Protection From Exposure to Smoke Particles Using New Technology
Topics

What we will cover

• Introductions
• History of firefighter protective clothing
• Firefighter stresses and fatality statistics
• Smoke particles, toxicity and their impacts
• Existing PPE vs protection
• New technology – Nomex® Nano Flex
• Summary
Introductions
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FDNY Battalion Chief- Retired
Consultant
Jian Xiang
Global Technical Leader
Emergency Response
DuPont Protection Solutions
Kevin Roche
Phoenix Fire Department - Retired Consultant
History of Firefighter Protective Clothing and Equipment
• Rubber coats and ¾ boots
• Chemox rebreather masks
• Self-Contained Breathing Apparatus - SCBA
• Better bunker gear – new fabrics replace rubber
• Full bunker gear – bunker pants replace ¾ boots
• Personal Alert Safety Systems – PASS
• Hoods for head protection
History of Firefighter Protective Clothing and Equipment

Each advancement in firefighter PPE

- Allowed firefighters to survive
- Better protection
- Additional weight – physical stress
- Heat stress
Firefighter Stresses
and Fatality Statistics
Fire Environment Exposures

- Burns and thermal injuries
- Heat stress
- Physiological stress – high rate of work
- Emotional – danger and urgency
- Physical – structural collapse, explosion
- Chemical exposure – smoke, liquids, gases, vapors

Not the Typical Workplace
2015 Firefighter Fatality Statistics

• Approximately 100 Line-of-Duty Deaths (LODD’s) each Year
  – 90 in 2015
  – 65 in 2016 (9/30/2016)

• Down from the 1970’s

• Statistics do NOT count occupational diseases such as cancer

On-Duty Firefighter Deaths 1977-2015

Firefighter Cancer Deaths

Rise in Firefighter Cancer Deaths Since 1950


More Lives Lost to Cancer Than to LODD
Smoke Is Deadly

You guys do realize that the smoke is just as dangerous as the fire, right?
Studies of Cancer in Firefighters

NIOSH Study

• Chicago, San Francisco, Philadelphia fire departments from 1950 - 2009

• Phase I – 30,000 Firefighters,
  – Firefighters had more cancer deaths and cancer cases than expected
  – These were mostly digestive, oral, respiratory and urinary cancers

• Phase II - 20,000 Firefighters
  – Significantly positive association between fire hours and lung cancer and leukemia mortality

Cancer Risk Higher Than General Population

https://www.cdc.gov/niosh/firefighters/pdfs/FAQ-NIOSHFFCancerStudy.pdf
https://www.youtube.com/watch?v=hOvBypsaHq
Smoke Particles,
Toxicity and Their Impacts
Why Are Smoke and Soot Particles Toxic?

Smoke is an aggregate of gases, aerosols, and solids that are toxic, flammable and volatile

**Gases**
- Carbon monoxide
- Hydrogen cyanide
- Sulfur dioxide
- Formaldehyde

**Aerosols**
- A mixture of liquid droplets and solid particles
  - Volatiles
  - Semi-volatiles

**Solids**
- Soot
- Asbestos fibers

**Soot Particles**
- Byproduct of incomplete combustion
- Small size but large surface area
- Absorbs multiple chemicals
- Particle size less than 1 micron

**Impacts on Health**
- Coronary heart disease
- Stroke
- Cancer
- Upper and lower respiratory diseases

Soot is a Carrier for Toxic Chemicals

**Semi-Volatile Organic Compounds**
(Gas & condensed form with low vapor pressure)
- Phthalates
- Perfluorinated surfactants
- Polycyclic Aromatic Hydrocarbons (PAH)
- Polybrominated flame retardants (PBDE)

**Volatile Organic Compounds**
(Evaporate at room temperatures)
- Benzene
- Toluene
- Naphthalene
- Xylene

**Typical Toxic Chemicals in Fire Suppression**

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Fabian et al, Characterization of Firefighter Smoke Exposure
Carcinogens Found during and after Fires

### International Agency for Research on Cancer (IARC)

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Place</th>
<th>IARC Group*</th>
<th>Physical State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbestos</td>
<td>Fire Ground, PPE</td>
<td>1</td>
<td>Aerosol, particulate</td>
</tr>
<tr>
<td>Soot</td>
<td>Fire Ground, PPE</td>
<td>1</td>
<td>Particulate</td>
</tr>
<tr>
<td>Benzene</td>
<td>Fire Ground,</td>
<td>1</td>
<td>Gas</td>
</tr>
<tr>
<td>Benzo[a]pyrene</td>
<td>Fire Ground, PPE</td>
<td>1</td>
<td>Aerosol, particulate</td>
</tr>
<tr>
<td>1,3- Butadiene</td>
<td>Fire Ground, PPE</td>
<td>1</td>
<td>Aerosol, particulate</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>Fire Ground</td>
<td>1</td>
<td>Gas</td>
</tr>
<tr>
<td>Dioxin</td>
<td>Fire Ground, PPE</td>
<td>1</td>
<td>Aerosol, particulate</td>
</tr>
<tr>
<td>Diesel engine exhaust</td>
<td>Fire Station, PPE</td>
<td>1</td>
<td>Aerosol, particulate</td>
</tr>
<tr>
<td>Wood combustion</td>
<td>Fire Ground, PPE</td>
<td>1</td>
<td>Aerosol, particulate</td>
</tr>
<tr>
<td>Creosote</td>
<td>Fire Ground, PPE</td>
<td>2A</td>
<td>Aerosol, particulate</td>
</tr>
<tr>
<td>Polybrominated diphenyl ethers</td>
<td>Fire Ground, PPE, Station</td>
<td>2A</td>
<td>Aerosol, particulate</td>
</tr>
</tbody>
</table>

- Group 1 – Carcinogenic to humans
- Group 2A – Probably carcinogenic to humans
- Group 2B – Possibly carcinogenic to humans
- Group 3 – Not carcinogenic to human
- Group 4 – Probably not carcinogenic to humans

http://monographs.iarc.fr/ENG/Classification/index.php
Toxic Exposure Pathways vs PPE Protection

Absorption

Distribution

Metabolism

Ingestion
• Protected by SCBA

Inhalation
• Protected by SCBA

Skin Contact
• Protected by Turnouts
  – Gloves
  – Hoods
  – Boots

Is Existing Protection from PPE Enough?
Studies on Particle Exposures

**Study Objectives**
- Where are chemicals?
- What are the chemicals?
- Are the chemicals toxic?
- Do they exceed federal regulation limits
- What does this mean to firefighters

**Sample sources**
- Air
- Skin
- Urine
- Blood
- Soiled gear, glove, hood, etc.

Toxic Substances Are Measurable
Study Conclusions

- Smoke and chemical vary.
- Exposure in overhaul is as dangerous as in suppression.
- Wearing SCBA correctly reduces particle exposure.
- Amount chemicals on skin correlate with the concentration found in air.
- Particle chemicals are more prevalent in air than on skin and gear.
- PPE helps to reduce chemicals permeation to skin.
- Concentration of the toxic organic chemicals on neck was higher than other skin areas.

PAH on Necks Are Higher than Other Areas
Existing PPE vs Protection
**Skin Absorption Rates vs Protection**

- Forehead, Ear and Jaw Are Highly Absorptive but Least Protected
- Current Hood Is the Least Expensive of the Entire PPE

<table>
<thead>
<tr>
<th>Item</th>
<th>Average ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helmets</td>
<td>350</td>
</tr>
<tr>
<td>Hoods</td>
<td>45</td>
</tr>
<tr>
<td>Turnout Coats</td>
<td>1300</td>
</tr>
<tr>
<td>Flashlights</td>
<td>90</td>
</tr>
<tr>
<td>Gloves</td>
<td>80</td>
</tr>
<tr>
<td>Glass 2 Harness</td>
<td>650</td>
</tr>
<tr>
<td>Pagers</td>
<td>150</td>
</tr>
<tr>
<td>turnout Pants</td>
<td>900</td>
</tr>
<tr>
<td>Leather Fire Boots</td>
<td>350</td>
</tr>
<tr>
<td>SCBA</td>
<td>3500</td>
</tr>
<tr>
<td>SCBA Face Piece</td>
<td>300</td>
</tr>
<tr>
<td>Corective lens holder</td>
<td>90</td>
</tr>
<tr>
<td>Portable Radios</td>
<td>1500</td>
</tr>
<tr>
<td>Thermal Image Camera</td>
<td>2500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11805</strong></td>
</tr>
</tbody>
</table>

[http://www2.ca.uky.edu/agcomm/pubs/pat/pat6/pat6.pdf](http://www2.ca.uky.edu/agcomm/pubs/pat/pat6/pat6.pdf)
Taking Action Against Cancer in the Fire Service

Skin Absorption Rate Increases with Temperature Rise

Increase in absorption for every 5° increase in skin temperature

Neck Exposure vs Protection

FAST TEST
(Fluorescent Aerosol Screen Test)

Test Conditions
• 10 MPH
• 0.1-10 microns
• 30 minutes

Neck and ear exposure
• Very thin skin
• Open pores
• Fast absorption
• Used for heat awareness

Protection
• Two layers of knit for comfort
• Air permeable - breathability

Neck is Insufficiently Protected from Particulates

Sponsored by: International Association of Fire Fighters Washington, D.C
New Technology
Nomex® Nano Flex
**Particle Barrier 101**

**Particle Blocking Mechanism**

**Blocking efficiency**
- A measure of the ability of barrier to stop particles in the airstream

**Key critical factors to performance**
- Size of fibers (fiber diameter)
- Number of fibers
- Closeness of fibers (pore size)
- A coating to repel soils

**System of Particle Filtration Application**

<table>
<thead>
<tr>
<th>Type</th>
<th>Size Range (µm)</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Filtration</td>
<td>75-2000</td>
<td>Beach Sands</td>
</tr>
<tr>
<td>Fine Filtration</td>
<td>1.5 - 75</td>
<td>Flour &amp; Yeast</td>
</tr>
<tr>
<td>Microfiltration</td>
<td>0.1-1.5</td>
<td>Smog &amp; Smoke</td>
</tr>
<tr>
<td>Ultrafiltration</td>
<td>0.002-0.1</td>
<td>Viruses</td>
</tr>
<tr>
<td>Hyper filtration</td>
<td>0.0001-0.002</td>
<td>Molecules &amp; Ions</td>
</tr>
</tbody>
</table>

http://www.fischer-robertson.com/tools_filtration_101.htm
Particle Barrier Hood Requirements

- Soot blocking
- Fire resistant
- Durable
- Breathable
Introduce DuPont Nomex® Nano Flex

Nonwoven Fibers

Submicron Continuous

Inherently Flame Resistant

- At least 1/100 smaller than human hair
- Between submicron and nano scale
- Stand-alone in sheet or in roll
- Elastic and non-elastic form
  - Nomex® Nano – non-elastic
  - Nomex® Nano Flex - elastic

Nomex® Nano Flex Is a Thin, Light, Breathable, Highly Flame Resistant Material
Improved Thermal Protection

Typical Particle Barrier hood Composition

- Knit
- Barrier
- Knit

Performance vs. Function of layers in Particle Barrier Hood

- Filtration efficiency
- Thermal protection
- Breathability
- Durability
  - Wash
  - Mechanical challenges
  - UV

Contributed by Barrier

Contributed by Knit

Thermal Protection Performance (TPP)

- Hood without Nomex® Nano Flex
  - Before Wash: 27.1
  - After wash: 28.5
- Hood with Nomex® Nano Flex
  - Before Wash: 34
  - After wash: 37.6

• Improve TPP by 26%
• Add only 10gm or 6% additional weight
• Increase thickness only by 4%
Particle Blocking Efficiency

% Particle Blocking Efficiency
(Air Flow 1.6 cm/s)

% Efficiency

Particle Size (µm)

Current Hood  Nomex® Nano Flex + Knit  25 Wash Nomex® Nano Flex + Knit

0.1  99.7  99.6  99  98.9  99  99  99.3  98.7  99.7  99.2
0.2  99  99  99  99  99  99  99.3  98.7  99.7  99.2
0.3  99  99  99  99  99  99  99.3  98.7  99.7  99.2
0.5  99  99  99  99  99  99  99.3  98.7  99.7  99.2
0.8  99  99  99  99  99  99  99.3  98.7  99.7  99.2

* ASTM F2299 & AATCC 135

• Barrier Hood Improved Efficiency by 3-4X
• Efficiency Maintained after 25 Washes
Dramatically Reduces Particle Penetration

Test Conditions
• 10 MPH
• 0.1 – 10 Micron
• 30 minutes

No Barrier | With Barrier
Without Nomex® Nano Flex | With Nomex® Nano Flex
FAST Swab Test – Quantitative Validation

**Test Protocol**
- Take swab sample 1 inch diameter circular areas
  - Control - from helmet
  - Test samples - four samples at locations shown in the pictures
- Performed particle count

<table>
<thead>
<tr>
<th>Aerosol Mass (µg/in²)</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Barrier</td>
<td>With Barrier</td>
<td>No Barrier</td>
<td>With Barrier</td>
</tr>
<tr>
<td>Samples on Head Form</td>
<td>54.35</td>
<td>*BDL</td>
<td>57</td>
<td>*BDL</td>
</tr>
<tr>
<td>Control on Helmet</td>
<td>34.66</td>
<td>93.72</td>
<td>58.16</td>
<td>66.32</td>
</tr>
</tbody>
</table>

*BDL - Below Minimum Detection Limit. MDL = 0.18 (µg/in²)

No Particles Were Detected When Protected by Nomex® Nano Flex Barrier Hoods
### Breathability

<table>
<thead>
<tr>
<th>COMPOSITE</th>
<th>THL (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Turnout Gear</td>
<td>268</td>
</tr>
<tr>
<td>2 x 6.25 osy Nomex® IIIA + Nomex® Nano Flex</td>
<td>431</td>
</tr>
<tr>
<td>2 x 8.5 osy Nomex® + Nomex® Nano Flex</td>
<td>349</td>
</tr>
</tbody>
</table>

### AIR PERMEABILITY (CFM/FT² @ 0.5" H₂O)

- **DUPONT SIERRA FACE MASK ML3700**: 46.2 CFM/FT²
- **2 x 7.0 OSY + NOMEX® NANO FLEX**: 24.5 CFM/FT²
- **PBI/KEVLAR® OUTER SHELL**: 14.8 CFM/FT²
- **IMPERMEABLE BARRIER**: 0 CFM/FT²

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**Superior THL and Air Permeability**
Wear Trial Validation

Outside of Hybrid Hood
w & w/o
Nomex® Nano Flex

Hood Inside-out
with
Nomex® Nano Flex

Hood Inside-out
without
Nomex® Nano Flex

Fine Particles Barrier,
Breathable,
Heat Flux Sensitive
## NFPA 1971 Current Standards

<table>
<thead>
<tr>
<th>NFPA Standard</th>
<th>Nomex® Nano Flex Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Resistance</td>
<td>√</td>
</tr>
<tr>
<td>Flame Resistance</td>
<td>√</td>
</tr>
<tr>
<td>Thermal Shrinkage</td>
<td>√</td>
</tr>
<tr>
<td>TPP &gt;= 20 Cal/cm²</td>
<td>√</td>
</tr>
</tbody>
</table>

## NFPA 1971 -2018 New Standards

<table>
<thead>
<tr>
<th>Performance Criteria</th>
<th>NFPA Proposed Standard</th>
<th>Nomex® Nano Flex Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle Blocking Efficiency (%)</td>
<td>&gt;90</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Comfort – THL (W/m²)</td>
<td>&gt;=325</td>
<td>&gt; = 350</td>
</tr>
<tr>
<td>Durability – Burst Strength (lbs.)</td>
<td>&gt;= 102 lbs. (Composite)</td>
<td>&gt; 102 (composite)</td>
</tr>
</tbody>
</table>

**Met Current and New NFPA 1971**
Summary
Nomex® Nano Flex Provides:

• Protection from most common particulates
  – Areas not protected by current PPE
  – High absorption areas
• Flexibility
• Breathability
• Thermal protection
Cancer Prevention Strategies

**In Station**
- Reduce exposure to diesel exhaust
- Change HVAC filters regularly and frequently

**During fire and Overhaul**
- Stay on-air through overhaul
- Wear particle barrier hood and other PPE

**After Fire**
- Gross Decon at the scene
- PPE laundering
- Shower within the hour – or sauna
- Drink a lot of liquids

**General Health**
- Exercise
- Healthy diet – Tobacco Cessation
- Annual Medical Exams

Challenge Mindset
Challenge the Way We Fight Fires
Thank You

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Robert Key    fdnyconsulting@gmail.com
Kevin Roche   kevin.roche@facetsllp.com
Questions

For More Information about Nomex® Nano Flex and Nomex® Nano

DuPont™ Website

Globe Website

Fire-Dex Website
http://www.firedex.com/product/h41-interceptor/

PGI Website
http://www.pgi-inc.com/
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