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**Advanced Personal Protection System (APPS), Wildland
Firefighter Personal Protection Equipment (WLFF PPE)
Clothing System Program, Final Report
Version 1.1**

by

Responder Technologies (R-Tech) Program

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and

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Executive Summary

This report documents the Advanced Personal Protection System (APPS) Wildland Firefighter Personal Protection Equipment (WLFF PPE) program conducted by the U.S. Army Natick Soldier Research, Development and Engineering Center's (NSRDEC), between April 2011 and December 2013. The Department of Homeland Security (DHS) Science and Technology Directorate's Responder Technologies (R-Tech) Program and the Department of Agriculture's U.S. Forest Service (USFS) sponsored NSRDEC to develop an improved WLFF PPE garment system for wildland firefighters.

This program sought to develop a new PPE garment system that would:

1. Achieve the thermal protection specified in the risk assessment to improve protection;
2. Achieve the total heat loss rating specified in the risk assessment to reduce heat stress;
and
3. Improve the form, fit, and function of the PPE garment system.

To achieve these objectives, the DHS APPS process was modified to develop the new WLFF PPE garment system. An Integrated Process Team (IPT) comprised of experienced wildland firefighters from the USFS and state, county, and city fire departments from California were selected to participate in the program. The IPT validated a risk assessment, defined operational requirements, and selected the materials for the PPE garment system. The product development process consisted of technical testing to identify and objectively validate the performance of materials for this application. The design of the new WLFF PPE garment system was certified to National Fire Protection Association 1977¹ requirements to ensure that the prototype test garments were suitable for use in wildfire operations. A 15-month operational assessment (Wear Trial) involving almost 1,000 wildland firefighters was performed to subjectively validate the operational suitability and effectiveness of the APPS WLFF PPE garment system. The results of the test and evaluation process indicate that the APPS WLFF PPE successfully meets all program objectives.

A significant development of this program is the use of system-level testing to evaluate PPE garment performance. System-level testing of WLFF PPE garments indicates that the new single-layer APPS WLFF PPE garments will reduce the rate of core body temperature increase and significantly increase work durations when compared to double-layer WLFF PPE configurations. Reducing the rate of core body temperature increase should translate to fewer heat stress injuries. Longer work durations should lead to greater work output by an individual. The new APPS WLFF PPE not only can reduce heat injury rates, but also should act as a "force multiplier," by increasing the operational effectiveness of the wildland firefighter and potentially improving the probability for success of the overall wildland firefighting operation.

This effort validates the application of the APPS process to new product development and for meeting the operational requirements of wildland firefighters.

1.0 Program Summary

The U.S. Army Natick Soldier Research, Development and Engineering Center’s (NSRDEC) conducted the Advanced Personal Protection System (APPS) Wildland Firefighter Personal Protection Equipment (WLFF PPE) program between April 2011 and December 2013. The Department of Homeland Security (DHS) Science and Technology Directorate’s (S&T) Responder Technologies (R-Tech) Program, also known as TechSolutions, and the Department of Agriculture’s U.S. Forest Service (USFS) sponsored NSRDEC to develop an improved WLFF PPE garment system for wildland firefighters. This program sought to develop a new PPE garment system that would:

1. Achieve the thermal protection specified in the risk assessment to improve protection.
2. Achieve the total heat loss rating specified in the risk assessment to reduce heat stress.
3. Improve the form, fit, and function of the PPE garment system.

The APPS WLFF PPE process modified the approach (Appendix B) originally used for the APPS tactical law enforcement PPE selection process² to address a product development application. Both processes established a user-based Integrated Process Team (IPT); characterized baseline PPE; conducted a risk (threat) assessment; identified and prioritized operational requirements in an Operational Requirements Document (ORD); conducted a market survey to determine the availability of existing solutions; and performed operational assessments (Appendix E) to validate the operational suitability and effectiveness of the solution. The APPS process follows the flowchart shown in Figure 1.

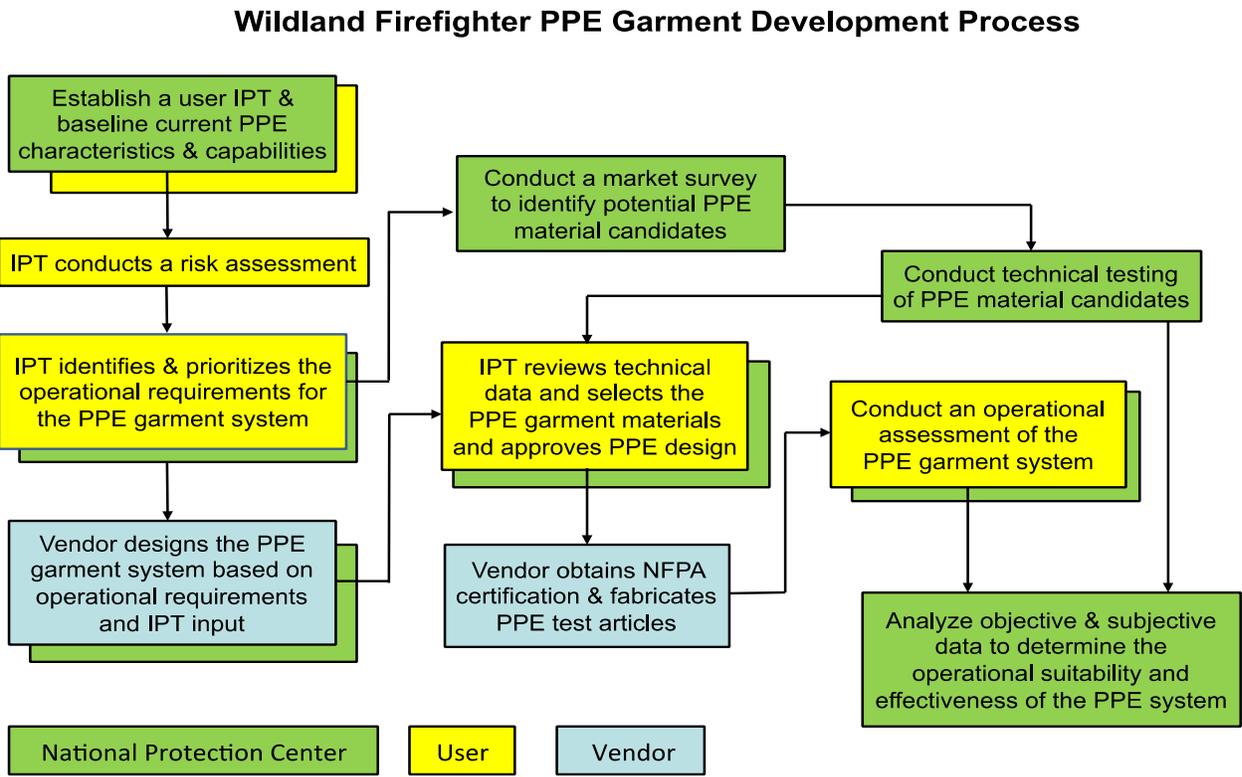


Figure 1 – APPS Process Flowchart

The operational requirements of the garment system were based on the *Wildland Fire Fighting Hazard and Risk Assessment*³ performed by the California Department of Forestry and Fire Protection (CAL FIRE) in 2010. The thermal protection requirements were based on a reasonable maximum exposure (RME) that their firefighters could experience during normal (i.e., ordinary) wildfire working conditions (i.e., direct attack). To establish a baseline of current performance, laboratory testing under controlled conditions objectively measured the performance of existing PPE materials and garment systems. The test and evaluation process utilized objective laboratory data (Appendix C) to select PPE materials and to achieve National Fire Protection Association (NFPA) certification. However, objective measurements of fabric and system characteristics cannot accurately characterize the operational suitability and effectiveness of a PPE system under actual operating conditions. This requires a subjective validation by users wearing the PPE under operational conditions. A garment designer was selected to design the new PPE garment system, and a garment manufacturer was then selected to manufacture and certify the test garments for use in the operational assessment (Appendix D). An operational assessment, or Wear Trial, was conducted to subjectively validate the operational suitability and effectiveness of the new PPE garment system under actual operational conditions over an extended period of time (Appendix E). The Wear Trial surveys asked evaluators to rate the performance attributes of the new WLFF PPE garment system relative to the performance of the baseline PPE garment systems. The survey generated data that characterized the operational suitability and effectiveness of the new WLFF PPE garment system in a direct comparison to the evaluators' baseline PPE systems (Appendix E). The late start of the Wear Trial in 2012 resulted in insufficient operational experience fighting wildfires. The IPT decided to extend the Wear Trial into the 2013 wildfire season. To resolve garment design deficiencies identified during the 2012 Wear Trial, the original APPS WLFF PPE garment system was redesigned. The redesigned WLFF PPE system was designated GEN II and a limited number of GEN II WLFF PPE garments were fielded to Wear Trial evaluators late in the 2013 wildfire season for evaluation.

2.0 Summary of Results

The test and evaluation process consisted of objective and subjective testing. The objective laboratory testing quantitatively determined if a fabric could meet the minimum performance requirements defined in the ORD. The objective testing consisted of material testing and system-level testing. However, laboratory data cannot accurately assess the operational suitability and effectiveness of a garment system when used under operational conditions. Critical attributes, such as comfort, appearance, durability, freedom, and range of motion, could not be fully evaluated under laboratory conditions. The user's subjective perception for the operational suitability and effectiveness of the garment system was determined by conducting a 15-month Wear Trial of the WLFF PPE system under actual operational conditions. This subjective evaluation proved essential to differentiating the performance of the various fabrics manufactured into the test garments. Most importantly, the operational assessment provided feedback on the functionality of the PPE garment design.

The results of the test and evaluation process indicate that **the APPS WLFF PPE meets all program objectives** by:

- Achieving the thermal protection performance specified in the ORD (Appendix D).
- Reducing heat stress burden on the wearer based on fabric and system-level testing results (Appendix D).

- Improving the operational suitability and effectiveness of the WLFF PPE garment system when compared to baseline PPE garment systems based on Wear Trial feedback (Appendix E).

2.1 Fabric Test Results

The ORD identified two Key Performance Parameters (KPP) for PPE fabrics (Appendix B, Section 2.4). Based on the risk assessment, the ORD requires a minimum Radiant Protection Performance (RPP) of 10 and a Total Heat Loss (THL) of 500 Watts per square meter (W/m²). The laboratory testing performed at the Textile Protection and Comfort Center (T-PACC) of North Carolina State University (NC State) indicates that the fabrics selected for the APPS WLFF PPE system meet or exceed the minimum performance requirements of the ORD (Appendix D).

Table 1 – New Single-layer PPE Fabric Performance

Fabric	Garment Application	RPP	THL, W/m ²
Sigma [®] Four Star [™] , 6.5 osy	APPS PPE shirt and pants (uniform and tactical)	11.5	752
TenCate S/469, 7.7 osy	APPS PPE shirt and pants (uniform and tactical)	11.1	680
TenCate Defender [™] M900, 9.0 osy	APPS PPE shirt	10.6	699
TenCate Comfort [™] MP950, 9.5 osy	APPS PPE pants (uniform and tactical)	11.2	650
Springfield Protera [®] 165, 6.5 osy	APPS PPE overpants	8.5	895

Data from T-PACC testing, per NFPA 1977, 2005 Edition

2.2 System-Level Test Results

To gain a better understanding of the heat stress burden caused by different PPE configurations on wildland firefighters, system-level testing was performed on various WLFF PPE garment systems (Appendix D). System-level testing of garments is not required by NFPA 1977. However, THL testing only evaluates a single layer of fabric, which does not reflect how garments are actually constructed or worn. System-level testing of a complete garment system provides a better indicator of actual total heat loss performance as it considers the effects of the baselayers and the garment design in the testing. Manikin testing was performed at the T-PACC to generate objective data regarding the predicted heat loss characteristics of the APPS WLFF PPE system relative to two baseline PPE systems.⁴ Table 2 indicates that single-layer WLFF PPE garment systems have greater Predicted Heat Loss (Q value) than double-layer WLFF PPE.

Table 2 – System-level Manikin Testing of PPE Systems

PPE System	Pants Configuration	Baselayers	Q – Predicted Heat Loss, W/m ²
CAL FIRE Legacy PPE system	Double layer pants	Cotton	174.3
USFS PPE system – Synergy [®] /Synergy [®]	Single layer pants	Cotton	192.8
APPS PPE system – Sigma [®] /Sigma [®]	Single layer pants	Wicking Flame Resistant (FR)	191.6

PPE System	Pants Configuration	Baselayers	Q – Predicted Heat Loss, W/m ²
APPS PPE system – S/469, S/469	Single layer pants	Wicking FR	198.5
APPS PPE system – M900/MP950	Single layer pants	Wicking FR	195.4

Data from T-PACC manikin testing

In 2010, the USFS Missoula Technology and Development Center (MTDC) conducted human physiological testing⁵ of WLFF PPE at the University of Montana’s Department of Health and Human Performance. MTDC used nine human test subjects; each wore the CAL FIRE Legacy PPE system (as tested by T-PACC) and two USFS PPE configurations (one of which was tested). Test subjects were made to walk a 4% grade at 3 miles per hour on separate days at 98.6° F and 30% relative humidity for three hours, with a 10-minute break at the end of each hour to replicate the work rates of wildland firefighting. The MTDC test results indicate that core body temperatures rise significantly faster during physical exertion when wearing double-layer WLFF PPE compared to single-layer WLFF PPE. The faster rise in core body temperature increases the risk of heat stress occurring sooner. The MTDC testing also indicates that the lower core body temperature rate increase experienced when wearing single-layer WLFF PPE allows test subjects to work four times longer before core body temperatures reach critical stages than when wearing double-layer WLFF PPE. Comparison of identical WLFF PPE garment fabrics and configurations allowed correlation between the USFS human physiological test results to the T-PACC manikin test results of this program. The USFS physiological test results could then be correlated to the APPS WLFF PPE (single layer, all fabrics) systems by comparing the Q values of the T-PACC study. Based on a comparison of Q values, test subjects wearing the APPS WLFF PPE systems should approximate the total work duration predicted for the single-layer USFS PPE under similar work rates. This means the estimated work durations for firefighters wearing the APPS WLFF PPE should be four times longer than the work durations when wearing the CAL FIRE PPE. In addition to a likely reduction in risk of heat stress injuries, changing from a double-layer PPE garment system to the single-layer APPS WLFF PPE can act as a force multiplier: where the same workforce can accomplish significantly greater work output due to the increases in work duration before the symptoms of heat stress occur.

2.3 Wear Trial Results

The subjective evaluation ratings from the Wear Trial reflect the overall operational suitability and effectiveness of the APPS WLFF PPE garment system relative to the evaluator’s baseline PPE system. The evaluator’s preference for a specific PPE system or component is relative to the evaluator’s baseline PPE, when considering all attributes of the component or system. N represents the number of evaluators that responded to the survey. The system comparison and preference rating data in Table 3 tabulates the total number of evaluators that responded to the survey in 2012 (N=709) and in 2013 (N=428) and the GEN II PPE evaluators (N=32). The data is based on a 1 to 7 rating scale and indicates the APPS WLFF PPE garment system is operationally suitable and effective compared to existing WLFF PPE garment systems.

2.3.1 PPE System-Level Ratings

Table 3 contains the overall PPE system preference ratings of Gen I and GEN II PPE from the 2012 and 2013 wildfire seasons. The ratings for the Gen I PPE shirt, PPE pants, and overall PPE system are very similar between 2012 and 2013 and reflect a slight preference for the Gen I

APPS WLFF PPE system over baseline PPE systems. The ratings for the GEN II APPS WLFF system indicate a significant improvement in the preference ratings, based on the design changes to the garments. This indicates that the redesign of the GEN II PPE successfully addressed the design deficiencies of the Gen I PPE garments and significantly increased the operational suitability and effectiveness of the APPS WLFF PPE system.

Table 3 – APPS WLFF PPE System Preference Ratings

Year	PPE	N Evaluators	Overall PPE System Preference Rating
2012	Gen I APPS WLFF PPE	709	5.08
2013	Gen I APPS WLFF PPE	428	5.02
2013	GEN II APPS WLFF PPE	31	6.45

The distribution of the APPS WLFF PPE system-level preference ratings (Table 4) indicates that two-thirds of Wear Trial evaluators expressed some level of preference for the Gen I WLFF PPE relative to their baseline PPE. However, 22% of evaluators still preferred their baseline PPE systems. The level of preference for the redesigned GEN II WLFF PPE increased to 90% of Wear Trial evaluators. Only 6% of evaluators expressed a slight preference for their baseline PPE. The minor design deficiency in the PPE pants (excess material) will be corrected in production versions of the APPS WLFF PPE specification. Based on the Wear Trial survey data, both the Gen I WLFF PPE system and the redesigned GEN II WLFF PPE system are considered operationally suitable and effective. Figures 2 and 3 graphically depict the data in Table 4.

Table 4 – APPS WLFF PPE System Preference Ratings Distribution

	N	Ratings Distribution						
		1	2	3	4	5	6	7
2012 Gen I System Preference	709	36	41	79	73	125	158	197
		22%			10%	68%		
2013 Gen I PPE System Preference	428	18	38	35	48	94	78	117
		22%			11%	67%		
2013 GEN II PPE System Preference	31	0	0	2	1	0	6	22
		6%			3%	90%		

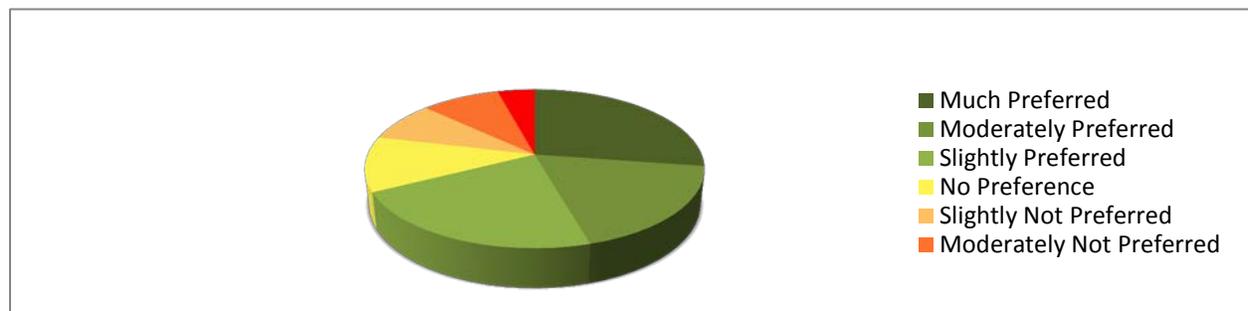


Figure 2 – Gen I PPE Systems Preference Rating Distribution

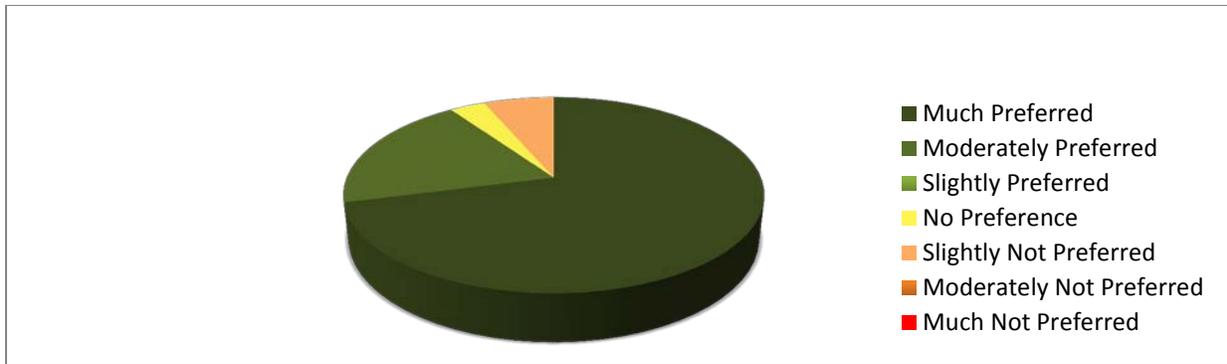


Figure 3 – GEN II PPE Systems Preference Rating Distribution

Table 5 indicates that Overall System Preference ratings are directly related to the baseline WLFF PPE system worn prior to the Wear Trial. Evaluators who wore a single-layer PPE pants system as their baseline exhibited only a slight preference for the APPS WLFF PPE. However, evaluators who wore a double-layer PPE pants system for their baseline exhibited a higher degree of preference for the APPS WLFF PPE.

Table 5 – 2013 APPS WLFF PPE System Preference Ratings, by Baseline Configuration

Baseline PPE	APPS PPE	Evaluators	N	System Configuration	System Heat Dissipation	System Thermal Protection	Overall System Preference
Single Layer PPE	APPS Single Layer	All Evaluators	211	4.69	4.63	4.68	4.72
Double Layer PPE	APPS Single Layer	All Evaluators	181	5.46	5.74	4.80	5.43

Note: Some evaluators did not identify their baseline PPE configurations.

The distribution of the APPS WLFF PPE system-level preference ratings (Figure 5) indicates a much larger percentage (79%) of Wear Trial evaluators who wore a double-layer PPE pants system as their baseline have some level of preference for the APPS WLFF PPE when compared to Wear Trial evaluators (58%) who wore a single-layer pants system as their baseline (Figure 4). This indicates that evaluators who wear double-layer pants as their baseline PPE perceive greater benefits and improvements due to the single-layer APPS WLFF PPE. Table 6 contains the data used to build Figures 4 and 5.

Table 6 – APPS WLFF PPE System Preference Ratings Distribution, by Baseline Configuration

Baseline PPE	APPS PPE	N	Ratings Distribution						
			1	2	3	4	5	6	7
Single Layer	Single Layer	211	9	27	16	36	44	33	46
			25%			17%	58%		
Double Layer	Single Layer	181	6	9	14	9	42	37	64
			16%			5%	79%		

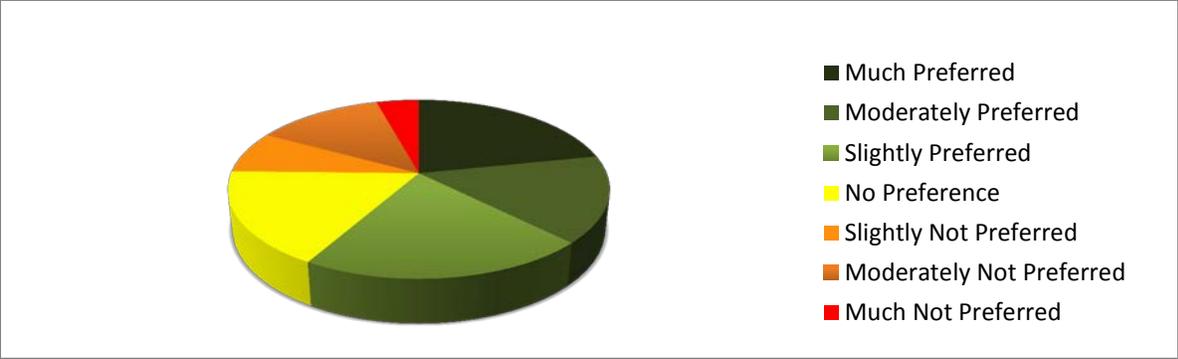


Figure 4 – Single-layer PPE Pants Baseline

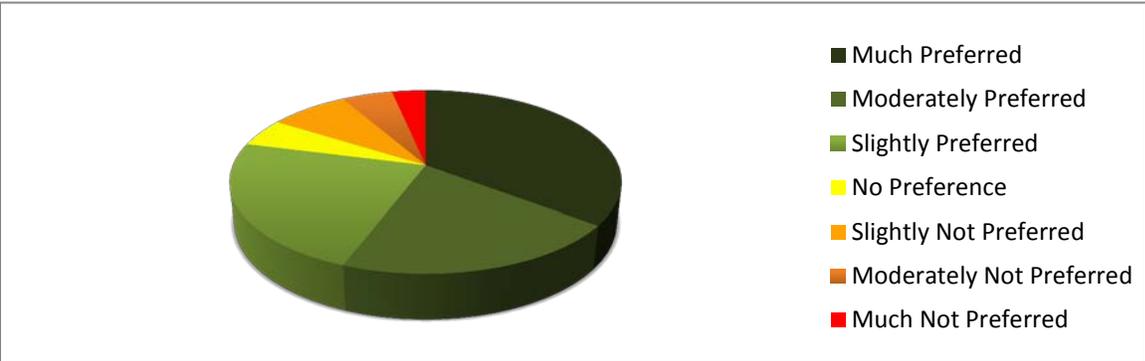


Figure 5 – Double-Layer PPE Pants Baseline

2.3.2 PPE Component Wear Trial Data Analysis

Table 7 contains the PPE component preference ratings of Gen I and GEN II PPE from the 2013 wildfire season. The ratings for the Gen I PPE shirt and PPE pants reflect a slight preference for the Gen I APPS WLFF PPE components relative to baseline PPE components. The ratings for the GEN II APPS WLFF components indicate a significant increase in the preference ratings, based on the design changes to the garments. The improvement in ratings indicates that the redesign of the GEN II PPE components successfully addressed the design deficiencies of the Gen I PPE components and significantly increased the operational suitability and effectiveness of the GEN II WLFF PPE components and system.

Table 7 – 2013 APPS WLFF PPE Component Preference Ratings

	N	APPS PPE Shirt Preference Rating	APPS PPE Pants Preference Rating
Gen I APPS WLFF PPE	398	4.92	5.12
GEN II APPS WLFF PPE	31	6.03	6.23

The distribution of the APPS WLFF PPE shirt ratings in Table 8 indicates that a majority of Wear Trial evaluators prefer the Gen I APPS WLFF PPE shirt to their current baseline PPE component. However, 32% of all Gen I PPE shirt evaluators identified a preference for their baseline PPE shirt. For the redesigned GEN II PPE shirt, the level of preference increased to

88% of Wear Trial evaluators. Only 6% of evaluators expressed any preference for their baseline PPE shirt. Based on the Wear Trial survey data, the redesigned GEN II PPE shirt is operationally suitable and effective for wildfire operations. Figures 6 and 7 graphically depict the data in Table 8.

Table 8 – 2013 APPS WLFF PPE Shirt Preference Ratings Distribution

PPE	N	Ratings Distribution						
		1	2	3	4	5	6	7
Gen I APPS PPE Shirt	398	70	29	29	43	58	64	105
		32%			11%	57%		
GEN II APPS PPE Shirt	31	0	1	1	1	2	8	18
		6%			6%	88%		

Note: Not all evaluators provided ratings for all PPE components.

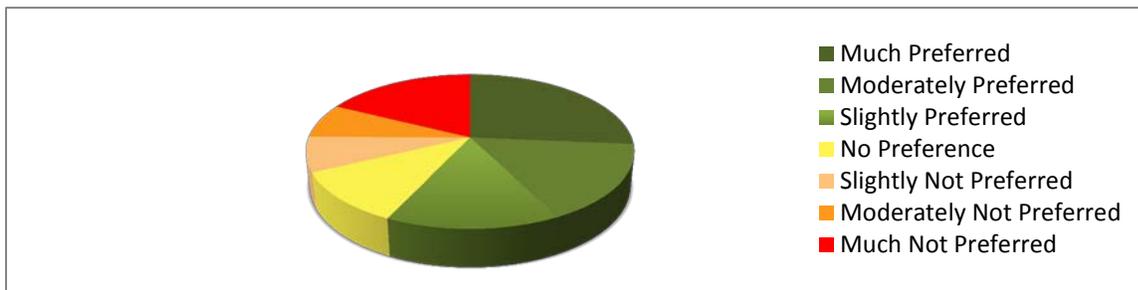


Figure 6 – Gen I PPE Shirt Preference Ratings Distribution

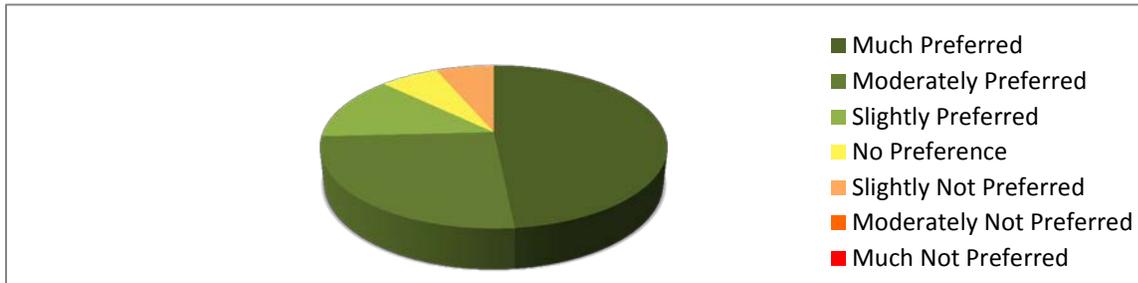


Figure 7 – GEN II PPE Shirt Preference Ratings Distribution

The distribution of the Gen I APPS WLFF PPE pants ratings in Table 9 indicates that two-thirds of Wear Trial evaluators prefer the Gen I APPS WLFF PPE pants to their current baseline PPE component. However, 23% of all evaluators identified some preference for their baseline PPE pants. For the redesigned GEN II PPE pants, the level of preference for the GEN II WLFF PPE pants increased to 90% of Wear Trial evaluators. Only 6% of evaluators expressed any preference for their baseline PPE pants. Based on the Wear Trial survey data, the redesigned GEN II PPE pants are operationally suitable and effective for wildfire operations. Figures 8 and 9 graphically depict the data in Table 9.

Table 9 – 2013 APPS WLFF PPE Pants Preference Ratings Distribution

Attribute	N	Ratings Distribution						
		1	2	3	4	5	6	7
Gen I APPS PPE Pants	370	42	20	22	30	51	59	146
		23%			8%	69%		
GEN II APPS PPE Pants	31	0	0	2	1	0	6	22
		6%			3%	90%		

Note: Not all evaluators provided ratings for all PPE components.

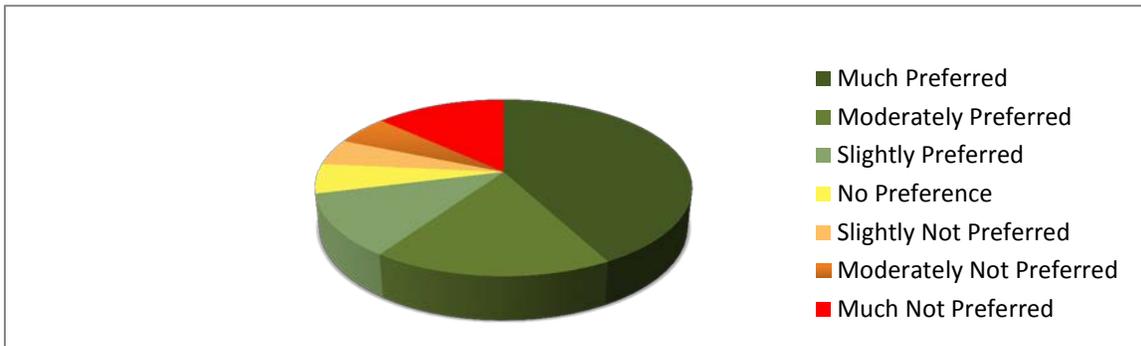


Figure 8 – Gen I PPE Pants Rating Distribution

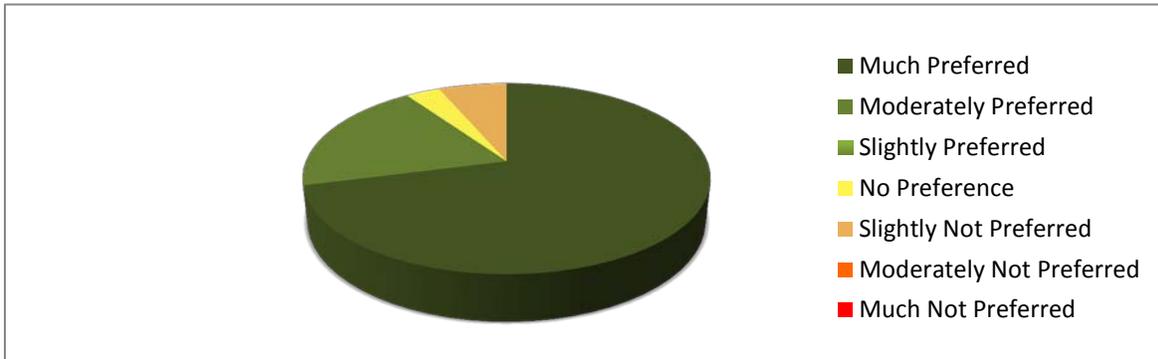


Figure 9 – GEN II PPE Pants Rating Distribution

2.3.3 Baselayer Preference Ratings

Table 10 contains the baselayer component preference ratings for the 2013 wildfire season. The ratings for the APPS T-shirts and socks reflect a slight preference for the APPS baselayer components relative to baseline baselayer components and no particular preference for the APPS boxer relative to baselayer boxers.

Table 10 – 2013 APPS Baselayer Preference Ratings

APPS PPE Component	N	PPE Component Preference Rating
APPS T-shirts	412	5.26
APPS Boxers	354	4.27
APPS Socks	416	5.06

The distribution of the preference ratings in Table 11 indicates that two-thirds of Wear Trial evaluators prefer the APPS T-shirts and a majority of evaluators prefer the socks to their current baseline baselayers. However, only 38% of evaluators expressed some level of preference for the APPS boxer shorts. Based on the Wear Trial survey data, the APPS T-shirts and socks are considered operationally suitable and effective for wildfire operations. Figures 10, 11, and 12 graphically depict the data in Table 11.

Table 11 – 2013 APPS Baselayer Preference Ratings Distribution

Attribute	N	Ratings Distribution						
		1	2	3	4	5	6	7
APPS T-shirt	412	37	15	33	47	50	66	164
		21%			11%	68%		
APPS Socks	416	26	13	26	106	48	64	133
		16%			25%	59%		
APPS Boxers	354	50	14	27	128	38	32	65
		26%			36%	38%		

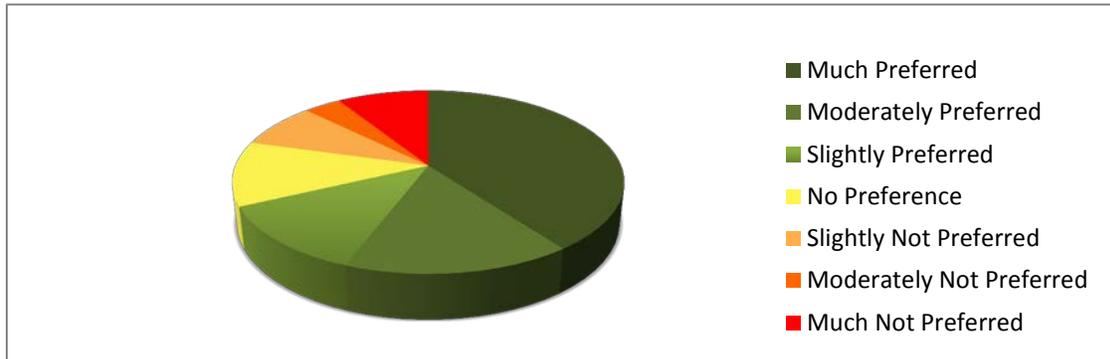


Figure 10 – Baselayer T-shirts Preference Ratings Distribution

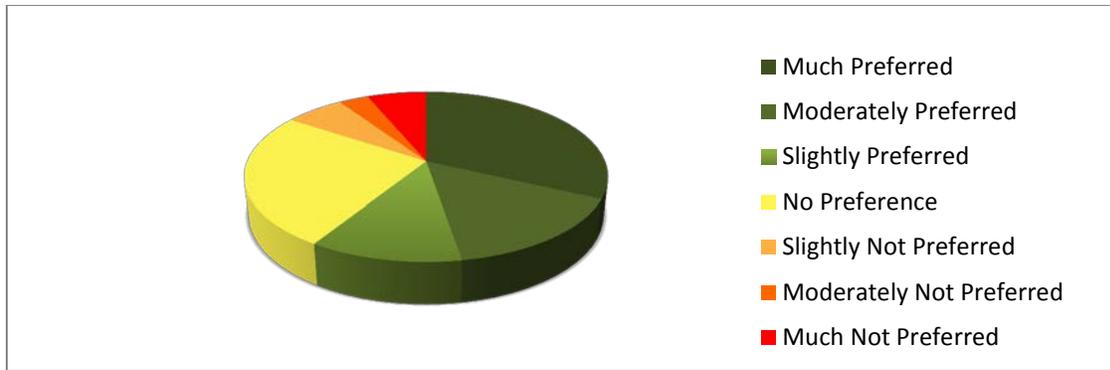


Figure 11 – APPS Socks Preference Ratings Distribution

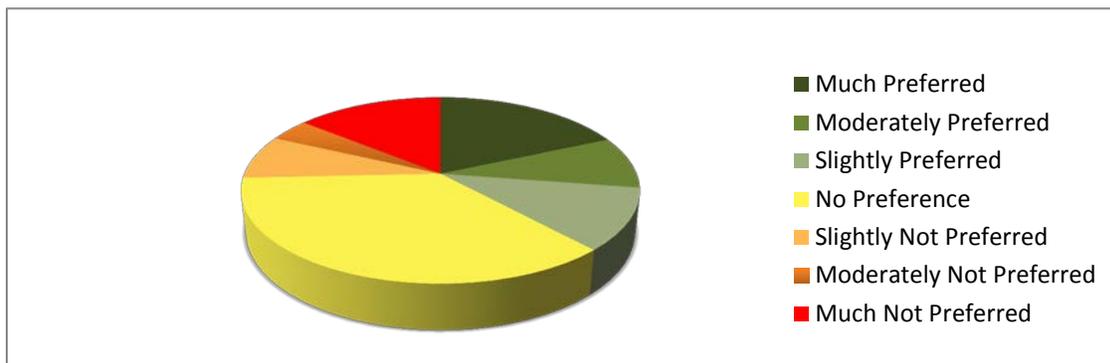


Figure 12 – APPS Boxers Preference Ratings Distribution

2.3.4 CAL FIRE Wear Trial Data Analysis

As CAL FIRE represents the largest homogeneous sub-group of respondents in the Wear Trial, the 2013 Wear Trial results for CAL FIRE respondents are separated from the other Wear Trial responses. The CAL FIRE community is homogeneous in that its baseline PPE ensemble consists of a double-layer PPE pants configuration. The tactical pants received the highest PPE component preference rating (6.18) and the overpants received the lowest preference ratings (4.12). The PPE component preference ratings in Table 12 indicate that the operational suitability and effectiveness of most APPS WLFF PPE components is as good as or better than the CAL FIRE baseline PPE.

Table 12 – 2013 CAL FIRE APPS WLFF PPE Component Preference Ratings

APPS PPE Component	N	PPE Component Preference Rating
APPS Response Shirt	152	4.84
APPS Uniform Pants	108	5.31
APPS Tactical Pants	22	6.18
APPS Overpants	24	4.12
APPS T-Shirts	148	4.81
APPS Boxers	127	4.20
APPS Socks	157	5.17

Note: Not all respondents provided ratings for all PPE components as evaluators did not wear some garments due to fit issues.

The distribution of the CAL FIRE PPE component ratings (Table 13) indicates that a majority of CAL FIRE Wear Trial evaluators prefer the APPS WLFF PPE components (except for the boxers) to their current baseline PPE components. The ratings distribution indicates evaluators have a strong preference for the single-layer PPE pants configuration. This ratings distribution indicates that the Gen I APPS WLFF PPE garment components are operationally suitable and effective when compared to current baseline CAL FIRE PPE components. Figures 13 and 14 graphically depict the data in Table 13.

Table 13 – 2013 CAL FIRE APPS WLFF PPE Component Ratings Distribution

Attribute	N	Ratings Distribution						
		1	2	3	4	5	6	7
APPS PPE Shirt	155	16	5	17	18	30	35	34
		25%			12%		64%	
APPS PPE Pants	154	15	5	11	7	28	30	58
		20%			5%		75%	

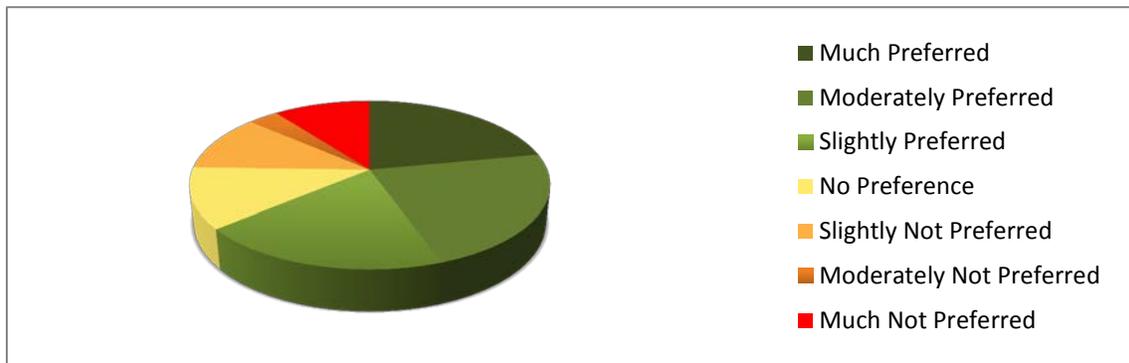


Figure 13 – CAL FIRE PPE Shirt Preference Rating Distribution

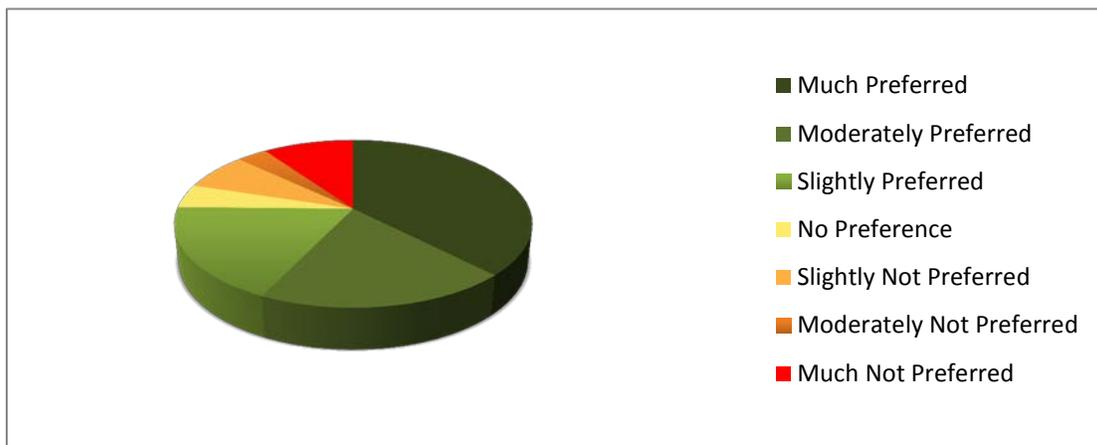


Figure 14 – CAL FIRE PPE Pants Preference Rating Distribution



Photo 1: Wildland firefighters walking in front of a line of trees and wall of smoke.

3.0 Conclusions

Based on the objective testing and subjective evaluations performed during this program, the APPS WLFF PPE program successfully meets the program objectives by:

1. Achieving the protection performance required by the ORD and the risk assessment.
2. Reducing heat stress burden on the wearer based on system-level testing results.
3. Improving the PPE garment system's operational suitability and effectiveness when compared to baseline PPE garment systems.

The APPS WLFF PPE garment design is government owned and available, at no cost, to any certified manufacturer. The use of a PPE specification means that PPE performance can be standardized and that the manufacturer of the PPE remains transparent to the performance of the PPE garment system. By increasing the number of PPE manufacturers, the level of commercial competition should increase, thereby driving down the cost of procurement.

System-level testing demonstrates that the transition from double-layer PPE pants to single-layer PPE pants will reduce the risk of heat stress injury and can act a force multiplier by increasing the work output of an existing firefighting crew before the onset of heat stress symptoms.

The APPS WLFF PPE garment system will cost more than existing commercial WLFF PPE systems due to greater complexity in manufacturing and the use of advanced materials in both the PPE and baselayers. However, the APPS WLFF PPE will offset the higher procurement cost by creating cost savings due to the greater work output that can be accomplished with the same workforce. In addition, the likely reduction in heat stress injuries, with a corresponding reduction in the associated cost of health care and compensation claims associated with heat stress injuries, should further reduce costs.

The authors acknowledge and thank the members of the IPT and the participating organizations for their support of this program. This program could not have been completed successfully without their support throughout this effort.

4.0 Recommendations

The WLFF PPE IPT recommends the following actions:

- This effort used the CAL FIRE risk assessment to characterize the threat environment for PPE development. The IPT recommends that any organization choosing to use this risk assessment should ensure that its tactics, techniques, and procedures (TTPs) are commensurate with the reasonable maximum exposure of the risk assessment. Wildland firefighters should be trained to any changes in TTPs required to ensure the RME is not exceeded.
- System-level testing of complete WLFF PPE garment systems provides a more accurate predictor of potential heat stress created by a complete WLFF PPE garment system when compared to fabric swatch testing for THL. The IPT recommends that system-level testing for predicted heat loss be performed on all commercial WLFF PPE garment systems to better understand the true heat stress burden created by those WLFF PPE garment systems.
- The subjective Wear Trial assessments indicate that the wicking baselayers (T-shirts) provide noticeable improvements in comfort and heat stress reduction. Insufficient lab test data was generated to objectively determine the improvements created by the different wicking baselayers. The IPT recommends that this additional testing be performed to objectively determine the contributions of the wicking baselayers to heat stress reduction.
- The program evaluated and validated multiple fabric and garment options. To select the optimal WLFF PPE solution, the IPT recommends that the System Assessment and Validation for Emergency Responders (SAVER) program's *Wildland Fire Fighter Personal Protective Equipment Selection Guide 6* be used to determine the most appropriate fabrics and garment configuration for agency needs.
- This effort represents the first time the wildland firefighting community has dictated WLFF PPE requirements to industry to meet. To facilitate the process of continuous product improvement, the IPT recommends that this program be continued on a periodic basis to monitor technology developments and evaluate potential technology insertions into the WLFF PPE garment system.

Appendix A – Background

The Technology Clearinghouse / R-Tech (TCR), also known as the TechSolutions Program, addresses mission capability gaps identified by the emergency response community. TechSolutions fields technologies that meet a minimum of 80 percent of the operational requirement, in a 12- to 15-month time frame. To achieve these objectives, the original Department of Homeland Security (DHS) Advanced Personal Protection System (APPS) program defined a repeatable systematic evaluation process to improve the selection and validation of Personal Protection Equipment (PPE) for tactical law enforcement [i.e., special weapons and tactics (SWAT)] applications.² This program leveraged the Department of Defense investment in PPE development to transfer this technology to the tactical law enforcement sector. The APPS process used a system integration approach to select and validate PPE by establishing a user-based Integrated Process Team (IPT), determining user-specific operational requirements, identifying and evaluating integration and interoperability issues, and validating the operational suitability and effectiveness of the solution using operational assessments. The APPS process facilitated use by federal, tribal, state, and local responders by complying with DHS policies and procedures and incorporating in-house resources (e.g., Responder Knowledge Base) currently in use.

The APPS Wildland Firefighter (WLFF) PPE program extends the previous APPS program into product development and applies lessons learned from other related PPE research and development (R&D) efforts, such as the Law Enforcement Advanced Protection (LEAP) program. The APPS WLFF PPE program modified the original APPS process to develop the new WLFF PPE garment system. The program strategy was developed to be consistent with TechSolutions objectives. The process developed by the APPS program is based on the premise that the fundamental principles for selecting or developing effective PPE solutions apply to any user. These principles are:

1. Improve user protection against current mission threats.
2. Reduce the burdens imposed on the user by the PPE to improve the operational performance of the user.

PPE plays a critical role in ensuring the survivability of the emergency responder against a broad range of threats. However, PPE also imposes trade-offs by increasing the physical burdens on the wearer by adding weight, bulk, and heat stress. These burdens can reduce the user's performance, which increase the potential for injury and compromise mission success. This often requires the user to make choices to trade off some level of protection for a reduction in the burdens imposed by the PPE. The threats to wildland firefighters include the external heat source, which can cause burn injuries, and the internal heat created by physical exertion, which can lead to heat stress injuries. An increase in protection against one threat typically requires an increase in vulnerability to the other threat.

The National Fire Protection Association (NFPA) 1977– *Standard on Protective Clothing and Equipment for Wildland Fire Fighting*¹– currently defines the design and performance requirements for WLFF PPE. NFPA 1977 was established in 1993 to “specify the minimum design, performance, testing, and certification requirements for protective clothing, helmets, gloves, and footwear that are designed to protect fire fighters against adverse environmental effects during wildland fire-fighting operations.”¹ The WLFF PPE manufacturing industry uses NFPA 1977 protection level requirements in the design and certification of its WLFF PPE.

However, these protection performance levels were based on the performance of existing materials when NFPA 1977 was originally established and were not based on a risk assessment of wildland firefighting operations. Consequently, the protection levels specified by NFPA 1977 may or may not provide adequate protection against the actual operational threat. Other concerns about commercial WLFF PPE are that users have little or no input into the garment requirements or design. Consequently, currently available commercial PPE does not fully reflect the operational needs of the wildland firefighter.

In 2010, the California Department of Forestry and Fire Protection (CAL FIRE) Personal Protection Equipment Working Group performed a risk assessment, the *CAL FIRE Wildland Fire Fighting Hazard and Risk Assessment*,³ to characterize the operational wildfire threat to define their actual operational protection requirements. This risk assessment characterized the threat by defining a “reasonable maximum exposure”³ posed by wildfire operations and identified the level of personal protection required to mitigate the threat. The operational requirements for the new APPS WLFF PPE garment system are based on the personal protection performance levels specified in the CAL FIRE risk assessment.

This study recommended establishing a minimum radiant protection performance (RPP) rating of 10 and a minimum total heat loss (THL) rating of 500 watts/m². At the time this study was issued, few commercially available PPE that could meet both of these new performance requirements existed. As most current WLFF PPE could not achieve these protection performance levels, it was necessary to initiate this product development program. This program adapted the previous APPS process to manage the development of a WLFF PPE garment system to optimize garment system performance and address operational deficiencies in current WLFF PPE garment systems.

NFPA 1977, *Standard on Protective Clothing and Equipment for Wildland Fire Fighting*, recognizes the relationship between these two threats and seeks to “provide thermal protection for the wildland fire fighter against external heat sources with flame resistant clothing and equipment while not inducing an extraordinary internal heat stress load.”¹ Although the APPS process cannot eliminate the operational burden created by PPE, it can optimize the balance between protection and associated burdens through the careful selection of materials and the design and integration of components.

Appendix B – APPS Process

The Advanced Personal Protection System (APPS) process is a methodical and repeatable procedure originally developed for the selection and validation of tactical Personal Protection Equipment (PPE). The APPS process was modified for this application to conduct a new product development. The Wildland Firefighter APPS (WLFF – APPS) program demonstrates that this process-based approach is applicable to any emergency responder community. Its use is equally appropriate for selecting or developing a single PPE component or a system of PPE components.

The APPS WLFF PPE program objectives sought to:

1. Develop a PPE garment system to improve protection against current threats by:
 - a. Defining operational requirements to address the specific threats.
 - b. Validating PPE performance against those requirements through technical testing and certification to standards.
2. Improve the user's operational performance by:
 - a. Reducing the heat stress burden imposed by PPE on the wearer.
 - b. Optimizing the garment design to improve operational performance.
 - c. Validating the operational suitability and effectiveness of the garment system during an operational assessment.

The APPS process follows the flowchart shown in Figure B-1.

Wildland Firefighter PPE Garment Development Process

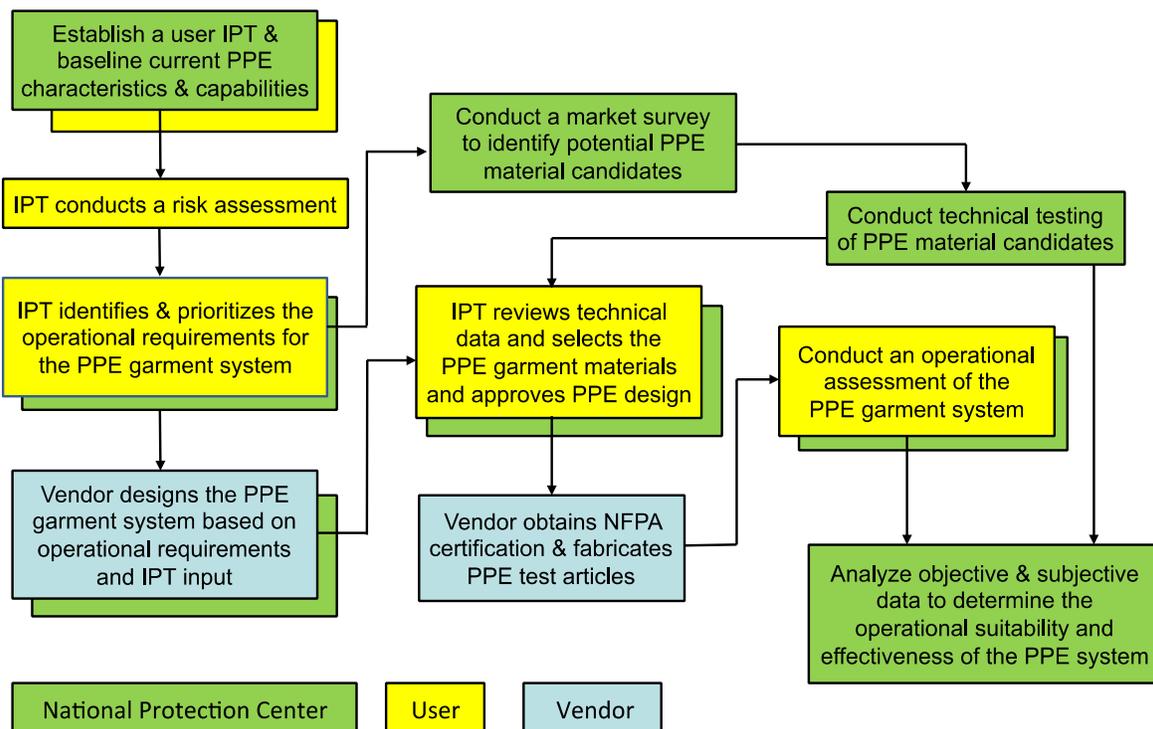


Figure B-1 – APPS Process Flowchart

The APPS WLFF PPE process modified the approach originally used for the APPS tactical law enforcement PPE selection process. Both processes established a user-based Integrated Process Team (IPT), characterized a baseline PPE, identified and prioritized operational requirements, conducted a market survey to determine the availability of existing solutions, and performed operational assessments to validate operational suitability and effectiveness. The special weapons and tactics SWAT program focused on selecting PPE products from existing commercial items, whereas the WLFF PPE program focused on developing new products because no PPE solutions existed that could meet the operational requirements established by the IPT. The product development phase added the following tasks:

1. Test and evaluation of materials
2. Selection of materials
3. System and garment design
4. Garment certification to National Fire Protection Association (NFPA) requirements
5. Manufacturing of test articles

The process utilized objective laboratory data to select PPE materials and to achieve NFPA certification. To establish a baseline of current performance, laboratory testing under controlled conditions objectively measured the performance of existing PPE materials and garment systems. The technical performance results of the new PPE materials and garment systems were then directly compared to the previous existing PPE materials and garment systems to determine the

relative improvement to protection, heat stress reduction, and operational performance. However, objective measurements of fabric and system characteristics cannot accurately reflect the operational suitability and effectiveness of a PPE system under actual operating conditions. To determine the true operational suitability and effectiveness of a new PPE garment system, the APPS process uses an operational assessment to subjectively evaluate the new PPE garment system under actual operational conditions over an extended period of time. A garment designer was selected to design the new PPE garment system, and a garment manufacturer was then selected to manufacture the test garments for use in the operational assessment. The operational assessment evaluator surveys asked for ratings of various performance attributes of the new WLFF PPE garment system relative to the performance of the baseline PPE garment systems. The survey generated data that characterized the operational suitability and effectiveness of the new WLFF PPE garment system in a direct comparison to their baseline PPE systems.

Integrated Process Team

The first step in the APPS process is to establish an IPT to govern the product development process. The IPT consisted of user representatives from the federal, state, and local levels within the wildland firefighting community. The user-based IPT serves as the primary decision-making body for the APPS program. The IPT establishes program priorities, develops the risk assessment, selects materials, approves the garment configuration, and conducts the operational assessment during the APPS product development process. As the actual users of the end product, the IPT members are best suited to evaluate the trade-offs and make decisions during the material selection process. A combination of experienced senior user representatives and knowledgeable PPE subject matter experts (SMEs) were selected to serve on the IPT. The Federal IPT representative was a PPE SME from the U.S. Forest Service (USFS) Missoula Technology and Development Center (MTDC) in Missoula, Montana. The state-level IPT representatives were from CAL FIRE and the remaining IPT user representatives were from county or city fire departments within California. The IPT members determined the risk assessment, defined the operational requirements for the PPE garment system and were tasked to make final material and configuration decisions. DHS S&T and U.S. Army Natick Soldier Research, Development and Engineering Center’s (NSRDEC) program managers provided technical oversight and facilitated execution of the APPS process by coordinating and providing technical support, data collection, and analysis. Table B-1 identifies each member and organization that participated on the WLFF PPE IPT.

Table B-1. WLFF PPE IPT Members

IPT Member	Position	Organization	Level
Fred Chan*	NSRDEC Program Manager	NSRDEC	Federal
Bill Deso	Program Sponsor/DHS Program Manager	R-Tech, DHS S&T	Federal
Matt Hurley	NSRDEC Program Manager	NSRDEC	Federal
Tony Petrilli	PPE Specialist	MTDC, USFS	Federal
Tom Foley*	Deputy Chief	CAL FIRE, Riverside	State
Rick Hutchinson	Unit Chief	CAL FIRE, Monterey	State
Brent Stangeland	Battalion Chief	CAL FIRE, Sacramento	State
Rick Swan*	Deputy Chief	CAL FIRE, San Luis Obispo	State
Dave Teter	Battalion Chief	CAL FIRE, Cameron Park	State
Mike Weaver	Battalion Chief	CAL FIRE, Redding	State
Woody Enos	Operations Chief	Santa Barbara County Fire Department	County
Hector Garcia	Firefighter	Ventura County Fire Department	County

IPT Member	Position	Organization	Level
Mike Inman	Battalion Chief	Los Angeles County Fire Department	County
Kirk Kushen	Battalion Chief	Kern County Fire Department	County
Kat Opliger	Battalion Chief	San Bernardino County Fire Department	County
Tim Thompson	Battalion Chief	Marin County Fire Department	County
Scott Zeller	Battalion Chief	Ventura County Fire Department	County
Jonathan Wilby	Risk Manager	Orange County Fire Authority	County
Dan Eddy	Logistics Officer	San Diego Fire Department	City
Rich Cramton	Captain	Chino Valley Fire District	City
Ed Marquez	Captain	Glendale Fire Department	City
Scott Quinn	Captain	Los Angeles City Fire Department	City
Dick Weise	President	Southern Area Fire Equipment Research	Other

* Retired during program

Baseline PPE Performance

The APPS process uses the currently issued PPE as a reference point (i.e., baseline) for comparison during the subjective evaluation process. The baseline for existing WLFF PPE performance was established by identifying the different PPE components currently in use by the various user groups participating in this program (Table B-2). Since the IPT was comprised of multiple organizations, many different PPE configurations and ensembles were used by the different organizations, establishing a variable baseline of performance. The variable baseline affected the comparison and preference ratings since the new PPE was judged from different PPE baselines. Appendix E, which includes the operational assessment data analysis section, addresses this issue. The following chart identifies some of the baseline WLFF PPE garment systems, materials, and configurations in use by various members of the WLFF PPE IPT. In terms of performance, NFPA 1977 defines performance and configuration requirements for WLFF PPE, while NFPA 1975, *Standard on Station/Work Uniforms for Emergency Services*,⁷ identifies requirements for stationwear uniform garments.

Table B-2. Baseline PPE Materials and Configurations

Agency	PPE Shirt Fabric	PPE Pants Fabric	Pants Configuration
USFS	Synergy [®] 3541	Synergy [®] 7531	Single layer pants
USFS	Synergy [®] 3541	Advance [™]	Single layer pants
CAL FIRE Legacy PPE	Synergy [®] 3531 w/Indura [®] sleeve liner	Synergy [®] 3531	Double layer pants
CAL FIRE Interim PPE	S/362 Torso & S/469 sleeve	S/362	Double layer pants
Los Angeles County	Nomex [®] IIIA	Nomex [®] IIIA	Double layer pants
San Diego City	PBI TriGuard [®]	PBI TriGuard [®]	Double layer pants
Ventura County	Nomex [®] IIIA	Nomex [®] IIIA	Single layer pants
Orange County	Nomex [®] IIIA	Nomex [®] IIIA	Single layer pants

Departments use either a single-layer or double-layer PPE pants configuration during wildland firefighting operations. The USFS and other federal agencies (e.g., Bureau of Indian Affairs, Bureau of Land Management, Fish and Wildlife Service, and National Park Service), as well as many state fire departments, wear a single-layer WLFF PPE pant. Several California county and city (i.e., Chino Valley, Kern County, Orange County, Santa Barbara City, and Ventura County,) fire departments wear or authorize the wearing of single-layer PPE pants during wildland firefighting operations. CAL FIRE and the remaining county and city fire departments use a

double-layer PPE pants configuration. The CAL FIRE “Legacy” PPE system consisted of a response shirt with Indura cotton sleeve liners sewn under the Nomex[®] IIIA sleeve and a PPE overpant worn over the stationwear uniform pants. The sleeve liners were retrofitted to the original response shirt design to increase the thermal protection in the sleeve region. However, this increase in protection also reduces the freedom of motion and evaporative heat transfer in the sleeve region of the garment. The newer CAL FIRE “Interim” PPE system consisted of a response shirt constructed of two different fabrics (no sleeve liners) and a PPE overpant worn over the stationwear uniform pants. Single-layer PPE pants can be worn in two ways: (1) the firefighter can wear stationwear uniform pants and then doff their uniform pants and don single-layer WLFF PPE pants prior to conducting firefighting operations; or (2) the firefighter can wear dual certified (both NFPA 1977 and NFPA 1975 certified) pants, which can be worn as stationwear uniform pants and as PPE during wildland firefighting operations. This single-layer pants configuration serves to reduce the weight and bulk of the PPE garment worn below the waist and reduces the heat stress burden on the users. Double-layer PPE pants configurations consist of a single-layer (typically made of Nomex[®] IIIA) uniform pant that is NFPA 1975 certified as station wear and a WLFF pant, typically NFPA 1977 certified, worn over the uniform pants. This pants configuration results in much higher thermal protection; however, greater thermal protection performance did not appear to be the primary reason for the double-layer PPE pants policy. Several reasons were given for this PPE configuration. Firefighters often change into their WLFF PPE at the fire location (sometimes in populated locations at the wildland-urban interface) which typically lack changing facilities for both male and female personnel to disrobe and change garments. Consequently, unable to doff uniform pants, donning the overpants over the uniform pants became the standard operating procedure. Other factors, such as shorter times to get ready (i.e., don overpants vs. disrobe and don PPE pants), were also identified. Although the double-layer pant configuration increases the level of radiant protection below the waist, it decreases evaporative heat transfer and air permeability, which increases the heat stress burden created by the PPE pants.

The NFPA 1977 defines thermal protection and evaporative heat transfer as the two protection performance parameters for WLFF PPE. Thermal protection is defined as the Radiant Protection Performance (RPP) rating of a fabric. RPP is equivalent to one half the time it takes for a second-degree burn (TSDB) injury to occur behind a fabric exposed to a heat flux of 21 kW/m² (Kilowatts/square meter) based on the Stoll burn criteria.⁸ The Stoll burn curve correlates the level of thermal energy to the duration of exposure required to receive a second degree burn injury. Higher RPP values equate to greater radiant heat protection. Evaporative heat transfer is defined by the THL rating, which indicates the insulation and evaporative resistance of a fabric. The THL rating is characteristic of the heat stress relief provided by a fabric and is measured in watts per square meter (W/m²). Higher THL values generally provide greater heat stress relief. Current single-layer WLFF PPE garment systems made from traditional WLFF PPE fabrics afford moderate RPP performance with reasonable THL ratings. Table B-3 summarizes the performance ratings of traditional single-layer PPE and uniform pants fabrics:

Table B-3 – Traditional Single-layer PPE Fabric Performance

Fabric	Garment Application	RPP	THL, W/m ²
Synergy [®] 3531, 5 osy	CAL FIRE Legacy PPE shirt and pants	7.7	759
Nomex [®] S/362, 5.8 osy	CAL FIRE Interim PPE shirt torso and pants	8.1	780
Nomex [®] S/469, 7.7 osy	CAL FIRE Interim PPE shirt sleeve	10.0	672

Fabric	Garment Application	RPP	THL, W/m ²
Synergy [®] 3541, 5.5 osy	USFS PPE shirt	7.4	644
Synergy [®] 7531, 6.5 osy	USFS PPE pants	8.2	637
PBI BaseGuard™, 4.8 osy	Commercial WLFF PPE shirt and pants	6.7	785
Nomex [®] IIIA, 7 osy	NFPA 1975 Uniform pants	8.4	725

Note: Data from Intertek testing and UL NFPA certification data

osy = ounces per square yard

To increase thermal protection using the traditional WLFF PPE fabrics, fabrics were layered. Test data indicates that layering fabrics can increase RPP ratings significantly. However, the data also indicates there is a corresponding decrease in the THL ratings when layering fabrics. This indicates that the layering of fabrics to achieve higher levels of thermal protection creates a trade-off in evaporative heat transfer performance of the garment. This trade-off means that improving thermal protection for the wildland firefighter increases the risk of heat stress injury when layering traditional PPE fabrics. Table B-4 identifies the changes in the performance ratings when traditional PPE fabrics are used in multi-layer configurations.

Table B-4 – Traditional Multi-Layer PPE Fabric Performance

Outer Fabric	Inner Fabric	Garment Application	RPP	THL, W/m ²
Synergy [®] 3531, 5 osy	Indura [®] Cotton, 7 osy.	CAL FIRE Legacy shirt sleeve ^a	21.2	449
Synergy [®] 3531, 5 osy	Nomex [®] IIIA, 7 osy	CAL FIRE Legacy PPE pants Worn over NFPA 1975 certified uniform pants ^b	13.3	500
S/362, 5.8 osy	Nomex [®] IIIA, 7 osy	CAL FIRE Interim PPE pants Worn over NFPA 1975 certified uniform pants ^b	13.8	492

a – Data from CAL FIRE, b – Data from Intertek testing

Table B-4 test data shows THL reductions between 259 W/m² to 327 W/m² due to the layering of garments. A W.L. Gore assessment⁹ of a 1998 International Association of Fire Fighters field trial examining the effects of THL ratings on firefighter physiological response concluded a “90% confidence that garments that were different by 40 W/m² produced a physiologically significant difference in core temperature.”⁹ The assessment also concluded a “95% confidence that garments that were different by 65 W/m² produced a physiologically significant difference in core temperature.”⁹ Based on the W. L. Gore assessment, there is a very high statistical confidence that layering WLFF PPE garments will induce a physiologically significant difference in human core body temperature. These predictions are validated by our system-level testing and by studies conducted by the USFS MTDC.⁵

Base layer undergarments are not typically considered a PPE component. However, testing has shown that undergarments can increase the level of radiant heat protection due to layering. NFPA 1977 does not define performance requirements for base layer undergarments. In most departments, WLFF PPE garments are worn over natural cotton underwear. In most departments, the cotton T-shirt serves as the de facto uniform top when the uniform shirt is removed during station operations (e.g., cleaning and maintenance). Cotton underwear is affordable, comfortable

to wear under normal conditions, and readily available. Although not inherently flame resistant, untreated cotton will not melt or drip after ignition. Untreated cotton does not contribute to a burn injury as some synthetic fabrics can due to melting. Testing shows that 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 reduced. In addition, the time to dry after saturation is significantly longer for cotton when compared to synthetic fabrics. Baselayers made from fast drying and wicking synthetic fabrics have 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 MTDC conducted testing which showed that "fire fighters wearing non-flame resistant synthetic undergarments may be more likely to suffer burn injuries because synthetic materials might melt and stick"¹⁰ onto a burn wound. Consequently, many fire departments prohibit the wearing of synthetic non-flame resistant undergarments during firefighting operations.

Risk Assessment

In the previous APPS program for tactical law enforcement, a threat matrix defined the various threats encountered by tactical law enforcement. The threat matrix correlated the operational threat to the specific PPE component used to address the threat. The threat levels were based on protection levels defined in National Institute of Justice (NIJ) standards. In the WLFF PPE program, a risk assessment replaced the threat matrix. NFPA 1851, *Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*,¹¹ recommends using a risk assessment as the basis for selection of all PPE. The most critical component of the risk assessment is properly characterizing the threat. This allows agencies and fire departments to define the PPE protection levels needed to protect against that threat. Simply using the minimum protection requirements defined in NFPA 1977 should not be considered a risk assessment. 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, not upon a risk assessment of wildland firefighting operations. Defining an RME offers 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 constantly changes. Radiant heat and heat stress represent the primary threats to wildland firefighters. A firefighters' proximity to a flame front, the size of the flame front, and the duration of exposure determine the radiant heat threat. The heat stress threat results from the firefighter's internally generated heat when engaging in strenuous activity in a hot environment. The heat stress threat increases when the WLFF PPE cannot transfer the internally generated heat faster than the firefighter produces it.

For this program, the IPT agreed that the CAL FIRE risk assessment provided a reasonable approximation of their wildland firefighting environment due to the similarities in operational conditions and tactics and was used to define the threat in this program. In 2010, CAL FIRE convened a workshop of SMEs to conduct a wildland firefighting hazard and risk assessment.³ The workshop sought to define CAL FIRE's thermal protection requirements based on an RME that their firefighters could experience during normal (i.e., ordinary) wildfire working conditions (i.e., direct attack). CAL FIRE based their RME on conducting normal wildfire operations one foot from a hypothetical flame front that is 1 meter (3.3 feet) high, 100 meters wide, and 3

meters deep. The computational analysis for this work condition predicted a heat flux of 7.1 kW/m². This calculation is considered conservative as the computer model is designed to “over predict” the hazard. This predicted RME is consistent with the RME calculations of other wildland firefighting studies,¹² which predicted an RME between 6.3 kW/m² to 8.6 kW/m² for various wildfire operational scenarios.

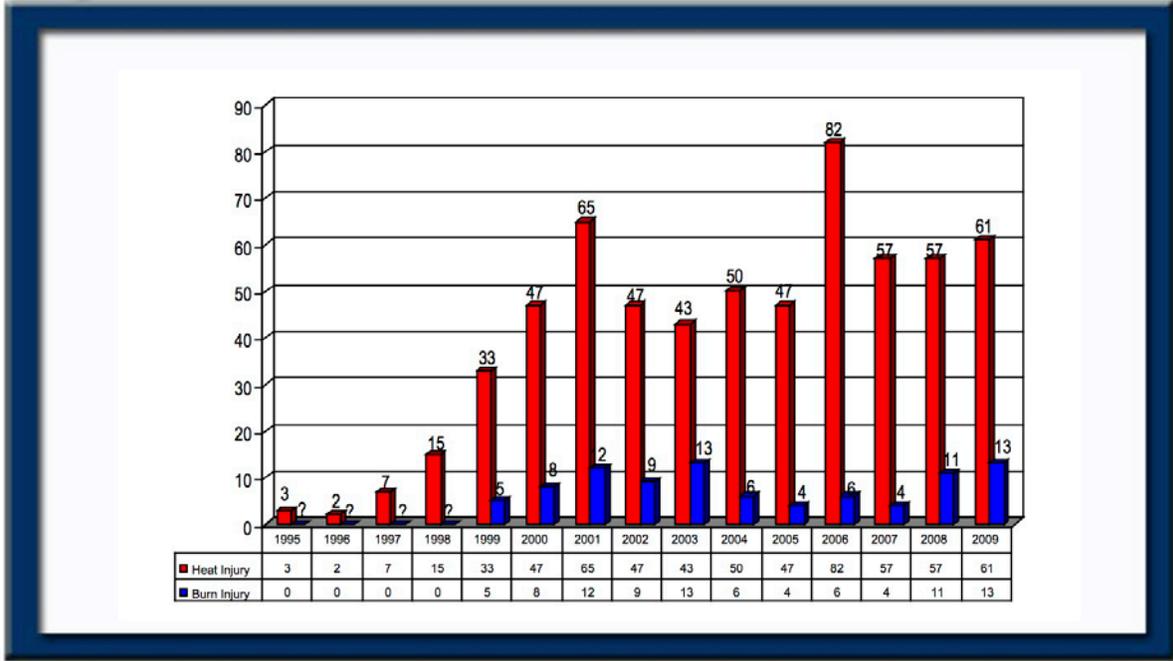
To define its RPP requirements, CAL FIRE compared the TSDB performance of its two-layer PPE garment system when exposed to various heat fluxes, ranging from 7.5 kW/m² to 21 kW/m². Using the NFPA 1977 required heat flux of 21 kW/m², a washed CAL FIRE PPE double-layer pants system provided a TSDB of 22.1 seconds, which equates to an RPP of approximately 11. Using the predicted heat flux of 7.5 kW/m², the TSDB increased to 76 seconds. Given the inherent conservatism of the calculations, CAL FIRE determined that their minimum RPP rating for ordinary conditions should exceed the NFPA 1977 minimum requirement of 7 to 10. This RPP value is the total thermal protection required and can be addressed by individual fabric performance or by layering fabrics.

To reduce heat stress-related injuries, the CAL FIRE risk assessment also recommended exceeding the THL rating from the NFPA 1977 minimum of 450 W/m² to 500 W/m². Throughout the past decade, CAL FIRE experienced a gradual but sizeable increase in heat stress injuries associated with wildland firefighting operations.¹² Although the specific cause and effect of this increase in heat stress-related injuries is unknown, increasing the minimum THL of the PPE fabric was intended to address this issue.



CAL FIRE Statewide PPE Standards

CAL OSHA, NFPA Compliance and New Standards Training



Examining
CAL FIRE
Protection Needs

CAL FIRE

Figure B-2 – CAL FIRE Historical Heat Injury Data¹³

Operational Requirements

Operational requirements for the PPE garment system should be defined following the risk assessment and identify and document all of the PPE's required characteristics. The operational requirements should identify the following attributes of the PPE garment system:

1. The garments included within the PPE system;
2. The key performance parameters of each PPE garment;
3. Other performance requirements of PPE components or the system;
4. Any physical requirements of PPE components or the system; and
5. Any requirements for interoperability and/or maintenance.

In defining WLFF PPE operational requirements, it is important to differentiate between the mission-essential Key Performance Parameters (KPPs) that must be achieved and other desirable product characteristics that can be compromised during the design phase. The KPPs are non-negotiable requirements that must be achieved. Other non-KPP requirements, such as garment configuration, can be compromised during system design in order to achieve a more important benefit. Product requirements were expressed as capabilities to allow the broadest definition. The IPT characterized performance requirements with threshold and objective levels of performance. The threshold requirements represent the minimum level of acceptable performance. Objective requirements are the desired level of performance, which may not be achievable at this time.

However, by identifying this desired capability, the operational requirements document (ORD) provides industry with useful feedback on needed capabilities and where to invest research and development resources. The WLFF PPE IPT adopted the recommended minimum performance requirements for RPP and THL from the CAL FIRE risk assessment as the KPPs. The APPS WLFF PPE ORD is provided in Attachment 1.

NFPA 1977 was established in 1993 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 fire-fighting operations.”² Given that most city and county fire departments require WLFF PPE be certified to NFPA 1977, this requirement was applied to the WLFF PPE developed under this program. Any uniform garment worn by WLFFs must also be certified to NFPA 1975, 2009 Edition, *Standard on Station/Work Uniforms for Emergency Services*. 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. Although uniform garments are not specifically PPE, many firefighting organizations require stationwear or uniform garments to be worn underneath PPE, such as “turnout,” “bunker gear,” or WLFF PPE. Consequently, stationwear uniforms must meet the requirements of NFPA 1975. The WLFF PPE IPT determined that this requirement should apply to any single-layer pants worn as uniforms and developed under this program.

After defining the performance parameters of the PPE, the requirements for the garment configuration were identified. The APPS WLFF PPE system consists of a response shirt and three different pants styles: a uniform pant, a tactical pant, and an overpant. The response shirt can be worn with all three pants styles. The uniform pant is dual certified to both NFPA 1975 and NFPA 1977 requirements, allowing it to be used as both stationwear and WLFF PPE. The uniform pants would emphasize a uniform appearance over PPE functionality. The tactical pants were also dual-certified but deemphasized appearance and featured an ankle closure. All single-layer garments specified the use of single-layer fabrics that could meet the KPP requirements. The overpants were to be worn over the standard NFPA 1975 certified uniform pants as a double layer PPE pants system. Consequently, the overpants did not require a fabric that met the RPP KPP requirement as a single-layer but could meet the requirement when layered.

Most departments use untreated natural cotton undergarments as the standard issue baselayer. Cotton is not inherently flame resistant but does provide no-melt/no-drip capability. High performance (wicking and fast drying) underwear used in the outdoor industry offer an alternative. However, the University of Alberta/USFS study identified hazards associated with using synthetic undergarments when exposed to thermal threats and most firefighting organizations banned its operational use. As the current NFPA standards do not address performance requirements for undergarments, fire departments must establish their own performance criteria. Many fire departments determined that full flame resistance of undergarment fabrics is not required because they are worn under PPE. The most common undergarment performance requirement is no-melt/no-drip so that a burn injury is not made worse by the undergarment exposed to a thermal threat. Currently worn cotton baselayers offer this minimum level of performance. Because this program adopted a system-level system-level approach to designing a comprehensive WLFF PPE ensemble, the WLFF PPE IPT included baselayer undergarments as a part of this WLFF PPE system and specified no-melt/no-drip as the KPP for baselayer fabrics.

Market Survey

A market survey was performed to identify potential PPE material solutions capable of meeting the previously defined operational requirements. This was accomplished by placing a solicitation on the FedBizOpps website on March 29, 2011. Minimum levels of performance for physical comfort and protection were identified. Ten companies responded and submitted 45 fabrics for evaluation. Six fabrics from two manufacturers (Safety Components and TenCate™) were identified as potentially being capable of meeting the single-layer fabric requirements and were selected for additional testing. The fabric with the highest THL rating (Springfield Protera® 165) was selected for the double-layer overpants requirement.

The sources for no-melt/no-drip T-shirt fabric were selected from the military's list of approved flame-resistant baselayer undergarment manufacturers. The following companies were identified as capable of meeting the ORD requirements: DRIFIRE®, Elite Issue, Kenyon Consumer Products Acquisition, Massif, New Balance, Polartec®, Springfield, TenCate™, and XGO®. These manufacturers submitted 17 fabrics for consideration. Based on data provided by manufacturers, 10 fabrics were then selected for further testing by the NSRDEC.

Appendix C – Design, Certification, and Manufacture of the Garment System

The Advanced Personal Protection System (APPS) acquisition strategy dictated that the design of the wildland firefighter personal protective equipment (WLFF PPE) system be owned by the government. This would allow the government to distribute the National Fire Protection Association (NFPA) certified WLFF PPE garment patterns, at no cost, to any garment manufacturer interested in building and selling the WLFF PPE garments upon completion of this program. This would reduce the cost of entry into the WLFF PPE market and promote greater competition in the marketplace, thereby reducing the commercial cost of the garment system. Beyond Clothing, a technical outdoor clothing designer and manufacturer, was selected to perform the WLFF PPE design based on their experience designing outdoor and military tactical garments. Beyond Clothing used this expertise to incorporate specific design features and functionality into the WLFF PPE garment system. Input from the WLFF Integrated Process Team (IPT) influenced the design of the WLFF PPE garment system. The garment system consists of four garments including a response shirt and three separate pants designs. The response shirt can be worn with any of the three WLFF PPE pants designs. The primary design improvements to the response shirt include the use of back shoulder bellows (“action back”) to enhance range of motion, articulated elbows to improve freedom of motion, and the addition of a radio-specific chest pocket. The three pants designs consisted of uniform pants, tactical pants, and overpants. The uniform and tactical pants were designed to be worn in a single-layer configuration when conducting wildfire operations and also to be suitable as uniform stationwear. Consequently, these pants were certified to both NFPA 1975 and NFPA 1977 requirements. The tactical pants were similar to the uniform pants design but had a slightly different front pocket design, eliminated the leg crease, and included closures around the ankles. The overpants were intended to be worn over NFPA 1975 compliant stationwear uniform pants in the traditional double-layer configuration. The overpants were NFPA 1977 certified only and were included in the evaluations in case the single-layer pants were deemed to be operationally unsuitable. The primary design features incorporated in all pants designs included articulated knees and a gusseted crotch to enhance freedom of motion, a French fly to equalize waist pressure, and cargo thigh pockets.

Since Beyond Clothing is not an ISO-certified manufacturer, they had no capability to build the test garments or to manufacture the final version of the WLFF PPE garments. Consequently, an ISO-certified clothing manufacturer was needed to build the WLFF PPE test garments. Three vendors (Fechheimer, CrewBoss, and New Balance) submitted bids to build the initial run of WLFF PPE test garments. The initial production run of test garments was projected to be less than 100 units due to financial constraints. The IPT selected ISO-certified manufacturer Fechheimer, which submitted the lowest cost proposal for test garment manufacture, to build the test garments. In January 2012, the program received a significant funding increase from the USFS. This allowed the program to expand the scope of the Wear Trial from 100 evaluators to more than 1,000 evaluators. Consequently, the program expanded to include multiple fabrics for evaluation during the Wear Trial to reduce risk. This maximized the probability for identifying a fabric solution that could be determined to be operationally suitable and effective. The response shirt was made in Sigma[®], S/469, and M900 fabrics. The tactical and uniform pants were made in Sigma[®], S/469, and Comfort MP fabrics, and the overpants were made of Protera 165. The USFS evaluated only pants made in the tactical design. In addition, the USFS requested the manufacture of 70 sets of test garments (shirts made of Synergy[®] 3541 and pants made of

Synergy[®] 7531 and Advance[™]) using its current PPE fabrics for comparative testing. The manufacturing of the test garments required coordination of multiple tasks, including garment design and fabric certification to NFPA requirements, ordering and delivery of fabric and trims to Fechheimer, and manufacturing of the test garments. The inclusion of multiple fabrics created a variety of complexities. In addition, determining the proper sizing for 1,000 evaluators represented a significant challenge. Fechheimer built most test garments to fit against specific sizing, while the USFS chose to use a sizing tariff. The program adopted an aggressive production schedule that could not be achieved on time. The program intended to test garments in the field by mid-summer 2012, allowing evaluators to wear the test garments through half of a wildland fire season. Fechheimer encountered complications during the NFPA design certification process, which delayed the manufacturing process. Consequently, Fechheimer did not deliver the test garments until September 2012 and the Wear Trial did not start until October 2012.

Appendix D – Technical Testing

The test and evaluation process consisted of objective and subjective testing. The objective laboratory testing quantitatively determined if a fabric could meet the minimum performance requirements defined in the operational requirements document (ORD). However, laboratory data cannot accurately assess the operational suitability and effectiveness of a garment system when used under operational conditions. Critical attributes, such as comfort, appearance, durability, freedom, and range of motion cannot be fully evaluated under laboratory conditions. An extensive operational assessment (Wear Trial) of the wildland firefighter personal protective equipment (WLFPP) systems under actual operational conditions determined the user’s subjective perception for the operational suitability and effectiveness of the garment system. This subjective evaluation proved essential to differentiating the performance of the various fabrics used to manufacture the test garments. Most importantly, the operational assessment provided feedback on the functionality of the PPE garment design.

PPE Fabric Testing

The laboratory testing consisted of material level fabric testing, per National Fire Protection Association (NFPA) 1977, and system-level garment testing. Material testing validated the material performance and ensured compliance to NFPA certification requirements. Two certified laboratories (Intertek and Underwriters Laboratories), the Textile Protection and Comfort Center (T-PACC) of North Carolina State University (NC State), and NSRDEC performed the testing. T-PACC conducted the system-level manikin testing.

The ORD identifies Radiant Protection Performance (RPP) ≥ 10 and Total Heat Loss (THL) ≥ 500 Watts per square meter (W/m^2) as the two Key Performance Parameters (KPPs) for PPE fabrics. To select the fabric materials for the PPE system, Intertek conducted the initial performance testing of PPE fabric candidates in August 2011. Intertek conducted the testing in accordance with NFPA 1977, 2011 revision. THL test results confirmed that all fabrics under consideration (Safety Components Sigma 4 Star, TenCate S/469, M900 and MP950, and Protera 165 fabrics) exceeded the minimum required THL rating of $500 W/m^2$ by a considerable amount. However, some of the Intertek RPP results indicated that these fabrics did not meet the minimum RPP requirement, which was inconsistent with RPP ratings previously obtained by the vendors when testing with the NFPA 1977, 2005 revision test protocol. Consequently, RPP testing was repeated at the NC State T-PACC using the revision (NFPA 1977, 2005 revision), which was in effect when the Risk Assessment was completed. The RPP test results from T-PACC confirmed that all fabrics exceeded the minimum RPP requirement of 10, when tested in accordance with the 2005 edition of NFPA 1977. The test data (Table D-1) indicates the new PPE fabrics provide higher levels of single-layer fabric performance and exceed the protection performance requirements of the risk assessment and ORD KPPs.

Table D-1 – New Single-layer PPE Fabric Performance

Fabric	Garment Application	RPP	THL, W/m^2
Sigma® Four Star™, 6.5 osy	APPS PPE shirt and pants (uniform and tactical)	11.5	752
TenCate™ S/469, 7.7 osy	APPS PPE shirt and pants (uniform and tactical)	11.1	680
TenCate™ Defender™ M900, 9.0 osy	APPS PPE shirt	10.6	699

Fabric	Garment Application	RPP	THL, W/m ²
TenCate™ Comfort™ MP950, 9.5 osy	APPS PPE pants (uniform and tactical)	11.2	650
Springfield Protera® 165, 6.5 osy	APPS PPE over pants	8.5	895

Note: Data from T-PACC testing, per NFPA 1977, 2005 Edition

Most of these high performance fabrics achieve double-digit RPP ratings in a single-layer, eliminating the need to layer fabrics. Although a slight reduction in THL rating occurs when compared to traditional single-layer PPE fabrics, there is a significant improvement in the THL rating when compared to multi-layered fabric configurations. The performance of these new fabrics allows the development of single-layer WLFF PPE garments that can achieve a higher level of thermal protection while maintaining a high degree of heat stress relief in the garment system. It was decided that multiple fabrics would be used to manufacture the test garments and be considered in the Wear Trial. This would increase the likelihood that one or more fabrics would be determined to be operationally suitable and effective by the Wear Trial. Based on the RPP and THL testing results (Table D-1 above), Safety Components Sigma® 4 Star (6.5 osy), TenCate™ S/469 (7.7 osy), M900 (9.0 osy), and MP950 (9.5 osy) were selected for the single-layer PPE application in the Wear Trial. Springfield Protera® 165 (6.5 osy) had the highest THL rating (895 W/m²) of all the fabrics tested but did not meet the minimum requirement for single-layer RPP, so this fabric was selected for use in the double-layer PPE pant (overpants) applications only.

Baselayer Fabric Testing

NFPA 1977 does not identify any performance criteria for baselayer undergarments. To select the baselayer fabrics for the operational assessment, a variety of comfort-related T-shirt fabric performance tests were identified and performed. The T-shirt fabric performance attributes evaluated were air permeability (ft³/min), moisture vapor transport rate (MVTR) (gm/m²/24 hr), moisture wicking (in/min), pilling, and drying time (min). NSRDEC performed the testing. The IPT then conducted an abbreviated subjective evaluation to select the T-shirt fabrics for use in the full-scale Wear Trial. Ten T-shirt fabrics were submitted for testing. Elite Issue, Massif (2), New Balance, Polartec® (2), Springfield, TenCate™, and XGO® (2) submitted fabrics for testing. The Textile Material Testing Team of NSRDEC conducted the testing; Table D-2 summarizes the results.

Table D-2 – T-shirt Fabric Performance

	Fabric Weight, osy	Air Permeability, ft ³ /min	MVTR, gm/m ² /24 hr	Wicking, in/min	Drying Time, min	Cost/yd, \$
ORD Requirement	n/a	300	2500	6"@15 6"@15	75	-
Cotton	7.0	98	1780	0.4@60 0.1@60	178.9	~\$3.00
Elite Issue	4.5	326	1780	6"@15 6"@15	Not tested	~\$12.00
Massif	4.5	326	2205	5.7@60 5.3@60	Not tested	\$29.24
Massif	3.5	312	2676	5.2@60 5.2@60	Not tested	\$18.76

	Fabric Weight, osy	Air Permeability, ft ³ /min	MVTR, gm/m ² /24 hr	Wicking, in/min	Drying Time, min	Cost/yd, \$
New Balance	5.2	433	2194	6"@10 6"@10	60.7	\$9.78
Polartec [®]	5.0	272	2522	6"@10 6"@10	Not tested	\$11.30
Polartec [®]	3.8	477	2305	6"@10 6"@10	49.8	\$9.50
Springfield	4.7	353	1988	6"@10 6"@10	230.7	\$11.99
TenCate [™]	6.1	226	2579	6"@15 6"@15	77.1	TBD
XGO [®]	4.5	437	2590	6"@15 6"@20	50.3	\$11.00
XGO [®]	5.0	389	1337	6"@10 6"@15	62.8	\$10.50

Data from NSRDEC testing, vendors provided cost data RED = Did not meet ORD requirement
ft³/min = Cubic feet per minute gm/m²/24 hr = Grams per square meter in 24 hours
In/min = Inches per minute min = Minutes

The WLFF PPE ORD specified minimum thresholds for air permeability of 300 ft³/min per ASTM D737; an MVTR of at least 2500 gm/m²/24 hr per ASTM E96 test B; moisture wicking to 6 inches in no more than 15 minutes, per the NSRDEC protocol; and a drying time of less than 75 minutes, per the NSRDEC protocol. No-melt/no-drip performance per ASTM F 6413 was the only threshold KPP for baselayer undergarments. Undergarment fabric vendors provided test data from certified laboratories that validated no-melt/no-drip performance. The IPT used Table D-2 test data to select the best performing T-shirt fabrics for an abbreviated subjective evaluation of performance and appearance attributes. Based on the test results, the Springfield Tri-blend[®] Jersey was eliminated from consideration due to failure to meet the drying time requirement. The two fabric samples from Massif did not meet the wicking criteria and were eliminated from further consideration due to the high cost per yard. The TenCate[™] fabric did not meet air permeability or MVTR criteria and was eliminated from further consideration. The IPT selected the New Balance 71430-L592 5.2 ounces per square yard (osy) fabric, Polartec[®] PowerDry[®] 2015 3.8 osy fabric, and XGO[®] 2008 5.0 osy fabrics for the abbreviated 30-day subjective evaluation. This subjective evaluation considered comfort, durability, and appearance factors, as the T-shirt is considered a uniform component by some fire departments. The IPT selected XGO[®] 2008 as the only T-shirt fabric suitable for use in the full-scale Wear Trial, primarily based on appearance issues. The IPT selected additional T-shirt fabrics for further subjective evaluation. This was done to create multiple T-shirt options at the conclusion of the program to increase commercial competition and lower procurement costs. Although the Elite Issue and TenCate[™] fabrics did not meet all ORD criteria, the requirements were not KPPs, so the IPT selected these fabrics for the additional subjective evaluation. The IPT determined the Elite Issue fabric to be more suitable than the TenCate[™] fabric and selected the Elite Issue T-shirt fabric. However, the predicted retail cost of the selected T-shirts was expected to exceed \$25 per shirt.

To identify a more affordable option, a low cost T-shirt fabric (Cocona[®] since renamed 37.5) was identified, evaluated by the IPT, and determined to be acceptable. The Cocona[®] T-shirt had a projected retail cost of less than \$15 per shirt. Since the objective performance data did not identify significant performance differences amongst the T-shirt fabrics, the selection of baselayer undergarment fabrics was determined primarily on the subjective operational assessment conducted by the IPT. Due to the limited availability of female fire-resistant (FR) undergarments, commercial off-the-shelf solutions by Elite Issue and New Balance were selected for the female baselayers.

System-level Testing

To gain a better understanding of the heat stress burden caused by PPE on wildland firefighters, system-level testing was performed on the WLFF PPE garment systems. The NFPA 1977 does not require system-level testing of garments and the testing protocol for THL evaluates a single-layer of fabric only. System-level testing of a complete garment system provides a better indicator of actual heat loss performance as it considers the effects of the baselayers and the garment design in the testing. NC State T-PACC performed manikin testing to generate objective data regarding the predicted heat loss characteristics of the APPS WLFF PPE system relative to two baseline PPE systems.⁴ The manikin testing consisted of the double-layer baseline PPE system (CAL FIRE Legacy) using cotton baselayers, a single-layer baseline PPE system (USFS) using cotton baselayers, and a single-layer APPS WLFF PPE system comprised of three different PPE fabrics; these three system all used the same wicking FR baselayers during testing. The results in Table D-3 indicate that the Q value of the double-layer CAL FIRE PPE garment system is noticeably less (10% – to 14% lower) than both the single-layer USFS PPE system with cotton baselayers and the single-layer APPS WLFF PPE systems with wicking baselayers. Compared to the USFS PPE system, one APPS WLFF PPE system was slightly lower (0.6%), and the other two PPE systems had greater Q values (up to 3% greater). Until recently, objective system-level manikin performance data has not been correlated to human physiological response.

Table 7 – System-level Manikin Testing of PPE systems

PPE System	Pants Configuration	Baselayers	Q – Predicted Heat Loss, W/m ²
CAL FIRE Legacy PPE system	Double layer pants	Cotton	174.3
USFS PPE system – Synergy [®] & Synergy [®]	Single layer pants	Cotton	192.8
APPS PPE system – Sigma [®] & Sigma [®]	Single layer pants	Wicking FR	191.6
APPS PPE system – S/469 & S/469	Single layer pants	Wicking FR	198.5
APPS PPE system – M900 & MP950	Single layer pants	Wicking FR	195.4

Data from T-PACC manikin testing

In 2010, the MTDC conducted human physiological testing⁵ of WLFF PPE at the Department of Health and Human Performance at the University of Montana. MTDC used nine human test subjects and had them each wear the CAL FIRE Legacy PPE system (tested above) and two USFS PPE configurations (one of which was tested above). Each instrumented test subject wore a PPE garment system, a hardhat, gloves, and a 20 kg field pack. The test subject walked a 4% grade at 3 miles per hour on separate days at 98.6° F and 30% relative humidity for three hours, with a 10 minute break at the end of each hour. The results were analyzed using a repeated analysis of variance (ANOVA) test. Test subjects wearing the USFS PPE displayed “a

significantly lower physiological strain index (PSI)¹ than participants wearing the CAL FIRE Legacy PPE.¹ The MTDC test results indicate that core body temperatures rise significantly faster during physical exertion when wearing double-layer WLFF PPE compared to single-layer WLFF PPE. The faster rise in core body temperature increases the risk of heat stress occurring sooner. The MTDC testing also indicates that wearing single-layer WLFF PPE allows test subjects to work four times longer before core body temperatures reach critical stages than when wearing double-layer WLFF PPE. The core body temperatures for three of the nine test subjects wearing the CAL FIRE Legacy PPE exceeded the 104° F test termination temperature before the end of the three-hour test duration, and their tests needed to be halted. Five of the remaining six test subjects reached core body temperatures of 103° F or more before the end of the three-hour test. The faster rise in core body temperature translates to significantly longer work durations for individuals wearing single-layer PPE. Extrapolating the results, the MTDC found that the average total work duration (the time to reach critical core temperature of 104° F) for test subjects wearing the double-layer PPE was approximately 5.8 hours. Test subjects wearing the single-layer USFS PPE were projected to reach critical core temperature in 25 hours. This increases the potential work output of a firefighter wearing single-layer PPE by a factor of four, compared to one wearing double-layer PPE.

Comparison of identical WLFF PPE garment fabrics and configurations allowed correlation between the USFS human physiological test results to the T-PACC manikin test results of this program. The USFS physiological test results could then be correlated to the APPS WLFF PPE (single layer, all fabrics) systems by comparing the sweating manikin Q values of the T-PACC study. Based on this comparison of Q values, test subjects wearing the APPS WLFF PPE systems should approximate or exceed the total work duration predicted for the single-layer USFS PPE under similar work rates. In addition to the likely reduction risk of heat stress injuries, changing from a double-layer PPE garment system to the single-layer APPS WLFF PPE can act as a “force multiplier:” where the same workforce can accomplish significantly greater work output due to the increases in work duration before the symptoms of heat stress occur.

¹ PSI is a combination of heart rate and core body temperature.

Appendix E – Operational Assessment

The operational assessment (Wear Trial) was conducted to subjectively determine the operational suitability and effectiveness of the advanced personal protection system wildland firefighter personal protective equipment (APPS WLFF PPE) garment system. One WLFF PPE pair of pants and a shirt were issued to each evaluator as a matched set based on fabric. Each WLFF PPE shirt or pants was assigned a unique serial number that was used for accessing the online survey. Each evaluator was also assigned two identical T-shirts made of a single fabric. There were nine possible combinations of single-layer PPE fabrics and T-shirt fabrics. The distribution of test garments was coordinated to equalize the distribution of the system-level fabric combinations. The program issued approximately 1,000 test garments. This allowed data collectors to obtain similar survey response rates for each fabric combination so they could determine the system-level effects of the different fabric combinations. Male evaluators received two boxers and female evaluators received a sports bra and boy shorts, all in no-melt/no-drip fabrics. Evaluators were directed to wear the garments as much as possible during the fire season and to wash them in a normal manner.

The Wear Trial survey consisted of 19 questions (Attachment 2). Survey questions 1 through 7 asked for background information on the evaluator's organization, level of experience, and baseline PPE system. Survey questions 8 through 11 asked evaluators for feedback to characterize how and where the PPE was used (e.g., locations, number of fires, environmental conditions). Survey questions 12 through 14 asked evaluators to assess the fit of the APPS WLFF PPE system, whether any repairs were required, and if the general garment design was satisfactory. Survey questions 15 through 17 asked evaluators to rate the differences in material performance for comfort, performance, appearance, and durability attributes of the APPS WLFF PPE components when compared to the evaluator's baseline PPE garment system. Survey question 18 asked evaluators to rate the system-level performance differences between the test PPE system configuration, garment system heat dissipation characteristics, and system-level radiant heat protection when compared to the evaluator's baseline PPE garment system. Survey question 19 asked evaluators to rate their preference for the test PPE components and garment system relative to their baseline PPE. The survey used a rating scale of 1 to 7. A rating of 1 indicated the baseline PPE system is much better or much preferred to the APPS WLFF PPE. A rating of 4 indicated no differences or preference between the two PPE systems for that attribute. A rating of 7 indicated the test PPE system is much better or much preferred to the baseline PPE. Assuming the baseline PPE system is considered to be operationally suitable and effective, then any rating of 4 or better indicates the APPS WLFF PPE system achieves a level of operational suitability and effectiveness that is as good as or better than the baseline PPE system.

Initially the 2012 Wear Trial was planned to begin in July 2012, upon delivery of all test garments, and to last approximately five months. The baselayer undergarments were received and distributed in July. However, the WLFF PPE test garments were not delivered until September. The Wear Trial officially began in October 2012. The late start for the Wear Trial resulted in a significantly shorter operational assessment. The duration of the Wear Trial was constrained to less than 60 days in most locations. At the conclusion of the Wear Trial, evaluators logged onto the online Wear Trial Survey. A total of 709 evaluators responded and provided feedback on the WLFF PPE system performance. Of the respondents, 315 (44%) were from CAL FIRE, 325 (46%) were from local and municipal fire departments, and 69 (10%) were from the USFS. Additionally, 693 (98%) respondents were male and 16 (2%) were female. The

shortened Wear Trial resulted in an insufficient data response from evaluators who actually participated in wildfire operations. The survey recorded a total of 18,703 workdays wearing the test PPE garments, an average of only 26 workdays per respondent. Furthermore, the survey recorded only 2,651 workdays on a fire line, an average of less than four days per respondent and approximately 14% of the total workdays recorded. This data indicates limited operational experience fighting wildfires when using the test PPE. At the conclusion of the 2012 wildfire season, the IPT met in November 2012 and determined that there was insufficient data to determine acceptability of the new WLFF PPE garment system and requested that the Wear Trial be continued into the 2013 wildfire season in order to capture greater operational experience using the WLFF PPE. This request was granted.

The results of the 2012 Wear Trial indicated that the APPS WLFF PPE system achieved its objectives. When asked to identify a preference between the APPS WLFF PPE garment system (all fabric combinations) and their baseline PPE garment system, 675 respondents (the other respondents wore USFS fabrics) gave the overall APPS WLFF garment system (all fabric combinations in all garment configurations) a rating of 5.20. This score indicates a slight preference by users for the new WLFF PPE system and a satisfactory level of operational suitability and effectiveness. Although the data indicates that the original APPS WLFF system demonstrated an acceptable level of operational suitability and effectiveness, evaluators provided significant feedback on various design and sizing deficiencies within the system. Several changes were made in response to evaluator feedback from the 2012 Wear Trial.

- Boxer shorts – PVI manufactured the original boxer shorts using the same XGO[®] fabric as the T-shirt. In 2012, the boxer shorts received the lowest preference ratings in the survey (3.06). A review of the respondent feedback indicated that this low rating largely resulted from poor garment design and fit, not material performance; the XGO[®] T-shirt was the highest rated T-shirt. Feedback indicated that 226 (33%) male respondents indicated that the “boxers did not fit” and 143 (21%) male respondents indicated that the boxers could not be worn. The feedback indicated that the poor fit was due to the design pattern used for the boxers (too baggy). The IPT decided to replace all boxer shorts for the 2013 Wear Trial. The IPT selected replacement boxer shorts, made in two different fabrics, from Elite Issue and issued to all male evaluators in 2013 to replace the previous boxer shorts from PVI.
- Female undergarments – The IPT selected the original sports bras and boy shorts from the Army-approved, flame-resistant female undergarments manufactured by New Balance and Elite. Only 16 female evaluators responded to the survey. Of those 16, 8 respondents (50%) indicated the sports bras fit properly and 11 respondents (69%) could actually wear the sports bras. Only 9 respondents (56%) indicated that the boy shorts fit properly and were worn. However, the fit issues appear to be related to garment sizing and not design or manufacturing. The IPT issued an alternative bra and boy shorts during the winter break to determine if they could be substituted for the original baselayers issued in 2012. However, limited feedback indicated the fit problems remained. Consequently, no new female undergarments were issued as part of the 2013 Wear Trial.
- PPE – Feedback from many of the 2012 Wear Trial respondents identified a variety of design and configuration deficiencies with the PPE shirt and pants. Twenty-one percent (21%) of all PPE response shirt evaluators felt the shirt required a redesign and 23% of all PPE pants evaluators felt the pant required a redesign. To correct these PPE design

deficiencies, the original PPE patterns were modified to incorporate a variety of changes. The garment changes are identified on page 52 and the revised garments were designated the GEN II WLFF PPE.

The 2013 Wear Trial commenced at the beginning of the wildfire season in April 2013. The 2013 Wear Trial resulted in significantly greater use by evaluators who participated in wildfire operations. The response rate dropped from 709 respondents in 2012 to 428 respondents in the 2013 survey. This response rate represented more than 40% of total test PPE evaluators. Of the 428 evaluators who responded, 36,109 workdays were recorded, an average of more than 84 workdays per respondent. For those 428 respondents, 10,616 workdays on a fire line were recorded, equating to an average of nearly 25 days of use per respondent and approximately 29% of the total workdays recorded. Of the respondents, 157 were from CAL FIRE, 158 were from local California fire departments, and 83 were from the USFS; 30 respondents did not identify their organizations. Based on this level of usage, the IPT deemed the data from the 2013 Wear Trial acceptable for determining the operational suitability and effectiveness of the APPS WLFF PPE garment system.

PPE System-level Wear Trial Data Analysis

The survey asked evaluators to rate the system-level performance and preference for the complete APPS WLFF PPE system relative to the evaluator’s baseline WLFF PPE system. Table E-1 tabulates system-level comparison and preference ratings for the complete PPE systems from the 2012 and 2013 Wear Trials. The Overall System Configuration rating evaluates the PPE garment design and configuration. The System Heat Dissipation and System Thermal Protection ratings evaluate the two protection performance parameters of the PPE system. The Overall System Preference is the evaluator’s preference for a specific PPE system when considering all attributes. N represents the number of evaluators that responded to the survey. The system comparison and preference rating data in Table E-1 tabulates the total number of evaluators that responded to the survey in 2012 (N=709) and in 2013 (N=428). The response rate in 2012 (~70%) was exceptionally high. The 43% response rate in 2013 was considered acceptable for minimizing sampling bias. The comparison ratings represent the average rating for all APPS PPE configurations (single layer and double layer) in all fabrics relative to all baseline PPE configurations. The data indicates a high level of consistency between 2012 ratings and 2013 ratings. The ratings reflect improvements in the system configuration and heat dissipation, which led to a slight preference by all evaluators for the APPS WLFF PPE system relative to the baseline PPE systems in use.

Table E-1 – APPS WLFF PPE System Comparison and Preference Ratings, 2012 vs. 2013

APPS PPE	Baseline PPE	N	Overall System Configuration	System Heat Dissipation	System Thermal Protection	Overall System Preference
2012 – APPS PPE, All Fabrics and Configurations	All Baseline PPE Configurations	709	5.11	5.30	4.77	5.08
2013 – APPS PPE, All Fabrics and Configurations	All Baseline PPE Configurations	428	5.02	5.10	4.70	5.02

Table E-2 tabulates the distribution of Overall System Preference ratings by the number of responses for each rating for the 2012 and 2013 Wear Trials. The ratings distributions were very

similar across the two Wear Trials. The ratings distribution indicates that two-thirds of all evaluators found the APPS WLFF PPE system to be preferable, to some degree, to their baseline PPE systems. One in 10 evaluators identified no preference between the two PPE systems. The remaining 22% of evaluators found the baseline PPE systems to be preferable to the APPS WLFF PPE system. This data also suggests that 78% of all Wear Trial evaluators found the APPS WLFF PPE garment systems to be as good as or better than the baseline PPE systems. This data indicates that most evaluators consider the operational suitability and effectiveness of the overall APPS WLFF PPE system is as good as or better than current baseline PPE systems.

Table E-2 – APPS WLFF PPE System Preference Ratings Distribution

	N	Rating						
		1	2	3	4	5	6	7
2012 Wear Trial	709	36	41	79	73	125	158	197
PPE System Preference		22%			10%	68%		
2013 Wear Trial	428	18	38	35	48	94	78	117
PPE System Preference		21%			11%	68%		

Table E-3 separates the 2013 system-level comparison and preference ratings into the three largest organizational segments that participated in the Wear Trial. Significant differences in PPE ratings by organization are apparent. The CAL FIRE system-level comparison and preference ratings were slightly higher than the average ratings from all 2013 evaluators except for system thermal protection. The local California fire departments rated the APPS WLFF PPE system higher than the average comparison and preference ratings from all 2013 evaluators. The USFS ratings indicate that USFS evaluators expressed no preference or preferred their baseline PPE system, as all average ratings were less than 4.0. As all ratings are relative to the baseline PPE being used, this data indicates that the USFS currently uses a high performing single-layer PPE system as its baseline PPE.

Table E-3 – 2013 APPS WLFF PPE System Preference Ratings, By Organization

Evaluators	Baseline PPE	2013 APPS PPE	N	System Configuration	System Heat Dissipation	System Thermal Protection	Overall System Preference
CAL FIRE	All Baseline PPE Configurations	All APPS PPE	157	5.17	5.38	4.52	5.15
Local CA Fire Departments	All Baseline PPE Configurations	All APPS PPE	158	5.50	5.65	5.32	5.56
USFS	All Baseline PPE Configurations	All APPS PPE	83	3.83	3.52	3.88	3.78

Note: Some evaluators did not identify their organizations or baseline PPE configurations.

To evaluate the effects of the baseline PPE system on the comparison and preference ratings for the APPS WLFF PPE system, Table E-4 separates the survey data by the configuration of the evaluator’s baseline PPE system. The largest number of responding evaluators (N=211) used a single-layer PPE system as their baseline PPE configuration and wore a single-layer APPS test garment. Their system preference ratings (4.72) were lower than the average system preference ratings (5.02) from all evaluators, indicating they experienced a lower level of performance

difference and preference between the PPE systems. However, evaluators who wore a single-layer PPE system as their baseline noticed a slight improvement in system heat dissipation. This is likely due to the new baselayer fabrics and/or the fabrics used in the PPE system. Evaluators (N=30) who wore a double-layer PPE system as their baseline PPE configuration and wore a double-layer APPS WLFF PPE test garment also submitted preference ratings (4.89) lower than the average system preference ratings from all evaluators, indicating they experienced lower performance and preference differences between the two systems. However, evaluators (N=181) who used a double-layer PPE system as their baseline configuration and wore a single-layer APPS WLFF PPE test garment submitted significantly higher comparison and preference ratings (5.43) than the average system-level ratings in three of the four rating categories. This indicates that these evaluators perceived a bigger difference (improvement) in performance between the PPE systems. Overall, these ratings reflect the importance of the baseline PPE configuration with respect to perceiving differences in performance and the comparison and preference ratings of the APPS WLFF PPE.

Table E-4 – 2013 APPS WLFF PPE System Preference Ratings, by Baseline Configuration

Baseline PPE	APPS PPE	Evaluators	N	System Configuration	System Heat Dissipation	System Thermal Protection	Overall System Preference
Single Layer PPE	APPS Single Layer	All Evaluators	211	4.69	4.63	4.68	4.72
Double Layer PPE	APPS Double Layer	All Evaluators	30	4.57	4.36	4.29	4.89
Double Layer PPE	APPS Single Layer	All Evaluators	181	5.46	5.74	4.80	5.43

Note: Some evaluators did not identify their baseline PPE configurations.

PPE Component Wear Trial Data Analysis

The PPE component ratings analysis only utilizes the 2013 Wear Trial response data due to similarities between the 2012 and 2013 system-level data. The survey asked for the evaluators' preference for a specific APPS WLFF PPE component relative to their baseline PPE component. The PPE component preference rating data in Table E-5 tabulates ratings from all evaluators who responded to the Wear Trial survey in 2013 (N=428). The preference ratings represent the average for each test PPE component (all fabrics) relative to the evaluators' baseline PPE. The ratings reflect an overall preference for most for the APPS WLFF PPE components relative to the various baseline PPE components currently in use. The tactical pants received the highest preference ratings (5.27). The two APPS WLFF PPE components with relatively lower preference ratings were the replacement boxer shorts and overpants. However, the ratings for the replacement boxers (4.26) show a significant improvement over the 2012 boxer rating (3.06). The ratings for the APPS overpants (4.13) indicate no preference for this PPE garment relative to their baseline PPE.

Table E-5 – 2013 APPS WLFF PPE Component Preference Ratings

APPS PPE Component	N	PPE Component Preference Rating
APPS Response Shirt	398	4.92
APPS Uniform Pants	166	5.13
APPS Tactical Pants	174	5.27
APPS Overpants	30	4.13
APPS T-shirts	412	5.26
APPS Boxers	354	4.27
APPS Socks	416	5.06

Note: Not all respondents provided ratings to all PPE components as evaluators did not wear some garments due to fit issues.

The distribution of the APPS WLFF PPE component ratings in Table E-6 indicates that a majority of Wear Trial evaluators prefer the APPS WLFF components (except the boxers and overpants) to their current baseline PPE component. The evaluators noted the greatest preference for the uniform and tactical pants (each preferred by 71%) even though 25% of evaluators thought the PPE pants should be redesigned. However, only 57% of evaluators preferred the new APPS response shirt and 24% of all shirt evaluators thought the response shirt required a redesign. The preference ratings distribution indicates that most APPS WLFF PPE components are operationally suitable and effective when compared to their baseline PPE components.

Table E-6 – 2013 APPS WLFF PPE Component Preference Ratings Distribution

Attribute	N	Ratings Distribution						
		1	2	3	4	5	6	7
APPS Response Shirt	398	70	29	29	43	58	64	105
		32%			11%	57%		
APPS Uniform Pants	166	22	9	8	9	19	29	70
		23%			5%	71%		
APPS Tactical Pants	174	16	9	10	16	24	25	74
		20%			9%	71%		
APPS Overpants	30	4	2	4	5	8	5	2
		30%			15%	50%		
APPS T-Shirt	412	37	15	33	47	50	66	164
		21%			11%	68%		
APPS Boxers	354	50	14	27	128	38	32	65
		26%			36%	38%		
APPS Sock	416	26	13	26	106	48	64	133
		16%			25%	59%		

Note: Not all evaluators provided ratings for all PPE components.

PPE Fabric Wear Trial Data Analysis

Tables E-7 and E-8 tabulate the 2013 Wear Trial comparison ratings for PPE fabrics used in the APPS WLFF PPE shirts and pants. These survey ratings compare various fabric attributes relative to the fabrics used in the baseline PPE.

Table E-7 tabulates APPS response shirt fabric performance comparison and preference ratings relative to the fabrics used in their baseline WLFF PPE shirts. The ratings indicate that all response shirt fabrics were rated slightly better and no worse than baseline PPE shirt fabrics. Although laboratory data indicates the response shirt fabrics provide greater thermal protection when compared to most baseline PPE shirt fabrics, the subjective ratings do not reflect any significant perceived improvement in System Radiant Protection. There were bigger perceived performance improvements in System Heat Dissipation, even though the test shirt fabrics had slightly lower THL ratings and were heavier than the baseline PPE shirt fabrics. This perception of improved heat dissipation performance may be due to the baselayer garments used in the Wear Trial. Sigma[®] fabric received a slight overall preference with S/469 and M900 receiving slightly lower preferences. Radiant Protection performance and Durability ratings were about equal for all three fabrics, with Sigma[®] receiving the highest ratings by a slim margin. The higher preference ratings for Sigma[®] are most likely due to the better heat transfer performance, as the Sigma[®] fabric received the highest ratings in both System Heat Dissipation and Comfort by a noticeable margin. The M900 received the lowest preference ratings in the five categories and could be attributed to the higher fabric weight, relative to other PPE shirt fabrics. Evaluators selected Sigma[®] fabric as the top rated fabric in each performance comparison category (by very small margins) and as the most preferred fabric for a PPE shirt application.

Table E-7 – 2013 APPS WLFF PPE Shirt Fabric Comparison and Preference Ratings

	S/469	Sigma[®]	M900
N	140	112	128
Response Shirt Preference	4.55	4.92	4.15
Overall System Preference	5.21	5.12	5.07
System Heat Dissipation	5.09	5.50	5.15
System Radiant Protection	4.76	4.79	4.71
Appearance	4.73	4.78	4.52
Durability	4.80	4.97	4.88
Comfort	4.66	5.09	4.27

Table E-8 tabulates PPE pants fabric performance comparison and preference ratings relative to the fabrics used in the baseline WLFF PPE pants. The PPE pants preference ratings for the single-layer pants fabrics were tightly grouped within a 0.11 range and reflect a higher level of preference compared to the response shirt fabrics. Sigma[®] fabric received the highest ratings for System Heat Dissipation and Comfort, which is consistent with the response shirt data. S/469 fabric received the highest ratings for RPP, Durability, and Appearance by larger margins. MP950 fabric received the highest PPE pants preference rating even though it was not rated the best in any performance category. Based on a review of the Appearance sub-attributes (fading, pilling, shrinkage, and washability) ratings, S/469 received the highest ratings in all Appearance sub-attributes. This indicates that S/469 would be the most suitable fabric for a uniform pant application. If heat stress relief is the primary requirement and appearance is less important,

Sigma[®] should be considered as a possible alternative fabric. Based on its high preference rating, MP950 is also a suitable pants fabric. The low comparison rating for the Protera[®] fabric is likely due to the greater weight of the Protera[®] fabric. The Protera[®] fabric weight is 12% to 30% more than the current CAL FIRE Interim and Legacy overpants.

Table E-8 – 2013 APPS WLFF PPE Pants Fabric Comparison and Preference Ratings

	S/469	Sigma[®]	MP950	Protera
N	129	104	111	30
PPE Pants Preference	5.29	5.20	5.31	4.13
Overall System Preference	5.29	5.29	5.00	4.90
System Heat Dissipation	5.33	5.66	5.31	4.48
System Radiant Protection	5.16	4.89	4.70	4.32
Appearance	4.99	4.51	4.20	4.20
Durability	4.94	4.28	4.45	4.45
Comfort	5.49	5.65	4.31	4.31

A color evaluation of PPE pants fabrics worn during the 15-month Wear Trial was performed to determine the fading performance of the various pants fabrics. This testing was performed to generate objective data to identify the PPE fabrics that would be most suitable for uniform pants applications. A total of 52 uniform and tactical pants, in the three fabrics, were randomly selected from the inventory of pants that had completed the 15-month Wear Trial. The lab evaluations objectively rated color fading relative to the unwashed baseline color. This objective evaluation indicates that Sigma[®] has better fade resistance than the other pants fabrics. However, Sigma[®] cannot be dyed into a dark navy color (color preferences may vary by department, but navy blue is a very common color choice). The subjective evaluations rated S/469 better in appearance, as this fabric can be dyed into a darker shade of navy.

Table E-9 – PPE Pant Fabric Color Fading Evaluation

Fabric	N	Uniform	Tactical	Average Rating
S/469	17	3.35	3.29	3.32
MP950	19	2.82	2.06	2.50
Sigma[®]	16	3.67	3.40	3.50

Baselayer Wear Trial Data Analysis

Table E-10 tabulates the 2013 Wear Trial evaluator comparison and preference ratings for baselayer T-shirt fabrics worn in the Wear Trial. These survey ratings compare various T-shirt fabric performance attributes relative to the fabric used in their baseline T-shirt. The ratings for all T-shirt fabrics were closely grouped in each rating category. The subjective ratings indicate a perceived improvement in System Heat Dissipation and a significant improvement in Comfort for all test T-shirt fabrics. The T-shirt fabric performance comparison and preference ratings indicate that all T-shirt fabrics rated slightly better than baseline T-shirt fabrics. XGO[®] and Cocona[®] fabrics received a slightly higher overall preference rating compared to the Elite fabric and all three T-shirt fabrics generated high performance ratings for Comfort. Based on the ratings, all three T-shirt fabrics represent suitable and effective choices for a baselayer garment.

Table E-10 – 2013 APPS WLFF PPE T-Shirt Fabric Comparison and Preference Ratings

	XGO®	Cocona®	Elite
N	118	150	122
T-Shirt Preference	5.46	5.25	5.13
Overall System Preference	5.49	5.39	5.33
System Heat Dissipation	5.60	5.43	5.65
System Radiant Protection	4.93	4.96	5.04
Appearance	5.20	4.90	4.83
Durability	4.55	4.39	4.32
Comfort	6.12	6.09	5.95

Note: Not all evaluators who provided T-shirt ratings identified their T-shirt fabric

CAL FIRE Wear Trial Data Analysis

As CAL FIRE represents the largest homogeneous sub-group of respondents in the Wear Trial, the 2013 Wear Trial results for CAL FIRE respondents are separated from the other Wear Trial responses. The CAL FIRE community is homogeneous in that its respondents all wore a double-layer PPE pants configuration as part of their baseline PPE ensemble. The total number of responses (N=157) from the CAL FIRE community creates a reasonable level of statistical reliability for its ratings. As previously noted, the CAL FIRE system-level preference ratings were slightly higher than the average ratings from all 2013 evaluators (a value of 5.02 from Table E-1) except for system thermal protection. Table E-11 tabulates the CAL FIRE APPS WLFF PPE component preference ratings. The tactical pants received the highest preference rating (6.18) and the overpants received the lowest preference ratings (4.12). The PPE component preference ratings indicate that the operational suitability and effectiveness of all APPS WLFF PPE components are as good as or better than the CAL FIRE baseline PPE.

Table E-11 – 2013 CAL FIRE APPS WLFF PPE Component Preference Ratings

APPS PPE Component	N	PPE Component Preference Rating
APPS Response Shirt	152	4.84
APPS Uniform Pants	108	5.31
APPS Tactical Pants	22	6.18
APPS Overpants	24	4.12
APPS T-Shirts	148	4.81
APPS Boxers	127	4.20
APPS Socks	157	5.17

Note: Not all respondents provided ratings for all PPE components as some garments were not worn due to fit issues

The distribution of the CAL FIRE PPE component ratings (Table E-12) indicates that a majority of CAL FIRE Wear Trial evaluators prefer the APPS WLFF PPE components (except for the boxers) to their current baseline PPE component. The ratings distribution indicates evaluators strongly preferred the single-layer PPE pants configuration. For all PPE components, the ratings distribution is weighted toward “better than the baseline” except for the boxers. The distribution of CAL FIRE ratings tended to be slightly more favorable than the average ratings distribution

for all evaluators (Table E-6) except for the T-shirt. This ratings distribution indicates the operational suitability and effectiveness of the APPS WLFF PPE garment components when compared to current baseline CAL FIRE PPE components.

Table E-12 – 2013 CAL FIRE APPS WLFF PPE Component Ratings Distribution

Attribute	N	Ratings Distribution						
		1	2	3	4	5	6	7
APPS Response Shirt	155	16	5	17	18	30	35	34
		25%			12%	64%		
APPS Uniform Pants	108	12	4	7	4	16	18	47
		21%			4%	75%		
APPS Tactical Pants	22	0	0	0	0	5	8	9
		0%			0%	100%		
APPS Overpants	24	3	1	4	3	7	4	2
		33%			13%	54%		
APPS T-Shirt	148	18	5	20	15	21	24	45
		29%			10%	61%		
APPS Boxers	127	22	5	12	32	20	15	21
		31%			25%	44%		
APPS Socks	154	14	4	6	24	26	30	50
		16%			16%	69%		

The Table E-13 PPE shirt fabric ratings from CAL FIRE respondents were somewhat different from the overall Wear Trial results. Although Sigma[®] fabric received the highest APPS response shirt fabric preference ratings from all Wear Trial respondents (Table E-7), S/469 fabric received the highest APPS response shirt preference ratings from CAL FIRE evaluators. This appears to be primarily due to the CAL FIRE’s higher ratings for System Heat Dissipation and Comfort for this fabric. The ratings for the other two fabrics were largely unchanged from the ratings provided by all Wear Trial respondents.

Table E-13 – 2013 CAL FIRE PPE Shirt Fabric Ratings

	S/469	Sigma [®]	M900
N	56	49	50
PPE Shirt Preference	5.32	4.86	4.12
Overall System Preference	5.47	4.92	5.02
System Heat Dissipation	5.58	5.57	4.96
System Radiant Protection	4.82	4.24	4.45
Appearance	4.83	4.41	4.21
Durability	4.74	4.59	4.61
Comfort	5.38	5.14	4.33

In Table E-14, S/469 pants fabric received the highest ratings in all rating categories from CAL FIRE PPE evaluators. S/469 fabric received noticeably higher ratings from CAL FIRE evaluators in Pants Preference and Overall System Preference than the other PPE pants fabrics. CAL FIRE evaluators also found S/469 to be the highest rated PPE pants fabric for Comfort, Appearance,

and Durability attributes. The low preference ratings for the Protera[®] overpants indicate a difference between the objective test data and the subjective human evaluation of fabric performance. Lab test data can quantify objective differences in fabric performance. However, human perception of those performance differences varies and, in many cases, the differences do not appear to be detectable. Physical differences (e.g., fabric weight) appear to be more easily detectable. This could explain why Protera[®] 165 did not receive better preference ratings. Although this fabric demonstrated significantly superior THL performance in the lab compared to baseline PPE overpants fabrics, the 6.5 osy fabric weighed more than the baseline PPE overpants fabric (5.0 osy for the Legacy PPE and 5.8 osy for the Interim PPE). This trend is consistent with Wear Trial feedback on PPE shirt fabrics. This indicates that fabric weight could have a greater influence on wearer perception and should be given greater consideration, relative to fabric performance, when selecting PPE fabrics.

Table E-14 – 2013 CAL FIRE PPE Pants Fabric Ratings

	S/469	Sigma[®]	MP950	Protera[®]
N	47	42	43	24
Pants Preference	5.96	4.86	5.26	4.12
Overall System Preference	5.79	5.05	4.70	4.92
System Heat Dissipation	5.94	5.69	5.16	4.16
System Radiant Protection	5.11	4.21	4.40	4.16
Appearance	5.00	3.89	3.62	4.20
Durability	4.58	4.15	4.00	4.46
Comfort	6.03	5.71	5.38	4.21

The results of the Wear Trial indicate that CAL FIRE evaluators slightly preferred most of the APPS WLFF PPE components relative to their baseline PPE garment system. The uniform and tactical pants were rated to have the greatest relative improvement over the baseline CAL FIRE pants system. Evaluators also preferred other garment components, such as the socks.

U.S. Forest Service Wear Trial Data Analysis

The 2013 Wear Trial results for USFS respondents are analyzed separately from the other Wear Trial responses because the USFS represents the second largest homogeneous sub-group of respondents in the Wear Trial. A relatively homogeneous community, the USFS respondents all wore a single-layer pants configuration (in one of two fabrics) as their baseline PPE. The baseline USFS configuration utilizes a response shirt typically worn over a cotton T-shirt. The lower number (N=83) of USFS responses introduces an increased likelihood for sampling bias due to the small sample size. In addition, the USFS evaluated the APPS WLFF PPE designs made in its current shirt (Synergy[®] 3541) and pant (Synergy[®] 7531 and Advance[™]) fabrics. These additional fabric candidates further diluted and reduced the response rate for each fabric. Since the USFS wears a tactical-style pant as its baseline, all USFS test PPE pants were manufactured in the tactical pants style only. Table E-15 tabulates the USFS PPE component preference ratings. Overall, USFS evaluators gave the APPS WLFF PPE components lower preference ratings than the average rating from all evaluators. The response shirt received the lowest preference ratings from any evaluators within the survey. Fifty-three percent of USFS evaluators indicated the response shirt required a redesign and 49% indicated the PPE pants required a redesign. The evaluators rated the APPS pants and the socks as “no preference”

between the test PPE and their baseline PPE. The T-shirts and boxers received ratings that were comparable to the average preference ratings from all evaluators.

Table E-15 – 2013 USFS APPS WLFF PPE Component Preference Ratings

APPS PPE Component	N	PPE Component Preference Rating
APPS Response Shirt	65	2.79
APPS Tactical Pants	77	4.18
APPS T-Shirts	72	5.13
APPS Boxers	72	4.07
APPS Socks	74	3.95

Note: Not all respondents provided ratings for all PPE components as some garments were not worn due to fit issues

The distribution of the USFS PPE component ratings in Table E-16 indicates that a slight majority of USFS Wear Trial evaluators prefer the APPS WLFF PPE pants and T-shirt to their current baseline PPE component. Evaluators rated the APPS response shirt very poorly, with 65% of respondents rating the APPS response shirt worse than the baseline USFS PPE shirt. The majority of evaluators found the boxers and the socks to be no better or worse than their baseline components. Overall, the USFS results indicate that most of the APPS WLFF PPE components, excluding the response shirt, are operationally suitable and effective when compared to the baseline PPE systems.

Table E-16 – 2013 USFS APPS WLFF PPE Component Ratings Distribution

Attribute	Ratings Distribution							
	N	1	2	3	4	5	6	7
APPS Response Shirt	62	25	12	3	7	7	4	4
		65%			11%	24%		
APPS Tactical Pants	67	10	6	7	10	12	13	9
		34%			15%	51%		
APPS T-Shirt	72	4	0	5	22	7	11	23
		13%			31%	57%		
APPS Boxers	72	2	3	2	56	2	4	3
		10%			78%	12%		
APPS Socks	74	6	5	6	42	5	5	5
		23%			57%	20%		

Table E-17 tabulates the USFS PPE shirt fabric ratings. The PPE shirt fabric ratings from USFS respondents differed noticeably from the overall Wear Trial ratings. Although the rating order (Sigma[®] rated highest, followed by S/469 and MP950) remained the same, the magnitude of the PPE shirt preference rating was considerably lower than the average shirt preference ratings from all Wear Trial respondents. The Wear Trial included an additional baseline PPE shirt fabric (Synergy[®] 3541), which received the highest USFS preference rating. The order of PPE shirt preference ratings corresponded to the weight of the PPE shirt fabric. The lighter the fabric weight, the higher the preference ratings. The ratings order for Heat Dissipation also corresponded to the fabric weights, with the exception of M900. The M900 System Heat Dissipation rating (4.17) is inconsistent with previous shirt rating trends and the M900 rating for

Comfort (1.19) and Overall Preference (1.36). These ratings inconsistencies, combined with the small sample size, indicate that these ratings may not be as reliable as other ratings in this study. These ratings indicate the USFS evaluators are satisfied with the baseline Synergy[®] 3541 PPE shirt fabric and do not prefer any of the new PPE shirt fabrics relative to their baseline.

Table E-17 – 2013 USFS PPE Shirt Fabric Ratings

	S/469	Sigma [®]	M900	Synergy [®] 3541
N	26	12	14	13
PPE Shirt Preference	2.25	3.33	1.36	4.80
Overall System Preference	3.97	3.80	3.72	3.71
System Heat Dissipation	3.07	3.87	4.17	4.00
System Radiant Protection	3.80	4.07	3.89	3.57
Appearance	3.70	4.29	3.70	3.89
Durability	3.78	4.85	4.00	5.23
Comfort	2.03	3.13	1.19	4.00

Table E-18 tabulates the PPE pants comparison and preference ratings; these ratings are considerably lower in magnitude than the average PPE pants preference ratings from all Wear Trial respondents. In particular, the USFS System Heat Dissipation ratings for all three APPS fabrics are more than 1.0 lower than the average ratings given by all Wear Trial respondents. This may be due, in part, to the use of a single-layer PPE pant as part of the USFS baseline PPE system. The preference rating for the USFS baseline Synergy[®] pants fabric was the second lowest rating, even though this was one of the lightest (6.5 osy) PPE fabrics evaluated. These ratings indicates the USFS evaluators’ satisfaction with the baseline Advance[™] PPE pants fabric, but indicated a preference for two of the new PPE pants fabrics (Sigma[®] and MP950) when compared to the baseline Synergy[®] 7531 PPE pants fabric. However, the relatively small sample size in these ratings may reduce the reliability of any conclusions.

Table E-18 – 2013 USFS PPE Pants Fabric Ratings

	S/469	Sigma [®]	MP950	Advance [™]	Synergy [®] 7531
N	33	14	18	5	7
Pants Preference	3.97	5.00	4.78	4.80	3.43
Overall System Preference	4.22	3.81	3.72	4.50	3.13
System Heat Dissipation	3.28	3.94	4.17	4.33	3.75
System Radiant Protection	3.94	4.06	3.89	4.33	3.00
Appearance	4.53	4.25	4.40	4.35	1.93
Durability	5.02	4.29	3.64	4.40	2.29
Comfort	4.41	4.98	5.05	3.80	5.34

The USFS results of the Wear Trial survey indicate that the APPS WLFF PPE system provides limited improvements when compared to the baseline USFS WLFF PPE garment system. The T-shirts appear to offer the greatest component level improvement in performance over the baseline USFS PPE components. Evaluators indicated a slight preference for two of the APPS pants fabrics. However, the small sample size of the USFS feedback may reduce the reliability of any conclusions drawn from this data.

GEN II WLFF PPE

The survey response to the initial Wear Trial completed in 2012 included many comments regarding the improper fit and design issues associated with the test garments. In response to Question 14 on the 2012 survey, 23% (N=160) of evaluators indicated the PPE pants required redesign and 21% (N=146) indicated the response shirt required redesign. The athletic profile of the PPE, which restricted the freedom of movement of larger evaluators, caused fit issues. Since the Wear Trial continued into the 2013 wildfire season, it was determined that the original WLFF PPE garment design should be modified to address this operational feedback. The resulting modified PPE garment design, designated GEN II WLFF PPE, incorporated feedback from the 2012 Wear Trial to address the design deficiencies identified by evaluators. The primary change was the addition of a relaxed fit sizing for all garments, which could accommodate larger physiques of the same height and address the improper fit issue. The relaxed fit response shirt features increased circumferences for the chest, waist, and bottom. The relaxed fit pants incorporate increased circumferences for the seat and thigh. Other generic pants improvements included additional, larger belt loops and replacing the front hook and loop waistband closure with a positive closure. For tactical pants, the front pocket design was changed to be identical to the uniform pants (to simplify manufacturing) and the ankle closures were redesigned. For the response shirt, the elbow patches were removed to enhance freedom of motion and the neck opening was enlarged to accommodate larger necks. As the GEN II PPE represented a garment pattern change only, the IPT decided to use a single material (Sigma[®]) deemed to be satisfactory during the 2012 Wear Trial. Additional fabric testing was not required since the Sigma[®] fabric already received NFPA 1977 certification.

Fechheimer was asked if they could meet the desired production schedule for building the GEN II WLFF PPE test garments, to allow evaluation in 2013. Fechheimer indicated it could not meet the desired schedule. Therefore, the IPT sought alternative GEN II WLFF PPE production vendors. To reduce schedule risk and increase the number of vendors building the WLFF PPE system, the IPT selected two manufacturers to build the GEN II WLFF PPE. Propper submitted the lowest cost bid but had limited experience in building WLFF PPE garments. CrewBoss is a large WLFF PPE designer and manufacturer but submitted a higher cost of production. Given the limited amount of funding remaining in the program, the delivery order was split between these two manufacturers, which allowed the program to maximize the total number of GEN II WLFF PPE test garments built (100) and hedged the schedule risk by having two different manufacturers participate.

CrewBoss delivered 72 sets of their version of GEN II PPE in October 2013. The late delivery was due to certification issues encountered during prototyping. This late delivery did not allow significant operational use by evaluators. Propper delivered 28 sets of its version of GEN II PPE in March 2014. This extremely late delivery resulted from certification and quality assurance issues encountered during prototyping. This precluded an evaluation by Wear Trial evaluators. IPT members inspected and assessed the fit of the system during the final IPT meeting. The IPT found the quality of the Propper garments to be very good, but no ratings for Propper GEN II PPE were included in the program evaluation data. Evaluators of the GEN II WLFF PPE received an abbreviated survey to determine if the redesigned PPE successfully addressed the fit and design issues encountered in the GEN I PPE design. The three survey questions asked evaluators to provide preference ratings for the redesigned response shirt, pants, and overall garment system, relative to their baseline PPE. This allowed a direct comparison against the

ratings for the Gen I WLFF PPE. Thirty-one of the 72 evaluators (43%) who received the complete GEN II WLFF PPE ensemble responded to the survey. Table E-19 summarizes the mean average preference ratings for the response shirt, the PPE pants (tactical, uniform, and overpants combined), and the overall PPE system for the GEN I WLFF PPE and GEN II WLFF PPE. The results reflect a significant increase in the component and system-level preference ratings for the GEN II WLFF PPE when compared to the original GEN I WLFF PPE ratings. Even though these garments received limited operational use, the ratings clearly indicate that the design changes identified by the IPT and incorporated into the PPE garment system greatly improved the fit and functionality of the garment system.

Table E-19 – Comparison between Gen I and GEN II Preference Ratings

	Gen I N	Gen I PPE Rating	GEN II N	GEN II PPE Rating	Change in Preference Rating
Response Shirt Preference Rating	398	4.92	31	6.03	+ 1.11
PPE Pants Preference Rating	340	5.20*	31	6.23*	+ 1.03
Overall PPE System Preference Rating	428	5.02	31	6.45	+ 1.43

* The 2013 average rating of both single-layer APPS WLFF PPE pants only

The distribution of the GEN II WLFF PPE preference ratings in Table E-20 indicates that the overwhelming majority of evaluators prefer the GEN II WLFF PPE relative to their baseline PPE. When analyzing the survey response data, most ratings clustered in the 6 to 7 range. One evaluator gave the pants ratings a 2 rating. When this evaluator was asked for the rationale behind his rating, he responded that the PPE garments performed well during wildland firefighting, but they were found to be incompatible with his structural turnout gear due to excessive pants material, which hindered freedom of motion and which he determined to be unacceptable. When other evaluators were asked to measure their GEN II WLFF PPE, it was discovered that the finished dimensions of the PPE pants were significantly larger than what was specified in the patterns provided to the manufacturer. This issue highlights the need to assess PPE for interoperability and compatibility with other operational PPE. It also identifies the need for better quality assurance surveillance of manufactured garments, since a design change that benefits one operational application (wildland firefighting) can compromise a different operational application (structural firefighting) of the garment.

Table E-20 – Distribution of GEN II WLFF PPE Preference Ratings

Attribute	Ratings Distribution							
	N	1	2	3	4	5	6	7
Response Shirt Preference	31	0	0	2	2	4	8	15
		6%			6%	87%		
PPE Pants Preference	31	0	1	1	1	2	8	18
		6%			3%	90%		
Overall System Preference	31	0	0	2	1	0	6	22
		6%			3%	90%		

Appendix F – References

1. National Fire Protection Association (NFPA) 1977, *Standard on Protective Clothing and Equipment for Wildland Fire Fighting*, 2011 edition
2. *Advanced Personal Protection System (APPS) Program, Process and Application to Tactical Law Enforcement*, Final Report, Department of Homeland Security Science and Technology Directorate, R-Tech Program, February 2011
3. *Wildland Fire & Hazard Risk Assessment*, California Department of Forestry and Fire Prevention (CAL FIRE), Draft report, January 2010
4. *Thermal and Evaporative Heat Transfer Properties of Eleven Garment Systems*, Textile Protection and Comfort Center, North Carolina State University, April 2013
5. *Wildland fire uniform configurations on physiological measures of exercise-heat stress*, Joseph Domitrovich, Missoula Technology and Development Center, U.S. Department of Agriculture (undated)
6. System Assessment and Validation for Emergency Responders (SAVER) *Wildland Fire Fighter Personal Protective Equipment Selection Guide*, Draft report
7. NFPA 1975, *Standard on Station/Work Uniforms for Emergency Services*, 2009 edition
8. *Understanding the Stoll Curve*, Oberon Company, 2005
9. *What Is The Minimum Perceivable THL Difference*, Fabrics Division, W. L. Gore & Associates, Inc., April 2011
10. *Tests of Undergarments Exposed to Fire*, Tony Petrilli & Mark Ackerman, Missoula Technology and Development Center, U.S. Department of Agriculture, December 2008
11. NFPA 1851, *Standard on Selection, Care and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*, 2008 edition
12. *Blazing New Trails in Improving Heat Stress and Radiant Heat Protection in Wildland Firefighter Protective Clothing*, 2013 Fire Industry Equipment Research Organization (FIERO) presentation, Alex Hummel, Textile Protection and Comfort Center, North Carolina State University, March 2013
13. *CAL FIRE Statewide PPE Standards*, briefing to CAL FIRE Executive Management Council, Tom Foley & Dave Teter, November 10, 2010

Appendix G – Acronyms

ANOVA - analysis of variance

APPS – Advanced Personal Protection System

ASTM – American Society of Testing and Materials

CAL FIRE – California Department of Forestry and Fire Protection

DHS – Department of Homeland Security

FIERO – Fire Industry Equipment Research Organization

FR – flame resistant

IPT – Integrated Process Team

KPP – Key Performance Parameter

LEAP – Law Enforcement Advanced Protection

MTDC – Missoula Technology and Development Center

MVTR – moisture vapor transport rate

NC State – North Carolina State University

NFPA – National Fire Protection Association

NSRDEC – U.S. Army Natick Soldier Research, Development and Engineering Center

ORD – Operational Requirements Document

osy – ounces per square yard

PCERF – Protective Clothing and Equipment Research Facility

PPE – Personal Protection Equipment

PSI - physiological strain index

Q value - Predicted Heat Loss

R&D – research and development

R-Tech – Responder Technologies

RME – Reasonable Maximum Exposure

RPP – Radiant Protection Performance

S&T – Science and Technology Directorate

SAVER – System Assessment and Validation for Emergency Responders

SME – subject matter expert

SWAT – special weapons and tactics

T-PACC – Textile Protection and Comfort Center

TCR – Technology Clearinghouse / R-Tech

THL – Total Heat Loss

TTPs – Tactics, Techniques, and Procedures

U.S. – United States

USFS – U.S. Forest Service

W/m² – Watts per square meter

WLFF PPE – Wildland Firefighter Personal Protection Equipment

Attachment 1 – WLFF PPE Operational Requirements

1. WLFF PPE System Level Operational Requirements – The WLFF PPE garment system shall:
 - 1) 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.
 - 2) Be launderable a minimum of 25 times without degradation to performance.
 - 3) Have a minimum shelf life shall be no less than 5 years.
 - 4) Allow for rapid donning in less than 5 minutes.
 - 5) Be compatible and interoperable with existing WLFF operational equipment (e.g., backpacks, gloves, footwear, helmet shrouds, etc.).
 - 6) Accommodate the 5th to 95th percentile male and female firefighter.
 - 7) Comprised of the following components:
 - a. 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.
 - b. WLFF PPE shirt – The single layer of torso protection worn over the WLFF PPE T-shirt.
 - c. 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.
 - d. WLFF Uniform Pants – The single layer of lower body protection worn over the PPE underwear.

2. WLFF PPE Component Level Operational Requirements – The following operational requirements are specific to individual components of the WLFF garment system.
 - 1) 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.
 - a. Type of undergarments – The undergarment subsystem shall consist of:
 - a) Short sleeve top
 - b) Short drawers
 - b. Performance Requirements – The undergarments shall meet the requirements for:
 - a) No-Melt/No-Drip*, per ASTM 6413 [Threshold KPP]
 - b) Drying time < 75 min, per NSRDEC Protocol [Threshold]
 - c) Moisture Wicking to 6.0 mm, per NSRDEC Protocol [Threshold]
 - a. Wales – 15 sec
 - b. Courses – 15 sec
 - d) MVTR > 2500 $g/m^2/24hr$, per ASTM E 96 test B [Threshold]

- e) Air Permeability > 300 ft³/min per ASTM D737 [Threshold]
 - f) Char length < 6" per ASTM 6413 [Objective]
 - g) After flame < 2 second per ASTM 6413 [Objective]
 - h) Anti microbial* per AATCC 100 [Objective]
- c. Structural Requirements – The undergarment materials shall meet the requirements for:
- a) Burst Strength* > 80 lbs., per ASTM D 3787
 - b) Seam Strength* > 70 lbs., per ASTM D 1683
 - c) Breaking Strength Thread* >2.0 lbs., ASTM D 204
- d. Appearance Requirements – The undergarment materials shall meet the requirements for:
- a) Dimensional Stability (5X)*, per ASTM AATCC 135
 - a. Wales – 3%
 - b. Courses – 3%
 - b) Colorfastness to light* > 3, per AATCC 16
 - c) Colorfastness to crocking* > 3, per AATCC 8 (wet and dry)
 - d) Colorfastness to perspiration* > 4, per AATCC 15
 - e) Colorfastness to laundering (3X)* > 3, per AATCC 61
 - f) Pilling >4, per ASTM D 3512
- * Note: Criteria taken from Army Performance T-shirt Specification*
- e. WLFF PPE Under Garment System Level Design Requirements – The undergarments shall be constructed:
- a) Using flat lock seams
 - b) In Navy Blue
- f. WLFF PPE Under Garment Component Level Design Requirements
- a) The T-shirt shall be designed as follows:
 - a. Standard fit
 - b. Crew collar
 - c. Shall accept flame-resistant silk screened department logo
 - b) Short drawers shall be boxers
- 2) 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].
- a. Material Performance Requirements – The WLFF PPE shirt material shall:
- a) Meet the performance requirements of NFPA 1977 [Threshold KPP]
 - b) Exhibit a minimum RPP ≥ 10 [Threshold KPP]
 - c) Exhibit a minimum THL ≥ 500 W/m² [Threshold KPP]
- b. Structural Requirements – The WLFF PPE shirt materials shall meet the structural requirements for NFPA 1977 [Threshold KPP].

- c. Appearance – The WLFF PPE shirt shall be made in the following colors:
 - a) Yellow
 - b) Orange
 - d. WLFF PPE Shirt Design Requirements – The WLFF PPE shirt shall:
 - a) Meet the design requirements of NFPA 1977 [Threshold KPP]
 - b) Be compatible with the WLFF PPE Overpants and Uniform pants.
 - c) 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.
- 3) 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].
- a. Material Performance Requirements – The WLFF PPE Uniform Pants material shall:
 - a) Meet the performance requirements of NFPA 1975 [Threshold KPP]
 - b) Meet the performance requirements of NFPA 1977 [Threshold KPP]
 - c) Exhibit a minimum RPP ≥ 10 [Threshold KPP]
 - d) Exhibit a minimum THL $\geq 500 \text{ W/m}^2$ [Threshold KPP]
 - b. Structural Requirements – The WLFF PPE Uniform Pants materials :
 - a) shall meet the structural requirements for NFPA 1977 [Threshold KPP]
 - b) shall meet the structural requirements for NFPA 1975 [Threshold KPP]
 - c. Appearance Requirements – The WLFF PPE Uniform Pants materials shall meet the following requirements for:
 - a) Color shall be Midnight Navy Blue (Color chip 35044, per FED STD 595)
 - b) Colorfastness to light > 4 , per AATCC 16
 - c) Colorfastness to crocking > 4 , per AATCC 8 (wet and dry)
 - d) Colorfastness to perspiration > 4 , per AATCC 15
 - e) Colorfastness to laundering (3X) > 4 , per AATCC 61
 - d. WLFF Uniform Pants Design Requirements – The WLFF PPE Uniform Pants shall:

- a) Meet the design requirements for NFPA 1975 [Threshold KPP]
 - b) Meet the design requirements for NFPA 1977 [Threshold KPP]
 - c) Be compatible with bunker/turnout gear
 - d) Be compatible with WLFF PPE Shirt and Overpants
 - e) 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
 - ii. The Tactical configuration will include:
 - 1. External thigh cargo pockets
 - 2. A means of closing and securing the pants cuff
- 4) WLFF PPE Overpants (double 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].
- a. Material Performance Requirements – The WLFF PPE Overpants material shall:
 - a) Meet the performance requirements of NFPA 1977 [Threshold]
 - b) Exhibit a minimum RPP ≥ 10 when worn over an NFPA 1975 certified uniform pant [Threshold]
 - c) Exhibit a minimum THL $\geq 500 \text{ W/m}^2$ when worn over an NFPA 1975 certified uniform pant [Threshold]
 - b. Structural Requirements – The WLFF PPE Overpants materials shall meet the structural requirements for NFPA 1977 [Threshold KPP].
 - c. Appearance – The WLFF PPE Overpants shall be made in the following colors:
 - a) Yellow
 - b) Orange
 - d. 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:
 - a. Include a means of closing and securing the pants cuff.
 - b. Be compatible with WLFF PPE Shirt and uniform pants.
 - c. Not have rear storage pockets.
 - d. Have a pass-thru to allow access to uniform pants pockets.
 - e. Have external, thigh-mounted cargo pockets.

Attachment 2 – Wear Trial Survey



Wildland Firefighter Advanced Personal Protection System Wear Trial Survey



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1. Publicly available portions of the Wildland Firefighter Advanced Personal Protection System Wear Trial Survey are provided as a public service by the US Army NSRDEC - National Protection Center.
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[CLICK HERE TO BEGIN THE SURVEY](#)



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Demographics

1. Enter the Serial Number on the Pants that were evaluated:

 (xxxx-xxxx)

2. Enter the Serial Number on the Response Shirt that was evaluated:

 (xxxx-xxxx)

3. What is your Gender?

- Male
- Female

4. Please identify your current organization:

- CAL FIRE
- Local/Municipal Fire Department
- U. S. Forest Service

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Pants SN: 1111-222
Shirt SN: 2222-111

Background

5. How many years have you served as a Wildland Firefighter?

years

6. Please describe your current baseline firefighting garment configurations:

a. PPE Pants:

- CAL FIRE Uniform Pants beneath Legacy CAL FIRE Over Pants
- CAL FIRE Uniform Pants beneath Interim CAL FIRE Over Pants

b. Response Shirt:

- CAL FIRE Legacy Response Shirt
- CAL FIRE Interim Response Shirt

c. Undergarments: (Select all that apply)

- Cotton T-Shirt
- Cotton Drawers
- FR Rated T-Shirt
- FR Rated Drawers
- Synthetic, Non-FR Rated T-Shirt
- Synthetic, Non-FR Rated Drawers
- Cotton Socks
- Wool Socks
- Synthetic Socks

7. During THIS REPORTING PERIOD please identify the type of work you did while wearing the test PPE system and the approximate number of days for each.

Fireline work:

days

Station work:

days

Project work:

days

Other:

days

Total Working Days:

8. Did you work in any of the following terrains during the evaluation period? (Select all that apply)

- Desert
- Mountain
- Coastal
- Forest/Woodland
- Urban/Suburban

9. Did you experience any of the following weather over the evaluation period? (Select all that apply)

- Extreme Cold <32 F

- Cold 32' F-50' F
- Temperate 50' F-75' F
- Hot 75' F-90' F
- Extreme Hot >90' F
- Rain
- Snow

10. Did you wear your PPE Response Shirt Tucked or Un-tucked

- Tucked
- Un-tucked

11. How many times did you wash your PPE garments over the reporting period?

times

12. Do you feel that the garments worn during evaluation period fit you correctly?

- Yes
- No

If the garments worn during evaluation did not fit correctly, which garments AND did you choose not to wear it due to poor fit?

- | | |
|---|--|
| <input type="checkbox"/> Boxer Shorts | <input type="checkbox"/> I did not wear this garment due to poor fit |
| <input type="checkbox"/> T-Shirt | <input type="checkbox"/> I did not wear this garment due to poor fit |
| <input type="checkbox"/> Socks | <input type="checkbox"/> I did not wear this garment due to poor fit |
| <input type="checkbox"/> PPE Pants | <input type="checkbox"/> I did not wear this garment due to poor fit |
| <input type="checkbox"/> Response Shirt | <input type="checkbox"/> I did not wear this garment due to poor fit |

13. Did any of the garments require repair?

- Yes
- No

Which garments required repair?

- PPE Pants
- Response Shirt
- T-Shirt

Explain:

Explain:

Explain:

14. Was the general design and configuration of the garments satisfactory for their application to Wildland Firefighting?

- Yes
- No

Which garments require redesign?

- PPE Pants
- Response Shirt

Explain:

Explain:



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Pants SN: 1111-222
Shirt SN: 2222-111

Materials

Questions 15-17 will relate to properties of the materials composing each evaluation garment. Please consider ONLY the material properties indicated when responding to these questions.

15. Please compare the relative COMFORT/PERFORMANCE of the test garment MATERIALS against your current baseline material for the following attributes:

	Test PPE is Much Worse	Test PPE is Moderately Worse	Test PPE is Slightly Worse	Test PPE is Neither Better Nor Worse	Test PPE is Slightly Better	Test PPE is Moderately Better	Test PPE is Much Better
Outer PPE Pants							
a. Breathability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
b. Wicking	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
c. Drying Time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
PPE Response Shirt							
a. Breathability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
b. Wicking	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
c. Drying Time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
T-Shirt							
a. Breathability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
b. Wicking	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
c. Drying Time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

16. Please compare the relative APPEARANCE of the test garment MATERIALS against your current baseline material for the following attributes:

	Test PPE is Much Worse	Test PPE is Moderately Worse	Test PPE is Slightly Worse	Test PPE is Neither Better Nor Worse	Test PPE is Slightly Better	Test PPE is Moderately Better	Test PPE is Much Better
Outer PPE Pants							
a. Fading	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
b. Pilling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
c. Shrinkage	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
d. Washability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
PPE Response Shirt							
a. Fading	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
b. Pilling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
c. Shrinkage	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
d. Washability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
T-Shirt							
a. Fading	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
b. Pilling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
c. Shrinkage	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
d. Washability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

17. Please compare the relative DURABILITY of the test garment MATERIALS against your current baseline material for the following attributes:

Test PPE is Test PPE is Test PPE is

Outer PPE Pants

- i** a. Tear Resistant
- i** b. Puncture Resistant

Test PPE is Much Worse	Moderately Worse	Test PPE is Slightly Worse	Neither Better Nor Worse	Test PPE is Slightly Better	Moderately Better	Test PPE is Much Better
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

PPE Response Shirt

- a. Tear Resistant
- b. Puncture Resistant

Test PPE is Much Worse	Test PPE is Moderately Worse	Test PPE is Slightly Worse	Test PPE is Neither Better Nor Worse	Test PPE is Slightly Better	Test PPE is Moderately Better	Test PPE is Much Better
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

T-Shirt

- a. Tear Resistant
- b. Puncture Resistant

Test PPE is Much Worse	Test PPE is Moderately Worse	Test PPE is Slightly Worse	Test PPE is Neither Better Nor Worse	Test PPE is Slightly Better	Test PPE is Moderately Better	Test PPE is Much Better
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

If you have any additional comments on the materials, please list them below. Please identify which garment each comment refers to as well.

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Pants SN: 1111-222
Shirt SN: 2222-111

Garment System Characteristics

Question #18 deals with the radiant heat protection of the garments. Please consider the protection level of each garment against a radiant heat source.

18. Please compare the relative GARMENT SYSTEM characteristics against your current baseline system for the following characteristics:

Please Rate the overall configuration the entire system of garments compared to your current system of garments.

a. Overall Garment System Configuration

Test PPE is Much Worse Test PPE is Moderately Worse Test PPE is Slightly Worse Test PPE is Neither Better Nor Worse Test PPE is Slightly Better Test PPE is Moderately Better Test PPE is Much Better

Please Rate the ability of the entire system of garments to mitigate heat stress by dissipating bodily heat compared to your current system of garments.

b. Overall System Heat Dissipation

Test PPE is Much Worse Test PPE is Moderately Worse Test PPE is Slightly Worse Test PPE is Neither Better Nor Worse Test PPE is Slightly Better Test PPE is Moderately Better Test PPE is Much Better

Please Rate the ability of the entire system of garments to protect against radiant heat compared to your current system of garments.

c. Overall System Radiant Heat Protection

Test PPE is Much Worse Test PPE is Moderately Worse Test PPE is Slightly Worse Test PPE is Neither Better Nor Worse Test PPE is Slightly Better Test PPE is Moderately Better Test PPE is Much Better

If you have any additional comments on the performance of the garment system, please list them below.

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Pants SN: 1111-222
Shirt SN: 2222-111

PPE Preference

Questions #19 deals with properties of the evaluation garment system. Please consider the overall garment system (Undergarments and Jacket and Pants) as a whole when responding to these questions

19. Please report your relative PREFERENCE for test GARMENTS AND GARMENT SYSTEM against your current baseline garment system:

	Baseline PPE is Much Preferred	Baseline PPE is Moderately Preferred	Baseline PPE is Slightly Preferred	Neither PPE is Preferred	Test PPE is Slightly Preferred	Test PPE is Moderately Preferred	Test PPE is Much Preferred
PPE Pants	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Response Shirt	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
T-Shirt	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Boxer Shorts (Tan Fabric)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Boxer Shorts (Navy Fabric)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Socks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Overall Garment System	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

If you have any additional comments on your preference for the garments or the entire system, please list them below.

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SUBMIT SURVEY