Workshop on Fire Hose in Support of the Technical Committee

PROCEEDINGS

HELD:
24-25 May 2016, DoubleTree by Hilton Denver, CO

PREPARED BY:
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1 Batterymarch Park, Quincy, MA
Executive Summary

On Tuesday and Wednesday 24-25/May/2016, the Fire Protection Research Foundation facilitate a workshop on behalf of the National Fire Protection Association in support of the Technical Committee on Fire Hose. Immediately following the workshop the Technical Committee on Fire Hose held a technical committee meeting for the revisions of NFPA 1961 and 1962.

The firefighter ensemble, including personal protective equipment (PPE), self-contained breathing apparatus (SCBA), electronics, and tools, is a vital part of a firefighter’s equipment in the fire environment. Attack fire hose, used to protect firefighters in rescue efforts and extinguish the fire, is also an important part of the equipment subject to the firefighter operational environment. NFPA 1961 Standard on Fire Hose has provided the fire service and industry with a minimum standard of fire hose manufacturing since 1898. There are several other fire hose test standards including: UL 19, FM 2111, DIN 14811, and BS 6391.

Hose failure has been mentioned as a factor during incidents. This workshop aims to share information, receive stakeholder feedback, engage conversation to enhance understanding, and consider the question “Can fire hose be improved?” Several groups have begun to investigate failure of fire hose in the firefighter operational environment. As fire hose failure is investigated, it is important to consider fire hose characteristics (mechanical failure resistance, thermal impact, flow properties, usability, selection, care and maintenance, etc.) in the process moving forward.

The goal of this workshop is to support the Technical Committee on Fire Hose with the information necessary to ensure first responders have the fire hose to be safe and effective. Several objectives of the workshop include:

- Clarify fire fighter expectations for fire hose capabilities and characteristics
- Answer the question: Can fire hose be improved?
- Identify gaps, prioritize, and provide recommended approach forward
Acknowledgements

This workshop was supported by the National Fire Protection Association:

This workshop summary has been prepared by Daniel Gorham, Research Project Manager, at the Fire Protection Research Foundation. The information contained herein is based on the input of numerous professionals and subject-matter-experts. While considerable effort has been taken to accurately document this input, the final interpretation of the information contained herein resides with the report author. The content, opinions and conclusions contained in this report are solely those of the authors and do not necessarily represent the views of the Fire Protection Research Foundation, NFPA, Technical Panel or Sponsors. The Foundation makes no guarantee or warranty as to the accuracy or completeness of any information published herein.

About the Fire Protection Research Foundation
The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)
Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission. All NFPA codes and standards can be viewed online for free. NFPA's membership totals more than 65,000 individuals around the world.

Keywords: fire hose, attack hose, fire fighter equipment

Report number: FPRF-2016-11
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1) Background and Overview

The firefighter ensemble, including personal protective equipment (PPE), self-contained breathing apparatus (SCBA), electronics, and tools, is a vital part of a firefighter’s equipment in the fire environment. Attack fire hose, used to protect firefighters in rescue efforts and extinguish the fire, is also an important part of equipment subject to the firefighter operational environment. NFPA 1961 Standard on Fire Hose has provided the fire service and industry with a minimum standard of fire hose manufacturing since 1898. There are several other fire hose test standards including: UL 19, FM 2111, DIN 14811, and BS 6391.

Hose failure has been mentioned as a factor during incidents. This workshop aims to share information, receive stakeholder feedback, engage conversation to enhance understanding, and consider the question “Can fire hose be improved?” Several groups have begun to investigate failure of fire hose in the firefighter operational environment. As fire hose failure is investigated, it is important to consider fire hose characteristics (mechanical failure resistance, thermal impact, flow properties, usability, selection, care and maintenance, etc.) in the process moving forward.

The goal of this workshop is to support the NFPA Technical Committee on Fire Hose with the information necessary to ensure first responders have the fire hose to be safe and effective. Several objectives of the workshop include:
- Clarify fire fighter expectations for fire hose capabilities and characteristics
- Answer the question: Can fire hose be improved?
- Identify gaps, prioritize, and provide recommended approach(es) forward

The workshop format was three-fold: (1) baseline presentations and panel discussion, (2) breakout groups, and (3) wrap-up and summary observations. The full agenda is provided in Figure 2.

Baseline presentations provide an overview and pertinent information on the topic so all participants have the sufficient background for discussion. Additional information on the presentations is provided in the Presenter and Presentation Overview section starting on page 3.

After the baseline presentations a plenary discussion between the workshop participants and panel was moderated by Daniel Gorham. The panel members included: Jacqueline Wilmot, Jeff Hebenstreit, Kathy Notarianni, Adam St. John, Anthony Calomino, and Casey Grant.

Day one of the workshop concluded with the formation of breakout groups for day two. These groups were tasked with addressing the workshop goal and objectives by answering breakout question and through facilitated discussion. Additional information on the breakout groups and their work is provided in the Discussion on Needs sections starting on page 4.
After the breakout session all three breakout groups reported back on their responses to the questions. All workshop participants participated in a final group discussion on the information provided, research gaps, and paths forward. Additional information is provided in the Summary Observations section starting on page 6.

The workshop was well attended, including 11 fire service members and representatives from the fire hose manufacturing industry, research and testing laboratories, maintainers and installers, and key stakeholders. Following the workshop the NFPA Technical Committee on Fire Hose held an official technical committee meeting. Many workshop participants attended this meeting as a committee member or guest. This meeting was separate from the workshop and held in accordance to the Regulations Governing the Development of NFPA Standards. Additional information the technical committee meeting can be found on the appropriate document information page: www.nfpa.org/1961next; www.nfpa.org/1962next.
2) Presenter and Presentation Overview

Robert Duval is the Senior Fire Investigator/North East Regional Director at NFPA. As the fire investigator, he is responsible for gathering information on significant incidents and sharing that information for NFPA committees, members and the fire protection community. As Regional Director he serves as a point of contact in the NE states for adoption of NFPA codes, training and assisting with outreach to constituents. Robert presented on a fire in Keokuk, Iowa that he investigated. Slides from this presentation are provided in Annex B, Figure 4 through Figure 8.

Daniel Gorham is a Research Project Manager for the Fire Protection Research Foundation where he is responsible for planning, managing, and facilitating research in support of the NFPA mission. Daniel presented on the fire fighter equipment operational environment, including previous and on-going research on the topic. Slides from this presentation are provided in Annex B, Figure 9 through Figure 10.

Kathy Notarianni is an Associate Professor of Fire Protection Engineering at Worcester Polytechnic Institute where her research focuses on working to help the fire service with the tools and technologies that aid in carrying out their ever expanding mission without increasing costs. Joshua Donovan is a senior B.S./M.S. student at WPI studying mechanical engineering and fire protection engineering. Joshua has worked on the Next Generation Fire Attack Hose project for two years as an undergraduate research engineer. He is the Chief of WPI EMS Squad and an EMT-B for the Boylston Fire Department. Kathy and Joshua presented on a taxonomy of material properties for fire attack hose that is solidly based on the first-hand experience of firefighters and that is comprehensive enough to aid in the understanding of performance on the fire ground. Slides from this presentation are provided in Annex B, Figure 11 through Figure 15.

Casey Grant is the Executive Director of the Fire Protection Research Foundation where his responsibilities include oversight for multiple research projects in support of the Foundation’s mission to plan, manage, and facilitate research on behalf of the NFPA mission. Casey provided a presentation on fire fighter equipment performance attributes and his experience with the six “ilities” discussed in The Research Roadmap for Smart Fire Fighting (www.nfpa.org/SmartFireFighting). Slides from this presentation are provided in Annex B, Figure 16.

Jacqueline Wilmot is a Fire Protection Engineer at NFPA and the staff liaison responsible for the Technical Committee on Fire Hose. Jacqueline provided a presentation on fire hose history and NFPA 1961 Standard on Fire Hose and NFPA 1962 Standard for the Case, Use, Inspection, Service Testing, and Replacement of Fire Hose, Couplings, Nozzles, and Fire Hose Appliances. Slides from this presentation are provided in Annex B, Figure 17 through Figure 22.

Jeff Hebenstreit is a Principal Engineer for the Fire Suppression Department at Underwriters Laboratories (UL). He represents UL on several NFPA technical committees, including NFPA 1961. Jeff also works with several UL Standards, including UL 19, Lined Fire Hose and Hose Assemblies, and is involved with the evaluation of products for third party listing. Jeff provided a presentation on the UL standards development process and UL 19. Slides from this presentation are provided in Annex B, Figure 23 through Figure 27.

Adam St. John a fire research engineer at the Bureau of Alcohol, Tobacco, Firearms and Explosives ATF Fire Research Laboratory. He is on the ATF National Response Team and
conducts full-scale fire tests. He has been in the fire service for 12 years and is a captain in Montgomery County, Maryland. Adam provided a presentation on the thermal analysis of radiant heat on interior fire attack hose, work conducted at the request of the National Institute for Occupational Safety and Health (NIOSH). Slides from this presentation are provided in Annex B, Figure 28 through Figure 33. The work presented was part of Lisa Herb’s Certified Fire Investigator candidate project. A memorandum to the NFPA Technical Committee on Fire Hose was provided to the workshop participants. Additional information and a copy of the memorandum is provided in Annex D starting on page 62.

Anthony Calomino is a material and structures research engineer with the NASA Langley and NASA Glenn Research Centers. He is also a member of the Convective Heating Improvement for Emergency Fire Shelters (CHIEFS) team, a collaborative effort between the U.S. Forest Service and NASA. Anthony provided a presentation on his experience with new technologies and materials used in the NASA space program and working to incorporate the desirable properties in fire fighter equipment. Slides from this presentation are provided in Annex B, Figure 34 through Figure 37.

Kathy Notarianni provided a presentation on preliminary hose testing results from the WPI next generation fire attack hose project. Slides from this presentation are provided in Annex B, Figure 38 through Figure 42.

Jack Murphy is a student at Worcester Polytechnic Institute (WPI). Jack will graduate in May of 2017 with a Bachelor of Science in Chemical Engineering and is expected to achieve his Master of Science in Fire Protection Engineering in December of 2017. Jack is a member of Tau Beta Pi: The Engineering Honor Society and has professional experience in both the codes and standards development process as well as the fire protection consulting industry. Panyawat Tukaew has a Bachelor of Science in Mechanical Engineering and is currently pursuing a Master of Science in Fire Protection Engineering at Worcester Polytechnic Institute (WPI). Panyawat has a background in research in the field of combustion science. Jack, Panyawat, and Joshua Donovan provided a presentation on the thermal performance tests from the WPI next generation fire attack hose project. Slides from this presentation are provided in Annex B, Figure 43 through Figure 50

3) Discussion on Needs – Breakout Sessions

The purpose of the breakout sessions was to address the workshop objectives: clarify fire fighter expectations of fire hose capabilities and characteristics; answer the question “can fire hose be improved?” and identify gaps, prioritize, and provide recommend approach forward. Workshop participants were placed in one of three breakout groups (green, red, or blue), with distribution to provide perspective from the range of stakeholders in each group. The groups were tasked with addressing five breakout group questions (Figure 3).
### Breakout Group Question

1) What are the *capabilities* of current fire hose?
   a) What is currently available for consumers?
   b) What conditions can fire hose currently withstand?
   c) What are the experiences of fire hose consumers, users, and maintainers of fire hose?

2) What *expectations* do consumers, users, and maintainers have for fire hose?
   a) What environmental conditions do users expect the fire hose to operate in? Are these normal or emergency operating conditions?
   b) What are the expected performance attributes (durability, maintainability, operability, reliability, stability, availability) of fire hose?
   c) What is reasonable to expect (time, energy, frequency) for maintenance?
   d) What is necessary for maintenance?
   e) What is expected in the procurement of fire hose, both for manufacturer and purchaser?

3) What, if any, are feasibility restrictions in fire hose improvement?
   a) Are there technical issues?
   b) Are there constraints?
   c) Do standards requirements prove as obstacles to innovation?

4) What, if any, are the gaps between *expectations* and *capabilities* of fire hose?
   a) What are the differences between expectations and capabilities of currently available fire hose?
   b) What questions has current and previous research answered?
   c) What is the prioritization of these gaps and paths forward?

5) Are there any additional topics or questions that should be addressed?

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**Figure 3: Breakout group questions.**

Each group had a facilitator to guide them through the questions and a scribe to capture the discussion. Group discussion was captured on PowerPoint slides and used to brief the other groups. These slides are provided here in Annex C, Figure 51 through Figure 56.
4) Summary Observations

The Workshop on Fire Hose in Support of the Technical Committee aimed to share information, receive stakeholder feedback, engage conversation to enhance understanding, and consider the question “Can fire hose be improved?” Presentations were provided to establish baseline information on current research and standards. A panel discussion and Q&A session initiated the conversation about clarifying fire fighter expectations for fire hose and current capabilities. Breakout groups provided participants an opportunity to continue the conversation and address specific questions aimed at identifying gaps between capabilities. The groups reconvened to review their discussion and develop a prioritization and recommend paths forward for gaps identified between expectations and current capabilities of fire hose. Below are some key takeaways from the workshop:

Current Capabilities

- **Functionality** – packable on apparatus, mulit-use, repairable
- **Maneuverability** – within structures, including around corners and along stairways, and at the nozzle
- **Abrasion resistance** – dragged across pavements and asphalt
- **Chemical resistance** – exposure on the fire ground
- **Thermal resistance** – conductive heating “hot block” test; consistent with WPI database failure mechanism
- **Kink resistance** – important for constant-flow water delivery in structure
- **Range of incidents** – fire hose can be used for a variety of incidents under a range of conditions, including structure, industrial, vehicle, and wildland
- **Operating pressure** – internal pressures required for operating in a variety of incidents

Expectations

- **Water delivery to fire** – needs to reliably deliver water from source to the fire for extinguishment
- **Low friction-loss** – allows reasonable operating flow (pressure and volume)
- **Operating condition** – should operate as designed in the same environment fire fighters occupy
- **Multi-use** – service life of hose needs to provide departments enough time for reasonable replacement
- **Maintenance** – time and skill required for cleaning and inspection should be obtainable for line fire fighter
- **Minimum performance** – specifications based on hose use and extreme operating conditions
- **Full-system** – entire water delivery system should be evaluated together (water supply, pump, fire hose, appliance, etc.)

Gaps between capabilities and expectations

- **Fire hose rating** – a system that will allow purchasers to evaluate fire hose to determine what best fits their needs
- **Indicators of failure** – determine on-set of failure during inspection and maintenance
Performance evaluation – methods for evaluating new and used fire hose to determine whether it should be removed from service

Define failure – a clear and description definition of what constitute a failure (visual, performance, service-life, etc.)

Test methods – establish and refine valid test methods for fire hose characteristics including: pressure, thermal resistance, abrasion resistance, etc.

Data – national data collection for fire hose equipment failure

Paths forward

- Educate end-user of current fire hose capabilities and expected conditions in modern fire environment
- Consider relevancy of fire hose as part of the fire fighter ensemble and determine whether fire hose is a tool, safety equipment, or both
- Consider what are the performance attributes and how these should be considered as minimum specifications or part of a rating system
- Determine the criteria for hose failure and what are the failure modes are, whether these are worst-caste conditions or other
- Continue gathering data and information on fire hose failures and make available in a national database
- Develop and refine test methods that evaluate fire hose and provide consumers and users with information necessary to make purchasing decisions
- Promote innovative and novel solutions
Annex A: Workshop Participants and Attendees

The following were the workshop presenters on “Workshop on Fire Hose in Support of the Technical Committee”, held in DoubleTree by Hilton, Denver, CO on 24-25/May/2016.

Robert Duval, National Fire Protection Association
Daniel Gorham, Fire Protection Research Foundation
Kathy Notarianni, Worcester Polytechnic Institute
Josh Donovan, Worcester Polytechnic Institute
Jack Murphy, Worcester Polytechnic Institute
Panyawat (Oat) Tukaew, Worcester Polytechnic Institute
Casey Grant, Fire Protection Research Foundation
Jacqueline Wilmot, National Fire Protection Association
Adam St. John, ATF
Anthony Calomino, NASA
Andrew Ellison, Unified Investigations & Sciences

The following were the full list of workshop attendees on “Workshop on Fire Hose in Support of the Technical Committee”, held in DoubleTree by Hilton, Denver, CO on 24-25/May/2016.

Adam St. John, ATF
Andrew Ellison, Unified Investigations & Sciences
Anthony Calomino, NASA
Bill Betz, Fairfax County Fire & Rescue
Robert Duval, NFPA
Brian Fink, FDNY
Casey Grant, FPRF
Christopher Budzinski, City of Asheville Fire Department
Dan Rossos, Oregon Department of Public Safety Standards & Training
Daniel Gorham, FPRF
David Quick, Manchester Fire Department
David Walsh, Boston Fire Department
Duane Leonhardt, Mercedes Textiles/Fire Equipment Manufacturer’s Association
Gerard Garcia, TIPSA
Jack Murphy, WPI
Jacqueline Wilmot, NFPA
James Glatts, FireOne
Jason Goodale, Loveland Fire Rescue
<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>Jason Riggenbach</td>
<td>Akron Brass Company</td>
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<td>Jayme Kahle</td>
<td>Rincon Valley Fire District</td>
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<td>Jeff Hebenstreit</td>
<td>Underwriter’s Laboratory</td>
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<tr>
<td>Jonathan Cares</td>
<td>Town of Londonderry Fire Rescue</td>
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<td>Josh Donovan</td>
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<td>Leo Meli</td>
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<td>Mark Donovan</td>
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<td>Michael Mayer</td>
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<td>William Graves</td>
<td>William Graves Associates</td>
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Annex B: PowerPoint Slides

Figure 4: Presentation by Robert Duval (page 1 of 5)

Keokuk, Iowa Fatal Fire
December 22, 1999

Time: 8:24 a.m.
- Location: Multi-Family Dwelling (Occupied)
- Reported Building Fire with Children Trapped

Outcome:
- 8 Fatalities - Three Children & Three Fire Fighters

Keokuk, Iowa

Population: 13,500 - 25,000
10 sq.miles (26 sq. km)
Mississippi River

Response Area
- Light-Heavy Industry
- Commercial District
- Residential

Keokuk, Iowa

Fire Department, cont’d

Frontline Units
- Aerial 2 - 60 ft. ladder with 2000gpm pump
- Rescue Engine 3 - 1500 gpm pump

Three Reserve Units
- 100 ft. Aerial (Aerial 1)
- 1000gpm Pumper (Engine 6)
- 300gpm Mini Pump/Service Unit (Attack 1)

The Building - 1910 (1972)

- 2 story
- Wood Frame
- Divided into Three Apartments

Fire Apartment
- 1st Floor
- Kitchen
- Living/Dinning Rooms
The Building

2nd Floor
- Three Bedrooms
- Bathroom
- Wall/Floor Coverings
- Paneling-Plaster and Gypsum Board
- Carpeting and Wood

The Incident

- Units respond to a serious injury MV Accident at 7:30 a.m.
- Five FF’s on duty due to vacation
- One FF responds with Ambulance to Hospital to assist with injured victim of accident.
- While clearing from scene - notified of fire

The Incident - 8:24 a.m.
- Keokuk 911 Center receives several calls from neighbors reporting a structure fire with children trapped
- Notifies Units at MV Accident scene to respond

The Incident - 8:28 a.m.
- Both Units arrive on scene Request made for 6 “call-back” FF’s
- One FF (LT) at Hydrant to establish water supply
- Mother informs Assistant Chief (AC) of Trapped Children
- AC Enters the Building as Apparatus Operators set-up

The Incident - 8:29 a.m.
- Chief and FF Arrive in Chief's car
- Chief asks about the location of the AC
- Orders Apparatus Operators in Building to Assist in Search and Rescue
- Additional FF dons PPE and advances hose line to front door

Figure 5: Presentation by Robert Duval (page 2 of 5)
### The Incident - 8:30 a.m.
- First Child removed from Building (22 month old male)
- PD unit begins CPR and transports child to hospital in PD car
- Within seconds another child (22 month old female) is removed from building
- Child is handed to Fire Chief on front steps

### The Incident - 8:30 - 8:38 a.m.
- No EMS Units yet on Scene
- Chief Begins CPR on Child
- PD Officer drives Chief to Hospital ER
- Leaves Child with ER staff
- Returns to Fire scene
- A Size-up has not yet been completed of Building/Fire

### The Incident - 8:38 - 8:40 a.m.
- Still No Word from inside the Building
- FF at front of building notices flame spread in doorway
- Burns through hose line at door threshold
- Chief arrives Back at Scene
- Second line advanced to front door
- Engine 6 (Call-Back) arrives w/2 FF

### The Incident - 8:40 - 8:50 a.m.
- Report of possible victim in adjoining apartment
- Engine 6 crew with LT begin search of apartment

### The Incident 8:40 - 8:50 a.m.
- Chief continues to try to raise the AC and other FF’s, while conducting an external size-up of the building
- Ventilation Conducted in Rear - First Floor

### Search Negative for Occupant of Adjoining Apartment
- Aerial One arrives with 3 FFs
- Additional FFs arrive on scene

*Figure 6: Presentation by Robert Duval (page 3 of 5)*
Figure 7: Presentation by Robert Duval (page 4 of 5)
Lessons Learned - FD Operations

- Building Size-up
  (Risk vs. Benefit Analysis)
- Incident Management
- Accountability
- Resources
- Rapid Intervention Crew

Lessons Learned - Building

- NO WORKING SMOKE DETECTORS IN APARTMENT

NFPA Standards

- NFPA 1500 - Standard on Fire Department Occupational Safety and Health Program
- NFPA 1861 - Standard on Emergency Service Incident Management System
- NFPA 72 - National Fire Alarm Code®

Keokuk Report

Joint Investigation with NIOSH
NIST Fire Model
NFPA
Electronic or Printed Report
Summary Presentations

Questions?

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Sr. Fire Investigator
NE Regional Director
NFPA Fire Investigations Unit
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Quincy, MA 02169 USA
617-954-7476 (tel)
rduval@nfpa.org

Figure 8: Presentation by Robert Duval (page 5 of 5)
What is the FFEOE?
- Conditions that fire fighter equipment is subject to during operation (storage, incident, maintenance, etc.)
  - Mechanical
  - Chemical and contaminants
  - Thermal
  - Electrical

Research
- NIST Fire Research Division
- Fire Protection Research Foundation
- UL Fire Safety Research Institute

Changing fire environment
- Modern vs. Legacy

Technical Committee on Fire Control
- New project request with support from fire service and research organizations
- Membership from across the fire service (chiefs, operations, officers, firefighters)
- Last meeting ~ March 2016. Currently developing draft guide for structural firefighting

NFPA 1700, Guide for Structural Firefighting
Scope:
This guide addresses structural firefighting, including strategies, tactics, and tasks, as indicated by evidence-based research.

Purpose:
The purpose of this document is to provide guidance for the development of standard operating procedures/guidelines, including strategies, tactics, and tasks for structural firefighting.

--- Page 15 of 78 ---
Figure 10: Presentation by Daniel Gorham (page 2 of 2)
Next Generation Fire Attack Hose: Taxonomy

Kathy Notarianni, Ph.D
Associate Professor
Fire Protection Engineering

Joshua Donovan
Mechanical Engineering
Fire Protection Engineering

WPI

Methodology

- Engage the fire service to identify all functions/uses of a fire hose.
- Identify impacts each function has on the hose.
- Based upon the impact, determine requirements for the hose to survive the impact.
- Hose requirements are then defined quantitatively by material properties that can be tested for measured performance tests currently defined in the standard.
  - Identify gap due to lack of a specified test.
  - Identify gaps where current test is not adequate (heat only)

WPI

Example

- Function/Use: A fire attack hose is dropped into a building.
- Impact: A fire hose may be exposed to high temperatures.
- Requirement: A fire hose must be heat resistant.
- Material properties: Thermal conductivity, melting point, autoignition temperature, thermal diffusivity, flammability.
- Existing Test: NFPA 194 ranks the flammability of materials based on volatility.

WPI

Goal

Construct a taxonomy of material properties for fire attack hose that is solidarity based on the first-hand experience of firefighters and that is comprehensive enough to aid in the understanding of performance on the fire ground.

WPI

Methodology (cont.)

Function/Use → Impact → Requirement → Material property → Existing Test

WPI

Step 6: Methodology (cont.)

- Perhaps the most important step involves YOU!!!
- The last step in the methodology is to present it to stakeholders and have them refine/expand it.
- Examples of potential input:
  - More functions/uses
  - Impacts you have observed
  - Problems with fire hose?
  - Anything we missed or are delusional about?
- What uses do YOU see for the taxonomy?

WPI
**Task 1: Documenting Functions and Uses**

- Another member of the Next Generation Fire Attack Hose Project at WPI reached out to the Fire Service in order to document Functions/Uses of Fire Attack Hose.
- Visited Fire Hoses across New England and called a sample in other parts of the country – Christopher Scangas
- Used a “go-pro” lead off...
- All functions/uses from use on fire ground to being stored on apparatus
- Learned hoses can be used in rescue/damming oil spills...

**Functions/Uses Documented from Fire Service**

<table>
<thead>
<tr>
<th>Functions/Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual pressure testing</td>
</tr>
<tr>
<td>Stored on apparatus</td>
</tr>
<tr>
<td>Pulled off apparatus</td>
</tr>
<tr>
<td>Dropped into buildings</td>
</tr>
<tr>
<td>Carded up states</td>
</tr>
<tr>
<td>Conduct of water</td>
</tr>
<tr>
<td>‘Rope’ Rescue</td>
</tr>
<tr>
<td>Damming oil spills</td>
</tr>
</tbody>
</table>

**Task 2: Identifying impacts**

- Impacts from each function/use were identified
- These included impacts observed by the fire service as well as those implied through scientific analysis.

**Functions/Uses and Impacts**

<table>
<thead>
<tr>
<th>Function/Use</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual pressure testing</td>
<td>Exposed to high pressure</td>
</tr>
<tr>
<td>Stored on apparatus</td>
<td>Potential for spread of hazardous chemicals</td>
</tr>
<tr>
<td>Pulled off apparatus</td>
<td>Potential for spread of hazardous chemicals</td>
</tr>
<tr>
<td>Dropped into buildings</td>
<td>Exposed to high pressure</td>
</tr>
<tr>
<td>Carded up states</td>
<td>Exposed to high pressure</td>
</tr>
<tr>
<td>Conduct of water</td>
<td>Exposed to high pressure</td>
</tr>
</tbody>
</table>

**Task 3: Defining Requirements**

- Hose requirements are qualities a hose must possess in order to fulfill the functions documented in our discussion with the fire service.
- Requirements were determined based on the functions a hose must perform along with the impact the function has on the hose.

*Figure 12: Presentation by Kathy Notarianni and Josh Donovan (page 2 of 5)*
Requirements from Fire Service

<table>
<thead>
<tr>
<th>Function/Use</th>
<th>Impact on Hose</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hose tensioning</td>
<td>Resistant to high pressure</td>
<td>All around high pressure</td>
</tr>
<tr>
<td>Hose branch</td>
<td>Resistance to high pressure</td>
<td></td>
</tr>
<tr>
<td>Hose compression</td>
<td>Resistance to water flow</td>
<td></td>
</tr>
<tr>
<td>Hose expansion</td>
<td>Resistance to water flow</td>
<td></td>
</tr>
<tr>
<td>Hose friction</td>
<td>Resistance to water flow</td>
<td></td>
</tr>
<tr>
<td>Hose vibration</td>
<td>Resistance to water flow</td>
<td></td>
</tr>
<tr>
<td>Hose shock</td>
<td>Resistance to water flow</td>
<td></td>
</tr>
</tbody>
</table>

Requirements from Fire Service (cont.)

<table>
<thead>
<tr>
<th>Function/Use</th>
<th>Impact on Hose</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hose handling</td>
<td>Resistance to water flow</td>
<td>Durable</td>
</tr>
<tr>
<td>Hose storage</td>
<td>Resistance to water flow</td>
<td>Corrosion resistant</td>
</tr>
</tbody>
</table>

Requirements from Code

- Fire hose standards, although not mandatory, shape the manufacture of fire hose therefore it is necessary for hose performance tests to directly translate to performance on the fire ground.
- NFPA 1961 hose performance tests were identified and assigned corresponding requirements necessary for reliable performance on the fire ground.

Task 4: Assigning Material Properties

- Requirements must be defined quantitatively to be considered when manufacturing a fire attack hose. Material properties were identified for each requirement.
- A materials’ inherent properties can be tested or measured through existing testing procedures to ensure they can withstand the rigors of the fire ground.

Figure 13: Presentation by Kathy Notarianni and Josh Donovan (page 3 of 5)
**Figure 14: Presentation by Kathy Notarianni and Josh Donovan (page 4 of 5)**

**Mechanical and Physical Properties (cont.)**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Material Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potency Resistance</td>
<td>Hardness</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>Fracture Strength</td>
</tr>
<tr>
<td>Flammability</td>
<td>Fire-retardant</td>
</tr>
<tr>
<td>Fire Resistance</td>
<td>Flame Retardant</td>
</tr>
<tr>
<td>Water Resistance</td>
<td>Water Retardant</td>
</tr>
<tr>
<td>Flame Spread</td>
<td>Flame Spread</td>
</tr>
<tr>
<td>Lightness</td>
<td>Density</td>
</tr>
</tbody>
</table>

**Thermal and Fire Properties**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Material Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire retardant</td>
<td>Non-flammable</td>
</tr>
<tr>
<td>Water retardant</td>
<td>Water-repellent</td>
</tr>
<tr>
<td>Flame retardant</td>
<td>Flame-repellent</td>
</tr>
<tr>
<td>Fireproof</td>
<td>Fire-resistant</td>
</tr>
</tbody>
</table>

**Chemical and Electrical Properties**

<table>
<thead>
<tr>
<th>Department</th>
<th>Material Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion resistance</td>
<td>Corrosion resistance</td>
</tr>
<tr>
<td>Stability</td>
<td>Stability</td>
</tr>
<tr>
<td>Flammability</td>
<td>Flammability</td>
</tr>
<tr>
<td>Electrical resistance</td>
<td>Electrical resistance</td>
</tr>
<tr>
<td>Conductivity</td>
<td>Conductivity</td>
</tr>
</tbody>
</table>

**Analysis and Comparison**

- Requirements derived from fire service input differ from what is currently specified in NFPA performance tests.
- Performance test outlined in NFPA 1961 focus on the overall performance of the hose and not the properties of the materials used.

**Task 3: Taxonomy**

- Performance requirements, defined as material properties, are categorized by three performance properties:
  1. Mechanical and Physical Properties: Performance under stress or applied load and inherent properties of materials
  2. Thermal and Fire properties: Performance with respect to varying temperature
  3. Chemical and Electrical properties: Performance with an applied electrical current and performance with respect to chemical composition.
## Taxonomy

- **Mechanical and Physical properties**: Fatigue strength, Hardness, Flexural modulus, Tensile strength, Fracture toughness, Shear Modulus, Young’s Modulus, Permeability, Erosion, Yield Strength, Density
- **Thermal properties**: Thermal conductivity, Melting point, Auto-ignition, Thermal diffusivity, Flammability, Maximum service temperature, Minimum service temperature, Heat of combustion, Thermal expansion, Specific heat
- **Chemical and Electrical properties**: Surface roughness, Reactivity, Toxicity, Product of combustion, UV radiation, Ozone resistance, Mildew resistance, Electrical resistance

## Conclusion

- Achieved development of a process to capture the big picture
- Presented a first draft of the taxonomy
- We believe it is useful in the development of a Next Generation Fire Attack Hose
  - Screen potential new materials
  - Expected performance

## Task 6: Discussion

- The taxonomy of material properties based on NFPA code and fire service input will be used when designing a next generation attack hose.

---

*Figure 15: Presentation by Kathy Notarianni and Josh Donovan (page 5 of 5)*
Figure 16: Presentation by Casey Grant (page 1 of 1).
Proceedings for Workshop on Fire Hose in Support of the Technical Committee

**NFPA 1961, Standard on Fire Hose**

**History & Evolution**

- 1st edition in 1988
- 17 editions, including the current, 2013 edition
- 5 Year Revision Cycle

**NFPA 1961, Standard on Fire Hose**

**History & Evolution**

- 2002
- Cold Resistance Test
- Abrasion resistance
- Degradation from repeated from all pressures
- Flexibility and compressibility test method for forestry hose

**NFPA 1961, Standard on Fire Hose**

**History & Evolution**

- 1934
- Standard Specification for Cotton Rubber-Lined Fire Hose for Public and Private Fire Department Use

- 1960
- Newer synthetic materials

- 1972
- Single Jackal Supply Hose

**Figure 17: Presentation by Jacqueline Wilmot (page 1 of 6)**
Figure 18: Presentation by Jacqueline Wilmot (page 2 of 6)
Figure 19: Presentation by Jacqueline Wilmot (page 3 of 6)
Figure 20: Presentation by Jacqueline Wilmot (page 4 of 6)
Figure 21: Presentation by Jacqueline Wilmot (page 5 of 6)
Figure 22: Presentation by Jacqueline Wilmot (page 6 of 6)
NFPA Fire Hose Workshop

UL 19 – Lined Fire Hose and Hose Assemblies

May 24, 2016

Jeff Hebenstreit
Principal Engineer – Fire Suppression Products

UL Standards Development Organization
- Standards Technical Panel
- ANSI Standards Development Process

Certification Organization
- Independent Third Party Certifier
- ANSI Accredited

UL19 – Tests are referenced in NFPA 1961
*Indicates test referenced in NFPA 1961 - 2013

Figure 23: Presentation by Jeff Hebenstreit (page 1 of 5)
### UL 19 - Scope

**Single and Multiple Jacketed Hose**
- Sizes 1-1/2" – 6"

**Pressures**
- Single Jacketed – 150, 200, or 250 psi
- Multiple Jacketed – 200, 300, or 400 psi

**Inspection and Maintenance**
- Intended to be inspected and maintained in accordance with NFPA 1962

---

### UL 19 Construction Requirements

**Internal Diameter (ID)**
- ID not less than trade size
- Measured with tapered plug gauge

**Jacket and Inner Reinforcements**
- Free from visible defects, thread knots, lumps and irregularities

**Lining**
- Uniform thickness, free of pitting, irregularities, and imperfections

---

### UL 19 Construction Requirements

**Cover**
- Uniform thickness, free from pitting, blisters or other imperfections that would impair use

**Coatings/Treatments**
- Jackets may have treatment or coatings

**Couplings**
- Metals having corrosion resistance equivalent to yellow brass (C86500)
- Expansion ring smooth with rounded edges
- Uniform gaskets

---

### UL 19 – Performance Requirements

**Hydrostatic Proof-Pressure Tests**
- (Min 500 psi @ 2 X Service Pressure)
- Elongation (Max of 9 – 13% depending on type/size)
- Shall not leak, balloon, or thread breakage
- Twist
  - In direction to tighten couplings
  - Single-jacketed = Max Twist of 3 % to 10 based on hose size and pressure
  - Multiple-jacketed = Max Twist of 1 % to 4 % based on hose size and pressure

---

### UL 19 – Performance Requirements

**Kink Test**
- 1 1/2 X service test pressure while kinked
- No leakage, rupturing, or breaking of any thread

**Hydrostatic Strength Test**
- 3 X service test pressure
- Tested straight and curved
- No rupturing or breaking of any thread

---

**Figure 24: Presentation by Jeff Hebenstreit (page 2 of 5)**
UL 19 – Performance Requirements

Repeated Bending Test
- Applicable to 1 ½” through 3 ½” Hose
- 100,000 cycles of repeated bending
- Post cycling, hydrostatic strength test (3X)

UL 19 – Performance Requirements

Alternating Pressure Test
- 2000 cycles of alternating low/high pressure
- 0 psi to service test pressure
- Post cycling, hydrostatic proof pressure test
  - Elongation, pressure, twist, warp, rise

UL 19 – Performance Requirements

Abrasion Test
- No. 1 ½ coarse emery cloth w/ weight
- Single-jacketed hose – 300 cycles
- Multiple-jacketed hose – 500 cycles
- Post cycling, hydro @ 1 ½ X service test pressure

UL 19 – Performance Requirements

Heat-Resistance Test
- Solid steel block (2 ½” by 1 ½” by 8”)
- 260°C (500 °F) heated for 16 hours
- Sample filled with tap water
- Block placed on sample 60s
- Post exposure, hydrostatic strength test


UL 19 – Performance Requirements

Fold resistance test
- Folded and clamped with 120 lbf
- Placed in oven at 60°C (140°F) for 30 days
- Post exposure, hydrostatic strength test

Wet Hose Test
- 48 hours immersion without visible deterioration
- Post exposure, hydrostatic strength test

UL 19 – Performance Requirements

Low-Temperature Test
- All hose = cold flexing @ -20° C (-4° F)
- Or rated for -54° C = cold flexing @ -54° C (-65° F)
- Exposed to specified temp for 16 hours, removed and bent double on itself then thawed
- Post exposure, hydrostatic proof pressure (2X)

Figure 25: Presentation by Jeff Hebenstreit (page 3 of 5)
**UL 19 – Performance Requirements**

**Friction Loss Test**
- Maximum friction loss @ 100 psi based on size

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Friction Loss @ 100 psi (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4&quot;</td>
<td>100</td>
</tr>
<tr>
<td>1&quot;</td>
<td>125</td>
</tr>
<tr>
<td>1 1/4&quot;</td>
<td>150</td>
</tr>
<tr>
<td>1 1/2&quot;</td>
<td>185</td>
</tr>
</tbody>
</table>

**Ozone Exposure Tests of Lining and Covers**
- Optional rating
- Ozone stressed and exposed with partial pressure 100 mPa
  - Test Conditions: 48°C (140°F) for 70 hours
  - Shall show no visible signs of cracking

**Accelerated Aging Test of Linings and Covers**
- Air oven aged, 100°C (212°F) for 70 hours
- Must maintain at least 80% tensile strength
- Must maintain at least 65% ultimate elongation

**Adhesion Tests**
- Adhesion between lining, jacket/reinforcement, rubber backing
  - 1 1/2" strip ≤ 1 inch per minute @ 12 lb weight
- Adhesion between cover and woven jacket or reinforcement
  - 1 1/2" strip ≤ 1 inch per minute @ 10 lb weight

**Water Immersion Test of Linings**
- Immersion in distilled or DI water, 70°C (160°F) for 168 hours
- Tensile strength = 75% retention of original
- Ultimate elongation = 75% retention of original
- Maximum volume swell = 25% retention of original

**Marking Requirements**
- Manufacturer, trade name, date, service test press, factory ID
- Additional ratings - Low Temp, Ozone
- Required 3.5 – 4.5 feet from both ends of hose

**Production Line Testing**
- Proof Pressure Tests

---

Figure 26: Presentation by Jeff Hebenstreit (page 4 of 5)
UL 19 – UL Surveillance Program

UL Surveillance Program

- Ongoing verification of compliance with the UL 19 requirement
- Product Inspections through periodic audits
- Selection of samples for testing
- Testing of product at the manufacturing site
- Testing of product at UL

UL 19 – UL Surveillance Program / Proprietary Information

UL respects our client’s proprietary manufacturing and marketing information

Details on product construction, product manuals, test results, and ongoing investigation status cannot be divulged to outside parties

Listing information published in the UL Online Certifications Directory can be disclosed

Online Certifications

Online Certifications

We want your feedback!
The best way to improve our services is to tell us what you think.

Online Certifications

We want your feedback!
The best way to improve our services is to tell us what you think.

Thank you.

Figure 27: Presentation by Jeff Hebenstreit (page 5 of 5)
**Thermal Analysis of Radiant Heat on Fire Attack Hose**

ATF Fire Research Laboratory and National Institute for Occupational Safety and Health

**ATF Fire Research Laboratory**

- ATF FRL is the world's largest full-scale fire forensic laboratory
- Fire testing resource to support criminal fire investigators: federal, state and local

**ATF Fire Research Laboratory**

- Ongoing professional relationship with NIOSH and Firefighter Fatality Investigation and Prevention Program
- Regularly educate/train investigators/firefighters

**Work Product Produced**

At the request of NIOSH:

1. Quantify fire environment at time of thermal failure in actual structure (radiant heat flux)
2. Utilize heat flux values to establish repeatable laboratory test
3. Evaluate several types of hose and release data to NFPA/NIOSH

**Full-Scale Tests**

- Completed in August 2014 in Indianapolis
- Determine real-world rupture times and associated heat flux for Charged, Charged and flowing and Dry lines
- In both uni-directional AND bi-directional flow path scenarios

---

Figure 28: Presentation by Adam St. John (page 1 of 6)
**Figure 29:** Presentation by Adam St. John (page 2 of 6)
Full Scale Test Burns

Figure 30: Presentation by Adam St. John (page 3 of 6)
Video from Bench Scale Test

- Charged with water to @ 120 psi.
- Heat Flux = 30 kW/m^2

High-Speed Video

Figure 31: Presentation by Adam St. John (page 4 of 6)

Results

Visible damage to fire hose line after exposure to 40 kW/m². This particular hose failed in 51 seconds.

<table>
<thead>
<tr>
<th>Hose Model</th>
<th>Manufacturer</th>
<th>Length (ft)</th>
<th>Diameter (in)</th>
<th>Pressure Rating (psi)</th>
<th>Temperature Rating (°F)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>AquaFlow Jr</td>
<td>Independent</td>
<td>40</td>
<td>1.5</td>
<td>100</td>
<td>150</td>
<td>Fiber-Optic</td>
</tr>
</tbody>
</table>
**“Heat Sink” Effect of Water**
- Consistent with the “Full Scale Exposure Testing of Hoselines” performed by NIST (Madrzykowski, 2015). In the NIST testing, all three hoselines (charged with water (static); charged with air; and charged flowing water) failed within several seconds of each other.
- Wet outer jacket appears to increase failure time

**Video from Bench Scale Test**
- Charged with water to @ 120 psl.
- Heat Flux = 30 kW/m^2

**Results**
- Despite meeting the testing criteria outlined in NFPA 1971, the observed variation among the models tested supports the need for a standardized heat flux test to provide thermal resistance data to the fire service.
- Similar to TPP rating for turnout gear, this data would allow the end-user firefighter to better understand the limitations of their equipment and compare relative hoseline designs. (NFPA establishes min TPP, departments can elect for higher)
- Standardized heat flux test could also be advantageous for hoseline manufacturers attempting to develop and compare more thermally robust hoseline designs.

**Fire Environment**
- 1970’s vs Today
  - Comparison of Room Furnishings
    - Legacy Rooms
    - Modern Rooms
    - 03:50

**PPE vs Hose**
- Hoses consistently fail at the onset of flashover
- Gear is designed to ~84 kW/m2 (post flashover/fully involved room), however gear is also typically closer to radiant energy source
- Is it a fair comparison?
  - Hoses are exposed throughout entire length → firefighter’s environment may be tenable/survivable

---

*Figure 32: Presentation by Adam St. John (page 5 of 6)
Summary

- Additional research is necessary
- Significant variation for currently listed hose:
  - Failure times of **33 seconds to 106 seconds** at heat flux of 30 kW/m².
  - At 40 kW/m² range of **22 seconds to 70 seconds**.
- Updated thermal standard would:
  - Allow firefighters to know equipment limitations
  - Allow manufacturers to design more robust hoselines
  - Bring NFPA 1961 inline with current NFPA firefighter operational environment standard updates

Figure 33: Presentation by Adam St. John (page 6 of 6)
Figure 34: Presentation by Anthony Calomino (page 1 of 4)
Figure 35: Presentation by Anthony Calomino (page 2 of 4)
Figure 36: Presentation by Anthony Calomino (page 3 of 4)
Summary and Future Work

- NASA has been engineering emergency shelter layup designs for over 2 years.
  - 20+ unique layups and 70+ materials screened in convective tests
  - Full-scale shelter tests at NW Territories and Univ. of Alberta
  - Early examination of aerospace insulators and alternate geometries.
  - Lessons learned were carried forward to later shelter designs.
- Identified materials suitable to shelter design requirements:
  - Cost, weight, sustainability, toxicity, flammability, strength, durability.
  - 5 layup configurations, 1 shelter geometry, 2 wall seams, 2 floor seams.
  - Current progress shows 80% thermal improvement at 3% mass increase.
  - Continue with full-scale shelter testing at NC State and U of Alberta.

Future Work

- Decrease shelter mass & packed volume (alt. geometries), improvement in seam design, further investigation for improvements in thermal performance.

Additional Acknowledgements

Mary Beth Wulz, Anthony Calomino, Kamran Daryabeigi, Walt Bruce, Matt Wells, Wayne Geoghe, Jeff Knuckson, Arth Thinh
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NASA Langley Research Center

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NASA Langley Research Center (MDSC)

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Roger Barker, Sean Deaton, John Morton-Aldinis
North Carolina State University

CHIERT would like to thank the JEST System Modeling Project and the JANET Challenges Development Program Office, and the NASA Langley Engineering Directorate for their support.

Figure 37: Presentation by Anthony Calomino (page 4 of 4)
**Proceedings for Workshop on Fire Hose in Support of the Technical Committee**

**WPI**

**Next Generation Fire Attack Hose: Preliminary Hose Testing**

May 24-26, 2016

Kathy Notarianni, Ph.D.
Associate Professor
Fire Protection Engineering
Worcester Polytechnic Institute

---

**Fire Attack Hose Burn-through Database**

- Prompted by the common belief that burn-throughs are rare, isolated events and that hoses charged with water are immune to burn-throughs.
- Lack of any statistical data on the cause or number of burn-throughs:
  - They are not tracked by fire departments, incident reporting systems, etc.
- The WPI Database is the first and only tracking system for fire hose burn-throughs, and thus the sole way to inform a discussion.

---

**Burn-through Database Map**

- Created after the NIOSH Firefighter Fatality Map
- Shows location of department where burn-through occurred

---

**Lessons Learned From Database**

Modes of heat transfer involved:
- Conduction
  - hand railing
  - door frame
  - falling debris
- Radiation
  - Close proximity to flame
  - Hot upper gas layer
  - Radiation from exposure while exterior building

---

**Figure 38: Presentation by Kathy Notarianni (page 1 of 5)**
Lessons Learned – Role of Water

- Despite belief that charged hose lines do not burn-through:
  - 98% of hoses were charged with water when they failed
  - 68% were flowing with water
  - 30% were charged but not flowing

Findings From Database

- While tactics play a role is what fire hoses are exposed to, even hoses charged with water can experience failures
- Burn-throughs are occurring over a wide range of scenarios including interior, exterior, contact with a hot object or even radiative exposure
- This database provides evidence that Boston is not an isolated event

Modes of Thermal Failure

<table>
<thead>
<tr>
<th>Identified in the database</th>
<th>Tested for in NFPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>failure by conduction</td>
<td>NFPA 1961 and NFPA 1971</td>
</tr>
<tr>
<td>failure from convection / radiation</td>
<td>Only NFPA 1971</td>
</tr>
<tr>
<td>failure from direct flame contact</td>
<td>Only NFPA 1971</td>
</tr>
</tbody>
</table>

British Standards Institution- BS 6391

- Two thermal performance tests: Hot Surface and Heat Resistance.
- The Hot Surface Resistance Test requires a 0.5 meter piece to be pressurized and heated to 300°C or 400°C filament rod with a pressure of 4 N for 120 seconds.
- The Heat Resistance Test requires a 1 meter hose to be exposed to a 600°C, 0.5 inch steel cube for 15 seconds.

German Institute for Standardization-DIN 14811

- Contains one of the only fire hose flame tests:
  - Five 1.5 foot test pieces are prepared and placed in a stainless steel burning chamber.
  - A Bunsen burner is placed so that the hose is five inches from the top of the flame.
  - Each test piece is exposed to the flame for 10 seconds.
  - Four of the five test pieces must withstand the 10 second test without bursting, and the after-flame time must be less than 3 seconds.

German Standard Flame Test

- Ten hoses were selected from the list of 58 hose models found to vary in key hose characteristics
  - Jacket material
  - Inner liner
  - Coatings
  - Weight per 50 ft.
- Run in replicated (but not certified) DIN 14811 test apparatus
- 30% of the ten NFPA compliant hoses failed

Figure 39: Presentation by Kathy Notarianni (page 2 of 5)
**Differentiating Fire Hose**

- Researched hoses that are commercially available and labeled NFPA 1961 compliant
  - 58 hose models from 10 manufacturers
  - Single jacket, double jacket, single rubber
    - Different materials used for jackets, liners, coating (specified for function only)
    - Varying weights
- How does a fire department make the choice of hose?

**Fire Hose Testing**

- Both looking at material properties in small scale using a cone calorimeter, and testing existing hoses at full scale
- Working to development of test standards
  1. Help differentiate hose characteristics - something more than just passing NFPA 1961
  2. Use that information to inform the creation of a next generation fire attack hose
  3. Use information to inform the development of new test methodologies to more realistically represent fireground conditions

**Developing a Test Standard**

- Iterative process in developing a test standard
  - Looking at database results and other testing standards
  - Design a test
  - Run hoses through test
  - Analyze results
  - Look at consistency and repeatability
  - Redefine aspects of the test
    - Pressure on the hose from hot plate
    - Orientation of hose relative to hot plate - melting

**Study Conclusions**

- Burn-through Database
  - Not isolated or rare events
  - Even charged lines burn
  - Not one particular hose subject to problems
- Recommendations for strengthening NFPA 1961
  - Test fire hoses at conditions more representative of the modern fireground in convective / radiative thermal stresses
  - Look to other standards for testing model (NFPA 1971 - PPE)
    - Include testing of material fire properties

**Parametric Fire Attack Hose Matrix**

<table>
<thead>
<tr>
<th>Hose Number</th>
<th>Hose 1</th>
<th>Hose 2</th>
<th>Hose 3</th>
<th>Hose 4</th>
<th>Hose 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight per 50F (lb)</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Jacket Material</td>
<td>Polyester</td>
<td>Polyester</td>
<td>Polye</td>
<td>Polye</td>
<td>Polyester</td>
</tr>
<tr>
<td>Liner Material</td>
<td>EPDM</td>
<td>TPU</td>
<td>EPDM</td>
<td>TPU</td>
<td>TPU</td>
</tr>
<tr>
<td>Coating</td>
<td>Abrasion</td>
<td>Abrasion</td>
<td>Abrasion</td>
<td>Abrasion</td>
<td>Abrasion &amp; Heat</td>
</tr>
<tr>
<td>Hose Number</td>
<td>Hose 6</td>
<td>Hose 7</td>
<td>Hose 8</td>
<td>Hose 9</td>
<td>Hose 10</td>
</tr>
<tr>
<td>Weight per 50F (lb)</td>
<td>17</td>
<td>19</td>
<td>16</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>Jacket Material</td>
<td>Polyester</td>
<td>Polyester</td>
<td>Polye</td>
<td>Polye</td>
<td>Polyester</td>
</tr>
<tr>
<td>Liner Material</td>
<td>TPU</td>
<td>EPDM</td>
<td>EPDM</td>
<td>TPU</td>
<td>EPDM</td>
</tr>
<tr>
<td>Coating</td>
<td>None</td>
<td>Abrasion &amp; Heat</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

**TPU-Liner Failure**

- Figure 40: Presentation by Kathy Notarianni (page 3 of 5)
Figure 41: Presentation by Kathy Notarianni (page 4 of 5)
Proceedings for Workshop on Fire Hose in Support of the Technical Committee

Figure 42: Presentation by Kathy Notarianni (page 5 of 5)
Next Generation Fire Attack Hose: Thermal Performance Tests
May 25, 2016
Denver, CO

First Draft Meeting

- WPI Research Update
  - Codes and Standards
  - Database
  - Taxonomy of Performance Metrics
- NFPA 1961 Placeholder
  - Conduction Test
  - Radiation-Convection Test
  - Flame Impingement Test
  - Fire Hose Classification
- Charge to WPI

Project Teams

Conduction Test

<table>
<thead>
<tr>
<th>Name</th>
<th>Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patrick Gates</td>
<td>Civil Engineering</td>
</tr>
<tr>
<td>Adam Maccaro</td>
<td>Chemical Engineering</td>
</tr>
<tr>
<td>Christopher Scangas</td>
<td>Civil Engineering</td>
</tr>
</tbody>
</table>

Convection/Radiation Test

<table>
<thead>
<tr>
<th>Name</th>
<th>Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthony Capiano</td>
<td>Mechanical Engineering</td>
</tr>
<tr>
<td>Joshua Donovan</td>
<td>Mechanical Engineering</td>
</tr>
<tr>
<td>Camden Knoff</td>
<td>Mechanical Engineering</td>
</tr>
<tr>
<td>Jack Murphy</td>
<td>Chemical Engineering</td>
</tr>
<tr>
<td>Panyawat “Oat” Tukaew</td>
<td>Mechanical Engineering</td>
</tr>
</tbody>
</table>

Project Goals

- Develop a more repeatable and realistic conduction test for fire hoses.
- Design and fabricate testing apparatus.

Areas of Concern for Current Conduction Test

- Repeatability
  - Temperature consistency
  - Effects of ambient temperature
  - Constant force and block placement
- Functionality
  - Differentiating between hoses
- Intensity
  - 500°F (260°C) not representative of fireground conditions

Figure 43: Presentation by Joshua Donovan, Jack Murphy, and Panyawat Tukaew (page 1 of 8)
Figure 44: Presentation by Joshua Donovan, Jack Murphy, and Panyawat Tukaew (page 2 of 8)
Conclusion

- More accurate and consistent than current test.
- Temperature is monitored and regulated throughout the test.
- Ability to compare performance capabilities of numerous hoses.

Figure 45: Presentation by Joshua Donovan, Jack Murphy, and Panyawat Tukaew (page 3 of 8)

Project Goals

- Develop a repeatable and realistic fire hose convection and radiation thermal performance test.
- Construct thermal testing apparatus capable of delivering reliable and repeatable results.
- Conduct preliminary tests in order to verify apparatus performance capabilities.

Goals

1. Representative of fireground conditions
2. Regulated and monitored test environment
3. Adaptable for air and water pressurized hoses
4. Ease of operation
5. Operator safety

Apparatus Design
## Apparatus Design

- Test chamber
- Radiative Heat Transfer System
- Convective Heat Transfer System
- Data Acquisition

![Apparatus Design Image](image1)

## Test Chamber

- Hose lays flat within chamber on insulating material, minimizing conductive heat transfer.
- Observation window to provide clear view of the test specimen.

![Test Chamber Image](image2)

## Test Chamber

- Inlet and outlet allow heated air to flow above and along test specimen.
- Adjustable sliding panels for varying hose diameters
  - Distance from radiant panel to hose remains constant
- Radiant panel positioned above the hose specimen.

![Test Chamber Image](image3)

## Radiative Heat Transfer System

- Infrared heating panel capable of exposing the test specimen to varying levels of radiative heat transfer.
- Radiant panel is positioned directly above the test specimen.
- Intensity is monitored and regulated throughout the duration of each test.

![Radiative Heat Transfer System Image](image4)

## Convective Heat Transfer System

- Air is heated inside a separated chamber by electric heating elements.
- An adjustable inline fan is used to create flow within the system.
- Heated air travels through the ductwork and flows above and along the length of the hose.
- The temperature of the inlet air is monitored and regulated.

![Convective Heat Transfer System Image](image5)

## Data Acquisition

- Real-time data of the fire hose pressure is recorded and analyzed to determine time to failure.
  - Pressure transducer
- Temperature/heat flux within the test chamber constantly monitored and recorded through proportional integration derivative (PID) controllers.
  - Radiant panel
  - Duct heater

![Data Acquisition Image](image6)

---

*Figure 46: Presentation by Joshua Donovan, Jack Murphy, and Panyawat Tukaew (page 4 of 8)*
Preliminary Tests

- Phase I: System Calibration
- Phase II: Verification with Fire Hoses

Phase I: System Calibration

- The system was calibrated in order to develop a correlation between temperature and heat flux.
- Airflow velocity and airflow heater were kept constant.
- Recorded total heat flux at fire hose height for varying radiant panel temperatures.
- Used this correlation to determine the required radiant panel temperature for desired heat fluxes.
- Completed four calibrations and plotted average values and standard deviation.

Phase II: Verification with Fire Hoses

- Full system tests with fire attack hoses were performed to evaluate prototype consistency.
- These tests were performed to validate the reliability and consistency of the system, not as assessments of current fire attack hoses available on the market.
Figure 48: Presentation by Joshua Donovan, Jack Murphy, and Panyawat Tukaew (page 6 of 8)
**Preliminary Tests – Phase II**

**Nylon-EPDM**

**Apparatus Design Goals**

1. Representative of realistic fireground conditions
2. Fully regulated and monitored test environment
3. Adaptable for air and water pressurized hoses
4. Ease of operation
5. Operator safety

**Representative of Realistic Fireground Conditions**

- Radiation and convection
- Hot upper gas layer
- Convective flow above and along the hose
  - Flow through doorway or hallway
- Hose lays on the floor

**Fully Regulated and Monitored Test Environment**

- Ability to vary, monitor and regulate test conditions:
  - Total heat flux
  - Radiation
  - Convection
  - Airflow speeds
- Real time temperature pressure data throughout the duration of the test
  - Exact failure times

**Adaptable for Air and Water Pressurized Hoses**

- Air
  - Prototype successfully tested with air
- Water
  - Protected electrical equipment
  - Draining system

*Figure 49: Presentation by Joshua Donovan, Jack Murphy, and Panyawat Tukaew (page 7 of 8)*
Annex C: Breakout Session

The following were the notes from the Breakout sessions on “Workshop on Fire Hose in Support of the Technical Committee”, held at the DoubleTree by Hilton in Denver, CO on 24-25/May/2016.
GREEN Breakout Group Report

Fire Hose Workshop in Support of the Technical Committee

To support the Technical Committee on Fire Hose with the information necessary to ensure first responders have the fire hose to be safe and effective...

Denver, Colorado
24-25 May 2016

GREEN GROUP MEMBERS

- Bob Duval – Green Leader
- Casey Grant - Secretary
- David Walsh – Timer
- Joshua Donovan
- Jason Goodale
- Jayme Khale
- Jonathan Larabee
- Kathy Notarianni
- Michael Cerdone
- Michael Mayer
- Nicholas Nava
- Thomas Foruglia

BREAKOUT GROUP QUESTIONS - GREEN GROUP

1) What are the capabilities of current fire hose?

- Must be fully functional for final use: Lay flat, have abrasion resistance, readily reusable, not be weight restrictive, withstand rated pressures, thermal assault, etc.
- Needs to meet the “tights”
- All materials are thermally unstable.
- Fire hose are currently manufactured from materials not used in any other high heat environment (e.g., polyester undergarments per NFPA 1970)
- Needs to be reusable and durable.
- It is lighter, more mildew resistant, easier to clean
- Have had catastrophic failures, with thermal failure and other reasons such as mechanical impact.
- Inability to judge the quality of fire hose, with key performance qualities. Need to have similar ability to judge like with WPI.

BREAKOUT GROUP QUESTIONS - GREEN GROUP

2) What expectations do consumers, users, and maintainers have for fire hose?

- To mitigate or eliminate catastrophic failures in all cases, and withstand the realistic worst case modern fire fighting environments as defined by NFST and others (e.g., hose should never fail during pre-flashover).
- Special consideration needs to be focused toward attack hose.
- Include the option to go above and beyond established minimums.
- Promote open transparent publication by manufacturers of their critical performance characteristics (including mandatory publications). Give the end-user all critical and credible decision making purchasing variables (e.g., thermal performance, etc.) beyond cost.
- Explore the value added of third party certification
- Focus on primary purpose of fire hose (i.e., water conveyance), and not ancillary uses like rappelling.

BREAKOUT GROUP QUESTIONS - GREEN GROUP

2) What expectations do consumers, users, and maintainers have for fire hose?

- Depends on every case by case basis, to be determined by field maintenance and other methods.
- A prescriptive time frame requirement for end-of-life is a poor requirement, but fire departments should appropriate policies.
- This is addressed by NFPA 1962.
- Address other materials beyond the traditional fire hose materials.
- Non-destructive field evaluations for inspection testing and maintenance is lacking and needs attention.
- Need to better define the critical points of failure of inspection testing and maintenance.
- Promote open transparent publication by manufacturers of their critical performance characteristics (including mandatory publications). Give the end-user all critical and credible decision making purchasing variables (e.g., thermal performance, etc.) beyond cost.

BREAKOUT GROUP QUESTIONS - GREEN GROUP

3) What, if any, are feasibility restrictions in fire hose improvement?

- Affordability should not be overlooked (among the other “tights”)
- For thermal resistance, we need a test method and associated parameters (i.e., pass/fail criteria)
- Need an improved abrasion test, beyond a simple pass/fail like UL-19 and FM.
- Thermal resistance, cost, durability, weight. All of these are variable depending on the situation. Consider all the “tights”.
- Both: Yes, such that standards are restrictive in the name of safety, and No since the standards are minimum and innovative technology can always exceed the baseline minimum requirements.
- Open transparent sharing of fire hose manufacturers performance characteristic is needed to facilitate innovative progress.
- Promote a classification system, but it must be straightforward, meaningful, credible, effective, efficient, etc.
**GREEN GROUP**

4) What, if any, are the gaps between expectations and capabilities of fire hose?

- **Failure**: Consider fire hose as part of the critical life safety PPE like PPE. A radiant heat test failure is a sometimes hidden or non-obvious failure.
- **Data**: Need to define fire hose failure, and what constitutes a failure (e.g., a failure is a sometimes hidden failure).
- **Test Methods**: Need to define fire hose failure, and what constitutes a failure (e.g., a radiant heat test failure is a sometimes hidden or non-obvious failure).
- **Data**: Need better data analysis and analytics to match failure occurrences with proposed test methods. Guide the specifics of proposed test methods.
- **Case Studies**: Beyond the database, establish a portfolio of useful and educational case studies.
- **Test Methods**: Re-evaluate field test methods to better match true fireground conditions (e.g., need for dynamic pressure tests beyond only static).
- **Test Methods**: Need to clarify the parameters for a test method; e.g., pressures used for a test.
- **Test Methods**: Make sure that test methods are realistic and address all aspects of the test procedure, and do not inhibit other innovative approaches such as air gaps, weaving, etc.
- **Future Innovation**: Consider and promote innovative future materials, methods, and approaches (e.g., IoT RFID automatic tracking).

5) Are there any additional topics or questions that should be addressed?

- Fire hose and water delivery is a critical life safety tool on the fire ground, and needs to be considered as a high priority in the fire fighting equipment package.
- Consider addressing fire hose and related equipment in the water supply chain with similar importance with PPE.
- Consider the contamination issue of fire hose to address fire fighters long term health and safety.
- Coordinate with NFPA 1700 activities that address fireground tactics and the fire environment.

---

**Figure 52: GREEN Breakout Group Report (page 2 of 2)**
**RED Breakout Group Report**

*Fire Hose Workshop in Support of the Technical Committee*

To support the Technical Committee on Fire Hose with the information necessary to ensure first responders have the fire hose to be safe and effective...

Denver, Colorado
24-25 May 2016

---

**RED GROUP MEMBERS**

- Andrew Ellison – Red Leader
- Daniel Gorham – Secretary
- Adam St. John
- Dan Rossos
- David Quick
- Gerard Garcia
- Jeff Hebenstreit
- Kathy Crosby-Bell
- Marc Radecky
- Mark Donovan
- Michael Aubuchon
- Mike Reger
- Tim Vanderlip
- William Graves
- Jack Murphy

---

**BREAKOUT GROUP QUESTIONS - RED GROUP**

1) **What are the capabilities of current fire hose?**
   - Friction loss
   - Maneuverability
   - Kink resistance
   - Mildew resistance
   - Abrasion resistance
   - Packing
   - Cut resistance, snag resistance
   - Rigidity in support of nozzle maneuverability/operation
   - Operating pressure
   - Chemical resistance
   - Range of incidents (interior structure, industrial, vehicle, wildland)
   - Cheap hose – limited durability (abrasion resistance)
   - Liner delamination
   - Coupling failure prior to hose failure –
     - Fire hose failure

2) **What expectations do consumers, users, and maintainers have for fire hose?**
   - Fire hose above floor level
   - UV and weather resistance
   - Direct contact with hot material – weight of hose (below) and weight of object (above)
   - Nonconductive (electrically)
   - Friction loss tolerances
   - “Bring water to the fire”
   - Perform within the environment we are in
   - Same performance expectations of PPE
   - 15-year service life (multiple uses)
   - Fire hose fire proofing

3) **What, if any, are feasibility restrictions in fire hose improvement?**
   - Flex fatigue
   - Availability of materials
   - Market product potential to create unwanted problems by solving others
   - Time to development of new products
   - Testing – responsible and reproducible
   - Life expectancy
   - Budget of fire department
   - Trust in hose meeting the standard will meet the requirements of the user
   - Tests are inadequate for real-world conditions
   - Does not recognize products that exceed minimum requirements

---

*Figure 53: RED Breakout Group Report (page 1 of 2)*
### Breakout Group Questions - RED GROUP

**4) What, if any, are the gaps between expectations and capabilities of fire hose?**

- Expectations of equipment conforming to standard will perform in the modern fire environment
- Perception of equipment capabilities
- Service life of fire hose
- Availability of materials
- Performance evaluation – new vs. used
- Rotating fire hose
- Required 3rd party testing – new and in-service
- Off-gassing of materials
- Defining operational environment
  - Where on the fireground: actions of fire, front yard, back to water supply
  - Quantification of source vs. conditions
- Where on the fire curve do you test? What is the situation
- End-user education
- Determination of fire hose as tool or safety equipment
- What is the environment you are preparing for: worst-case or other?

**5) Are there any additional topics or questions that should be addressed?**

- Synthetic performance
- End-user (firefighter) education of what you are doing and why you are doing it to make better education on what to use
- Developing equipment that allows FFs to go where they should not be going
- Need to define lightweight hose
- Coordination for FF ensemble capabilities
- Tracking of fire hose failures
- Why is fire hose not be defined as a part of the life saving equipment?
- Rating of equipment – needs to be recognizable by users
- Tool vs. Safety equipment
### BLUE Breakout Group Report

**Fire Hose Workshop in Support of the Technical Committee**

To support the Technical Committee on Fire Hose with the information necessary to ensure first responders have the fire hose to be safe and effective...

Denver, Colorado  
24-25 May 2016

---

#### BREAKOUT GROUP QUESTIONS - BLUE GROUP

1) What are the capabilities of current fire hose?
   - Lack of information to determine what capabilities of current fire hose is
   - Thermal resistance
   - Abrasion resistance
   - Chemical resistance
   - Packability
   - Flexibility
   - Based on comments (or lack of) from users of fire hose (firefighters) it seems to meet their needs

2) What expectations do consumers, users, and maintainers have for fire hose?
   - More than one material
   - Manageable weight
   - Easy storage – lay flat in hose bed
   - Consumer expects tool and PPE – only tool that puts the fire out
   - Fire hose can be in a location different than firefighter (unlike PPE)
   - Fire hose will be used to cool down before advancing into building
   - Not realistic to take house out-of-service to dry and hang – time required, need backup hose
   - Maintenance records (including age) should be known for hose.

3) What, if any, are feasibility restrictions in fire hose improvement?
   - Cost to customer
   - Material properties limit capabilities (e.g. Kevlar provides good thermal resistance but is brittle)
   - Use of fire hose and tactics differ between fire departments
   - One-size-fits-all approach limits ability for users to get what they need
   - Perception that NFPA 1961 compliant is sufficient for all needs
   - Fire service culture has not changed has the job and conditions have
   - Manufacturer-purchaser interaction not required with online purchases – questions can go unanswered
   - Distinction between quality and capabilities of hose is not clear in purchasing process – leads to price being the primary decision point

#### BREAKOUT GROUP QUESTIONS - BLUE GROUP

3) What, if any, are feasibility restrictions in fire hose improvement?
   - Technology is ahead of standards
   - Reactive vs. proactive nature of standard – needs of the fire service will drive change
   - Lack of data makes standard development difficult

---

Figure 55: BLUE Breakout Group Report (page 1 of 2)
Annex D: ATF Memo

Adam St. John presented a memorandum to the workshop participants on Tuesday 24/May/2016. The memo incorporates minor editorial revisions to the one distributed at the workshop.
MEMORANDUM TO: Technical Committee Members, NFPA 1961

FROM:
Lisa A. Herb
Special Agent/Certified Fire Investigator – Candidate
Bureau of Alcohol, Tobacco, Firearms and Explosives

Adam St. John P.E.
Fire Protection Engineer
ATF Fire Research Laboratory

SUBJECT: Thermal Analysis of Radiant Heat on Interior Fire Attack Hose

BACKGROUND

The National Institute of Occupational Safety and Health (NIOSH) Fire Fighter Fatality Investigation and Prevention Program (FFFIPP) contacted the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) Fire Research Laboratory (FRL), requesting thermal analysis of several popular models of firefighting interior attack hoses. NIOSH documented several incidents of attack hoseline thermal failure (rupture) during firefighting operations. A notable recent incident involved two firefighter fatalities in a multi-unit brownstone structure in Boston, Massachusetts on March 26, 2014. While attempting suppression operations, two Boston firefighters became trapped in the basement of the structure after their hoseline burned through. The firefighters transmitted several MAYDAY requests over the radio following the hoseline rupture. The following is an excerpt from the NIOSH Firefighter Fatality Investigation report (Report #F2014-09, 2016):

“During this incident, the 1¾-inch attack hoseline used by Engine 33 was burned through during the initial fire-fighting operations. Engine 33 had stretched the hoseline down the stairs from the first floor to the basement. This placed the hoseline in the flow path of the fire and super-heated gases coming up the stairs. The 1¾-inch hoseline was burned completely in two. The 2½-inch hoseline that Engine 7 stretched to the first floor was severely damaged as well.

During the investigation of this incident, NIOSH Fire Fighter Fatality Investigation and Prevention Program (FFFIPP) investigators reviewed previous cases and identified several instances in which hoselines had been burned through during structural fire-fighting operations. Current hoseline standards do not address the thermal performance of attack hoselines, and technical information published by manufacturers does not include thermal performance data. Attack hose is defined by
NFPA 1961 *Standard on Fire Hose* as “hose designed to be used by trained fire fighters and fire brigade members to combat fires beyond the incipient stage. Attack hose is designed to convey water to hoseline nozzles, distributor nozzles, master stream appliances, portable hydrants, manifolds, standpipe and sprinkler systems and pumps used by fire departments.” The hoseline serves not only as a tool to help extinguish the fire but also provides a measure of safety to the hoseline crew. Attack hose can be used as a means to locate an escape route in the event of Mayday or other emergency.

In an effort to better understand the thermal performance of attack hose, NIOSH FFFIPP investigators contacted the Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF) for assistance. In response, the ATF Fire Research Laboratory began a series of tests to explore the impact of radiant heat on attack hose. The ATF Research Laboratory established heat flux values and developed full-scale tests to replicate fireground conditions. To date, the testing has included full-scale burns and bench testing using samples of new and used 1 1/2-inch attack hose of varying grades and construction” (p. 63).

Several other significant fire incidents involving hoseline thermal failure have occurred as recently as February 7th, 2016 in Raytown, Missouri, where firefighters were trapped inside an apartment building and two civilians, a grandmother and her grandson, perished in the fire (Eckert & Webster, 2016). Worcester Polytechnic Institute recently developed a database to track hoseline burn-through incidents. As of October 2015, according to the database, there have been over 172 reported hoseline burn-through incidents (Notarianni & Ranfone, 2015).

Research has shown that structure fires involving modern fuels develop significantly faster than several decades ago. The modern fire environment can change rapidly when ventilation is added during firefighting operations. While improvements have been made to firefighter protective clothing (turnout gear) and respiratory protection (Self Contained Breathing Apparatus) over the past two decades, the thermal standards to which fire hose is evaluated has remained unchanged.

ATF research was conducted in two phases: full scale scoping fire testing and bench scale laboratory testing. The intent of the bench scale laboratory testing was to establish a repeatable, small scale testing protocol to evaluate hoseline samples. The samples of pressurized fire attack hose were exposed to constant levels of radiant heat (expressed in units of kW/m²) in a laboratory environment. Several full scale scoping tests were also conducted in acquired structures with the goal of validating and expanding on the bench scale data. In both tests, the elapsed time to hoseline failure was recorded. Failure was defined as a significant loss of operating pressure, usually associated with rupture of the interior lining of the fire hose. Failure and rupture are used interchangeably throughout this document and are referencing the same end result. The purpose of the tests was to provide general data regarding the thermal performance of fire attack hose to the FFFIPP, the fire service and fire investigation community.
EXPERIMENTATION

Full Scale Scoping Test Method

Prior to conducting bench scale laboratory testing, a series of full scale scoping fire tests were conducted in four acquired structures to gain a better understanding of thermal conditions on the fireground at the time of hoseline rupture. The purpose of the full scale scoping tests was to...
record the approximate heat flux level (radiant exposure) and temperature at the time of rupture. The measured heat flux at the time of failure in the full scale scoping tests was then used for subsequent bench scale testing in the laboratory.

Three 1 ¾ inch (4.45 centimeter) hoselines were routed in parallel throughout the first and second stories of an acquired structure as shown in Figure 6. One hose was dry and unpressurized; one hose was pressurized with water (static) and the third hose was pressurized with water flowing through the nozzle as documented in Figure 5. The time to rupture and associated heat flux level was recorded for each test burn.

Figure 3: Front exterior of townhouse structures used in full scale scoping tests.

Figure 4: Interior of townhouse unit used in full scale scoping tests. Note the hoselines running through the front doorway.
Figure 5: Examples of parallel hoseline labeling from the 2nd full scale scoping test burn.

Figure 6: Interior stairway and parallel positioning of fire hose in full scale scoping tests (post-fire).
Figure 7: Heat flux values (y-axis) versus time (x-axis) for full scale scoping test - burn 1.

Figure 8: Heat flux values (y-axis) versus time (x-axis) for full scale scoping test - burn 4.
Full Scale Scoping Test Results

In the four full scale scoping tests, the measured heat flux values at the time of hoseline failure varied. The hoselines ruptured when the measured radiation levels at the floor ranged from 14-35 kW/m². These heat flux values were typically measured as flames extended along the ceiling (rollover) above the hoseline, just prior to the flashover transition. All hoselines in all four full scale scoping tests failed when the heat flux exceeded 40 kW/m².

Accordingly, in the bench scale laboratory testing, each hoseline was tested at two relative (low and high) heat flux levels, 30 and 40 kW/m². These heat flux values are typically experienced as a room transitions through the flashover stage. As listed in the table (Figure 9), the heat flux measured in a post-flashover or “fully-involved” room can exceed 150 kW/m². Common heat flux exposures associated with compartment fires are listed below as published in NFPA 921: Guide for Fire and Explosives Investigations, 2014 Edition (p. 27).

<table>
<thead>
<tr>
<th>Approximate Radiant Heat Flux (kW/m²)</th>
<th>Comment or Observed Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Nominal solar constant on a clear summer day.</td>
</tr>
<tr>
<td>5.0</td>
<td>Human skin experiences pain with a 13-second exposure and blisters in 29 seconds with second-degree burn injury.</td>
</tr>
<tr>
<td>10.0</td>
<td>Exposed Human skin experiences pain with a 5-second exposure and blisters in 10 seconds with second-degree burn injury.</td>
</tr>
<tr>
<td>20.0</td>
<td>Heat flux on a residential family room floor at the beginning of flashover.</td>
</tr>
<tr>
<td>29.0</td>
<td>Wood ignites spontaneously after prolonged exposure.</td>
</tr>
<tr>
<td>[30.0]</td>
<td>“Low” Heat Flux Value used for ATF thermal analysis of hoselines (based on full scale scoping test data).</td>
</tr>
<tr>
<td>[40.0]</td>
<td>“High” Heat Flux Value used for ATF thermal analysis of hoselines (based on full scale scoping test data).</td>
</tr>
<tr>
<td>52.0</td>
<td>Fiberboard ignites spontaneously after 5 seconds.</td>
</tr>
<tr>
<td>[−]180.0</td>
<td>Heat flux for protective clothing Thermal Protective Performance (TPP) test.</td>
</tr>
<tr>
<td>170.0</td>
<td>Maximum heat flux as currently measured in a post flashover fire compartment.</td>
</tr>
</tbody>
</table>

Figure 9: Excerpt from NFPA 921 (2014 Edition) Chapter 5, Table 5.5.4.2 “Effect of Radiant Heat Flux” with ATF thermal analysis of hoselines heat flux values incorporated.

The heat flux values recorded at the floor of a compartment fire will vary significantly as a fire develops. It is difficult to quantify a “typical” firefighting operating environment as incident Thermal Analysis of Radiant Heat on Interior Attack Hose Bureau of Alcohol, Tobacco, Firearms and Explosives May 21, 2016

Figure 63: ATF memo to the technical committee (Page 7 of 16)
heat flux values fluctuate significantly as a fire develops. The elapsed time for firefighting equipment to thermal failure is dependent on both time and relative heat flux values. Failure of Personal Protective Equipment (PPE) can occur at relatively low heat flux levels (less than 10 kW/m²) for long durations or high levels (80 kW/m²) for short durations.

Accordingly it was decided to maintain constant heat flux levels at 30 and 40 kW/m² and compare the relative times to failure for the various models of hose line tested. NFPA 1971 Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting follows a similar protocol for establishing a Thermal Protective Performance (TPP) rating for turnout gear. NFPA 1971 establishes a TPP test method that turnout gear is evaluated at a constant heat flux of about 84 kW/m² and the elapsed time for skin burns to develop is recorded. This analysis method allows for a relative comparison between firefighter turnout gear designs.

**Bench Scale Laboratory Test Method**

A series of 78 Bench Scale Laboratory Tests were conducted at the ATF FRL using an electric resistance coil heater affixed to a metal platform. The bench scale laboratory testing was intended to simulate the same heat flux exposure seen in the full scale scoping tests at the time of hose line failure in a repeatable environment. Each test was conducted with the hose line pressurized with air or water to a typical operating pressure of 120 psi (827 kPa).

For repeatability purposes, the bench scale testing followed the ignition testing protocol outlined in the American Society for Testing and Materials testing standard - ASTM E 1354-14e1. It was the intent of the researchers to follow an existing thermal exposure standard in order to ensure that future additional testing could be conducted by other interested parties. The electric resistance coil heater used is the industry standard for evaluating heat flux and ignition times of laboratory samples as detailed in ASTM E 1354-14e1.

Once the hose line was pressurized, it was then positioned 1-inch (25.4 mm) below the electric resistance coil heater. A 6-inch (152.4 mm) portion was exposed to the radiant heater. Reference Figures 12-14 for an overall view of the test setup.

![Diagram of the electric resistance coil heater from cone calorimeter from Standard ASTM E1354-14e1.](image)

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Figure 11: Diagram of cross-section view of the electric resistance coil heater from the cone calorimeter ASTM standard E1354-14e1.

Figure 12: Close-up of the resistance coil heater with fire hose line placed horizontally 1 inch (25.4 mm) below.
Rupture times were recorded using a stopwatch, starting when the coil heater shutter opened, exposing the hose sample to radiant heat and ending when the hose exhibited significant pressure loss (rupture).
Figure 15: Visible damage to fire hose after exposure to 40 kW/m².
This particular hose failed in 51 seconds. It performed the best out of the commercially available hose tested demonstrated by the longest recorded elapsed times to failure when exposed to 40 kW/m².

Bench Scale Laboratory Test Results

All hoselines evaluated during the bench scale laboratory tests were new with the exception of Mercedes Textiles Aquaslow Plus, which was evaluated both new and used. The used sections of hose were samples provided by the Boston Fire Department. The hose models were selected and provided to ATF by NIOSH in an attempt to evaluate a range of popular models and construction techniques. It is important to note that the brand name, model and materials were included in this document for informational purposes only. No endorsements are being made and the brands selected by NIOSH for evaluation may not represent the most thermally robust hoselines available in the current fire hose market.

During hose testing with pressurized water, dynamic and sometimes violent failure of the hose occurred. At the time of hose failure rupture, water was documented traveling over 30 feet vertically and significant damage to the electric resistance coil heater occurred on several occasions requiring replacement of the heating element. Accordingly, each hose was first tested with charged air and then the results were verified with a limited number of pressurized water tests to avoid unnecessary damage to the coil heater. Hoseline data from the 78 bench scale laboratory tests are listed in Figure 16.
<table>
<thead>
<tr>
<th>Hoseline Model</th>
<th>Hoseline Manufacturer</th>
<th>Time to Rupture (Seconds)</th>
<th></th>
<th></th>
<th></th>
<th>Manufacturer Supplied Product Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquaflex Plus</td>
<td>Mercedes Textiles</td>
<td>40:37</td>
<td>29:30</td>
<td>40</td>
<td>43</td>
<td>14</td>
</tr>
<tr>
<td>Aquaflex Plus (USFD)</td>
<td>Mercedes Textiles</td>
<td>40:37</td>
<td>29:30</td>
<td>40</td>
<td>43</td>
<td>14</td>
</tr>
<tr>
<td>Combat Ready</td>
<td>Key Hose</td>
<td>40:30</td>
<td>34:52</td>
<td>40</td>
<td>47</td>
<td>19</td>
</tr>
<tr>
<td>Cotton Blended Double Jacket</td>
<td>Prototype</td>
<td>49</td>
<td>34</td>
<td>99</td>
<td>42</td>
<td>Prototype; Cotton/Poly; Rubber Lining</td>
</tr>
<tr>
<td>Duraflow</td>
<td>Key Hose</td>
<td>51</td>
<td></td>
<td>69</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>Evo-10</td>
<td>Key Hose</td>
<td>50:00</td>
<td>37:30</td>
<td>47</td>
<td>42</td>
<td>14</td>
</tr>
<tr>
<td>Flexline Premier</td>
<td>Angus Fire</td>
<td>76:00</td>
<td>47:44</td>
<td>106</td>
<td>78</td>
<td>19</td>
</tr>
<tr>
<td>Kirfor Jacket</td>
<td>Prototype</td>
<td>73:70</td>
<td>55</td>
<td>115:100</td>
<td>54</td>
<td>Prototype</td>
</tr>
<tr>
<td>Kraken Exo</td>
<td>Mercedes Textiles Limited</td>
<td>57:58</td>
<td>42:52</td>
<td>65</td>
<td>52</td>
<td>15</td>
</tr>
<tr>
<td>Magnum Lite</td>
<td>Key Hose</td>
<td>55:40</td>
<td>39:20</td>
<td>40</td>
<td>45</td>
<td>14</td>
</tr>
<tr>
<td>XL-400</td>
<td>Niederer</td>
<td>36:32:34</td>
<td>26:32:25</td>
<td>33</td>
<td>22</td>
<td>13</td>
</tr>
</tbody>
</table>

**Figure 16:** Bench scale laboratory testing results of hoseline models listed in alphabetical order; Several hoselines of the same model were subjected to multiple tests at the same heat flux; The rupture time is recorded under the appropriate column title and separated with slash marks.

**DISCUSSION**

NFPA 1961 currently includes a single test that addresses thermal failure of attack hoseline. The existing standard addresses heat transfer to the hoseline via conduction through a steel block placed on a non-pressurized hoseline as outlined below:

"Requirements: An 18 in. (455 mm) length hose assembly shall be subjected to a hydrostatic pressure of three times the service test pressure, without leakage or other damage, after exposure to a heated steel block."

**Test/Verification:** The hose sample shall be filled with water, evacuated of all air, capped at both ends, and conditioned at room temperature for 24 hours. A 2 1/2 x 8 in. (65 x 205 mm) steel block shall be conditioned in an oven maintained at 500°F (260°C) for a minimum of 16 hours. Within 5 seconds of removal from the oven, the steel block shall be placed on the hose so that the longitudinal axis of the block is perpendicular to the longitudinal axis of the hose. The contact area shall be the midpoint of the 2 1/2 in. (65 mm) side of the block and the midpoint of the hose. A metal knife edge shall be used as a support near one end of the block to obtain maximum force on the hose. The block shall be removed after 60 seconds. The hose shall then be allowed to cool and shall be
hydrostatically pressurized to three times the service test pressure” (FM Approvals LLC, 2014, p. 14).


According to the fire hose manufacturers, all hoselines tested (excluding the prototype models) met or exceeded the performance requirements of NFPA 1961; however, significant variation was observed. The 1¼ inch (4.45 centimeter) hoselines charged with water to 120 psi (827 kPa) demonstrated failure times that ranged from 33 seconds to 106 seconds at the lower heat flux of 30 kW/m². At 40 kW/m², the failure times varied for water charged hoselines from 22 seconds to 70 seconds. This thermal performance data is not available to the fire service and the end-user firefighter has no relative data indicating how thermally robust their hoseline is.

The relative “heat sink” effect of water in the hoseline also had varied results. Some hoselines experienced significantly greater times to failure (~50 seconds longer) in the bench scale laboratory tests when charged with water while others showed little, if any greater thermal endurance. In the first full scale scoping test, the flowing water hoseline failed prior to the hoseline charged with water (static). In the fourth full scale scoping test, the hoseline charged with water (static) failed prior to the flowing water hoseline. More testing is required to understand the variables affecting these results.

In the bench scale laboratory testing, it appeared that radiant heat degraded the exterior hoseline materials, causing rupture of the pressurized hoseline before the water inside the hoseline could absorb significant heat energy. The limited “heat sink” effect of water inside the hoseline is consistent with the “Full Scale Exposure Testing of Hoselines” performed by NIST (Madrzykowski, 2015). In the NIST testing, all three hoselines (charged with water (static); charged with air; and charged flowing water) failed within several seconds of each other.

**Heat Transfer Comparison Analysis of Firefighter Turnout Gear**

It was requested by members of the NFPA 1961 Technical Committee that ATF evaluate a swatch of popular firefighter turnout gear at the same 30 kW/m² and 40 kW/m² heat flux values used to evaluate the hoselines. The data was compared to the relative thermal failure times of the hoselines. The purpose of the analysis was to provide general data to the fire service community estimating which event; thermal hoseline failure or skin burns, would be expected to occur first at constant heat flux levels. Additional research is necessary in order to formulate conclusions involving these test comparisons.

It should be noted that the electric resistance coil heater is not the typical testing apparatus used to evaluate firefighter turnout garment thermal performance, however a direct comparison to the hoseline thermal exposure was of interest. A common turnout gear garment with a published TPP rating of 37 was selected. NFPA 1971: Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting requires a minimum TPP rating of 35. It should be
noted that a higher TPP rating would be expected to delay the elapsed time to skin burns at both heat flux exposures tested in these experiments.

A heat flux gauge was placed underneath the turnout garment swatch and heat flux values were recorded throughout the test. NFPA 921: Guide for Fire and Explosion Investigations states that at a heat flux value of 5 kW/m² “human skin experiences pain with 13-second exposure and blisters in 29 seconds with second degree burn injury” (p. 27; also see Figure 9). This data is consistent with the “Stoll Burn Curve” developed by Alice Stoll, which is used to establish turnout garment TPP rating (Stoll & Chianta, 1968). The elapsed time for the heat flux gauge to read 5 kW/m² on the inside layer of the swatch was recorded and used as the estimated point in time when second degree skin burns could be expected to possibly occur for the purposes of this comparison. Four tests were conducted, two at each heat flux value used for the hoseline testing (30 kW/m² and 40 kW/m²). The estimated time to reach the 5 kW/m² threshold was 61 seconds for 30 kW/m² and 49 seconds for the 40 kW/m². Many variables affect exactly when human skin would be expected to blister or burn, this comparison should be used only for general comparison purposes.

SUMMARY

Despite each hoseline meeting the testing criteria outlined in NFPA 1961, the observed variation among the hoseline models tested support the need for a standardized heat flux test to provide thermal resistance data to the fire service. Similar to a TPP rating for turnout gear, this data would allow the end-user firefighter to better understand the limitations of their equipment and compare relative hoseline designs. A standardized heat flux test could also be advantageous for hoseline manufacturers attempting to develop and compare more thermally robust hoseline designs.

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