are getting burned through your bunker gear, you will be burned regardless of the rating of your station wear.”* Participants described that they believe their bunker gear provides sufficient thermal protection and that if they find themselves in a flashover scenario where their turnout gear fails, an NFPA 1975 compliant uniform is not going to save them.

From a material and design standpoint, fire fighters preferred 100% cotton as it, *“is cost effective, provides breathability, and moisture management better than any 1975 uniform ensemble for our climate.”* One participant explained that he or she wears 100% cotton shorts that are not certified because, *“I believe the ability to operate at a high physical level in short sleeves*

and/or shorts is more important than the additional safety factor for long sleeves and/or pants.”

From multiple comments it is also apparent that fire fighters are not aware if 100% cotton garments are considered NFPA 1975 certified or compliant.

Additional comments were primarily coded per the same categories as the previous question: “No Change,” “NFPA,” “Fire Organization Issued/Mandated,” and “Education/Awareness.” Fifteen (15) comments indicated the fire fighter would not change their current station wear or base layers. Some of these comments were justified with the explanation that from their many years of experience, they did not feel certified apparel was needed or that it was necessary for their base layers to be flame resistant. Such responses included: *“Only in the most extreme dynamic fire event where thermal burns would be sustained regardless will the content of the fire fighter’s undergarments become an issue,”* and *“We use top of the line turnouts and I wear mine correctly. I am betting that if a fire gets through my turnouts having on a Nomex® shirt won't help that much.”* Some comments were coded which referred specifically and primarily to the NFPA and/or 1975 certification, for example, *“I believe the NFPA oversteps its bounds. Allowing manufacturers on committees allows them to drive the conversation. This equates to profits for them. While I understand their expertise may be relevant, they should only be afforded an advisory role to answer questions and to provide information.”* These comments illustrate the current pulse of fire fighters’ opinions regarding the need for certification of their station wear per NFPA 1975 requirements. However, there were also multiple comments that supported the use and wear of NFPA 1975 certified and certified FR station wear.

Two hundred and twenty-nine (229) responses indicated participants wear the station wear that is selected and/or provided to them by their local fire jurisdiction having authority. Cost was oftentimes associated with these comments indicating it influenced the fire organization’s choice

of station wear. Ultimately, comments pertaining to selection and the need, or lack thereof, for NFPA certified base layers worn underneath turnout suits was related to fire fighter education and awareness of the NFPA 1975 standard and the risks associated with synthetic materials that will melt or drip onto the skin. Fourteen (14) comments mentioned being “*uninformed*” or “*unaware of the standard.*” Others simply expressed that they cannot justify the need for certified flame resistant materials when worn underneath their turnout suit: “*As previously stated, I have yet to see LODD [line of duty death] or injury data that supports the assertion that station wear is a factor. When structural FF [fire fighter] PPE is destroyed and the human skin is damaged, the station wear alone is not a root cause. Additionally, the cost per unit is 4 times [greater per the] standard as the NFPA 1975 garments wear twice as fast and cost twice as much. Lastly, NFPA 1975 garments give a poor appearance after several launderings.*”

Burn Injury Incidents due to Synthetic Materials: A key goal of this research was to determine, either through the literature or from the end users themselves, the prevalence of burn injuries occurring due to synthetic station wear being worn underneath a NFPA 1971 certified structural turnout suit. Therefore, the third open-ended question asked participants if they were aware of any such incidents in which wearing a synthetic station wear or base layer garment underneath their turnout suit caused burn injuries specifically due to the melting of the fabric onto the skin. If they were aware, they were asked to elaborate and describe the scenario.

Seven hundred and thirty-one out of eight hundred and eight (731/808) (90%) of responses indicated that participants were unaware of any such burn incidents caused by wearing synthetic station wear or base layers underneath a turnout suit. Some of these responses (61/731; 8.3%) described hearing of or reading about such incidents but never witnessing or experiencing them first-hand. Others described being aware of incidents that had happened to others due to improper

use of the gear or in situations in which it could have been avoided. Seventy (70) responses (8.7%) indicated being aware of such incidents but most of these did not provide any description of the specific situation.

Of those that were aware, they explained: *“Never seen it on a person who survived. I have seen it on persons who died of their injuries,”* and *“Only when the structural PPE ensemble was destroyed by thermal degradation.”* Some specific incidents included: *“During a training burn one of the instructors had their shoulders burnt when their undershirt melted with no warning or damage to their exterior shell,”*; *“Yes. I am aware of firefighters wearing moisture wicking synthetics under turnout gear who received burns from thermal exposure causing some melting of the moisture wicking synthetic,”*; and *“A fireman was caught in a flashover event and subjected to intense heat and it caused his shorts or underwear to melt to his legs and waist.”* Other scenarios were mentioned, however, they were found to be outside the scope of this research as they pertained specifically to military operations or wildland firefighting and were not specific to wearing a structural fire fighter turnout ensemble.

Additional Comments for Structural vs. Wildland Firefighting Station Wear: The final two open-response questions provided participants with the opportunity to express any other comments or concerns pertaining to their station wear when worn underneath a structural or wildland firefighting ensemble, respectively. For structural firefighting station wear, 196 comments were made; 19 related primarily to cost, 39 to comfort, 1 to durability, 9 to mobility, 22 to protection, 3 to laundering, 20 to design, 37 to materials, 13 to no desired change, 10 to fire organization’s mandates, 9 to relevance, and 14 to education/awareness. Some participants felt that their *“department spends too much money on station uniforms that are uncomfortable, too hot and do not fit right,”* or that fire departments are, *“too often concerned with cost or appearance of station*

wear instead of comfort, durability, fit, protection or serviceability.” Fire fighters expressed comfort needs such as, *“the station wear must be light enough to not hinder range of motion and comfort when worn under turn-out ensembles.”*

Protection was highly valued by some fire fighters and expressed as their primary concern: *“Station wear is of the utmost importance to a firefighter and represents the last level, but yet most important, level of protection. I feel uncomfortable not being provided or allowed to wear a NFPA compliant uniform.”* Others do not see the value in wearing an NFPA certified station wear uniform, stating *“The injuries I sustained when I received 3rd degree burns to my leg would have been the same whether it be a 75 dollar NFPA approved pair of pants or a 20 dollar pair of Dickies,”* and *“the threat of poly melting in a fire seems overblown, will it really melt before I suffer other thermal injuries and in situations that are of far more concern.”* Most of these comments are related to cost, as well: *“I personally believe that with the new protective gear there is no need to wear station wear that complies with NFPA. The NFPA approved station wear is cost prohibitive for our department.”*

The same question was asked for those who indicated they performed wildland firefighting operations. 54 participants responded; 12 comments pertained primarily to comfort, 1 to protection, 11 to design, 10 to materials, 6 to education, 9 to relevance, and 5 to selection. Given the opportunity to express additional comments or concerns pertaining to station wear worn underneath a wildland firefighting ensemble, fire fighters desired lighter weight, more breathable garments for increased heat transfer. They felt that wildland firefighting base layers should be minimal as it is too hot to wear multiple layers in such conditions. Moisture management, flexibility for full range of motion, and moisture wicking were all properties mentioned. One participant felt that, *“long sleeve tees and long pants should be worn due to the fact that wildland*

turnouts have no lining like a structural turnout has.” On the opposite side of this spectrum, one participant explained, “I would wear synthetic, high temperature T-shirts if available.” Another response explained the importance of station wear under wildland ensembles because, “of the level of exposure to flames in an open environment. Thermal heat and environmental conditions (temp, humidity, etc.) add to the level of stress for a firefighter. Having a garment that provides sufficient thermal protection with air permeability is beneficial to wildland firefighting operations.”

Conclusion

The findings of this research highlight the current gap in the literature regarding the burn injury potential of wearing synthetic clothing materials, and other fiber blends, underneath a structural fire fighter turnout suit. Although heavily researched, to the authors’ knowledge, no specific burn injury data exists which reports or links causation of fire fighters’ burn injuries to the station wear or base layers worn underneath a structural fire fighter turnout suit. While injuries and fatalities are reported each year by the NFPA, and specific statistics on the number of burn injuries are included, the level of reporting necessary to attribute these burns to station wear either does not exist or is not adequately captured and reported. Therefore, future research is needed to establish an accurate reporting system for burn injury data in order to understand the true scope of station wear’s impact on fire fighters’ burn injuries.

The comprehensive nationwide questionnaire, with over 1,800 responses, provided in-depth insight into the current motivations and perceptions that United States fire fighters have pertaining to the selection and use of their station wear. In conclusion, the majority of fire fighter participants indicated that they are familiar with the NFPA 1975, *Standard on Emergency Services Work Clothing Elements* and that they are aware of the risks associated with wearing non-certified,

or synthetic, station wear that can melt or drip onto the skin, underneath their NFPA 1971 certified structural fire fighter turnout ensemble. However, given their familiarity and awareness, a significant number of participants indicated that they do not wear NFPA 1975 certified station uniforms or base layer garments due to multiple factors. The most common reason being that most fire organizations, especially those that were volunteer by nature, found NFPA 1975 certified garments to be cost prohibitive, both initially and over time, as their durability (colorfastness, abrasion, and shrinkage) is perceived to be less than that of non-certified garments. Beyond cost and durability, comfort and mobility were additional primary reasons for selecting non-certified base layers, as they are perceived to be more breathable, lighter weight, and manage moisture better.

Ultimately, it can be summarized that station wear selection comes down to the overarching balance between comfort and protection and the fire fighter's perception of risk versus reward. The risk of wearing a more comfortable, ergonomic, lower cost, and durable garment seems to outweigh what fire fighters perceive to be an extreme, and unlikely risk of thermal exposure in which synthetic materials underneath the turnout suit would melt or drip onto their skin prior to extreme injury or fatality. As one response summarized, *"I think firefighters understand the risks associated with synthetic materials, but I think they accept the risks given that fire acuity for most organizations pales in comparison to other call types."*

While some fire fighters are well-educated regarding NFPA 1975 certification requirements for station wear and are aware of potential burn injury risks when wearing base layers that will melt or drip, or that are not flame resistant, *"most firefighters feel that if it is hot enough to melt station clothing under bunker gear then it was a non-survivable incident anyways."* Therefore, the majority of respondents did not perceive the risk to be greater than the reward of

wearing materials (i.e., synthetics and synthetic blends) and garments (i.e., short sleeve T-shirts and shorts) that provide better comfort, mobility, durability, and are more cost effective. Results from the questionnaire indicate that, “*better education and scientific studies to help guide department decisions,*” are necessary, as one participant described.

Future Research

This study provides a well-rounded foundation for future research which should include material, garment, and full-systems human wear testing of specific station wear materials, alone and in conjunction with structural firefighting turnout suit material layers, in order to measure the true thermal injury potential of such scenarios. Results from this research indicate the majority of fire fighters are not aware of any incidents that pose a significant thermal injury threat when wearing non-certified station wear. Therefore, material level data needs to be collected in a controlled, laboratory setting to determine the significance of such a threat. Further, burn injury data linked directly to base layer materials needs to be adequately captured and reported in order to gain a better understanding of the scope and burn injury potential when wearing non-certified station wear materials underneath a structural turnout ensemble.

Future research should include testing to evaluate the thermal protection, heat loss, moisture management, and durability of multiple station wear material types, both alone (as single layers) and in conjunction with the three-layer turnout base composite. In addition, full-systems human wear testing should be conducted to assess the physiological and thermal comfort, as well as ergonomic mobility and range of motion, of various station wear configurations. This testing is essential as fire fighters indicated they place greater importance on comfort and mobility when selecting station wear than on safety or protection.

The findings of this report and of future research should be disseminated to key stakeholders in the fire service in order to educate fire fighters and those in charge of making station wear selection decisions within their fire organizations. This report should also be used to inform members of the NFPA 1975 and 1971 technical committees of the current user needs of United States fire fighters. In addition, designers, product developers, and manufacturers of station wear uniforms, firefighting base layers, and turnout suits may benefit from this research, as well.

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Appendix A (Questionnaire)

Firefighter Station Wear Information Gathering Questionnaire

Start of Block: Informed Consent

You are being invited to take part in a research study to collect information regarding firefighter station wear including both National Fire Protection Association (NFPA) 1975 certified and non-certified garments in relation to firefighter burn and heat injury while worn under a certified NFPA 1971 garment. You are invited to take part in this research study because you are an active-duty structural or wildland firefighter in the United States. If you volunteer to take part in this study, you will be one of hundreds to do so nationally.

This study is being conducted by Dr. Meredith McQuerry (Principal Investigator, PI) of the Retail, Merchandising and Product Development department in the College of Human Sciences at Florida State University. The purpose of this study is to determine current firefighter use of both certified NFPA 1975 and non-certified station wear garments in relation to firefighter burn and heat injury while worn under a certified NFPA 1971 garment. Results will be used to better understand the potential risk of wearing non-certified garments and to develop a material testing program for station wear in combination with structural turnout ensembles.

If you are not currently an active-duty firefighter in the United States, we ask that you do not complete this survey.

If you agree to be in this study, we ask you to do the following things: Complete an online survey gathering demographic (gender, age, years in fire service industry, etc.) and station wear selection information for base layer garment and material feedback. It is estimated that the survey will take approximately 15-20 minutes to complete.

To the best of our knowledge, there are no possible risks associated with completing this study. Benefits of this study include participant contribution regarding the understanding of burn protection, thermal stability of station wear, and risks of wearing non-certified station wear. The study is anonymous, meaning no one, not even members of the research team, will know the information you gave came from you. Your information will be combined with information from other participants taking part in the survey. Publication of the feedback will only include the combined information written up together. It is a possibility that research information may be shared with the FSU Institutional Review Board (IRB) and others who are responsible for ensuring compliance with laws and regulations related to research, including people on behalf of the Office for Human Research Protections (OHRP).

Participation in this study is completely voluntary. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any point during the study and still keep

the benefits and rights you had before volunteering. If you do not want to be in the study, you do not need to take part in the survey.

There are no costs associated with taking part in the study. You will not receive any rewards or payment for taking part in the study. Before you decide whether to accept this invitation to take part in the study, please ask any questions that may come to mind now. Later, if you have questions, suggestions, concerns, or complaints about this study, you may contact the investigator, Dr. Meredith McQuerry via email: mmcquerry@fsu.edu; or telephone: (850) 644-6838. If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher(s), you are encouraged to contact the FSU IRB at 2010 Levy Street, Research Building B, Suite 276, Tallahassee, FL 32306-2742, or 850-644-8633, or by email at humansubjects@fsu.edu.

You can provide consent below by choosing the “Yes, I consent to the terms and conditions of this study,” option and proceeding forward with the survey.

- Yes, I consent to the terms and conditions of this study (1)
- No, I do not wish to participate in this study (2)

Skip To: End of Survey If You are being invited to take part in a research study to collect information regarding firefight... = No, I do not wish to participate in this study

End of Block: Informed Consent

Start of Block: Background Information

This information gathering questionnaire will allow the National Fire Protection Association to better develop standards for firefighter uniforms. Results will help evaluate the impact that both certified NFPA 1975 and non-certified station wear garments have in relation to firefighter burn and heat injury while worn under a certified NFPA 1971 garment in a system-level testing environment. The report will be useful for the fire service and NFPA 1975 and NFPA 1971 technical committees.

End of Block: Background Information

Start of Block: Section 1: Demographics

What is your age (in years)?

What is your gender?

Male (1)

Female (2)

Which of the following ethnic groups do you consider yourself to be a member (check all that apply)?

White or Caucasian (1)

Black or African American (2)

American Indian or Alaska Native (3)

Asian (4)

Native Hawaiian or Pacific Islander (5)

Hispanic or Latino (6)

Other (7) _____

Department Service Type:

Career (1)

Volunteer (2)

Fire Service Commitment:

Full-Time (1)

Part-Time (2)

Years of Experience in Fire Service:

Rank in Fire Service:

Current City, State of Service:

Number of uniformed personnel in your department:

End of Block: Section 1: Demographics

Start of Block: Section Two: Station Wear Selection

Please familiarize yourself with the following terms: **Certified Station Wear:** work apparel that is certified as compliant with the mandatory thermal stability requirements of NFPA 1975 which means the material must not melt, drip, separate, or ignite. **Certified FLAME RESISTANT Station Wear:** work apparel that in addition to being certified to the mandatory base requirements of NFPA 1975, ALSO meets the optional requirements for flame-resistance which include passing a vertical flammability test

with a char length less than 6 in. and an afterflame time of no more than 2 seconds. **Base Layers:** shirts, shorts, or pants either worn underneath station wear or worn directly underneath the firefighting ensemble (i.e. turnout suit).

Are you familiar with NFPA 1975: Standard on Emergency Services Work Clothing Elements requirements?

- Yes (1)
 - No (2)
 - Not Sure (3)
 - Other/Comments: (4) _____
-

Are you aware of the risk associated with wearing non-certified base layer garments under your NFPA 1971 certified bunk gear?

- Yes (1)
 - No (2)
 - Not Sure (3)
 - Other/Comments: (4) _____
-

Does everyone in your department wear the same base layer/station wear under their turnout gear?

- Yes (1)
 - No (2)
 - Not Sure (3)
 - Prefer not to answer (4)
 - Other/Comments: (5) _____
-

Does your department provide you with or instruct you to wear specific station wear?

- Yes (1)
 - No (2)
 - Not Sure (3)
 - Prefer not to answer (4)
 - Other/Comments: (5) _____
-

Display This Question:

If Does your department provide you with or instruct you to wear specific station wear? = Yes

If yes, is your station wear NFPA 1975 certified? (i.e. is there a certification label on your station wear)?

- Yes (1)
- No (2)
- Not Sure (3)
- Prefer not to answer (4)

Display This Question:

If If yes, is your station wear NFPA 1975 certified? (i.e. is there a certification label on your st... = No

If no, has your department considered or wear tested NFPA 1975 certified station wear in the past? If so, why did the department choose not to? (please use comments section next to "yes" for second part)

- Yes (1) _____
 - No (2)
 - Not sure (3)
-

Does your department require you to wear NFPA 1975 certified flame resistant station wear (please reference terms at the beginning of this section)?

- Yes (1)
- No (2)
- Not Sure (3)
- Prefer not to answer (4)
- Other/Comments: (5) _____

Display This Question:

If Does your department require you to wear NFPA 1975 certified flame resistant station wear (please... = Yes

If yes, please describe your station wear in detail (i.e. garment style, manufacturer, fiber content, etc.) This information can be found on the garment label.

Display This Question:

If Does your department require you to wear NFPA 1975 certified flame resistant station wear (please... = No

If no, what do you wear as station wear? Be as descriptive as possible (i.e. garment style, manufacturer, fiber content, etc.):

How did you choose the station wear that you use now? (select all that apply).

- It was chosen for me (1)
 - I chose my own (2)
 - I purchased my own (3)
 - It was given to me (4)
 - Other/Comments: (5) _____
-

Please indicate the level of IMPORTANCE you place on each of the following factors when selecting your station wear:

	Not important (1)	Fairly Important (2)	Neutral (3)	Slightly Important (4)	Very important (5)
Comfort (1)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mobility (2)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Safety/protection (3)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

End of Block: Section Two: Station Wear Selection

Start of Block: Section 3: Station Wear Use

Do you wear shorts or long pants under your turnout suit? Please indicate the frequency below:

Never wear shorts (required to wear pants always) (1)

Rarely wear shorts (2)

Sometimes wear shorts (3)

Very frequently wear shorts (4)

Always wear shorts (5)

Other/Comments: (6) _____

If you wear shorts, what months out of the year do you where them? Check all that apply.

January (1)

February (2)

March (3)

April (4)

May (5)

June (6)

July (7)

August (8)

September (9)

October (10)

November (11)

December (12)

Other/Comments: (13) _____



Do you wear long sleeve or short sleeve shirts under your turnout suit?

- Short sleeve (1)
 - Long sleeve (2)
 - Both (short under long sleeve) (3)
 - Other (i.e. short over short sleeve): (4)
-

Please indicate the frequency that you wear each shirt configuration below:

- Never wear long sleeve (1)
 - Rarely wear long sleeve (2)
 - Sometimes wear long sleeve (3)
 - Very frequently wear long sleeve (4)
 - Always wear long sleeve (5)
 - Other/Comments: (6) _____
-

If you indicated that you wear long sleeves above, do you wear a long sleeve shirt on top of a short sleeve t-shirt?

Yes (1)

No (2)

Sometimes (3)

Other/Comments: (4) _____

If you wear a short sleeve shirt, what months out of the year do you wear it? Check all that apply.

January (1)

February (2)

March (3)

April (4)

May (5)

June (6)

July (7)

August (8)

September (9)

October (10)

November (11)

December (12)

Other/Comments: (13) _____

If you wear a long sleeve shirt, what months out of the year do you wear it? Check all that apply.

January (1)

February (2)

March (3)

April (4)

May (5)

June (6)

July (7)

August (8)

September (9)

October (10)

November (11)

December (12)

Other/Comments: (13) _____

Which of the following shirt configurations do you wear most often AT THE FIRE STATION?

- T-shirt only (1)
 - Station wear shirt only (2)
 - T-shirt + Station wear shirt (3)
 - Other/Comments: (4) _____
-

Which of the following shirt configurations do you wear most often UNDERNEATH YOUR TURNOUT SUIT?

- T-shirt only (1)
 - Station wear shirt only (2)
 - T-shirt + Station wear shirt (3)
 - Not applicable (i.e. wildland firefighter) (4)
 - Other/Comments: (5) _____
-

Which of the following shirt configurations do you wear most often UNDERNEATH YOUR WILDLAND FIREFIGHTER GEAR?

- T-shirt only (1)
- Station wear shirt only (2)
- T-shirt + Station wear shirt (3)
- Not applicable (i.e. structural firefighter) (4)
- Other/Comments: (5) _____

End of Block: Section 3: Station Wear Use

Start of Block: Section 4: Station Wear Materials

Is your station uniform certified as flame resistant according to NFPA 1975?

- Yes (1)
 - No (2)
 - Not Sure (3)
 - Prefer not to answer (4)
-

What is the fiber content of the station uniform you currently wear? Please provide this information in detail (i.e. 50% cotton, 50% polyester)

Do you prefer to wear synthetics (polyester, nylon, etc.) instead of cotton or wool station wear?

Yes (1)

No (2)

Not Sure (3)

Prefer not to answer (4)

Display This Question:

If Do you prefer to wear synthetics (polyester, nylon, etc.) instead of cotton or wool station wear? = Yes

If Yes, why do you prefer synthetics (i.e. comfort, feels cooler, easier to move in, etc.):

Does your station uniform have a printed (not embroidered) graphic located somewhere on the surface (i.e. sleeve or chest)?

Yes (1)

No (2)

Not Sure (3)

Prefer not to answer (4)

Display This Question:

If Does your station uniform have a printed (not embroidered) graphic located somewhere on the surfa... = Yes

If yes, where is the printed graphic(s) located (i.e. sleeve, upper thigh of pant leg, etc.):

End of Block: Section 4: Station Wear Materials

Start of Block: Section 5: Station Wear Design

Please indicate your level of SATISFACTION with your current station wear for the following factors:

	Very Dissatisfied (1)	Dissatisfied (2)	Neutral (3)	Satisfied (4)	Very Satisfied (5)
Comfort (1)	<input type="radio"/>				
Mobility (2)	<input type="radio"/>				
Safety/Protection (3)	<input type="radio"/>				

What features are most important to you in a station wear uniform? (Choose only 3)

- Thermal protection (1)
 - Liquid protection (2)
 - Chemical/Biological Contaminant protection (3)
 - Comfort (breathability) (4)
 - Moisture management (5)
 - Mobility and range of motion (6)
 - Design and aesthetic appeal (7)
 - Other/Comments: (8) _____
-

Do you think your current station wear provides sufficient thermal protection?

- Yes (1)
 - No (2)
 - Not Sure (3)
 - Prefer not to answer (4)
-

Why or why not?

Do you think your current station wear provides sufficient comfort?

- Yes (1)
- No (2)
- Not Sure (3)
- Prefer not to answer (4)

Why or why not?

Would you sacrifice the heat resistance (meaning no melting would occur) of your station wear in order to improve your comfort?

- Yes (1)
 - No (2)
 - Not Sure (3)
 - Prefer not to answer (4)
-

Why or why not?

End of Block: Section 5: Station Wear Design

Start of Block: Section 6: Base Layers & Wildland Firefighting

Are you currently a wildland firefighter or do you participate in wildland fire suppression activities?

(If Yes, please proceed with answering the following questions. If No, the questionnaire will skip to the last section.)

- Yes (1)
- No (2)

Skip To: End of Block If Are you currently a wildland firefighter or do you participate in wildland fire suppression activ... = No

How often does your department/station respond to wildfire emergencies?

What base layers (worn underneath your wildland firefighting ensemble) do you wear for wildland fire fighting (check all that apply):

Short Sleeve Shirt (1)

Long Sleeve Shirt (2)

More than one shirt layer (3)

Shorts (4)

Pants (5)

More than one pant layer (6)

Other/Comments: (7) _____

Does your department require you to wear NFPA 1975 certified station wear underneath your wildland firefighting ensemble?

- Yes (1)
- No (2)
- Not Sure (3)
- Prefer not to answer (4)
- Other/Comments: (5) _____

Display This Question:

If Does your department require you to wear NFPA 1975 certified station wear underneath your wildlan... = Yes

If yes, is your certified station wear also certified flame resistant?

- Yes (1)
- No (2)
- Not sure (3)
- Prefer not to answer (4)
- Other/Comments: (5) _____

Please describe your station wear worn underneath your wildland firefighting ensemble in detail (i.e. garment style, manufacturer, fiber content, etc.). This information can be found on the garment label.

Do you wear different base layers for wildland fire responses compared to structural fire responses?

- Yes (1)
- No (2)
- Not Sure (3)

Display This Question:

If Do you wear different base layers for wildland fire responses compared to structural fire respons... = Yes

If yes, please describe in detail the differences between the two:

Display This Question:

If Do you wear different base layers for wildland fire responses compared to structural fire respons... = No

If no, do you feel that you would benefit from having a different garment for different situations? Please explain.

End of Block: Section 6: Base Layers & Wildland Firefighting

Start of Block: Section 7: Open-Ended Questions

If you could change the materials and/or design of your station wear, what would you change and why?

If you choose to wear a non-certified 1975 station uniform, please explain why:

Are you personally aware of any incidents in which wearing a synthetic station wear or base layer garment underneath a turnout suit caused burn injuries due to melting of the fabric onto the skin? If so, please describe the scenario below:

Are there any other comments or concerns that you have pertaining to your station wear when worn under a 1971 structural firefighting ensemble?

Are there any other comments or concerns that you have pertaining to your station wear when worn under a wildland firefighting ensemble?
