Firefighter Turnout Coat Configurations: Performance Data for Acquisition Decisions

Hayden Brown
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Abstract

This report describes the essential components of turnout coats, specifies the relevant performance tests, and documents the collected performance data that can support cost-effective acquisition and utilization decisions. A turnout coat is a system of separate components. Each component has many commercially available alternatives. Critical measures of performance are described. For each performance measure, the test method, reference, and significance are all explained. These measures fall into four categories:

1. Heat Resistance: Includes measures of resistance to heat and flame such as thermal protective performance (TPP), thermal efficiency (derived), and vertical flame char length.

2. Tactile Performance: Includes measures of weight, thickness, and bending stiffness.

3. Durability: Includes measures of outer shell durability, lightfastness, abrasion (two types), trap tear, and grab strength.

4. Comfort: Includes measures of breathability, face cloth friction, and face cloth wicking.

These performance characteristics are key to making selection decisions. Data on the performance characteristics have been compiled along with in this report. There are three distinct data sets in this report: a comprehensive universe of all suit components gathered without corresponding performance measures; and two data sets including performance data provided by Dupont and Southern Mills.

The decision support tool will help fire departments apply these data to their turnout coat selection procedures. The conceptual framework is the Analytic Hierarchy Process, a multiattribute model developed in the operations research field. The tool will implement the Analytic Hierarchy Process to help fire departments select the best turnout coats for their applications, given the relative importance they place on each of the performance characteristics presented here, and taking into account the acquisition cost. The software will be available directly on the Internet in a convenient, readily accessible form.

Key Words: firefighter, cost effective, multiattribute decision analysis, performance data, selection criteria, turnout coat
Preface

This study was conducted by the Office of Applied Economics in the Building and Fire Research Laboratory at the National Institute of Standards and Technology. This report describes the essential components of firefighter turnout coats, specifies the relevant performance tests, and documents the collected performance data that support the use of the Analytic Hierarchy Process (AHP) so that cost-effective acquisition and utilization decisions can be made. The intended audience is the National Institute of Standards and Technology as well as other government and private sector organizations that are concerned with evaluating and selecting turnout coats.

Disclaimer: Certain trade names or company products are mentioned in the text to specify adequately the experimental procedure and equipment used. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the equipment is the best available for the purpose.

Disclaimer Regarding Non-metric Units: The policy of the National Institute of Standards and Technology is to use metric units in all its published materials. Since this report is intended for U.S. users of firefighter turnout coats who evaluate performance using customary units, it is more practical and less confusing to use the customary rather than metric units to indicate turnout coat performance.
Acknowledgements

Thanks are due to Dave Evans, Randy Lawson, and Kuldeep Prasad of the Building and Fire Research Laboratory for starting this project and for their many helpful comments and suggestions on the turnout coat performance measures and data. Thanks are also given to Harold Marshall, Robert Chapman, Laura Schultz and Stephen Weber for their comments and suggestions, and to Grace Lin and Christine Izzo for data input and organization.
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1. Introduction

1.1 Background

Firefighters use a variety of equipment for protection from injury and death. Examples include self-contained breathing gear, thermal imaging equipment, and protective clothing. Information about the multiple performance characteristics of such equipment is sparse and not organized for informing cost-effective decisions on acquisition and utilization. The long-range goal of this research is to develop and implement a decision support tool for the evaluation of several types of firefighters’ equipment. The current effort focuses on protective clothing. This report is specifically focused on firefighter turnout coats.

The decision support tool will help fire departments apply these data to their turnout coat selection procedures. The tool will implement the Analytic Hierarchy Process (AHP), a multiattribute model, to help fire departments select the best turnout coats for their applications, given the relative importance they place on each of the performance characteristics presented here, and taking into account the acquisition cost. The software will be available directly on the Internet in a convenient, readily accessible form.

The AHP is one of a set of multiattribute decision analysis methods that considers nonmonetary attributes (qualitative and quantitative) in addition to common economic evaluation measures (such as life-cycle costing or net benefits) when evaluating project alternatives. The AHP has several significant strengths: it is well known and well-reviewed in the literature; it includes an efficient attribute weighting process of pairwise comparisons; it incorporates hierarchical descriptions of attributes, which keep the number of pairwise comparisons manageable; and it has been accepted by ASTM as a standard practice.¹

1.2 Purpose and Scope of Approach

This report is the supporting documentation for the decision support tool. This report defines turnout coats that will be included in the decision support tool, describes the relevant performance tests, and documents the collected performance data that can support cost-effective acquisition and utilization decisions. Users of the decision support tool will need this report to develop individualized rankings of the importance of each performance characteristic.

Section 2 describes the performance tests and measures. Suit component and assembled suit selection decisions are based on performance. Section 3 explains the scope of the three data sets that were compiled. Section 3 also contains the collected data for the Dupont data set, the source data that will be used in the decision support tool. Section 4 concludes with a summary of the data, discussion of the decision support tool, and directions for future research. There are three appendices. Appendix A lists the ASTM test standards that were consulted in this report. Appendix

B lists most of the alternatives available for each suit component, based on an independent review of the market. Appendix C provides performance data from Southern Mills.
2. Performance Criteria

2.1 Available Performance Measures and Sources

A comprehensive investigation was completed to identify appropriate testing standards for available published test results. The testing standards referenced in this report are from the National Fire Protection Association (NFPA), ASTM International, and the American Association of Textile Chemists and Colorists (AATCC).

<table>
<thead>
<tr>
<th>Organization</th>
<th>web site</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Fire Protection Association (NFPA)</td>
<td><a href="http://www.nfpa.org">www.nfpa.org</a></td>
</tr>
<tr>
<td>ASTM International</td>
<td><a href="http://www.astm.org">www.astm.org</a></td>
</tr>
<tr>
<td>American Association of Textile Chemists and Colorists (AATCC)</td>
<td><a href="http://www.aatcc.org">www.aatcc.org</a></td>
</tr>
</tbody>
</table>

Appendix A cites the performance tests used in this report. The major NFPA tests are outlined in NFPA 1971 and NFPA 1976. In addition, NFPA 1851 is useful for its assistance in developing selection criteria, based on the risks that emergency responders face.

The NFPA standards for turnout coats specify tests that the coats must pass in order to be labeled “compliant.” Manufacturers report NFPA compliance according to these tests. The tests include Thermal Protective Performance (TPP), flame resistance, tear resistance, liquid penetration resistance, shrinkage resistance, and water absorption resistance. Manufacturers have the Underwriters Laboratories (UL) and other independent laboratories perform the tests.

In this report, the test data fall into one of four natural groupings, explained in the next chapter. Additionally, the decision support software will permit the user to enter specific cost quotes obtained from suppliers.

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2 The National Institute of Standards and Technology (NIST) Building and Fire Research Laboratory (BFRL) fire researchers are developing new test methods to collect more data on the thermal performance of turnout coats in non-optimal conditions. A test apparatus was developed to measure heat transfer on a fabric sample that is compressed and submerged in water—a situation that might occur at a firefighter’s knees or elbows. Also, heat transfer tests have been performed on turnout gear after exposure to wear (cleaning, prior exposure to heat). The Protective Clothing Performance Simulator (PCPS), developed by R. Lawson and K. Prasad, adds a skin model to the heat transfer model, and estimates the time to first degree burn and second degree burn. Kukuck and Prasad (2003), Simulating a TPP Test for Single-Layered Fabrics (NISTIR 6993), is an extension of earlier work by Mell and Lawson (1999) on developing a heat transfer model. In the future, the decision support tool for Fire Protective Clothing could use performance data calculated according to NIST-specified performance measures, when they are finalized and become widely available.
2.2 Introduction to Performance Tests

The performance measures listed below tend to fall into four groupings.3

1. Heat Resistance: Includes measures of resistance to heat and flame such as thermal protective performance (TPP), thermal efficiency (derived), and vertical flame char length.

2. Tactile Performance: Includes measures of weight, thickness, and bending stiffness.

3. Durability: Includes measures of outer shell durability, lightfastness, abrasion (two types), trap tear, and grab strength.

4. Comfort: Includes measures of breathability, face cloth friction, and face cloth wicking.

2.3 Performance Test and Measure Descriptions

Presented below is the following information for each performance test: (1) the test name, (2) what the test shows regarding performance, (3) a reference to the test standard (such as ASTM or NFPA), (4) a short description of the test, (5) the test outcome measure, (6) whether better performance is indicated by increasing or decreasing performance numbers, and (7) whether the test measure units are proportional to the impact on performance.

The mathematical framework used in the decision support tool requires that the performance measures be denominated in units that are proportional to the performance impact. Proportional units are those that are directly proportional—a measure that is twice as high indicates performance that is twice as good—and inversely proportional—a measure that is twice as high indicates performance that is half as good.

Thermal Protective Performance (TPP)

The thermal protective performance (TPP) test measures the thermal insulation of a suit. Thermal efficiency—TPP divided by the turnout coat weight—can be derived. The TPP indicates how long a firefighter can wear the suit under specific conditions before being burned. The test is referenced in NFPA 1971, Chapter 6-10, p. 43-47. The NFPA minimum requirement of a TPP rating of 35 equates to 17.5 s until second degree burn in a flashover situation. A test apparatus is described for exposing a turnout coat sample to a heat source. A calorimeter measures the heat during the exposure process. The heat exposure is described using a plot of energy versus the time to cause a second-degree burn in human tissue. The TPP rating is calculated as the product of exposure energy heat flux—calories per square centimeter per second, or cal/(cm²·s)—and the time to burn in seconds (s). The resulting measure is cal/cm², calories per square centimeter. A suit with a higher TPP number gives the wearer more protection than a suit with a lower number. The measure is proportional, so that a suit with a TPP twice as high as another suit offers twice as much protection.

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3 The hierarchy used in the decision support tool can accommodate, at most, seven characteristics. This first version of the decision support software will allow the user to select seven performance characteristics. Future versions of the decision support tool software will use the groupings developed in this section to allow consideration of all performance characteristics.
Vertical Flame Char Length

Vertical flame char length measures the deterioration of a suit when exposed to flame. This shows the stability of the suit. The test method is given in "Standard Test Method for Flame Resistance of Textiles (Vertical Test)," ASTM Test Method D 6413-99. A specimen is positioned vertically above a controlled flame and exposed for 10 min. The fabric is folded, a weight is attached, and the fabric is lifted. Char length is the linear measure, in inches, of the tear produced. There is a linear measure of the tear along the warp (the continuous length) of the fabric, and a linear measure of the tear along the fill (the cross length) of the fabric. A higher length indicates a longer tear. The measure is inversely proportional, meaning that a suit fabric that has a tear that is twice as long as another suit fabric is only half as stable.

System Mass (Weight)

System Mass (Weight) indicates how heavy the suit is. In order to simplify the terminology, “weight” should be read as “mass (weight)” throughout this report. The test method "Standard Test Method for Mass Per Unit Area (Weight) of Fabric," is provided in ASTM Test Method D 3776-96. This test measures the fabric mass per unit area (weight). A larger number—ounces per square yard, or opsy—indicates a heavier weight. The measure is inversely proportional.

System Thickness

System thickness indicates how bulky the suit is. The test method "Standard Test Method for Thickness of Textile Materials," is provided in ASTM Test Method D 1777-96 (Reapproved 2002). A specimen is placed on the base of a thickness gauge and a weighted presser foot is lowered. The displacement between the base and the presser foot is measured as the thickness of the specimen, given in mils \( \left( \frac{1}{1000} \text{ inch} \right) \). Higher numbers indicate greater thickness. The measure is inversely proportional.

Thermal Liner Bending Stiffness

Thermal liner bending stiffness indicates the effort of the firefighter to both put on and to move around in a suit. The test method "Standard Test Method for Stiffness of Fabrics," is provided in ASTM Test Method D 1388-96 (Reapproved 2002). The test result is the required force per inch (in grams force per inch, gf/in) to bend a sample of fabric 90°. A higher number indicates a higher force required to bend the fabric. The measure is inversely proportional, meaning that a fabric that requires twice as much force to bend compared to another fabric, is half as flexible.

Lightfastness (Colorfastness) Rating

This test measures the color change of the outer shell of the suit. Color change in some suits is an indicator of age and reduced protective performance. The test is referenced in AATCC Test Method 16-1998, "Colorfastness to Light.” The test is a color shift rating after 20 h based on a grey scale color difference. Samples of the textile material to be tested are exposed to a light source under specified conditions. The colorfastness to light of the specimen is evaluated by comparison of the

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4 The decision support tool could either use the longest tear length, or it could multiply the warp and fill to get the area of the tear.
grey-scale change of the exposed portion to the masked control portion of the test specimen. The maximum lightfastness rating of 5 indicates that there was no color shift. The lowest lightfastness rating of 1 indicates that there were more than 13 AATCC Fading Units (AFU) between the exposed and unexposed fabric. The measure is proportional, meaning that a fabric with a lightfastness rating twice that of another fabric is twice as stable.

**Tabor Abrasion (CS10 and H18)**

Tabor abrasion measures the durability of a fabric when subjected to wear. The test method "Standard Guide for Abrasion Resistance of Textile Fabrics (Rotary Platform, Double-Head Method)" is provided in ASTM Test Method D 3884-01. A specimen is abraded using rotary rubbing action from an abrading wheel. The CS10 wheel is mildly abrasive. The H18 wheel has a medium-coarse texture. The tabor abrasion number is the number of revolutions of the specified wheel until a hole has formed in the fabric. A hole is defined as breaking both the warp and fill fibers. A higher number—more wheel revolutions—indicates a higher fabric durability. The measure is proportional, so that a fabric that requires twice as many wheel revolutions to form a hole, compared to another fabric, is twice as durable.

**Trapezoidal Tear**


The test is described as follows: An outline of an isosceles trapezoid is marked on a rectangular specimen cut for the determination of tearing strength, and the nonparallel sides of the trapezoid marked on the specimen are clamped in parallel jaws of a tensile testing machine. The separation of the jaws is continuously increased so the tear propagates across the specimen. At the same time, the force (pound-force, or lbf) developed is recorded and averaged for the test. A higher number indicates a greater number of pounds of force necessary to tear the fabric. The measure is proportional, so that a fabric that requires twice as much force to tear compared to another fabric, is twice as strong and durable.

**Grab Strength**

Grab strength is a measure of fabric strength. Grab strength is referenced in NFPA 1971, Chapter 6-50 (called the Breaking Strength Test using ASTM D5034). The test method is given in "Standard Test Method for Breaking Strength and Elongation of Textile Fabrics (Grab Test)," ASTM Test Method D 5034-95 (Reapproved 2001). In this test, a continually increasing load (pound-force, or lbf) is applied longitudinally to the specimen until the fabric ruptures. This test is performed separately along the warp direction and fill direction of the fabric. A higher grab strength indicates a greater number of pounds of force necessary to rupture the fabric. The measure is proportional, so that a fabric that requires twice as much force to rupture compared to another fabric, is twice as strong.

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5 The pound-force (lbf) is a unit of force or weight equal to a mass of one pound multiplied by the standard acceleration of gravity, approximately 32.17405 ft/s²).
6 For the trapezoidal tear test and the grab strength test, the decision support tool will use the lower number.
Breathability

Breathability indicates the flow of heat and moisture from the skin to the environment, by measuring the amount of energy required to maintain a constant suit temperature. The test is referenced in NFPA 1971, Chapter 6-34, p. 62-63. The specific test method "Standard Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate," is provided in ASTM Test Method F 1868-02. Breathability is the Total Heat Loss (Q_t), which is defined as watts per square meter (W/m²). A higher THL indicates that the suit is more breathable—it allows more flow of heat and moisture to the environment. The measure is proportional, so that a suit with a THL twice that of another suit is twice as breathable.

Face Cloth Friction

Face cloth friction indicates the ease of donning and removing fire suits over station wear. The test method is the "Standard Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting," ASTM Test Method D 1894-01, using a weighted sled (400 g) wrapped with NOMEX fabric (to simulate station wear) pulled across a length of face cloth (0.5 in/min). Face cloth friction is the coefficient of sliding friction of a suit face cloth material when sliding over a reference fabric. The measure is free of units. Larger numbers indicate more friction, and hence more difficulty in donning fire suits. The measure is inversely proportional, meaning that a fabric with twice as much face cloth friction as that of another fabric is half as easy to don.

Face Cloth Wicking

Face cloth wicking indicates the ability of the face cloth to draw heat and moisture away from the skin, improving comfort. This is a Dupont-specified test. A sample fabric (1 in x 7 in) is suspended in a pan of water containing 1.8 in ± 0.2 in water. The vertical progress of water up the fabric is measured at specific time intervals. The data in this report list the vertical height (inches) after 10 min. A higher number indicates more absorption and thus more comfort. The measure is proportional.
2.4 Summary of Performance Measures

These performance standards can be summarized as follows:

<table>
<thead>
<tr>
<th>Group</th>
<th>Measure</th>
<th>Measurement Units</th>
<th>Test Reference</th>
<th>Direction Indicating Improved Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Resistance</td>
<td>TPP</td>
<td>cal/cm²</td>
<td>NFPA 1971</td>
<td>higher (more protection)</td>
</tr>
<tr>
<td></td>
<td>Vertical Flame Char</td>
<td>in (per 10 min)</td>
<td>ASTM D 6413-99</td>
<td>lower (resistance to charring)</td>
</tr>
<tr>
<td>Tactile Performance</td>
<td>Weight</td>
<td>oz/yd²</td>
<td>ASTM D 3776-96</td>
<td>lower (lighter)</td>
</tr>
<tr>
<td></td>
<td>Thickness</td>
<td>mils</td>
<td>ASTM D 1777-96</td>
<td>lower (thinner)</td>
</tr>
<tr>
<td></td>
<td>Bending Stiffness</td>
<td>gf/in</td>
<td>ASTM D 1388-96</td>
<td>lower (flexible)</td>
</tr>
<tr>
<td>Durability</td>
<td>Lightfastness Rating</td>
<td>index A</td>
<td>AATCC 16-1998</td>
<td>higher (more colorfast)</td>
</tr>
<tr>
<td></td>
<td>Abrasion</td>
<td>cycles</td>
<td>ASTM D 3884-01</td>
<td>higher (resistance to abrasion)</td>
</tr>
<tr>
<td></td>
<td>Trap Tear</td>
<td>lbf</td>
<td>ASTM D 5587-96</td>
<td>higher (resistance to tearing)</td>
</tr>
<tr>
<td></td>
<td>Grab Strength</td>
<td>lbf</td>
<td>ASTM D 5034-95</td>
<td>higher (resistance to tearing)</td>
</tr>
<tr>
<td>Comfort</td>
<td>Breathability</td>
<td>W/m²</td>
<td>ASTM F 1868-02</td>
<td>higher (body moisture escapes)</td>
</tr>
<tr>
<td></td>
<td>Face Cloth Friction</td>
<td>dimensionless</td>
<td>ASTM D 1894-01</td>
<td>lower (less friction)</td>
</tr>
<tr>
<td></td>
<td>Face Cloth Wicking</td>
<td>in (per 10 min)</td>
<td>Dupont test</td>
<td>higher (more wicking)</td>
</tr>
</tbody>
</table>

* A Lightfastness Rating is given by an index from 1 to 5.

These performance measures will be used in the decision support tool. The tool will help users understand tradeoffs between performance measures. As an example, the standard method of increasing TPP ratings is by adding more insulation. This makes the turnout coat heavier. There is a tradeoff between weight—and perhaps associated measures such as stiffness—and the TPP rating. Again as an example, one way to reduce char length is to increase the weight of the fabric. This makes the turnout coat heavier. Again, there is a tradeoff between weight—and perhaps stiffness—and the char length rating. The decision support tool will help the user make individualized tradeoffs between weight, stiffness, TPP, char length, and other performance characteristics. The decision support tool will present the user with the best firefighter turnout coat choices based on his or her individualized performance tradeoffs and budget.
3. Data Set Organization and Collection

A firefighters’ turnout coat is made of four basic components. Figure 3-1 shows these components from the interior (bottom layer) to the exterior (top layer). The first two are the face cloth and thermal liner combination, represented together in Figure 3-1. The third and fourth components are the moisture barrier and the outer shell. The face cloth is closest to the skin of the wearer and attaches to the thermal liner. The thermal liner protects against heat penetration. The integrated moisture barrier component consists of the actual moisture barrier which is a plastic-like non-fabric product laminated to a fabric liner. The moisture barrier is designed to keep water out while allowing a limited amount of moisture vapor to exit. The exterior turnout coat component is the outer shell, which protects against flames and heat. The performance of a whole turnout coat depends on the choice of each of the four components (face cloth, thermal liner, moisture barrier, and outer shell).

![Figure 3-1. Components of Firefighters’ Turnout Coat](image)

Three data collection efforts were undertaken for this project. The first effort resulted in a data set, presented in Appendix B, describing the composition of turnout coats, by component. It is a detailed description of the composition of available thermal liners, moisture barriers, and outer shells; and provides the most comprehensive picture available of all possible suit configurations. No performance data are included for this data set. The second data set, obtained from Southern Mills, denotes a complete suit as the combination of four components: the face cloth, thermal liner, moisture barrier, and the outer shell. The third data set, obtained from Dupont, denotes a complete suit as the combination of three components, because the face cloth is considered part of the thermal liner. The Dupont data will be used in this first version of the decision support tool. Therefore, these data are presented in the body of this report, specifically Section 3.5 Table 3-1.

3.1 Composition of Fire Turnout Coats, by Component

The first data set, available in Appendix B, was compiled from company-provided specifications on available products on the market. Information sources included web sites, brochures, and corporate documents. The face cloth, thermal liner, moisture barrier, and outer shell are the separate components that must be combined to produce a complete suit. The face cloth and thermal liner combination is treated as a single component in this data set. Information such as fabric type, fabric
blends, weight, weave, and finishes were compiled for thermal liners and outer shells. In Appendix B, the first table lists the available fibers. The second table details fabrics used in thermal liners and outer shells. Because both components use the same fabrics, they were combined into one table for ease of presentation. The third table details moisture barriers.

The component-level approach has many advantages. Component-level evaluation provides more flexibility to the data set user. Protective clothing can be specified as any combination of components—not just the combinations that were tested together. Second, gathering component performance data is more efficient and more cost effective than collecting turnout coat performance data. The number of choices for each component results in a large number of possible combinations of turnout coats. Turnout coats are often made to custom specifications, and the performance information on all possible completed turnout coats is not available.

This approach also has some deficiencies. Not all tests are performed or disclosed by the manufacturer for each component. The cooperation of the manufacturer is needed to obtain specific measures when they are not presented in the published product literature.

Second, because the data are limited to tests on individual turnout coat components and not entire suits, some performance measures are not available. Simple additive measures such as weight and thickness are possible to construct, and some single-component performance tests can indicate the whole turnout coat performance. For example, a moisture penetration test performed on the moisture barrier component indicates the moisture penetration performance of a whole suit. Also, the tabor abrasion tests and lightfastness tests performed on the outer shell component will indicate the durability of the whole turnout coat. There are, however, performance tests that require all the suit components to be tested together—such as the thermal protective performance (TPP) test. For the TPP, it is necessary to either locate actual test data for the suit or to estimate performance data based on the components used. Performance algorithms being developed at the NIST may eventually be able to calculate the TPP performance of the whole turnout coat from the performance of each individual component.7

3.2 Fiber and Fabrics in the Component-Level Data Set

Any specific turnout coat component, such as an outer shell, is created using specific steps that may involve several companies. For example, one manufacturer might make the fiber, a second weave the fiber into fabric, and a third use the fabric to make one or more of the components of a turnout coat. The most basic element of the turnout coat is the fiber, followed by the fabric. Both the fiber and fabric manufacturers provided performance information.

Properties of fabrics include weight, fiber, and fiber blends. This information was compiled separately for outer shells, moisture barriers, and thermal liners. In the data set, the moisture barrier component is entered as a single unit, typically a combination of the moisture barrier and a backing fabric.

Data on the composition of fire turnout coats, by component, are presented in Appendix B. Identified are 55 thermal liner and face cloth combinations, 22 moisture barriers, and 91 outer shell variations. Moisture barriers are a combination of the moisture barrier and a liner. Components are differentiated when they change fiber blends, when they have unique trade names or product names,

7 See footnote 2.
and when they have weave or finish variations. Entries are identified by product name, trade name, fiber content and blend, and manufacturer name.

Currently, these performance data are incomplete because components do not have performance data for all tests. The models for estimating thermal performance are not currently available and data are not available at the component level. Due to incomplete manufacturer testing information, the performance of components cannot be reliably compared.

To compensate for unavailable performance data, a new data collection effort was undertaken. The strategy was to look for data from a single-source that had several full turnout coat combinations and performance measures, where all the turnout coat combinations had been tested thoroughly and consistently. The collected data were compiled into the second (Southern Mills) and third (Dupont) data sets.

3.3 The Southern Mills Data Set

The second data set, presented in Appendix C, is from performance data provided by Southern Mills, a textile manufacturer. Southern Mills provides information on 50 suits that are the combinations of 5 thermal liners (with face cloths), 2 moisture barriers, and 5 outer shells. The performance measures used by Southern Mills are TPP, weight, thickness, and a price index (these data are shown in Appendix C).

Because of data limitations, it is not possible to combine the Southern Mills and Dupont data into a single, usable, data set.8

3.4 The Dupont Data Set

The third data set is from performance data provided by Dupont. The information contained in the Dupont data set is available on the Internet using the Dupont EZ-Spec configuration program (http://www.dupont.com/nomex/ezspec/splash.html). This data set includes 13 measures of performance on a total of 41 complete suits.9 Dupont uses a well-documented standard set of tests on all suits. The performance results of one suit can be meaningfully compared with those of another suit. One notable omission in these performance tests is the radiative protective performance (RPP) measure. The Dupont performance data presented are from tests of whole turnout coats. The Dupont data used in the decision support tool are presented in their entirety in Section 3.5, Table 3-1.

The multiattribute decision analysis algorithm requires a fully-populated data matrix. As more data become available, these data sets will be expanded and, where possible, merged. When relevant NIST models are developed, the data sets will incorporate these NIST-developed performance measures.

8 In order to use the analytic hierarchy process, all suit choices must have measures for all performance criteria. Because the Dupont data and Southern Mills data do not share all suit choices or all performance measures, it is not possible to combine them for use in the decision support tool.

9 Two tests in the Dupont data were omitted from this report. The Thermal Efficiency test is TPP divided by weight, and so may be constructed without a separate entry. The “Thermo-Man” test uses a Dupont-specific method that estimates percent of estimated burn. This test was omitted because it is not a required test and it is not often reported for other turnout coats that might be added to this data set in the future, thus eliminating its usefulness as a standard of comparison.
3.5 Complete Turnout Coat Performance Data for Internet Decision Tool

The following table lists the performance data from Data Set 3 (Dupont Data) for the 41 turnout coat combinations tested. These data will be used in the decision support tool. Table 3-1 column headings refer to the performance measures explained in Section 2.
| Outer Shell | Moisture Barrier | Thermal Liner | Face Cloth | TPP (cal/cm²) | Vertical Flame: Char Length (in) | Tear Test (lb) | Trap Test (lb) | Grab Strength (lb) | Tabor Abrasion | Lightfastness Rating | Face Cloth Friction | Face Cloth Wicking | System Weight (oz/yd²) | System Thickness (mil) | Breathability (Wt%) | Bending Stiffness (g/in) | Thermal Liner Bendability (g/in) | Thermal Liner | | |
|------------|-----------------|---------------|------------|--------------|-----------------|-----------------|-----------------|-------------------|----------------|-------------------|-------------------|-----------------|----------------------|-----------------------|------------------|---------------------|------------------------|-----------------|-------| |
| Nomex/Kevlar (Advance) | Breathe-Tex Plus/E89 | 3 Layer Nomex E89 | Nomex Woven | 47.7 | 0.8 x 0.8 | 31 x 22 | 233 x 178 | 740 | 165 | 1 | 0.47 | 2.2 | 19.7 | 147 | ~174 | 2.3 |
| Nomex/Kevlar (Advance) | Breathe-Tex Plus/E89 | Aralite | Caldura | 45.5 | 0.8 x 0.8 | 31 x 22 | 233 x 178 | 740 | 165 | 1 | 0.37 | 2.8 | 20.2 | 166 | ~145 | 4.1 |
| Nomex/Kevlar (Advance) | Breathe-Tex Plus/E89 | Aralite | Nomex Woven | 43.1 | 0.8 x 0.8 | 31 x 22 | 233 x 178 | 740 | 165 | 1 | 0.47 | 2.2 | 19.6 | 160 | ~145 | 3.0 |
| Nomex/Kevlar (Advance) | Crosstech/E89 | 2 layer Nomex E89 | Caldura | 41.3 | 0.8 x 0.8 | 31 x 22 | 233 x 178 | 740 | 165 | 1 | 0.37 | 2.8 | 18.4 | 125 | ~250 | 2.8 |
| Nomex/Kevlar (Advance) | Crosstech/E89 | 3 layer Nomex E89 | Nomex Woven | 44.3 | 0.8 x 0.8 | 31 x 22 | 233 x 178 | 740 | 165 | 1 | 0.47 | 2.2 | 19.0 | 135 | ~217 | 2.3 |
| Nomex/Kevlar (Advance) | Crosstech/E89 | Aralite | Caldura | 43.8 | 0.8 x 0.8 | 31 x 22 | 233 x 178 | 740 | 165 | 1 | 0.37 | 2.8 | 19.0 | 151 | ~200 | 4.1 |
| Nomex/Kevlar (Advance) | Crosstech/E89 | Aralite | Nomex Woven | 45.3 | 0.8 x 0.8 | 31 x 22 | 233 x 178 | 740 | 165 | 1 | 0.47 | 2.8 | 18.7 | 168 | ~200 | 3.0 |
| Nomex/Kevlar (Duralite) | Crosstech/E89 | SMS | 200 Denier | 40.4 | 0.6 x 0.6 | 90 x 108 | 288 x 262 | 861 | 292 | 3 | 0.27 | 2.5 | 16.4 | 140 | N/A | 2.1 |
| Nomex/Kevlar (Fusion) | Breathe-Tex Plus/E89 | 3 Layer Nomex E89 | Nomex Woven | 43.1 | 0.9 x 0.8 | 44 x 32 | 363 x 313 | 1233 | 247 | 2/3 | 0.32 | 4.0 | 19.6 | 125 | 174 | 2.3 |
| Nomex/Kevlar (Fusion) | Crosstech/E89 | 2 layer Nomex E89 | Glide | 36.1 | 0.9 x 0.8 | 44 x 32 | 363 x 313 | 1233 | 247 | 2/3 | 0.32 | 4.0 | 17.9 | 101 | ~250 | 1.9 |
| Nomex/Kevlar (Fusion) | Crosstech/E89 | 3 Layer Nomex E89 | Nomex Woven | 43.1 | 0.9 x 0.8 | 44 x 32 | 363 x 313 | 1233 | 247 | 2/3 | 0.50 | 1.9 | 20.5 | 140 | 225 | 2.3 |
| Outer Shell          | Moisture Barrier | Thermal Liner | Face Cloth | TPP (cal/cm²) | Vertical Flame: Char Length (in) | Trap Tear (lb) | Grab Strength (lb) | Tabor Abrasion: CS10 (cycles to hole) | H18 (cycles to hole) | Lightfastness Rating | Face Cloth Friction (lb) | Face Cloth Wicking | System Weight (oz/yd²) | System Thickness (mils) | System Weight: Breathability (W/m²) | Bendability (g/in) | Thermal Liner | Bending Stiffness (g/in) |
|----------------------|------------------|---------------|------------|---------------|---------------------------|----------------|-------------------|--------------------------------------|----------------------|-----------------------|------------------------|-----------------|----------------------|-----------------------|--------------------------|----------------------|------------------|
| Nomex/Kevlar (Fusion) | Crosstech/ E89   | Aralite       | Nomex Woven | 41.9          | 0.9 x 0.8         | 44 x 32         | 363 x 313         | 1233                                 | 247                  | 2/3                   | 0.47                   | 2.2             | 18.7                | 153                   | ~200                     | 3.0                 |                 |
| Kevlar/Basofil       | Crosstech/ E89   | 2 Layer Nomex E89 | Caldura    | 45.8          | 0.3 x 0.3         | 23 x 43         | 185 x 146         | 1042                                 | 137                  | 2                     | 0.38                   | 2.8             | 19.8                | 120                   | ~250                     | 2.8                 |                 |
| Kevlar/Basofil       | Crosstech/ E89   | Aralite       | Caldura    | 47.7          | 0.3 x 0.3         | 23 x 43         | 185 x 146         | 1042                                 | 137                  | 2                     | 0.38                   | 2.8             | 20.2                | 165                   | ~200                     | 4.1                 |                 |
| Kevlar/Basofil       | Crosstech/ E89   | Aralite       | Nomex Woven | 47.5          | 0.3 x 0.3         | 23 x 43         | 185 x 146         | 1042                                 | 137                  | 2                     | 0.47                   | 2.2             | 19.2                | 170                   | ~200                     | 3.0                 |                 |
| Kevlar/Basofil       | Crosstech/ E89   | Basofil Felt  | FRT Cotton | 53.5          | 0.3 x 0.3         | 23 x 43         | 185 x 146         | 1042                                 | 137                  | 2                     | 0.50                   | 3.0             | 24.1                | 170                   | N/A                      | 3.3                 |                 |
| Kevlar/PBI (Gold)    | Crosstech/ E89   | 2 Layer Nomex E89 | Caldura    | 39.3          | 0.3 x 0.2         | 30 x 35         | 258 x 234         | 870                                  | 119                  | 3                     | 0.38                   | 2.8             | 18.7                | 120                   | 250                      | 2.8                 |                 |
| Kevlar/PBI (Gold)    | Crosstech/ E89   | 3 Layer Nomex E89 | Nomex Woven | 43.0          | 0.3 x 0.2         | 30 x 35         | 258 x 234         | 870                                  | 119                  | 3                     | 0.47                   | 2.2             | 19.6                | 135                   | 217                      | 2.3                 |                 |
| Kevlar/PBI (Gold)    | Crosstech/ E89   | Aralite       | Caldura    | 43.5          | 0.3 x 0.2         | 30 x 35         | 258 x 234         | 870                                  | 119                  | 3                     | 0.38                   | 2.8             | 20.0                | 153                   | ~200                     | 4.1                 |                 |
| Kevlar/PBI (Gold)    | Crosstech/ E89   | Aralite       | Nomex Woven | 41.4          | 0.3 x 0.2         | 30 x 35         | 258 x 234         | 870                                  | 119                  | 3                     | 0.47                   | 2.2             | 18.7                | 150                   | ~200                     | 3.0                 |                 |
| Kevlar/PBI (Gold)    | Crosstech/ E89   | Rebound       | Slick      | 50.0          | 0.3 x 0.2         | 30 x 35         | 258 x 234         | 870                                  | 119                  | 3                     | 0.27                   | 2.5             | 22.3                | N/A                   | 120                      | 4.6                 |                 |
| Kevlar/PBI (Gold Plus)| Breathe-Tex Plas/E89 | 3 Layer Nomex E89 | Glide      | 43.2          | 0.5 x 0.5         | 38 x 40         | 239 x 248         | 862                                  | 183                  | 3                     | 0.32                   | 4.0             | 19.8                | 128                   | ~170                     | 2.4                 |                 |
| Outer Shell          | Moisture Barrier | Thermal Liner      | Face Cloth | TPP (cal/cm²) | Vertical Flame: Clear Length (in) | Trap Tear (in) | Grab Strength (lbf) | Tabor Abrasion | Lightfastness Rating | Face Cloth Friction | Face Cloth Welding | System Weight (oz/yd²) | System Thickness (mil) | System Thickness (mil) | Breathability (W/m²) | System Weight (oz/yd²) | System Thickness (mil) | Bending Stiffness (g/in) | Thermal Liner: Bending Stiffness (g/in) |
|----------------------|------------------|--------------------|------------|---------------|-----------------------------|----------------|---------------------|------------------|-----------------------|---------------------|---------------------|----------------------|------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Kevlar/PBI (Gold Plus) | Breathe-Tex Plus/E89 | Aralite Caldura | 44.1       | 0.5 x 0.5     | 38 x 40                   | 239 x 248       | 862                 | 183              | 3                     | 0.38                | 2.8                 | 20.0                 | 162                    | 142                  | 4.1              |
| Kevlar/PBI (Gold Plus) | Crosstech/ E89 | 3 Layer Nomex E89 | Nomex Woven | 44.5          | 0.5 x 0.5     | 38 x 40                   | 239 x 248       | 862                 | 183              | 3                     | 0.47                | 2.2                 | 20.3                 | 142                    | 217                  | 2.3              |
| Kevlar/PBI (Gold Plus) | Crosstech/ E89 | Aralite Nomex Woven | Nomex Woven | 45.6          | 0.5 x 0.5     | 38 x 40                   | 239 x 248       | 862                 | 183              | 3                     | 0.47                | 2.2                 | 19.5                 | 169                    | 200                  | 3.0              |
| Nomex Crosstech/ E89 | Nomex/ Kevlar Batt Woven Nomex Woven | Nomex Woven | 42.0       | 3.2 x 3.2     | 63 x 41                   | 295 x 256       | 1442                | 270              | 3                     | 0.50                | 1.9                 | 18.9                 | 172                    | ~207                 | 2.5              |
| Nomex Crosstech/ E89 | Aralite Caldura | Nomex Woven | 41.8       | 3.2 x 3.2     | 63 x 41                   | 295 x 256       | 1442                | 270              | 3                     | 0.37                | 2.8                 | 19.7                 | 186                    | ~207                 | 4.1              |
| Nomex Crosstech/ E89 | Aralite Nomex Woven | Nomex Woven | 42.8       | 3.2 x 3.2     | 63 x 41                   | 295 x 256       | 1442                | 270              | 3                     | 0.47                | 2.2                 | 19.3                 | 178                    | 207                  | 3.0              |
| Nomex Crosstech/ E89 | Q9- Aramid Nomex Woven | Nomex Woven | 46.0       | 3.2 x 3.2     | 63 x 41                   | 295 x 256       | 1442                | 270              | 3                     | 0.47                | 2.2                 | 20.9                 | 226                    | ~207                 | 4.0              |
| Nomex Neoprene Q9- Aramid Nomex Woven | Nomex Woven | 54.1       | 3.2 x 3.2     | 63 x 41                   | 295 x 256       | 1442                | 270              | 3                     | 0.47                | 2.2                 | 20.0                 | 140                    | ~207                 | 4.0              |
| Z200 Aquatech 2 Layer Nomex E89 | Nomex Filament - 100 Denier | 46.6       | 0.4 x 0.5     | 28 x 26                   | 215 x 200       | 890                 | 117              | 3                     | 0.26                | 1.2                 | 18.5                 | 124                    | 228                  | 1.9              |
| Z200 Aquatech 3 Layer Nomex E89 | Nomex Filament - 100 Denier | 54.0       | 0.4 x 0.5     | 28 x 26                   | 215 x 200       | 890                 | 117              | 3                     | 0.26                | 1.2                 | 20.0                 | 140                    | 207                  | 2.3              |
| Z200 Breathe-Tex Plus/E89 | Nomex Filament - 100 Denier | 46.2       | 0.4 x 0.5     | 28 x 26                   | 215 x 200       | 890                 | 117              | 3                     | 0.26                | 1.2                 | 18.8                 | 100                    | 235                  | 1.9              |
Table 3-1. Dupont Fire Suit Performance Data, continued

<table>
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<tr>
<th>Outer Shell</th>
<th>Moisture Barrier</th>
<th>Thermal Liner</th>
<th>Face Cloth</th>
<th>TPP (cal/cm²)</th>
<th>Vertical Flame: Char Length (in)</th>
<th>Tabor Abrasion</th>
<th>Lightfastness Rating</th>
<th>Face Cloth Friction (in)</th>
<th>Face Cloth Welding (in)</th>
<th>System Weight (oz/yd²)</th>
<th>System Thickness (mils)</th>
<th>System Weight (oz/yd²)</th>
<th>Breathability (W/m²)</th>
<th>Thermal Liner Bending Stiffness (g/in)</th>
</tr>
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<tr>
<td>Z200 Crosstech/ E89</td>
<td>2 Layer Nomex E89</td>
<td>Nomex Filament - 100 Denier</td>
<td>44.0</td>
<td>0.4 x 0.5</td>
<td>28 x 26</td>
<td>215 x 200</td>
<td>890</td>
<td>117</td>
<td>3</td>
<td>0.26</td>
<td>1.2</td>
<td>17.0</td>
<td>96</td>
<td>251</td>
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<tr>
<td>Z200 Crosstech/ E89</td>
<td>3 Layer Nomex E89</td>
<td>Nomex Filament - 100 Denier</td>
<td>52.0</td>
<td>0.4 x 0.5</td>
<td>28 x 26</td>
<td>215 x 200</td>
<td>890</td>
<td>117</td>
<td>3</td>
<td>0.26</td>
<td>1.2</td>
<td>18.5</td>
<td>108</td>
<td>230</td>
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<tr>
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<td>2 Layer Nomex E89</td>
<td>Nomex Filament - 100 Denier</td>
<td>40.9</td>
<td>0.4 x 0.5</td>
<td>28 x 26</td>
<td>215 x 200</td>
<td>890</td>
<td>117</td>
<td>3</td>
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<td>44.0</td>
<td>0.5 x 0.5</td>
<td>28 x 25</td>
<td>217 x 178</td>
<td>900</td>
<td>137</td>
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<td>0.32</td>
<td>4.0</td>
<td>18.8</td>
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<td>~250</td>
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<td>41.3</td>
<td>0.5 x 0.5</td>
<td>28 x 25</td>
<td>217 x 178</td>
<td>900</td>
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<td>1.2</td>
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<td>50.5</td>
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<td>900</td>
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<td>1.2</td>
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4. Summary and Suggestions for Future Research

4.1 Summary

The Firefighter Protective Clothing project has successfully developed a data framework and collected data to be used in the decision support tool for Firefighter Protective Clothing. The data set framework consists of four firefighter turnout coat elements: the face cloth, thermal liner, moisture barrier, and outer shell. Three data sets were created. In the first data set, the different product choices for each suit component were collected and entered into a comprehensive data set (available electronically from the author). When populating the data set with performance data, complications arose. Data on the performance of specific fire fighting gear, when available, did not cover the broad combination of suits that could be produced by combining the various choices of outer shell, thermal liner, moisture barrier, and face cloth. Second, when merging performance data from different sources, or even across different suit types, differences in test methods or in the way test results are reported, cause meaningful comparisons to be impossible. A second data set was obtained from Southern Mills. This data set provides four turnout coat performance measures for 50 suits (5 outer shells, 2 moisture barriers, and 5 thermal liners). A third source of data, the Dupont EZ-Spec Machine, included 13 performance measures on a total of 41 suits.

The decision support tool will help the user make individualized tradeoffs between weight, stiffness, TPP, char length, and other performance characteristics. The decision support tool will present the user with the best firefighter turnout coat choices based on his or her individualized performance tradeoffs and budget.

4.2 Suggestions for Future Research

The decision support tool, in the future, could incorporate additional performance tests and more combinations of turnout coat components. BFRL fire researchers are developing mathematical models to estimate heat transfer, time to skin burn, and TPP measures. The decision support tool for Firefighter turnout coats will be able to add performance data calculated according to new NIST-specified performance measures.

The decision support software could be revised. Based on input from users, the interface could add new functions that would provide an informative report on selected coats, or screen the coats for certain user-input criteria, such as a performance threshold. The decision support tool could also be expanded to encompass other protective clothing items such as helmets, gloves, pants, and boots. Lastly, the tool could be modified to encompass biological or chemical protective gear. A universal database would need to be developed to facilitate the use of different clothing items as well as clothing items that protect the wearer from different types of threats.
References


Appendix A
Test Standards


Appendix B
Composition of Fire Turnout Coats, By Component

The performance of a turnout coat is primarily based on fabric characteristics. The fabric used to make a turnout coat component has inherent properties such as weight, thickness, stiffness, resistance to abrasion/tearing, and protection from heat and flame. There can be more than one way to manufacture a fabric. Different blends have different properties. The fabric may be made into different styles of turnout coats that have different layering, stitching, sleeve design, and closures that affect performance.

Table B-1 identifies the different fibers that are available for manufacturing turnout coat components. Outer shells and thermal liners (with face cloth, if specified) are described in Table B-2. Table B-3 describes moisture barriers. The moisture barriers are laminated or cross-stitched to the fabrics in Table B-2. There is no performance data in this data set.
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<td>Iso-dri</td>
<td>X treated with Teflon</td>
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<td>Quattro-tech</td>
<td>Nomex filament face cloth with Kevlar fleece</td>
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# Appendix C

## Southern Mills Fire Suit Performance Data

Column headings are explained in Section 2.

### Table C-1. Southern Mills Fire Suit Performance Data

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<tr>
<th>Outer Shell</th>
<th>Moisture Barrier</th>
<th>Thermal Liner</th>
<th>composite price index</th>
<th>composite TPP rating (cal/cm²)</th>
<th>composite weight (oz/yd²)</th>
<th>composite thickness</th>
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Table C-1. Southern Mills Fire Suit Performance Data, continued

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