Research to Improve the Protection & Comfort of Structural Firefighter Gear

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T-PACC is the most advanced and comprehensive laboratory based facility in the world for supporting the development and testing of protective clothing.
Focus on the Firefighter
Thermal Protection
Stoll Curve

2nd Degree Burn

Change in Temp.

0 5 10 15 20 25 30

0 5 10 15 20 25 30

Time of Exposure (Seconds)
Stored Energy Burns

\[ q = \frac{MC_p}{\varepsilon A} \frac{dT}{dt} \]

- Skin Side
- Outer Shell
- Moisture Barrier
- Thermal Liner Batt
- Thermal Liner
- Face Cloth
PyroMan™ Results
PyroHands™ and PyroHead™
- Custom heat panels can produce exposures from 5 kW/m² to 21 kW/m²
- Water cooled heat shield will block heat during dressing and before exposure
- Motorized track will move RadMan™ in front of heater
Man-in-Simulant-Test (MIST)
Measuring Heat Stress

Sweating Hot Plate

Sweating Manikin

Physiological Testing
Advanced Comfort Turnout

• To demonstrate structural firefighter turnout suit with exceptional combined comfort and protective performance.

• To incorporate advance materials and designs that “push the envelope” to achieve significant advances.
Evolution of Turnout Gear*

- Early designs consisted of cotton canvas, leather, wool, rubber
- Project FIRES first systematic approach to development of PPE for structural firefighters
- Separate moisture barriers became commonplace during the late 70s / early 80s
- NFPA 1971 turnouts now incorporate heat resistant materials
- Moisture Barriers evolved to include protection from all liquids including blood and toxic industrial chemicals

*K. Ross/TPACC

Figure Source: Fire Link - Firefighter Gear: Then and Now
Project FIRES

• Conducted in late 1970’s by Grumman Aerospace for NASA and USFA with IAFF leadership
• PPE shall protect the FF from hazards ranging from “heat and flames, toxic smoke, moisture, impact and penetration”
• PPE shall provide protection while also affording “improved performance through increased maneuverability, lighter burdens and improved engineering designs”
• Few systematic independent lab based re-evaluation of structural FF suits since Project FIRES
• Few systematic comprehensive studies using advanced systems level testing technologies
CBRN Firefighter Suits

- IAFF-Project HEROES
- NCSU-CB Ready

http://www.iaff.org/hs/Project%20HEROES.htm
Modern Firefighter Turnout*

- **Outer Shell**
  - Protect body and internal components of garment from flame and physical hazards
- **Moisture Barrier**
  - Keep out water and other liquids including blood and chemicals while allowing a certain amount of sweat to evaporate
  - Breathable moisture barriers
- **Thermal Liner**
  - Thermal batting provides protection from heat
  - Next-to-skin face cloth designed for wearer comfort

Advances in heat stress related to improvements in turnout suit materials and designs have not kept pace with advances in burn protection

*K. Ross/TPACC
TPP

- TPP requirement of 35 cal/cm² major factor driving turnout bulk since it is so strongly correlated with composite thickness and weight.
- Unintended consequence: if TPP of 35 is minimum requirement, then TPP of 50 or 60 must provide even better protection?

![Thermal Protection Chart](chart.png)
NFPA Gear Regulation*

- Sweating Hot Plate Test
  - THL > 205 W/m²
  - Material level test
  - Base composite only

*K. Ross/TPACC
TPP/THL Distribution

TPP

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<tr>
<th>Part</th>
<th>Value</th>
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<tr>
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<td>Boot</td>
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THL

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<tr>
<td>Boot</td>
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</tbody>
</table>

BASE COMPOSITE TPP = 38.6
NFPA Minimum Requirement = 35 TPP Value

BASE COMPOSITE THL = 263.4
NFPA Minimum Requirement = 205 W/m² THL
Key Question

• Can turnout suit constructions be designed to affect meaningful improvement in firefighter heat stress with added mobility?
Key: Systems Testing
Advanced prototype: materials and designs

Phase Change Materials
1. Excess heat generated by the body is absorbed into the OUTLAST® Thermocules®
2. Stored heat is released back to your body as needed
3. Comfort zone is maintained next to your body

Innovative Designs
- Ventilated Turnouts
- Ergonomic Designs
- Moisture Management Materials
- Base Layer Effects

Shape Memory Alloys

http://www.backinaction.co.uk/
Effect of Garment Air Layers
Strategies to mitigate impact of turnout layers and air gaps?
Sweating manikin

- Include underwear, shorts & t-shirt under ensemble
- Include boots, gloves, helmet, & SCBA
- Sweating and non-sweating conditions based upon realistic venting application
  - Dry = convective heat loss
  - Wet = evaporative (sweat) heat loss
- Varying air speeds:
  - 0.4 m/s (still air simulation)
  - 2 m/s
- Varying physical activity
  - Stationary
  - Walking
Effect of Vent Location

Active Vertical Vents

Active Zipper Vents
Virtual Modelling

- Coupled Manikin and Physiological Model Control
  - Uses virtual model framework in a real-time interactive setting
  - Uses manikin measurements to predict human physiological response

Inputs: Activity Level Posture

Measurements: Clothing Effects Ambient Temperature Relative Humidity

Outputs: Clothing & Skin temperatures Core body temperature Thermal Sensation & Comfort

Figure Source: Measurement Technologies Northwest / ThermoAnalytics, Inc.
• 70 W/m² increase in THL led to a 1.1°C decrease in core temperature with passive open vents
1. Modular Approach

2. 1. OS only (USAR)
   2. OS+MB (Extrication)
   3. Full Turnout

3.
Modular Approach Experimentation

Manikin THL Comparison of Modular Approaches in Static Condition

- Control: 78.0
- OS+TL: 86.4
- OS+MB: 88.6
- OS Only: 111.9

Predicted THL (W/m²)
Ensemble Effects: Base layers?

Base Layer Approach THL Data

*Horizontal Line denotes minimum required THL of 205 W/m2*
Base Layer Approach TPP Data

Base Composite TPP + Station Wear with Thermal Liner Variations

*Horizontal Line denotes minimum required TPP value of 35*
Wear Trial Testing:

• Extrication scenario: ensemble worn without SCBA, mask, or hood
• Wind speed at 2 m/s
• Work rate = approx. 5 mets (3.5mph at 3% incline)
• 35°C/35% RH
• Raleigh Fire Fighters
Ergonomic study

Prototypes vs. Control

• Range of Motion study
  – Knee raises
  – Arm extensions
  – Rope pulls

• Timed training course
Ergonomics Evaluation of Garments

• Purpose: Establish quantifiable differences on:
  – Usability
  – Freedom of Movement
  – Fabrics + Design & Fit aspects

Current Ergonomics Design  Heavy duty  Standard
Impact on turnout TPP?
Pyroman™ Turnout Testing

• Current chamber is 11’ x 18’ with 8 burners
• New chamber is 30% larger with 12 burners
  – Will allow for longer exposure, up to 20 seconds
  – Increase energy that garment can be exposed to
Burn Injury Prediction

Burn Injury vs. Time
Resulting from 12.00 second Flash Fire

- % Burn vs. Time (sec)
- 60 s
- 120 s

Total Burn
3rd Degree

Burn Calculation Time (s) 239.5
150701D
Normalization of Manikin Heat Flux
Project Outcomes

• Firefighters will benefit by having a better understanding of consequences of discretionary choices in NFPA 1971 systems

• All turnout suit manufacturers and materials suppliers will benefit from scientific validation of heat stress reducing design concepts
Bulking Up = Heating Up
Project Outcomes

• Technical foundation for advancing NFPA 1971 performance testing and requirements
Project Team

NC State Team

• Roger Barker
• Alex Hummel
• Emiel Den Hartog
• Kevin Ross
• John Morton-Aslanis
• Meredith McQuerry
• Carl Escriva
• Shawn Deaton (Project manager)

National Fire Protection Research Foundation
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Data presented are from an ongoing research project and are, therefore, preliminary in nature. Data are not presented to qualify the safety benefits or to recommend or exclude any commercial product. No laboratory generated data can completely characterize the conditions of actual field exposures that are physically complex and diverse.