COMBINED THERMAL PROTECTIVE PERFORMANCE (TPP) OF SPECIMEN SAMPLES OF A FIREFIGHTER'S TURNOUT COAT, WORK UNIFORM SHIRT AND TEE SHIRT

EXECUTIVE LEADERSHIP

BY: Theodore Lee Jarboe
Deputy Chief
Department of Fire and Rescue Services
Montgomery County, Maryland

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Abstract

The **problem** that was identified for this applied research project was related to the thermal protective performance (TPP) test of a firefighter's turnout coat required by NFPA 1971. The test criteria do not include any reference to or evaluation of the thermal benefit of clothing (e.g., a work uniform shirt and tee a shirt) worn under the firfighter's turnout clothing. The **purpose** of this research was to measure the combined TPP of specimen samples of turnout coat, work uniform shirt and tee shirt fabrics worn by Montgomery County's firefighters. The **experimental research** method was used to obtain the TPP test data.

The **hypothesis** of this research was that the combined TPP of the turnout coat and underclothing would be appreciably higher that the TPP of the turnout coat itself. Related to this hypothesis were four **research questions**: What is the average TPP of the five turnout coat specimen samples as measured by the automated TPP test apparatus (Test group 1)? What is the average of the combined TPP of the three turnout coat and 65% polyester-35% cotton fabric specimen samples as measured by an automated TPP test apparatus (Test group 2)? What is the average of the combined TPP of the five turnout coat and 100% cotton tee shirt specimen samples as measured by the automated TPP test apparatus (Test group 3)? What is the average of the combined TPP of the five turnout coat, 100% cotton tee shirt and 65%polyester-35% cotton work uniform shirt specimen samples as measured by an automated TPP test apparatus (Test group 4)?

The **procedure** used to obtain the TPP test data involved the use of the automated

Thermal Protective Performance test apparatus at DuPont Laboratories, Wilmington, Delaware. Because this applied research project had not been done before other than by the author, no specific research data were available.

After a turnout coat, work uniform shirt and tee shirt specimen sample was weighed and the thickness recorded, it was placed on the specimen holder of the automated TPP test apparatus. Then, the sample was automatically positioned over the test burners and quartz tubes. At the point where the plotted test curve intercepted the baseline 2nd degree burn curve, the sample was automatically returned to its original position. This procedure was repeated for all the samples.

The **test results** indicated that the hypothesis was valid. The average TPP of test groups 1, 2, 3, and 4 were 52.0, 60.2, 68.4, and 81.2, respectively. These results clearly indicate the thermal protective benefit of clothing layers under the turnout coat. Based on these test results seven **recommendations** were identified: (1) conduct full-scale TPP tests using protective clothing and work uniform clothes; (2), (3), (4) (5) investigate the thermal protective benefit of firefighters wearing; a cotton tee shirt or other suitable material under their work uniform shirt; a light weight, cotton or fire resistant pants underneath their work uniform pants; a light-weight, fire resistant or cotton jump suit as night wear or added wear upon receipt of a fire alarm; a light-weight, fire resistant jump suit over top of the work uniform shirt (short-sleeve) and/or pants; (6) “reinforcing” the turnout coat and pants in thermally vulnerable areas; and (7) conduct research to develop better designed turnout clothing for quicker donning and doffing.

Table of Contents

Abstract ---------- ii

Table of Contents ---------- iv

Introduction ----------2

Scope of Research ---------- 3

Problem Statement ---------- 4

Purpose ---------- 4

Research Method ---------- 4

Hypothesis ---------- 4

Hypothesis-related Questions ---------- 4

Background and Significance ---------- 5

Literature Review ---------- 7

Procedures ---------- 8

Limitations ---------- 12

Selected Terms ---------- 13

Results ---------- 13

Discussion ---------- 14

Recommendations ---------- 17

References ---------- 21

Appendices ---------- 22

Introduction

The nature of fire fighting often requires firefighters to enter buildings that are on fire to rescue endangered or trapped occupants, protect property, or both. As a result, firefighters must wear protective clothing and use self-contained breathing apparatus (SCBA) to protect themselves against exposure to smoke, toxic gases, high radiant and convective heat conditions, and contact with flames.

The information contained in this applied research project should serve to improve the appreciation and understanding of fire chiefs, station officers, and firefighters to the limitations of turnout clothing when subjected to dangerous thermal conditions encountered immediately following flashover.

Turnout coat and pants worn by firefighters in Montgomery County exceed the thermal protective performance requirement of the National Fire Protection Association (NFPA) 1971 standard. The standard requires that the firefighter's turnout coat, pants, and gloves each have a minimum Thermal Protective Performance (TPP) value of 35 (Table 1). In contrast, Montgomery County's turnout coat and pants specifications provide a TPP rating of about 50. This value is about 30 percent higher than the minimum value required by the NFPA standard.

According to the NFPA 1971 standard, the protective hood is required to have a minimum TPP rating of 20. The protective hood and gloves were excluded from this applied research project.

Table 1.

Required Minimum TPP of Firefighter's Protective Clothing

Protective Clothing	Thermal Protective Performance (TPP)
turnout coat	35
turnout pants	35
gloves	35
hood	20

Source: NFPA 1971 (1997 Edition)

Scope of Research

The scope of this applied research project is limited to the testing of specimen samples of a firefighter's coat, work uniform and tee shirt fabrics only. It is also important to note that this applied research project did not address the thermal protective benefit of wearing work uniform pants and/or long underwear under the turnout pants. Further, the research excluded an examination of the thermal protective benefit of the overlap between the turnout coat and pants, turnout coat's throat strap and protective hood, and gloves and wristers.

Another notable point is that no reference or consideration was given to the impact of added thermal stress to the wearer of the turnout clothing resulting from layers of under clothing. Further, the affect of moisture from sweating and external water sources such as rain on the TPP of the test specimen samples, were not part of these tests. Also, heat

stress was not addressed as part of this applied research project.

Problem Statement

The firefighter's turnout coat and pants are each required by NFPA 1971 to have a minimum TPP of 35. The TPP contribution of clothing worn under the coat and pants are not addressed by the NFPA 1971 standard.

Purpose

The purpose of this research was to measure the combined thermal protective performance (TPP) of specimen samples of a firefighter's turnout coat, work uniform shirt and tee shirt and compare the results to the TPP values measured for the turnout coat only.

Research Method

The experimental research method was used. This research consisted of laboratory tests of specimen samples of a firefighter's turnout coat, work uniform shirt and tee shirt, using an automated TPP test apparatus. A detailed description of the methodology is noted under the Procedures heading of this applied research project.

Hypothesis

The hypothesis of this applied research project is that the combined thermal protective performance of a firefighter's turnout coat, work uniform shirt, and tee shirt fabrics, will provide more thermal protection than that provided by the turnout coat alone.

Research Questions

1. What is the average TPP of the five turnout coat specimen samples as measured by the TPP test apparatus?
2. What is the average of the combined TPP of the three turnout coat and 65% polyester-35% cotton blend work uniform shirt specimen samples as measured by the TPP test apparatus?
3. What is the average of the combined TPP of the five turnout coat and 100% cotton tee shirt specimen samples as measured by the TPP test apparatus?
4. What is the average of the combined TPP of the five turnout coat, 100% cotton tee shirt, and 65% polyester-35% cotton work uniform shirt specimen samples as measured by the TPP test apparatus?

Background and Significance

One of the deadly phenomena feared by firefighters is flashover. A popular definition of flashover used in the fire service is,"the point at which all combustible materials in a room ignite simultaneously." However, research scientists describe flashover in more descriptive ways. Some quantitative indicators, different, yet still essentially equivalent, include (Krasny, Rocket and Huang, May 1989, pp 8-9):

1. The point in a fire compartment when light fuels (such as crumpled newspaper), displayed in the open on the floor, ignite by radiation from the flames and smoke layer. The ignition of light fuels causes a further, rapid increase in the intensity of the fire and is usually followed closely by the involvement of all the remaining fuel.

2. The point in a fire development when flames first come out an open door or window. This is often synonymous with the ignition of light fuels but is not quite equivalent to the above. Flames out the door have been observed without flashover, if, for example, the object burning is close to the opening.

3. The point in the fire development when the average temperature of the gases in the upper part of the room reaches about 600°C (1100°F).

4. The point in a fire development when an upward-facing total heat flux sensor at floor level registers 20kW/m^2 [about 0.50 cal/cm^2-sec]. (Crumpled newsprint has been found to ignite at about this heat flux.)

No matter what definition is used, the dreaded consequences of a firefighter caught in a flashover or post-flashover are still the same - severe and often fatal burns.

Krasny and others reported that a turnout clothing assembly with a TPP rating of 35 exposed to an outside, constant heat flux of 2 cal/cm^2-sec (84 kW/m^2), must protect the wearer against a 2nd degree burn for a minimum of 17.5 seconds (Krasny, Rockett and Huang, May 1989). Peacock, Krasny, Rockett and Huang(May 1990, pp 202-203) noted that " in most room fires in which flashover occurs, the turnout coats would protect the wearer from injury only for a few seconds."

According to Krasny TPP is the product of the time-to-second degree burn and the applied heat flux of 2 cal/cm^2-sec.

TPP = 2 cal/cm^2-sec x time-to-burn (sec)

Both the minimum thermal protective performance required by the NFPA 1971 standard and the protective clothing specifications used by Montgomery County, do not reflect the thermal protective contribution of a work uniform worn with a cotton tee shirt by firefighters. Typically, firefighters employed by the Department of Fire and Rescue Services wear issued work uniforms during their awake hours. A cotton tee shirt is usually

worn under the work uniform. During sleep hours, however, firefighters wear as a minimum a tee shirt and a pair of physical fitness training shorts.

The work uniform consists of a woven 65% polyester-35% cotton blend fabric and the knit tee shirt is made of 100% cotton. Using this blend of shirt material provides many distinct benefits including comfort, appearance, ease of care, and low cost.

Executive Leadership Course

The Executive Leadership course of the Executive Fire Officer Program offered at the National Fire Academy provided guidance in the development of this applied research paper. Points covered in Units 8 and 11, Developing Decision-making Skills and Managing Change, respectively, emphasized the importance of recognizing the need for change and having the leadership to affect it.

Literature Review

Through an exhaustive review of literature available at the National Fire Academy's (NFA) Learning Resource Center and National Institute of Standards and Technology's (NIST) research library, the author did not find any evidence that the experimental research conducted as part of this applied research project had ever been done before.

References were found which related to thermal protective performance of firefighter's turnout clothing. However, not one of these tests examined the added thermal protective benefit of underclothing such as a work uniform shirt and tee shirt.

Procedures

Overview

All specimen samples were at ambient room temperature just before exposure to the constant heat flux of 2 cal/cm^2-sec, i.e., specimens were not exposed to preheating or thermal loading before exposure to the TPP test heat flux criterion.

Under the TPP test criteria, a specimen sample is exposed to a constant heat flux of 2 cal/cm^2-sec until the heat transfer through the specimen is sufficient to cause the temperature rise on a copper sensor to equate to a 2nd degree burn of exposed skin (Tom Neal, personal conversation, June 1997).

Specimen Samples

The Kevlar®/PBI three-layer protective clothing specimen samples were supplied by Globe Manufacturing Company. The fabric specimen samples were cut to 6-3/4 inch by 6-3/4 inch dimensions. All three-layer protective clothing specimen samples were new and were tested without washing or rinsing.

The polyester-cotton work uniform fabric was supplied by Elbeco Shirt Company. The 100% cotton tee shirts were purchased from Oneita Industries. The polyester-cotton work uniform shirt and cotton tee shirt fabrics were machine-washed separately, each with two rinse cycles and machine-dried. The fabric samples were cut into 6-3/4 inch by 6 3/4 inch specimens. After the TPP test exposure, each specimen sample was placed in a polyethylene bag and identified.

Thermal Protective Performance (TPP) Test Apparatus

Two Meker burners and nine quartz tubes were calibrated to supply a constant heat flux of 2 cal/cm^2- sec (Behnke, February 1977). The combined heat flux is adjusted so that 50% of the heat flux is convective heat and 50% is radiant heat. Approximately 75% of the total heat flux is from the combined radiant and convective heat of the two Meker burners, and the remaining 25% of the heat flux is supplied as additional radiant heat from the quartz tubes.

The weighted sensor block was heated to approximately 90° F. (32° C). This represented the temperature of the skin surface (Tom Neal, personal conversation, June 1997). The sensor block was then placed on top of the specimen and held in place by another weighted block. The sensor used was a copper calorimeter. Four thermocouples are embedded from the back side of the copper calorimeter disc. The copper calorimeter disc, measuring 1.5 mm thick by 4 cm in diameter, is coated with a thin layer of flat black spray paint to provide surface of controlled emissivity. The temperature rise of this sensor can be correlated to the heat transfer response of human skin and the point at which a 2nd degree burn would be predicted in terms of heat flux and exposure time.

Specimen Samples Testing Procedure

Specimen samples were grouped into multi-layer categories. Each consisted of three to five layers of fabric (Table 1). These specimen sample dimensions of 6-3/4 inches by 6-3/4 inches provided the necessary overlap when positioned on the horizontal TPP specimen holder. After weighing the multi-layer specimen and determining its thickness, it was positioned on the horizontal specimen holder of the TPP apparatus.

Test Methodology

When a signal is sent from the computer to the TPP test apparatus, the specimen holder is immediately positioned over the two Meker burners and the nine quartz tubes. The total heat transfer through the specimen is measured by the copper calorimeter. When the heat flux causes the temperature rise of the sensor to reach the 2nd degree burn threshold, the specimen holder automatically is returned to its original position. The 2nd degree burn threshold is defined by the Stoll Curve (Tom Neal, Personal conversation, June 1997).

The Stoll Curve was developed by experimental work on the response on human and animal tissue to heat exposure sufficient to cause 2nd degree burn injury (Tom Neal, personal conversation, June 1997). The TPP data are plotted with heat transmitted through the multi-layer fabric specimen on the vertical axis versus heat exposure on the outer surface of the multi-layer fabric specimen.

After removing the weighted sensor block, the sensor is removed and wiped to remove any residue of the burned specimen and then cooled back to 90° F (32° C). Another specimen is prepared and the testing process is repeated. Five specimens of each multi-layer scenario were tested in a planned sequence (Table 2).

Table 2

Fabric Test Scenarios

Group Number average weight (oz/yd^2)	**Composition of Layers**
1 (20.6)	Outer shell fabric - “Kombat 750" 7.5 oz/yd^2 60% Kevlar®/40% PBI blend in a rip-stop weave, and treated with a water repellent finish; moisture barrier - E-89 spunlaced Nomex®/Kevlar™ Aramid non-woven fabric laminated with a microporous breathable Teflon® film (Cross-Tech®); thermal liner - one layer of natural aramid batt quilt stitched to a Nomex® pajama check fabric
2 (23.8)	Group 1 plus 100% combed cotton tee shirt knit fabric
3(27.0)	Group 1 plus work uniform shirt
4 (31.3)	Group 1 plus work uniform shirt “open weave” 65% Fortel polyester/35% combed-cotton fabric with Teflon® fabric protector for additional comfort; plus 100% combed cotton tee shirt knit fabric

Limitations

Readers are cautioned not to draw conclusions just based on these test results. Although these tests were conducted using an automated Thermal Protective Performance test apparatus, the correlation of these laboratory tests to actual room fire scenarios will vary according to the burning fuel's heat release rate, compartment ventilation rates, room dimensions, thermal properties of interior walls and ceiling, and other parameters. Additionally, according to Lawson (1996 August), heat flux in a room fire can be as high as 17 kW/cm^2 (4 cal/cm^2-sec.) This end point is twice the heat flux measured with the automated TPP test apparatus used in this applied research project. It is also the heat flux required by NFPA 1971 to measure the minimum TPP of a firefighter's protective clothing.

Only three specimen samples were available to measure the combined specimen samples of turnout coat and 65% polyester-35% cotton work uniform fabrics. Therefore, the statistical reliability would be less than if five samples were used. Still, the results do provide some indication of thermal protective benefit.

Selected Terms

This list is provided to help readers to better understand uncommon terms and expressions noted in the body of this applied research project. For more extensive review readers are encouraged to read one or more of the cited references, or other related documents.

Escape time: The difference between the TPP time and pain time, expressed in seconds.

Heat flux: The thermal energy applied to a material per unit area per unit time, e.g., 2 cal/cm^2-sec.

Heat Stress: For purposes of this applied research project, it is the increase in a firefighter's body core temperature due to the body's inability to cool through evaporation of sweat.

Mil: A unit of length equal to one-thousand of an inch.

Pain time: The time for the applied heat flux to transfer through the turnout coat, with or without under clothing, to cause pain on the skin surface, expressed in seconds.

Thermal Protective Performance (TPP): The thermal protection provided by a firefighter's protective clothing (and underclothing) when exposed to a heat flux usually of 2 cal/cm^2-sec.

Results

1. What is the average TPP of the five turnout coat specimen samples as measured by the TPP test apparatus?

The Kevlar®/PBI turnout system had an average TPP value of 52.0.

2. What is the average of the combined TPP of the <u>three</u> turnout coat and 65% polyester-35% cotton blend work uniform shirt specimen samples as measured by the TPP test apparatus?

The combined Kevlar®/PBI turnout system with 65 polyester-35% cotton shirt fabric had an average TPP value of 60.2. This average value is 16.5% higher than the average TPP of the Kevlar®/PBI turnout system alone.

3. What is the average of the combined TPP of the five turnout coat and 100% cotton tee shirt specimen samples as measured by the TPP test apparatus?

The combined Kevlar®/PBI turnout system and 100% cotton tee shirt specimen samples had an average TPP value of 68.4. This average value is 31.5% more than the average TPP of the Kevlar®/PBI turnout system alone.

4. What is the average of the combined TPP of the five turnout coat, 100% cotton tee shirt, and 65% polyester-35% cotton work uniform shirt specimen samples as measured by the TPP test apparatus?

The combined Kevlar®/PBI turnout system with polyester-cotton shirt fabric, and the 100% cotton tee shirt fabric specimens had an average TPP value of 81.2. This average value is 56.2% higher than the average TPP of the Kevlar®/PBI turnout system alone.

Discussion

The test results showed that the wearing of clothing underneath the Kevlar®/PBI system can result in significantly higher average TPP values as compared with the average TPP value of only the Kevlar®/PBI turnout system. These values ranged from 68.4 to 81.2 as compared with the average TPP value of 52.0 for the Kevlar®/PBI system only (Table 3).

From a practical perspective, a firefighter wearing a polyester-cotton short-sleeve shirt and 100% cotton tee shirt under the Kevlar®/PBI turnout system, would not have

consistent thermal protection in the area of the forearms relative to the area of the upper arms, chest and back. Based on this test data, the firefighter would have more thermal protection in those areas covered by the polyester-cotton shirt and tee shirt than the unprotected area of the forearms. This simply indicates that the firefighter's time to pain and time to 2nd degree burn would be significantly shorter for the less protected areas as compared with the more protected areas.

This clothing arrangement could result in a very uneven skin exposure to the unsuspecting firefighter. Entering a fire compartment and later being subjected to total flame engulfment with an estimated protective clothing incident heat flux of 2 cal/cm^2-sec, the firefighter could experience both pain and 2nd degree burns to either or both arms within a matter of seconds. Although the exposed forearms represent a small percentage of the total body surface area, the resulting pain and burns are sufficient to cause the firefighter to abandon his mission and escape the dangerous environment. (Appendices A, B, C, and D, contain data about the pain time, TPP time, and "escape time" for the four groups of specimen samples.)

According to Lawson (June 1997), once a firefighter's turnout clothing has been heated and the skin temperature has risen to dangerous levels, it is unlikely that a firefighter can immediately remove the turnout clothing to start the cooling processes and prevent additional thermal injuries. This means that a firefighter escaping from a flashover encounter must do more than simply retreat to safety, but also must quickly remove the turnout clothing.

Table 3

Comparison of Average TPP Values - Kevlar®/PBI Turnout System

Clothing Assembly Fabrics	System Weigh oz/yd^2	TPP Average	% increase TPP
Kevlar®/ PBI turnout system	**20.6**	52.0	--
Kevlar®/PBI turnout system w/polyester-cotton shirt	**23.8**	60.6	16.5
Kevlar®/PBI turnout system w/ cotton tee shirt	**27.0**	68.4	31.5
Kevlar®/PBI turnout system w/polyester-cotton and cotton tee shirts	**31.3**	81.2	56.2

It is clear to the author that by adding clothing under the firefighter's turnout clothing would not only increase the overall TPP rating, but also would likely increase the heat stress. However, the author believes that heat stress can be effectively managed through good on-scene crew rotation and rehabilitation (rehab) procedures

Recommendations

The results of this applied research project should help fire chiefs, training officers, firefighters, and others to enhance their understanding of the thermal protective benefits and limitations of a firefighter's protective clothing system. As noted earlier, these test results were obtained using an automated Thermal Protective Performance (TPP) test apparatus. It is readily acknowledged that wearing or adding clothing underneath a firefighter's turnout coat will likely increase sweating and thereby increase heat stress. Fire chiefs must weigh the benefit of reduced heat stress and lower TPP against higher heat stress potential and higher TPP.

1. Research facilities which have instrumented manikins should conduct tests using the complete firefighter's protective ensemble (turnout coat and pants, hood, gloves, helmet, and self-contained breathing apparatus, with empty air cylinder) to measure the thermal protective benefit of the clothing when subjected to a constant incident heat flux of 2 cal/cm^2-sec.

The complete protective ensemble is representative of what firefighters wear. The "manikin tests" should show what impact the compression points (SCBA bracket and turnout coat) have on heat transfer and predicted severity of burn injuries. Additionally, these tests would provide comparative thermal-protective data among the different clothing layers covering the manikin. Comparing the data obtained from these tests with the data obtained from the applied research project should indicate any correlation.

2. A research facility such as the National Institute of Standards and Technology (NIST) should conduct full-scale fire tests using a test manikin articulated in a crawl position.

A manikin equipped with thermistors (thermocouples) and “dressed” in full firefighter protective clothing and SCBA with an empty cylinder, should be exposed to a constant heat flux of 2 cal/cm^2-sec. The data should be compared with test data obtained from previous data obtained from small-scale tests conducted by NIST or other recognized research facility.

3. Fire service leaders should investigate the thermal protective benefit of firefighters wearing a cotton tee shirt (or other suitable material) underneath their work uniform shirt.

Based on the results of this applied research project, the tee shirt improves the combined thermal protective performance of the turnout coat and work uniform shirt. This measure would increase the overall TPP.

4. Fire service leaders should investigate the thermal protective benefit of firefighters wearing light weight, cotton or fire resistance pants under their work uniform pants.

Based on the results of this applied research project, it seems reasonable that the added clothing under the pants would increase the overall TPP rating. This translates to more escape time should the firefighter be caught in a flashover.

5. Fire service leaders should investigate the thermal protective benefit of firefighters wearing light-weight, fire-resistant jump suit as night wear or added wear upon receipt of a fire alarm.

After retiring for the night and depending on room and/or outside temperature, firefighters might be wearing only a tee shirt and physical fitness training shorts. From a thermal exposure perspective, these firefighters would have thermal protection mainly from the turnout coat and pants. The jump suit would add to the overall thermal protection of the firefighters.

6. Fire service leaders should investigate the thermal protective benefit of firefighters wearing a light-weight, fire-resistant jump suit over their work uniform (with short-sleeve shirt), upon receipt of a fire alarm.

The jump suit would provide more thermal protection to that portion of the arms not covered by the shirt. Also, the jump suit would obviously improve the thermal protection over the firefighters' body from the neck down.

7. Manufacturers' of firefighter turnout clothing should investigate ways to improve the thermal protective performance of the protective clothing in the areas of the lower arms, knees, legs, and areas where the weight of the SCBA compresses the coat material.

Added protection in these areas should improve the thermal protection for fighters.

8. Manufacturers of firefighter turnout clothing should conduct research to develop better designed turnout clothing to allow quicker donning and doffing.

This was one of the recommendations made as a result of a Firefighter Thermal Exposure Workshop held at NIST, June 25-26, 1996. Providing a quicker way to remove their turnout clothing following exposure to a flashover and reaching safety, firefighters could reduce or prevent serious thermal injuries (Lawson and Jason, June 1996).

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Appendix A

Kevlar®/PBI Turnout Coat specimen Samples Test Raw Data

Fabric wt (oz/yd^2)	**Thickness (mil)**	**TPP time (s)**	**Pain time (s)**	**Escape time (s)**	**TPP (cal/cm^2)**
20.3	150	25.9	18.1	7.86	51.4
20.9	155	26.0	17.9	8.1	51.8
21.4	152	27.7	18.6	9.1	55.0
20.9	150	26.5	18.0	8.5	52.7
19.6	145	24.7	16.9	7.8	49.1
Average					
20.6	**150.4**	**26.2**	**17.9**	**8.3**	**52.0**

Appendix B

Kevlar®/PBI Turnout Coat and Polyester-Cotton Work Uniform Shirt Specimen Samples Raw Data

Fabric wt (oz/yd^2)	**Thickness (mil)**	**TPP time (s)**	**Pain time (s)**	**Escape time (s)**	**TPP (cal/cm^2)**
23.1	145	28.6	19.1	9.5	56.9
24.2	145	32.0	21.2	10.8	63.6
24.0	160	30.8	20.7	10.1	61.3
Average					
23.8	**150.0**	**30.5**	**20.3**	**10.1**	**60.6**

Appendix C

Kevlar®/PBI Turnout Coat and 100% Cotton Tee Shirt Specimen Samples Raw Data

Fabric wt (oz/yd^2)	**Thickness (mil)**	**TPP time (s)**	**Pain time (s)**	**Escape time (s)**	**TPP (cal/cm^2)**
27.3	183	35.8	23.6	12.2	71.2
26.1	190	34.3	22.5	11.8	68.3
27.2	180	34.5	22.6	11.9	68.7
27.7	180	34.5	22.7	11.8	68.6
26.6	185.4	32.8	21.9	10.9	65.3
Average					
27.0	**183.6**	**34.4**	**22.7**	**10.9**	**65.3**

Appendix D

Kevlar®/PBI Turnout Coat, 65% Polyester-35% Cotton Work Uniform Shirt and 100% Cotton Tee Shirt Specimen Samples Raw Data

Fabric wt (oz/yd^2)	**Thickness (mil)**	**TPP time (s)**	**Pain time (s)**	**Escape time (s)**	**TPP (cal/cm^2)**
31.6	195	41.9	27.5	14.4	83.4
31.1	197	40.0	26.1	13.9	79.6
30.4	190	39.9	26.3	13.6	79.3
31.6	204	40.9	26.8	14.1	81.3
31.7	208	41.6	27.5	14.1	82.9
Average					
31.3	**198.8**	**40.9**	**26.8**	**14.0**	**81.3**