System Assessment and Validation for Emergency Responders (SAVER)

Wildland Firefighter Personal Protective Equipment (PPE) Selection Guide

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FOREWORD

The U.S. Department of Homeland Security (DHS) established the System Assessment and Validation for Emergency Responders (SAVER) Program to assist emergency responders making procurement decisions. Located within the Science and Technology Directorate (S&T) of DHS, the SAVER Program conducts objective assessments and validations on commercially available equipment and systems, and develops knowledge products that provide relevant equipment information to the emergency responder community. The SAVER Program mission includes:

- Conducting impartial, practitioner-relevant, operationally oriented assessments and validations of emergency response equipment; and
- Providing information, in the form of knowledge products, that enables decision-makers and responders to better select, procure, use, and maintain emergency response equipment.

SAVER Program knowledge products provide information on equipment that falls under the categories listed in the DHS Authorized Equipment List (AEL), focusing primarily on two main questions for the responder community: "What equipment is available?" and "How does it perform?" These knowledge products are shared nationally with the responder community, providing a life- and cost-saving asset to DHS, as well as to Federal, state, and local responders.

The SAVER Program is supported by a network of Technical Agents who perform assessment and validation activities. As a SAVER Program Technical Agent, the U.S. Army Natick Soldier Research, Development, and Engineering Center (NSRDEC) has been tasked to provide expertise and analysis on key subject areas, including personal protective equipment (PPE), rapid deployment shelters, and shelf stable food, among others. In support of this tasking, NSRDEC prepared a guide for the selection of wildland firefighter personal protective equipment, which fall under AEL reference number 01LE-02-BDUS titled Specialized Clothing, NFPA 1975 or NFPA 2112.

Visit the SAVER website on First Responder.gov (http://www.firstresponder.gov/SAVER) for more information on the SAVER Program or to view additional reports on PPE or other technologies.

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EXECUTIVE SUMMARY

This SAVER Selection Guide provides information to assist fire departments in optimizing the selection of their personal protective equipment (PPE) clothing system to maximize the protection and performance of the wildland firefighter (WLFF). This selection guide provides an overview of current and emerging WLFF PPE products, technologies, designs, materials, standards, and testing methodologies. This guide also discusses the effects of layering garments and the use of base layer garments on system performance. Using this information and the proposed selection process can optimize the selection of WLFF PPE to reduce the probability for injury and improve WLFF operational performance.

The selection of WLFF PPE clothing appears very straightforward since most WLFF PPE is certified to National Fire Protection Association (NFPA) 1977, *Standard on Protective Clothing and Equipment for Wildland Firefighting*. However, WLFF PPE garment configurations and protection performance requirements can vary greatly between different fire departments. The selection of a poorly configured WLFF PPE garment system can actually increase the likelihood of injury.

The purpose of WLFF PPE is to provide protection against external thermal threats to prevent burn injuries and transfer internally generated heat to minimize heat stress injuries. When the level of thermal protection is increased, typically this causes a decrease in the ability to transfer internally generated heat. Consequently, increasing protection against one hazard can create an increased vulnerability to the other hazard. In wildland firefighting, most injuries to firefighters are due to heat stress, not burn injuries. Balancing the level of protection against these two threats is the most critical consideration when selecting WLFF PPE.

This selection guide will describe the interaction between garment configuration and material performance so that decision makers can better understand this interaction when configuring and selecting WLFF PPE that is optimized for their operational requirements.

This proposed process for the selection of WLFF PPE utilizes a system level approach to combine garment design and configuration, base layer garments, and new materials technologies to improve protection and operational performance. Using this approach to select WLFF PPE components will optimize the system for protection against both burn and heat stress injuries and maximize firefighter operational performance.

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1. INTRODUCTION

This SAVER selection guide outlines a systematic approach to the selection of personal protective equipment (PPE) to maximize the protection and performance of wildland firefighters (WLFFs).

There is currently little formal guidance available for the proper selection of WLFF PPE. Fire departments must independently determine which commercial product best meets their needs. WLFF PPE garment configurations and protection performance requirements can vary between different fire departments, which require different PPE solutions to satisfy those needs. Revisions to standards, changes in user requirements, and emerging new technologies have combined to create new and improved WLFF PPE capabilities. This selection guide provides an overview of WLFF PPE standards, emerging technologies, and factors that influence WLFF PPE performance so that an organization can better understand the characteristics and tradeoffs needed to select the optimal WLFF PPE for their organizational needs.

The scope of this selection guide focuses on protective garments (outer garments and under garments) worn by WLFFs. WLFF PPE such as footwear, eyewear, helmets, gloves, face shields or neck shrouds, chain saw protection, or load bearing equipment are outside the scope of this selection guide. While these other types of PPE provide essential protection to the WLFF, the garment system is the major PPE contributor to heat stress injuries, which comprises the majority of WLFF injuries[1].

The threats to WLFFs are the external heat source, which can cause burn injuries, and the internal heat created by physical exertion, which can cause heat stress injuries. The tradeoff is that increasing the protection against one threat typically causes an increase in vulnerability to the other threat. As a result of this tradeoff, if WLFFs overprotect themselves against the external heat source they usually increase their vulnerability to internally generated heat stress. This condition has been recognized in National Fire Protection Association (NFPA) 1977, *Standard on Protective Clothing and Equipment for Wildland Fire Fighting*[1], which "seeks to provide thermal protection for the wildland firefighter against external thermal heat sources with flame resistant clothing and equipment while not inducing an extraordinary heat stress load." Understanding this tradeoff and applying that knowledge to the selection of WLFF PPE can help to reduce the number of injuries associated with wildland firefighting. Every wildfire is unique and the risk for burn injury and heat stress changes along with the conditions. The variations in WLFF PPE, fire conditions, firefighting tactics, environmental conditions, terrain, operational workload, the physical condition of the firefighter, and other factors all play a role in determining the probability of burn or heat stress injuries occurring. Consequently, it is impossible to prevent all injuries in all situations. However, the selection of an optimal WLFF PPE system can help to reduce the overall number of injuries and the magnitude of these injuries.

[1]National Fire Protection Association (NFPA) 1977, Standard on Protective Clothing and Equipment for Wildland Fire Fighting, 2011 edition.

2. TECHNOLOGY REVIEW

2.1 Current WLFF PPE Technologies and Test Methods

Prior to the introduction of high performance flame resistant fabrics, most WLFFs wore basic work clothing, like heavy cotton dungarees, during wildfire operations. WLFF PPE material performance has evolved significantly since that time. In the 1960s, the U.S. Forest Service (USFS) pioneered the incorporation of flame resistant fabrics (treated cotton) in their WLFF PPE designs. In the 1970s, the USFS incorporated meta-aramid fabrics (e.g., Nomex®) into their PPE garments. These fabrics provided radiant heat protection and flame resistance, did not ignite, melt or drip and greatly improved the level of protection for WLFFs. This WLFF PPE was subsequently adopted by many state and local fire departments. Since that time, other flame resistant fabrics (e.g., PBI TriGuard™) have been introduced that blend various flame resistant fibers to achieve similar properties and are currently used in WLFF PPE.

Another technique to increase the radiant thermal protection in WLFF PPE is to layer fabrics or garments. While the layering of fabrics increases radiant protection, it comes with a tradeoff as the thicker garment adds overall weight, reduces the range and freedom of motion while decreasing the ability to transfer internally generated heat across the layered materials. This in turn increases the likelihood for heat stress injury.

Garment design is a factor in overall WLFF PPE performance that is often overlooked. As WLFF PPE evolved, functional features specific to wildland firefighting were added to WLFF PPE, such as ankle and neck collar closures. Recently, WLFF PPE garments have begun to include "technical" features that were developed for tactical garments, such as gusseted crotches, articulated joints, and shoulder pleats ("action back") to improve freedom and range of motion. Garment utility and functionality were also improved through the addition of more pockets and sizing the pockets for specific purposes (e.g., radios). Incorporation of these garment design features can help to improve the operational performance of firefighters.

Figure 2-1. WLFF

The configuration of a WLFF PPE garment system plays a major role in the performance of the system[2]. Federal agencies (e.g., USFS, Department of Interior – Bureau of Land Management, Bureaus of Indian Affairs, and the Fish and Wildlife Service) and many state and local agencies use single layer WLFF PPE pants. However, many fire departments that engage in both structural and wildland fires require their firefighters to wear a multi-layer WLFF PPE pant configuration consisting of WLFF PPE pants worn over their uniform pants during wildfire operations. This is

[2]A Multi-Layered Issue: Double Layer PPE doesn't protect against heat injury, Vaughan Miller, Fire Rescue Magazine, July 2009.

partly because fire departments must wear their uniform trousers during daily work activities within the stationhouse. When responding to a structural fire, a firefighter wears their turnout gear over their uniform clothing to improve response time. Similarly, when responding to a wildfire callout, they wear their WLFF PPE pants over their uniform pants to expedite their response. This multi-layering of garments greatly increases the radiant protection to the wearer. However, this multi-layering also significantly reduces the garment's ability to transfer internal heat generated by the wearer, which increases the potential for heat stress injury. The inverse relationship between thermal protection and heat stress relief creates a challenge when determining WLFF PPE configuration. Understanding this relationship and tradeoff is necessary to optimizing WLFF PPE garment configuration.

Base layer garments are not typically considered a part of the WLFF PPE system. NFPA 1977 does not address the issue or performance of base layer garments. While base layer garments are not technically considered PPE, testing has shown that base layer garments can increase the level of radiant heat protection (due to layering). In most departments, WLFF PPE garments are worn over natural cotton underwear. Cotton underwear is affordable, comfortable to wear under normal conditions, and readily available. While untreated cotton is not inherently flame resistant, it will not melt or drip after ignition. Untreated cotton does not contribute to a burn injury the way some synthetic fabrics can due to melting. Untreated cotton can provide a significant increase in thermal protection when worn under WLFF PPE fabrics due to the effects of layering fabrics. However, when cotton underwear becomes saturated with sweat, the fabric's ability to transfer internally generated heat is compromised. In addition, the time to dry after saturation is significantly longer for cotton when compared to synthetic fabrics. Underwear made from fast drying and wicking synthetic fabrics has recently been introduced in many different athletic and outdoor applications to reduce heat stress. These fabrics dry very quickly and increase evaporative heat loss by wicking moisture away from the body. However, the Protective Clothing and Equipment Research Facility (PCERF) at the University of Alberta and the USFS conducted testing, which showed that "firefighters wearing non-flame resistant synthetic undergarments may be more likely to suffer burn injuries because synthetic materials might melt and stick" onto a burn wound[3]. Consequently, many fire departments have prohibited the wearing of synthetic non-flame resistant base layer garments during firefighting operations.

Current testing technologies primarily focus on measuring the performance of fabric materials. The Radiant Protection Performance (RPP) rating indicates the level of radiant heat protection provided by a fabric and is specified in seconds. RPP is equivalent to half the time it takes for a second-degree burn injury (TSDB) to occur behind a fabric exposed to a heat flux of 21 kilowatts per square meter (kW/m^2) based on the Stoll burn criteria. The Stoll burn curve correlates the level of thermal energy to the duration of exposure required to receive a second degree burn injury. The Total Heat Loss (THL) rating indicates the insulation and evaporative resistance of a fabric. RPP and THL test protocols utilize a small sample (swatch) of the fabric material to determine if that material meets the performance requirements of the applicable standard. Once a fabric has been certified to NFPA 1977, it is deemed acceptable and can be used as a PPE garment. While this testing provides an important indicator of material performance, it does not

[3]Tests of Undergarments Exposed to Fire, Tony Petrilli & Mark Ackerman, Montana Technology & Development Center, US Department of Agriculture, December 2008.

always reflect the true overall performance of a garment system. The overall garment system performance can be influenced by garment configuration (e.g., single layer versus multi-layer), garment design, and choice of base layer garment materials. Testing has shown that the thermal protection and total heat loss performance of a system of garments can be significantly different from the performance characteristics of the fabrics that comprise the garments. To address this shortcoming, system level testing has been introduced.

System level testing consists of testing an instrumented manikin with the complete PPE ensemble and provides a better indicator of how garment design and the layering of multiple fabrics influence overall garment performance. Instrumented manikin testing (e.g., PyroMan™) has been developed to determine the level of protection a garment system provides when the PPE system is subjected to a uniform and repeatable flame threat (Figure 2-2). However, due to the high intensity, short duration heat exposure, this system testing is more applicable to structural firefighting than wildland firefighting. Sweating manikin testing has also been developed to measure the insulation and evaporative resistance of a complete PPE ensemble. In principle, the sweating manikin is similar to the sweating hot plate, which is used to determine the insulation and evaporative resistance of a fabric; however, sweating manikin testing considers a complete garment system configuration and measures the THL of a garment system, not just the garment's fabric. System level testing considers the increased air gap of looser fitting clothing, which can provide greater ventilation to reduce heat stress burden and increase thermal protection by creating an air layer. This data provides a more accurate indicator of how much heat an individual can lose wearing a complete garment system and provides a more realistic value when compared to a fabric swatch tested on a sweating hot plate.

Figure 2-2. Sweating Manikin

Image courtesy of T-PACC at North Carolina State University

2.2 Emerging WLFF PPE Technologies and Test Methods

New and improved flame resistant materials have emerged due to recent combat operations. As new battlefield threats emerged (e.g., improvised explosive devices), the U.S. military began to experience a new range of casualties, to include severe burn injuries. Traditional nylon/cotton blend duty uniforms did not provide sufficient protection against these emerging thermal threats. In addition, soldiers began to use the high performance fast drying and wicking polyester sports undergarments to reduce heat stress in the desert environment. However, these synthetic fabrics could melt onto burn wounds, thereby increasing the severity of burn injuries. While flame resistant fabrics were already being used in military aviation applications, those fabrics did not meet military duty uniform specifications for cost, durability, and breathability. The military sought new flame resistant fabrics better suited to duty uniform applications to address this threat.

Two types of fabrics were developed to address the requirements for duty uniform and base layer garment applications.

New duty uniform fabrics were flame resistant and provided more durability, and increased air permeability to reduce heat stress burden, relative to aviation uniform fabrics. While these new duty uniform fabrics were developed for their flame resistance, testing has indicated that some of these fabrics also offer improved RPP and THL ratings. NFPA 1977 currently requires a minimum RPP rating of 7 for a fabric used in WLFF PPE and some of these fabrics have attained RPP values greater than 11.

Several base layer garment fabrics have been developed that maintain the fast drying and wicking characteristics of polyester synthetics but do not melt or drip when exposed to high temperatures. Some of these undergarment materials satisfy the requirements (per ASTM D 6413, Standard Test Method for Flame Resistance of Textiles [Vertical Test]) for full flame resistance.

When worn together, these new fabrics can provide increased protection against flame threats while also reducing the heat stress burden on the wearer when compared to traditional multi-layer garments.

Applying a system level approach to PPE garment selection is a relatively new concept. WLFF PPE garments are typically designed and developed with limited consideration for the other garments or equipment being worn. In addition, WLFF PPE garments are selected and assembled by some departments without consideration of garment interaction or integration. The U.S. Army Natick Soldier Center developed the concept of the “Soldier as a System”, which requires that the soldier be considered a system of components and that all garments, individual equipment and weapons be designed, integrated and tested as a system of components. This concept has been applied to the development of the Advanced Personal Protection System (APPS) WLFF PPE system[4], a development program sponsored by the Department of Homeland Security, Department of Agriculture, and U.S. Army. This program combined high performance WLFF PPE garments with no-melt/no-drip, wicking, fast drying, flame resistant base layer garments to maximize thermal protection and reduce the heat stress burden on the wearer. A lengthy operational assessment of this garment system indicated a user preference for this system of garments over existing baseline WLFF PPE.

The testing of WLFF PPE is also undergoing major changes. A reasonable maximum exposure (RME) is now used to characterize the thermal threat environment typically seen in wildland firefighting. A RME is defined as the maximum exposure that can be expected under normal (“reasonable”) conditions[5]. Based on various studies[6], the RME predicted for several wildland firefighting scenarios is typically within the range of 6.3 kW/m^2 to 8.6 kW/m^2. The current RPP test method uses a higher intensity heat flux source (21 kW/m^2) for a shorter duration than the predicted RME. To better reflect actual operational conditions, it is desirable to reduce the heat flux to reflect the predicted RME and increase the duration of exposure used in testing. However, these changes in test method are not compatible with current test instrumentation, which cannot achieve the lower heat fluxes. The Textile Protection and Comfort Center (T-PACC) at North Carolina State University is conducting research to develop a modified RPP

[4]Wildland Fire Fighter Advanced Personal Protection Equipment System – Final Report, Department of Homeland Security Science & Technology Directorate, R-Tech Program, April 2014.

[5]Wildland Fire & Hazard Risk Assessment, California Department of Forestry and Fire Prevention (CAL FIRE), Draft report, January 2010.

test, which will use a lower, more consistent heat flux while increasing the duration of exposure, as shown in Figure 2-3[6]. This modified RPP test should generate fabric thermal protection level ratings that more accurately reflect actual firefighting conditions. Initial testing results indicate that the lower RME testing exposures tend to generate higher RPP values for a given fabric. This suggests that the thermal protection levels of current fabrics may be greater than previously thought and that using thinner PPE fabrics may still meet minimum thermal protection requirements while reducing the heat stress burden on the firefighter.

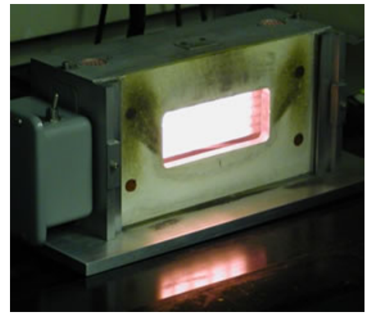

Figure 2-3. RPP Test

Image courtesy of T-PACC at North Carolina State University

System level testing is also seeing significant changes. The T-PACC is developing a manikin test (RadMan™) to address the shortcomings of PyroMan[7]. RadMan will use a low intensity, long duration, radiant heat exposure to better reflect the RME predicted for actual operational conditions and will obtain data from multiple heat flux sensors located across the entire manikin. This system level testing considers the effects of layering fabrics, air gaps, and garment fit and will yield data that reflects the total protection provided by all PPE components. Sweating manikins are now being used to generate objective heat stress data that reflects the as-worn configuration of PPE. Additional research at T-PACC is ongoing to correlate sweating manikin data to human physiological response. Once this research is completed, users will be able to better understand and compare the heat stress characteristics of complete WLFF PPE garment systems.

2.3 Standards and Regulations

Initially, there were no standards to govern WLFF PPE performance or fit. Every department selected PPE based on their own internal criteria and many departments simply used heavy cotton dungarees and other work clothes. In 1993, NFPA 1977, *Standard on Protective Clothing and Equipment for Wildland Firefighting* was established to "specify the minimum design, performance, testing, and certification requirements for protective clothing, helmets, gloves, and footwear that are designed to protect firefighters against adverse environmental effects during wildland firefighting operations"[1]. NFPA 1977 was the first effort to identify minimum levels of performance for WLFF PPE and continues to be periodically revised to consider and incorporate improvements in testing methods and material requirements. Certification of a WLFF PPE garment to NFPA 1977 provides significant assurance of performance and quality as NFPA 1977 imposes quality assurance measures for the manufacturing of WLFF PPE. While NFPA 1977 does not specify the design features of WLFF PPE garments, it does impose dimensional characteristics for all certified garments to ensure proper sizing and fit. Most domestic departments now use NFPA 1977 certification as the basis for selecting their WLFF PPE. Some departments must comply with local standards, such as California Occupational Safety and Health Administration (Cal/OSHA) to govern their WLFF PPE. Most foreign wildland firefighting departments use the International Organization for Standardization (ISO) 16073, *Wildland firefighting personal protection equipment – Requirements and test methods* for the

[6]Blazing New Trails in Improving Heat Stress and Radiant Heat Protection in Wildland Firefighter Protective Clothing, 2013 FIERO presentation, Alex Hummel, Textile Protection & Comfort Center, North Carolina State University, March 2013.
[7]Researchers hope to improve turnouts for wildland firefighters, Innovation in Textiles, July 2011.

certification of their WLFF PPE[8]. While NFPA 1977 and ISO 16073 are very similar, there are slight differences in test methodology and requirements.

NFPA 1977 currently requires a minimum RPP rating of 7 for a fabric used in WLFF PPE. The origin of the NFPA 1977 RPP criteria was not based on a risk assessment of the wildfire threat but rather, was based on the performance of Nomex fabrics, which had been proven effective over many years of USFS experience. At that time, the Nomex fabric used by the USFS was believed to have an RPP rating of 7, which was then specified as the RPP requirement in NFPA 1977. However, this RPP requirement was raised to 8 in 1998 but reduced back to 7 in the 2005 revision of NFPA 1977 because it was determined that variances in test results could not always validate an RPP rating of 8 for Nomex.

The introduction to NFPA 1977 (2011 Revision) states: "Based on information studied by this Committee, the majority of documented injuries to wildland firefighters are related to heat stress"[1]. Heat stress related injuries are extremely common in wildland firefighting due to the high exertion levels required in high heat environments. These injuries can require hospitalization and can even be fatal. To minimize the impact of PPE on heat stress related injuries, NFPA 1977 (2011 Revision) requires that WLFF PPE fabric have a minimum THL rating of 450 watts per square meter (W/m^2). The THL rating reflects the insulation and evaporative resistance of a single layer of fabric. However, this requirement only applies to the fabric used in WLFF PPE garment and does not consider the entire garment system. The NFPA 1977 Standard limits the amount of the garment that cannot meet the 450 W/m^2 THL (multi-layer) to 30 percent; however, it does not address using two garments, one over the top of another. Testing performed by the USFS and the University of Montana shows significant heat stress risk to firefighters wearing multi-layer PPE versus single layer[9]. The actual total THL of a complete WLFF PPE garment system is dependent upon the choice of base layer garments and the configuration (layering) of the garment system and is higher than the THL for a single layer fabric.

NFPA 1975, 2009 Edition, *Standard on Station/Work Uniforms for Emergency Services* establishes "requirements for flame resistant station uniform clothing" that are not primary protection garments[10]. NFPA 1975 is applicable to any uniform garments worn by WLFFs under their PPE. This standard specifies the requirements for the design, performance, testing, and certification of non-primary protective station/work uniforms and the individual garments comprising station/work uniforms. While uniform garments are not specifically PPE, many firefighting organizations require station wear or uniform garments to be worn underneath their PPE, such as turnout gear or WLFF PPE. In order to be worn with PPE, their station wear uniforms must also meet the requirements of NFPA 1975. NFPA 1975 recognizes that uniform garments can also serve as primary protection garments when they are dual certified to two NFPA standards (e.g., NFPA 1975 and 1977). At this time, there are no NFPA standards governing the performance or design of base layer garments used in wildland or structural

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[8]International Organization for Standardization (ISO) 16073, Wildland firefighting personal protection equipment – Requirements and test methods, 2010 edition.
[9]Wildland fire uniform configurations on physiological measures of exercise-heat stress, Joseph Domitrovich, Missoula Technology and Development Center.
[10]NFPA 1975, Standard on Station/Work Uniforms for Emergency Services, 2009 edition.

firefighting. Consequently, any performance requirements for base layer garments are established at the department level.

3. PPE SELECTION CONSIDERATIONS

3.1 The Effects of Garment Configuration

Testing has shown that garment configuration can dramatically alter the thermal protection and total heat loss performance of a fabric. When a new fabric material is certified to NFPA 1977, the fabric is tested as a single layer swatch in a test fixture with no other layering involved. Once a material is determined to meet NFPA 1977 requirements, it is certified for use in NFPA 1977-certified PPE garments. However, this tested condition is seldom how a WLFF PPE garment is actually worn. WLFF PPE shirts/jackets are typically worn over a long or short sleeve T-shirt made of cotton, wool-blend or other materials. For some fire departments, the WLFF PPE pants are worn as a second layer over their standard duty uniform pants. By adding these additional layers, the RPP and THL ratings of the fabric combinations change significantly from the single layer fabric characteristics. In some cases, the user does not realize that their garment configuration has changed the level of thermal protection and the heat stress relief characteristics of their garment system.

To demonstrate the effects of layering, Table 3-1 lists RPP and THL test data for a variety of fabrics used in single layer and multi-layer configurations[4]. The 5.0 ounce per square yard (oz.), 5.8 oz. and the 6.5 oz. fabrics are commonly used in WLFF PPE and the 7.0 oz. fabric is commonly used in NFPA 1975-certified duty uniform pants. The test data shows that the layering of fabrics can create a substantial increase in RPP protection and a correspondingly sizeable reduction in THL rating.

Table 3-1. Effects of Layering on Fabric RPP & THL Data

Traditional Single Layer PPE Fabric	RPP (s)	THL (W/m^2)
5.0 oz. WLFF PPE fabric (single layer)	7.7	759
5.8 oz. WLFF PPE fabric (single layer)	8.1	780
7.0 oz. Uniform pant fabric (single layer)	8.4	725
Multi-Layer Fabric Configurations		
5.0 oz. WLFF PPE fabric + 7.0 oz. Uniform pant fabric	13.3	500
5.8 oz. WLFF PPE fabric + 7.0 oz. Uniform pant fabric	>13.8	492
5.0 oz. WLFF PPE fabric + 7.0 oz. cotton fabric	>14.0	486
Notes: Test data from Wildland Fire Fighter Advanced Personal Protection Equipment System – Final Report, Department of Homeland Security Science & Technology Directorate, R-Tech Program, April 2014.		

The test data indicates that the RPP of WLFF PPE can more than double when the PPE is layered over a uniform pant. The increase in RPP is directly proportional to an increase in the time required to receive a second-degree burn. This significantly increases the firefighter's allowable exposure time to the thermal threat before he receives a second-degree burn injury. The test data also shows THL reductions between 259 W/m^2 and 327 W/m^2 due to the layering of garments.

A W. L. Gore assessment of a 1998 International Association of Fire Fighters field trial examining the effects of THL ratings on firefighter physiological response concluded that there is a “90% confidence that garments that were different by 40 W/m^2 produced a physiologically significant difference in core temperature”[11]. They also concluded that there is a “95% confidence that garments that were different by 65 W/m^2 produced a physiologically significant difference in core temperature”[10]. Based on the W. L. Gore assessment, there is a very high statistical confidence that the layering of WLFF PPE garments will induce a physiologically significant difference in human core body temperature. This means the layering of garments increases the likelihood for heat stress injury compared to single layer garments. This validates what many WLFFs have been subjectively feeling: That multi-layered garments increase the heat stress on the wearer. These numbers also demonstrate that the actual protection and comfort ratings of garments can change significantly from the fabric protection and comfort ratings achieved in the laboratory for NFPA certification. This reflects the importance of garment configuration to garment performance and must be considered in order to achieve the optimal balance between protection and heat stress relief when selecting PPE garments.

3.2 The Effects of Base Layer Garments

Base layer garments are not typically considered an integral component of the PPE system. However, the data in Table 3-1 reflects the dramatic change in RPP and THL that can occur when a PPE fabric is layered over an undergarment fabric. Wearing WLFF PPE over a base layer garment will increase the RPP and decrease the THL ratings of the single layer PPE fabric. Consequently, the selection of undergarment fabrics must be considered a part of the overall WLFF PPE garment system. Since current NFPA standards do not identify performance requirements for flame resistant base layer garments, fire departments must establish their own performance criteria. Many fire departments have determined that full flame resistance of base layer garment fabrics is not required because they are worn under flame resistant PPE. Most agree that undergarments, at a minimum, should have a no melt/no-drip capability so that the undergarment cannot melt onto the skin. A human study on the effects of base layer clothing worn under structural firefighting ensembles indicated that base layers “had little influence on physiological response”[12]. However, this is primarily attributed to the heavy layers of the turnout gear worn by structural firefighters. WLFF PPE ensembles are much lighter and more permeable. Manikin testing has demonstrated that the use of high performance wicking flame resistant base layer garments can increase the system level THL rating of a WLFF PPE system when compared to cotton base layer garments[4]. Both studies agree that base layers play a role in protection performance and heat stress relief. The subjective feedback from the APPS WLFF PPE Wear Trial indicates there is a high degree of user preference for high performance wicking undergarments when compared to traditional cotton undergarments[4,13]. The use of no-melt, no-drip, wicking, fast-drying base layer garments should be considered if heat stress reduction is a major priority in the selection of WLFF PPE.

[11]What Is The Minimum Perceivable THL Difference, Fabrics Division, W. L. Gore & Associates, Inc., April 2011.
[12]Base Layer Clothing: Part of the Protective Ensemble, Denise Smith, Firehouse, October 2013.
[13]Will Underwear Be the Key to Our Next Generation of Wildland PPE?, Fred Chan, Wildfire Magazine, January 2013.

3.3 New High Performance Fabrics

Previous single layer WLFF PPE garment systems made from the traditional WLFF PPE fabrics afforded moderate RPP performance with reasonable THL ratings. In order to increase thermal protection using the traditional WLFF PPE fabrics, multi-layered garment systems were used. While the RPP ratings of multi-layered garment systems increase significantly, the THL ratings of multi-layered garments decrease significantly, increasing the possibility for heat stress injury. Consequently, using traditional WLFF PPE fabrics to achieve higher levels of thermal protection required increasing the risk for heat stress injury. This tradeoff is evident based on the greater number of heat stress injuries that occur compared to the number of burn injuries that current WLFFs experience. The new generation of flame resistant fabrics appears to fill the capability gap by offering significant improvements in RPP rating while maintaining high levels of THL rating. Table 3-2 compares the performance differences of these fabrics and configurations.

Table 3-2 Comparison of Fabric Performance

Traditional Single Layer PPE Fabric	RPP (s)	THL (W/m^2)
5.0 oz. WLFF PPE fabric (single layer)	7.7	759
5.8 oz. WLFF PPE fabric (single layer)	8.1	780
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5.0 oz. WLFF PPE fabric + 7.0 oz. Uniform pant fabric	13.3	500
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5.0 oz. WLFF PPE fabric + 7.0 oz. cotton fabric	>14.0	486
New Single Layer WLFF PPE Fabrics		
6.5 oz. Safety Components Sigma 4 Star	11.5	752
9.5 oz. Tencate Comfort MP950	11.2	650
7.7 oz. Tencate S-469	11.1	680
9.0 oz. Tencate Defender M900	10.6	699
6.5 oz. Protera 165	8.5	895
Notes: Testing per NFPA 1977, 2005 edition RPP Testing performed by Underwriters Laboratory[4] THL Testing performed by Intertek[4]		

These fabrics eliminate the need to layer garments and can achieve a single layer fabric RPP rating that was previously not achievable without layering fabrics or garments. This results in more balanced protection, where protection levels are similar throughout the PPE garment. While there is a slight reduction in THL rating when comparing single layer fabric performance, there is a significant improvement in THL rating when compared to layered fabric configurations. The performance of these new fabrics allows the development of single layer WLFF PPE garments to potentially replace previously fielded multi-layer garment systems. These fabrics allow the PPE to achieve a balance between a relatively high degree of protection against thermal threats (relative to single layer fabrics) while maintaining a high degree of heat stress relief throughout the garment system (relative to multi-layered fabrics). The operational assessment conducted in the APPS WLFF PPE program clearly indicates a user preference for single layer WLFF PPE[4] in comparison to multi-layer WLFF PPE.

4. SELECTION PROCESS

There is currently no NFPA standard that provides specific guidelines for the selection of WLFF PPE. NFPA 1851, *Standard on Selection, Care and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting* provides guidelines for the selection of structural firefighting PPE and the basic principles of NFPA 1851 are applicable to the selection of WLFF PPE[14]. The WLFF PPE selection process proposed in this selection guide is a systematic approach to the selection of WLFF PPE to maximize the protection and performance of WLFFs and utilizes aspects of NFPA 1851 and Department of Defense acquisition processes. The following flowchart in Figure 4-1 describes the proposed step-by-step process for the selection of WLFF PPE.

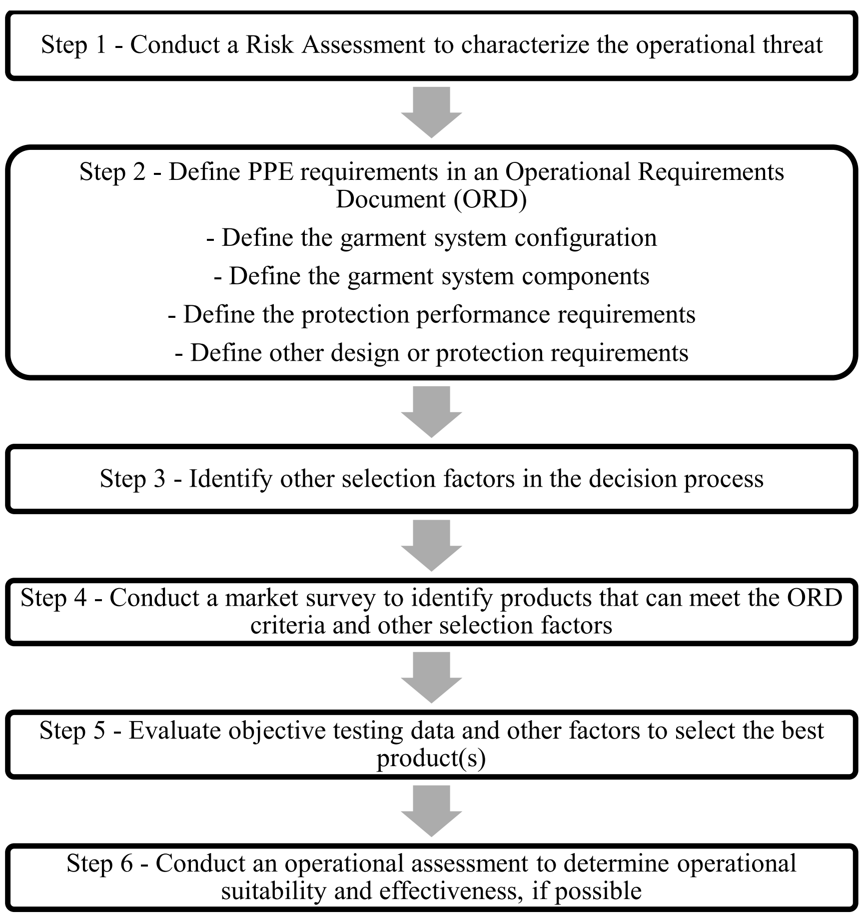

Figure 4-1. WLFF PPE Selection Process Flow Chart

[14]NFPA 1851, Standard on Selection, Care and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting, 2008 edition.

4.1 Step 1: Risk Assessment

It is necessary to properly characterize the threat before selecting the protection levels needed to mitigate the threat. NFPA 1851 and other sources recommend that a risk assessment should be the basis for selection of all PPE[15,16,17]. NFPA 1851 recommends considering or including the following factors when developing the risk assessment:

- Types of duties or operations performed when wearing WLFF PPE;
- Identification and characterization of the threats in those operations;
- Geographic location and climate during most operations;
- Garment configurations of the WLFF PPE; and
- Organizational experience and lessons learned with current WLFF PPE.

While it may appear that all wildfire risk assessments should be similar, this may not necessarily be the case. Fire departments can operate under very different conditions depending upon their location and operational responsibilities. Wildfires can vary by location due to the predominant fuel types involved (e.g., forest fire vs. brush fire). Location dictates the terrain and the environmental conditions that wildland firefighters operate in, which are a major factor in heat stress injuries. Wildfires near the wildland urban interface are more accessible to vehicles than remote regions that require firefighters to walk to the wildfire location. Mountainous terrain and hot or humid locations subject firefighters to greater risk of heat stress. Fire departments may have different operational responsibilities (e.g., direct attack versus indirect attack) in larger incidents, which can determine the workload and the proximity to the threat. Most importantly, a department's operational experience may indicate that a particular type of injury predominates and additional protection against that type of injury is required. To the contrary, mutual aid agreements may create similarities in risk assessments. Consequently, fire departments must base their risk assessment and their PPE operational requirements on the threats that are specific to their operational responsibilities in their location. The risk assessment should be documented so that it can be revised, as warranted, based on operational experience.

The most critical component of the risk assessment is properly defining the threat in order to characterize the PPE protection levels that are needed to protect WLFFs against that threat. Simply using the NFPA 1977 minimum RPP requirement (RPP $\geq$ 7) should not be the basis of threat characterization for every department. The NFPA 1977 RPP requirement was based on the historical performance of existing flame resistant fabrics at the time of its original publication in 1993 and was not based on a risk assessment of wildland firefighting operations. Defining a "reasonable maximum exposure" (RME) is one method to characterize the wildfire threat environment. Defining and characterizing a wildfire RME can be challenging since no two wildfires are identical and the wildfire threat is dynamic in nature as the size and intensity of a wildfire is constantly changing. The following example can be useful in characterizing the wildfire threat and developing a risk assessment.

[15]Considerations When Specifying PPE, Joel Calfee, FireRescue, September 2013.
[16]Writing PPE specifications: Risk assessments, Mike McKenna, FireRescue1.com, January 2011.
[17]WUI/Wildland PPE, Vaughan Miller, FireRescue, September 2011.

In 2010, the California Department of Forestry & Fire Protection (CAL FIRE) convened a workshop of subject matter experts to conduct a wildland firefighting hazard and risk assessment[18]. The workshop sought to define their thermal protection requirements (e.g., RPP) based on a RME that their firefighters could experience during normal wildfire working conditions (e.g., direct attack). CAL FIRE based their RME on conducting normal wildfire operations one foot from a hypothetical flame front one meter (3.3 feet) high, 100 meters wide and three meters deep. The computational analysis for this work condition predicted a RME heat flux of 7.1 kW/m^2. This predicted RME is consistent with the RME calculations of other wildland firefighting studies[5], which predicted a RME between 6.3 kW/m^2 to 8.6 kW/m^2 for various wildfire operational scenarios. In order to define their RPP requirements, CAL FIRE compared the time to second degree burn (TSDB) performance of their two-layer PPE garment system when exposed to various heat fluxes, ranging from 7.5 kW/m^2 to 21 kW/m^2. Using a heat flux of 21 kW/m^2, a washed CAL FIRE PPE multi-layer pants system provided a TSDB of 22.1 seconds, which equates to an RPP of approximately 11. Using the predicted heat flux of 7.5 kW/m^2, the TSDB increased to 76 seconds. Given the inherent conservatism of these calculations, CAL FIRE determined that their minimum RPP rating should be 10. This RPP value is the total thermal protection required and not just the fabric-level performance specified in NFPA 1977. Consequently, it can be addressed by individual fabric performance or by the layering fabrics. In an attempt to reduce heat stress related injuries, the CAL FIRE Risk Assessment also recommended that the minimum THL be increased from 450 W/m^2, as required by NFPA 1977, to 500 W/m^2.

This risk assessment is a good example of how analysis of a specific operational scenario can generate a different protection requirement from those specified by the applicable standard. Since most departments do not have access to the analytical capabilities required to quantify an RME, some estimation can be used to determine a suitable RME. A department should be able to determine if their predicted RME is higher, lower or the similar to the RME developed by CAL FIRE by comparing the size of their hypothetical flame front to the hypothetical flame front used by CAL FIRE. The minimum required RPP rating would then be higher or lower or the same as the CAL FIRE minimum RPP value (10). Since the current maximum RPP value of a single layer fabric suitable for WLFF PPE is approximately 11, a higher predicted RME than CAL FIRE would suggest the need for a multi-layer fabric PPE configuration. A similar or lower predicted RME could be satisfied with a single layer fabric PPE configuration.

4.2 Step 2: Operational Requirements Document

Like the risk assessment, the operational requirements for the WLFF PPE should be documented into an ORD. Documenting operational requirements creates a definitive baseline of PPE performance that may be adjusted in the future based on operational experience and lessons learned. The ORD should:

- Identify the garment configuration and the garment components that comprise the WLFF PPE system;
- Specify the key performance parameters of each WLFF PPE garment; and

[18]Wildland Fire & Hazard Risk Assessment, California Department of Forestry and Fire Prevention (CAL FIRE), Draft report, January 2010.

- Identify any other performance requirements of each WLFF PPE component.

In defining the operational requirements for a WLFF PPE system, it is important to differentiate the priority between the various requirements. A requirement that is considered mission critical (e.g., thermal protection performance) should be identified as a Key Performance Parameter (KPP). The KPP is essential for mission performance and drives the selection process. Non-KPP requirements are less critical product parameters or characteristics that can be compromised or traded off in order to achieve other objectives or benefits such as achieving a KPP or reducing product cost. An example of a WLFF PPE operational requirement document developed under the APPS WLFF PPE program is provided in Appendix A. The following considerations should be addressed in every WLFF PPE ORD:

- **Compliance with Standards** – Unless alternative standards or requirements have been established, it is recommended that compliance to NFPA 1977 (and NFPA 1975, if worn as station wear) be considered a mandatory requirement for all WLFF PPE selection and procurements[5]. NFPA 1977 specifies a wide range of requirements in addition to protection performance. These requirements include proper sizing and grading, quality assurance, annual NFPA recertification, etc. This ensures that the WLFF PPE satisfies a minimum level of performance over a broad range of requirements. NFPA certification requires that a manufacturer be certified to ISO 9000, which ensures that the manufacturing process complies with strict quality assurance procedures. Unless the buyer has alternative methods to ensure product performance and/or quality, NFPA certification of WLFF PPE should be considered a KPP.
- **Radiant Protection Performance (RPP)** – RPP is the primary form of thermal protection provided by WLFF PPE. While NFPA 1977 requires a minimum level of RPP in all WLFF PPE, it is important to understand that NFPA 1977 does not preclude a WLFF PPE manufacturer from exceeding these performance requirements or a fire department from seeking higher levels of RPP performance. For example, the CAL FIRE risk assessment concludes that the NFPA 1977 minimum required RPP level is not adequate for their predicted RME. Each department must conduct their own risk assessment to determine the appropriate level of RPP protection required for their operations. The garment system configuration must also be factored into this protection requirement as layering of fabrics can dramatically increase RPP but will also reduce the THL. The RPP should be considered a KPP.
- **Total Heat Loss (THL)** – The THL rating of PPE fabrics and the garment system is the primary indicator of vulnerability to heat stress injuries and should be given careful consideration when selecting WLFF PPE. The PPE garment system configuration must also be considered when developing the THL requirement as the layering of fabrics can dramatically decrease THL. In addition, the use of fast drying, wicking, no-melt/no-drip undergarments, as part of a comprehensive WLFF PPE garment system solution, should be considered to help to reduce the overall heat stress burden created by the WLFF PPE garment system. Since the majority of WLFF injuries are related to heat stress, the THL rating should be considered a KPP. Determining the appropriate balance between RPP and THL ratings is the greatest challenge when configuring and selecting the WLFF PPE system.

- **System Level Approach** – This proposed selection process recommends adopting a system level approach for the selection of WLFF PPE. A system level approach focuses on the performance of the complete system of PPE garment components rather than the performance of a single PPE component or material. This will more accurately reflect the actual performance of a WLFF PPE garment system when worn by the wildland firefighter.
- **Garment Configuration** – Garment configuration plays a major role in garment system performance as the layering of garments, including the use of undergarments, dramatically increases the RPP rating while reducing the THL rating of the garment system when compared to the ratings of the individual PPE fabric. This effect must be considered when configuring the WLFF PPE system. The configuration of the garment system will largely be determined by the protection performance requirements of the system. Multilayer PPE garments are needed to achieve the higher levels of RPP. Single layer PPE and wicking base-layer garments should be considered to maintain higher levels of THL. While sweating manikin data of a WLFF PPE garment system would provide an objective basis for comparison of heat stress relief performance, this data may not be readily available for the specific configuration of garments under consideration. Departments may want to conduct operational assessments in order to subjectively evaluate WLFF PPE system level performance.
- **Base Layer Garments** – The choice of base layer garments worn with the WLFF PPE can influence the system level RPP and THL ratings of a garment system. Fabric choices can range from cotton to wicking fabrics with no-melt/no-drip to wicking base layer fabrics that are fully flame resistant. Since NFPA 1977 does not specify performance criteria for base layer garments, each department must establish their own performance criteria for their base layers. During the APPS WLFF PPE program, the Integrated Process Team defined the performance requirements for WLFF base layers as no-melt/no-drip only. The rationale was that this level of performance was most similar to currently worn cotton base layers, and the base layers are worn under PPE so they do not require full flame resistance. The reduced level of performance also reduces the purchase cost making this option more cost effective. If higher performance fully flame resistant base layers are desired, refer to the SAVER *Flame Resistant Undergarment Market Survey Report* for available options[19]. The benefits of wicking, fast drying no-melt/no-drip undergarments have been documented and should be considered for reducing heat stress burden. Objective (instrumented manikin studies) and subjective (operational assessments) data have demonstrated that the use of fast drying, wicking no-melt/no-drip undergarments can help to reduce the heat stress burden on the wearer. The appearance requirements of fire departments may influence the selection of the fabric materials since the T-shirt is considered a de facto uniform component by many departments.
- **Fabric Selection** – Most WLFF PPE is bought as a garment set consisting of a matching shirt/jacket and pants from a single manufacturer. In many cases, the buyers select and procure a shirt/jacket and pants made of the same fabric. However, the PPE

[19]Flame Resistant Undergarment Market Survey Report, SAVER, Jan 2012.

shirt does not need to be of the same fabric as the pants nor does it need to be made by the same manufacturer. Fabric selection should be based on performance and optimized for that specific garment application. While the minimum RPP performance requirements can be the same across the garment components of the system, different fabrics can be selected to optimize RPP or THL performance, durability and/or the appearance of those specific garments. For example, the USFS uses one fabric for their PPE shirt and two different more protective and durable fabrics for their single layer pants. If a multi-layer pants configuration is used, testing data indicates that the WLFF PPE pants fabric should be selected for maximum THL rather than RPP since the multi-layering of pants fabrics will result in a significantly higher RPP level. If a single-layer pants configuration is used and the WLFF PPE pants are to be worn as station wear uniform pants, appearance factors (e.g., colorfastness, fabric smoothness, etc.) of the pants fabric become more important, which could eliminate some fabrics from consideration. Since the WLFF PPE response shirt and over pants are not considered uniform components, the appearance factors of the WLFF PPE shirt and over-pants fabrics are of less importance and other fabrics can be considered. Other material performance factors and characteristics play a role in the comfort of a PPE garment system. Air permeability can increase airflow within a garment and increase the perception of cooling. Fabric weight is more noticeable in a garment than the THL performance under normal conditions. Lower fabric weights tend to be perceived as more comfortable. Consequently, selection of the fabrics should be driven by the ORD requirements.

4.3 Step 3: Other Selection Considerations

- **Sizing** – Proper sizing of WLFF PPE garments plays a large role in user acceptance of a WLFF PPE garment system. While NFPA 1977 specifies minimum sizing attributes (e.g., garment dimensions, ease, etc.) to ensure proper fit, the APPS WLFF PPE Wear Trial demonstrated that achieving proper fit, even with NFPA 1977 certified garments, can be a big challenge[4]. Garments that are too tight will restrict freedom and range of motion and compromise operational performance. However, garments that are too loose will feel baggy and do not provide a proper uniform appearance. In addition, baggy pants may present compatibility issues when worn under turnout gear and can present a snagging hazard. Consequently, the finished dimensions of the PPE garments play a critical role in operational suitability and effectiveness. Under the APPS program, a relaxed fit (larger) garment sizing was added to the sizing spectrum under the GEN II WLFF PPE evaluation. The relaxed fit garment used a larger dimension in several critical dimensions in order to preserve the required garment ease (the additional space in a garment beyond the actual body dimensions) for larger individuals. In addition, the increased air gap of looser fitting clothing can provide greater ventilation to reduce heat stress burden and increase thermal protection by creating an air layer. This availability of larger sized garments greatly improved evaluator ratings for the fit and preference of the GEN II WLFF PPE garment system. The range of sizes available should be a factor when considering a WLFF PPE garment.

- **Garment Design Features** – Garment design features can influence the suitability and effectiveness of a WLFF PPE garment or garment system. Design features such as articulated knee or elbow joints, gusseted crotch and "action back" can improve freedom of motion and comfort. Other design features such as cargo or radio pockets can increase the utility of a garment. Simple design features such as a positive locking waist closure can also greatly improve the favorability of a garment. The ability to select the garment design features required can influence the selection of a garment. Some WLFF PPE manufacturers are now considering offering a modular platform approach to building WLFF PPE garments. For instance, the basic WLFF PPE shirt (the platform) would have no pockets attached. The buyer can then select from an array of pocket options for installation to customize their WLFF PPE garments to their specific applications.
- **Cost Considerations** – Cost is a major factor in the selection of WLFF PPE and the procurement budgets may be limited. Consequently, all procurement decisions involve a value judgment. Does an improvement in performance justify the additional cost? While this answer varies on a case-by-case basis, documentation of the risk assessment and operational requirements will help to satisfy any questions raised regarding the selection process and support the final selection decision of WLFF PPE.
- **Point of Manufacturing** – While the location of garment manufacturing has little bearing on the actual performance of a PPE garment, it is often a consideration during the garment procurement process. Some departments require that their WLFF PPE be purchased from specific organizations. While most WLFF PPE are built domestically using domestically sourced fabrics, some WLFF PPE is built overseas in order to take advantage of lower manufacturing costs. Production of WLFF domestically can be advantageous[20]. Preferred manufacturing location or any other manufacturing restrictions of the department should be specified in the ORD.

4.4 Step 4: Market Survey

Once the ORD is completed, a market survey should be conducted to identify any products that can satisfy the requirements. Using Internet search engines and the manufacturer's contact information listing in Section 4.7, technical product information and test data should be gathered to determine which WLFF PPE products meet operational requirements.

4.5 Step 5: Objective Test Data Evaluation

If the protection performance requirements are the same as the minimum fire department's protection performance requirements of NFPA 1977, NFPA certification is adequate to validate performance. If the protection performance requirements exceed the minimum protection performance requirements of NFPA 1977, objective laboratory test data should be requested from the manufacturer to validate the performance of the product being considered. Departments should request test data generated by a laboratory certified to conduct testing for NFPA certification (Intertek or Underwriters Laboratories) to ensure that the quality and consistency of the testing is adequate for comparison purposes.

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[20] NFPA 1977 & Wildland/Urban Interface PPE, Kevin Nunn, March 2013, FireRescue.

4.6 Step 6: Operational Assessment

The final recommended step of the selection process is to conduct an operational assessment of the WLFF PPE, if possible. An operational assessment is used to subjectively validate the operational suitability and effectiveness of a product and complements the objective technical data determined by laboratory testing. This assessment evaluates factors that cannot be characterized by laboratory testing, such as fit, comfort, or design features, and ensures that all issues of compatibility and interoperability are met. For instance, if the WLFF pants are to be worn under turnout gear, compatibility of WLFF pants with turnout gear should be assessed. The operational assessment can reveal that the highest performing product does not always have the highest level of operational suitability and effectiveness[4]. Operational assessments can also help to reveal garment design flaws, changes in performance levels due to PPE system configuration, and can identify other compatibility/interoperability issues[4]. Operational assessments should include use in actual wildfire suppression operations. Since individual opinions of the same product can vary greatly, it is helpful to have multiple evaluators assess a product's performance in order to statistically average the results. This can be very difficult to achieve due to the cost of purchasing multiple test samples. In situations where conducting an operational assessment is not possible, it is recommended that the PPE manufacturer be requested to provide a list of current users of their product. These current users of that product can then be queried as to their opinions regarding the operational suitability and effectiveness of the product under actual operational conditions.

4.7 Manufacturers' Contact Information

Fabric Mills' Contact Information

The following list of fabric mills may not be inclusive of all WLFF PPE fabric manufacturers:

- DuPont, http://www.dupont.com, Richmond, VA 23234
- Milliken, http://www.milliken.com, Spartanburg, SC 29304
- Mt Vernon Mills, http://www.mvmills.com, Trion, GA 30753
- PBI Performance Products, http://www.pbiproducts.com, Charlotte, NC 28273
- Safety Components, http://www.safetycomponents.com, Greensboro, NC
- Springfield LLC, http://www.springfieldllc.com, Jericho, NY 11753
- Tencate/Southern Mills, http://www.tencate.com, Union City, GA 30291

Garment Manufacturers' Contact Information

The following list of garment manufacturers may not be inclusive of all WLFF PPE manufacturers:

- Barrier-Wear, http://www.barrier-wear.com, Broomfield, CO 80020
- California Prison Industry Authority, http://pia.ca.gov, Folsom, CA 95630
- Coaxsher, http://www.coaxsher.com, Chelan Falls, WA 98817
- CrewBoss, http://www.crewbossppe.com, Eugene, OR 97402

- Fox Apparel, http://www.foxapparel.net, Asheboro, NC 27205
- Lion Apparel (Starfield), http://www.lionprotects.com, Dayton, OH 45414
- PGI (Fireline), http://www.firelinepgi.com, Green Lake WI 54941
- Propper, http://www.propper.com, Weldon Spring, MO 63304
- Topps Safety Apparel (Strikeforce), http://www.toppssafetyapparel.com, Rochester, IN 46975
- True North Gear (Dragonslayer), http://www.truenorthgear.com, Seattle, WA
- Weckworth Manufacturing, http://www.weckworth.com, Haysville, KS 67060
- Workrite Uniform Company, http://www.workrite.com, Oxnard, CA 93030

WLFF PPE Undergarment Manufacturers' Contact information

The following list consists of undergarment and undergarment fabric manufacturers that are suitable for WLFF applications:

- 37.5, http://www.protecttheforce.com, Wellesley, MA 02481
- Dri-Fire, http://www.drifire.com, Columbus, GA 31909
- Massif, http://www.massif.com, Ashland, OR 97520
- Peckham Vocational Industries, http://www.peckham.org, Lansing, MI 48906
- Polartec, LLC, http://www.polartec.com, Lawrence, MA 01841
- Potomac Field Gear, http://www.potomacfieldgear.com, Council, VA 24260
- XGO, http://www.proxgo.com, West End, NC 27376

5. CONCLUSION

Because the operational requirements vary by fire department, there is no single WLFF PPE design or material that is ideally suited for all wildland firefighting applications. In addition, no WLFF PPE will protect firefighters against all possible threat situations and conditions. However, it is possible to optimize the selection of WLFF PPE to improve operational performance, maximize protection and minimize the likelihood for injuries based on the operational conditions a department will most likely experience. The following items should be considered when selecting new WLFF PPE:

- Certification to NFPA 1977 should be the minimum qualification when considering WLFF PPE options. This standard covers garment performance, sizing requirements and assures proper manufacturing of the product. If a department determines in their risk assessment that their protection performance requirements are greater than what is required by NFPA 1977, the department should then seek specific garment performance data from the manufacturer to determine if the garment or garment system meets their specific operational requirements.

- A risk assessment should be performed to identify and characterize the maximum anticipated operational threat and the level of protection required to mitigate the threat. The risk assessment should be documented and then updated as operational experience dictates. If a department lacks access to the technical resources to predict a suitable RME, consider using a risk assessment performed by an organization whose operational responsibilities and location are similar.
- The operational requirements for the WLFF PPE system should be documented to define the characteristics of the PPE being sought. At a minimum, the ORD should identify key performance parameters (such as RPP and THL), garment configuration (e.g., single layer vs. multi-layer PPE), and other components (e.g., base layer garments) of the PPE system. Documenting the operational requirements will provide a historical record for selection criteria and will allow for future adjustment due to operational lessons learned.
- Objective laboratory data is the most reliable indicator of the performance of a fabric or garment system. However, objective lab data cannot determine or validate the operational suitability and effectiveness of a PPE garment system. It is recommended that a subjective operational assessment of a prospective WLFF PPE garment system be performed to determine the true operational suitability and effectiveness of the WLFF PPE garment system under actual operational conditions. If an organization cannot perform an operational assessment, consider using an assessment performed by another department for that specific WLFF PPE garment system.

6. REFERENCES

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7. ACRONYMS

AEL – Authorized Equipment List

APPS – Advanced Personal Protection System

ASTM – American Society for Testing & Materials

CAL FIRE – California Department of Forestry & Fire Protection

Cal OSHA – California Occupational Safety and Health Administration

DHS S&T – Department of Homeland Security Science & Technology

ISO – International Organization for Standards

KPP – Key Performance Parameter

NFPA – National Fire Protection Association

ORD – Operational Requirements Document

PPE – Personal protective equipment

RME – Reasonable maximum exposure

RPP – Radiant Protection Performance

SAVER – System Assessment and Validation for Emergency Responders

THL – Total Heat Loss

T-PACC – Textile Protection and Comfort Center (NC State University)

TSDB – Time to second degree burn

USFS – U. S. Forest Service

WLFF – Wildland firefighter

8. STANDARDS & TEST PROCEDURES

AATCC 8 – Colorfastness to Crocking, 2005 Edition

AATCC 15 – Colorfastness to Perspiration, 2002 Edition

AATCC 16 – Colorfastness to Light, 2004 Edition

AATCC 61 – Colorfastness to Laundering, 2006 Edition

AATCC 135 – Dimensional Changes of Fabric after Home Laundering, 2003 Edition

ASTM D 737 – Standard Test Method for Air Permeability of Fabrics, 2004 Edition

ASTM D 1683 – Standard Test Method Failure in Sewn Seams of Woven Apparel Fabrics, 2011 Edition

ASTM D 3787 – Standard Test Method for Bursting Strength of Textiles – Constant Rate of Traverse (CRT) Ball Burst Test, 2007 Edition

ASTM D 6413 – Standard Test Method for Flame Resistance of Textiles (Vertical Flame), 2011 Edition

ASTM E 96B – Standard Test Methods for Water Vapor Transmission of Materials, 2010 Edition

ASTM F 2370 – Standard Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin, 2010 Edition

International Organization for Standardization (ISO) 16073, *Wildland firefighting personal protection equipment – Requirements and test methods,* 2010 Edition

NFPA 1977, *Standard on Protective Clothing and Equipment for Wildland Fire Fighting,* 2011 Edition

NFPA 1975, *Standard on Station/Work Uniforms for Emergency Services,* 2009 Edition

NFPA 1851, *Standard on Selection, Care and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting,* 2008 Edition

APPENDIX A. SAMPLE OPERATIONAL REQUIREMENTS DOCUMENT FOR WLFF PPE

1. WLFF PPE System Level Operational Requirements – The WLFF PPE garment system shall:
    a. Exhibit an Evaporative Resistance [W/m^2] rating greater than current WLFF PPE garment system, as determined by sweating manikin tests per ASTM F 2370.
    b. Be launderable a minimum of 25 times without degradation to performance.
    c. Have a minimum shelf life no less than 5 years.
    d. Allow for rapid donning in less than 5 minutes.
    e. Be compatible and interoperable with existing WLFF operational equipment (e.g., backpacks, gloves, footwear, helmet shrouds, etc.).
    f. Accommodate the 5^{th} to 95^{th} percentile male and female firefighter.
    g. Comprise of the following components:
        i. WLFF PPE Undergarments –Worn underneath the WLFF PPE uniform pants, shirt, and/or Overpants. Consists of a Short sleeve T-shirt and Short drawers. Include female bra and undergarments.
        ii. WLFF PPE shirt – The single layer of torso protection worn over the WLFF PPE T-shirt.
        iii. WLFF Uniform Pants – The single layer of lower body protection worn over the PPE underwear.
        iv. WLFF PPE Overpants – The outer layer of multi-layer lower body protection and worn over an NFPA 1975-certified station pants and WLFF PPE undergarments.
2. WLFF PPE Component Level Operational Requirements – The following operational requirements are specific to individual components of the WLFF garment system.
    a. WLFF PPE Under Garment Operational Requirements – These undergarments are designed to improve wicking and reduce drying time to improve the comfort and increase operational performance of the wearer during firefighting operations. While they may have flame resistant characteristics, they are not intended to be the primary layer of protection and should not be worn without another garment layer during firefighting operations.
        i. Type of undergarments – The undergarment subsystem shall consist of:
            1. Short sleeve top
            2. Short drawers
        ii. Performance Requirements – The undergarments shall meet the requirements for:
            1. No Melt No Drip per ASTM 6413 [Threshold KPP]
            2. Drying time < 75 min per Natick Protocol [Threshold]
            3. Moisture Wicking to 6.0 mm per Natick Protocol [Threshold]
                a. Wales – 15 sec
                b. Courses – 15 sec
            4. MVTR > 2500 $g/m^2/24hr$ per ASTM E 96 test B [Threshold]
            5. Air Permeability > 300 ft^3/min per ASTM D737 [Threshold]
            6. Char length < 6” per ASTM 6413 [Objective]
            7. After flame < 2 sec per ASTM 6413 [Objective]

        8. Anti-microbial per AATCC 100 [Objective]
    iii. Structural Requirements – The undergarment materials shall meet the requirements for:
        1. Burst Strength > 80 lbs, per ASTM D 3787
        2. Seam Strength > 70 lbs, per ASTM D 1683
    iv. Appearance Requirements – The undergarment materials shall meet the requirements for:
        1. Dimensional Stability (5X), per AATCC 135
            a. Wales – 3%
            b. Courses – 3%
        2. Colorfastness to light > 3, per AATCC 16
        3. Colorfastness to crocking > 3, per AATCC 8 (wet and dry)
        4. Colorfastness to perspiration > 4, per AATCC 15
        5. Colorfastness to laundering (3X) > 3, per AATCC 61
    v. WLFF PPE Under Garment System Level Design Requirements – The undergarments shall be constructed:
        1. Using flat lock seams
        2. In Navy Blue
    vi. WLFF PPE Under Garment Component Level Design Requirements
        1. The T-shirt shall be designed as follows:
            a. Standard fit
            b. Crew collar
            c. Shall accept flame resistant silk screened department logo
        2. Short drawers shall be boxers

b. WLFF PPE Shirt Operational Requirements – This garment acts as the primary layer of torso protection. It is worn over the PPE T-shirt. The WLFF PPE Shirt shall be certifiable to NFPA 1977 [Threshold KPP].
    i. Material Performance Requirements – The WLFF PPE shirt material shall:
        1. Meet the performance requirements of NFPA 1977 [Threshold KPP]
        2. Exhibit a minimum RPP $\geq$ 10 [Threshold KPP]
        3. Exhibit a minimum THL $\geq$ 500 W/m^2 [Threshold KPP]
    ii. Structural Requirements – The WLFF PPE shirt materials shall meet the structural requirements for NFPA 1977 [Threshold KPP].
    iii. Appearance – The WLFF PPE shirt shall be made in the following colors:
        1. Yellow
        2. Orange
    iv. WLFF PPE Shirt Design Requirements – The WLFF PPE shirt shall:
        1. Meet the design requirements of NFPA 1977 [Threshold KPP]
        2. Be compatible with the WLFF PPE Overpants and Uniform pants.
        3. The shirt configuration shall:
            a. Use a zipper for closure.
            b. Include a collar that allows complete closure.
            c. Include a single storage pocket mounted on the right chest.
            d. Include a single radio pocket mounted on the left chest.

e. Have anchor points for miscellaneous equipment and lanyards.
f. Allow wearing in a tucked or untucked configuration.
g. Include 360 degree retro-reflective material.

c. WLFF PPE Uniform/Tactical Pants Operational Requirements – This garment acts as the primary single layer of lower body protection and is worn over PPE underwear only. The WLFF PPE Uniform Pants shall be certifiable to both NFPA 1977 and NFPA 1975 [Threshold KPP].
   i. Material Performance Requirements – The WLFF PPE Uniform Pants material shall:
      1. Meet the performance requirements of NFPA 1975 [Threshold KPP]
      2. Meet the performance requirements of NFPA 1977 [Threshold KPP]
      3. Exhibit a minimum RPP $\geq$ 10 [Threshold KPP]
      4. Exhibit a minimum THL $\geq$ 500 W/m^2 [Threshold KPP]
   ii. Structural Requirements – The WLFF PPE Uniform Pants materials shall:
      1. Meet the structural requirements for NFPA 1977 [Threshold KPP]
      2. Meet the structural requirements for NFPA 1975 [Threshold KPP]
   iii. Appearance Requirements - The WLFF PPE Uniform Pants materials shall meet the following requirements:
      1. Color shall be Midnight Navy Blue (Color chip 35044, per FED STD 595)
      2. Colorfastness to light > 4 per AATCC 16
      3. Colorfastness to crocking > 4 per AATCC 8 (wet and dry)
      4. Colorfastness to perspiration > 4 per AATCC 15
      5. Colorfastness to laundering (3X) > 4 per AATCC 61
   iv. WLFF Uniform Pants Design Requirements– The WLFF PPE Uniform Pants shall:
      1. Meet the design requirements for NFPA 1975 [Threshold KPP]
      2. Meet the design requirements for NFPA 1977 [Threshold KPP]
      3. Be compatible with bunker/turnout gear
      4. Be compatible with WLFF PPE Shirt and Overpants
      5. The WLFF Uniform pants shall:
         a. Be available in a Uniform and a Tactical configuration
            i. The Uniform configuration will reflect a clean pants design without external pockets
         b. The Tactical configuration will include:
            i. External thigh cargo pockets
            ii. A means of closing and securing the pants cuff
   v. WLFF PPE Overpants (multi-layer application) Operational Requirements – This garment acts as the primary layer of lower body protection and must be worn over an NFPA 1975 certified Uniform Pants. The WLFF PPE Overpants shall be certifiable to NFPA 1977 [Threshold KPP].
      1. Material Performance Requirements – The WLFF PPE Overpants material shall:

   a. Meet the performance requirements of NFPA 1977 [Threshold]
   b. Exhibit a minimum RPP $\geq$ 10, when worn over an NFPA 1975 certified uniform pant [Threshold]
   c. Exhibit a minimum THL $\geq$ 500 W/m^2, when worn over an NFPA 1975 certified uniform pant [Threshold]
2. Structural Requirements – The WLFF PPE Overpants materials shall meet the structural requirements for NFPA 1977 [Threshold KPP].
3. Appearance – The WLFF PPE Overpants shall be made in the following colors:
   a. Yellow
   b. Orange
4. WLFF PPE Overpants Design Requirements – The WLFF PPE Overpants shall:
   a. Meet the design requirements for NFPA 1977 [Threshold KPP]
   b. The PPE Overpants shall:
      i. Include a means of closing and securing the pants cuff.
      ii. Be compatible with WLFF PPE Shirt and uniform pants.
      iii. Not have rear storage pockets.
      iv. Have a pass-thru to allow access to uniform pants pockets.
      v. Have external thigh mounted cargo pockets.