Firefighter Chemical Exposure Research: What Firefighters Need to Know

Kenneth W. Fent, PhD, CIH

CDR, U.S. Public Health Service

Research Industrial Hygienist

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Outline

- Carcinogenic exposures
  - Exposure pathways
  - Inhalation
  - Dermal absorption
- Update on IFSI/UL/NIOSH studies
- Hood contamination study
- Recommendations for reducing exposures
- Ongoing and future research

EXPOSURE PATHWAY

Source → Composition → Transport / contact → Intensity → Duration → Absorption route → Dose

Firefighters' Carcinogenic Exposures

Current understanding and limitations

Source → Composition → Transport / contact → Intensity → Duration → Absorption route → Dose

- Materials used in vehicles, homes, and other structures are increasingly synthetic
  - Polymers: foams, plastics, resins, coatings
  - Chemicals added as flame retardants, stain resistance, plasticizers
- Modern structures burn faster than mid-20th century structures
  - 5 min to flashover vs. 30 min*
- Toxic combustion byproducts
  - Hundreds of chemicals produced

Homeadvisor.com

* Kerber (2011) Fire Technology

Potential Sources of Exposure

Residential fire (photo by IAFF.org)

Dumpster fire (public domain)

Vegetation fire (photo by Physics.org)

Industrial fire (photo by Eastern Daily Express)

Car fire (photo by NIOSH)

Training fire (photo by NIOSH)

Source → **Composition** → Transport / contact → Intensity → Duration → Absorption route → Dose

CHEMICAL CLASS	POTENTIAL HEALTH EFFECTS
Polycyclic aromatic hydrocarbons (PAHs)	**Carcinogenic** (benzo[a]pyrene)
Volatile organic compounds (VOCs)	**Carcinogenic** (benzene, 1,3-butadiene), central nervous system effects
Aldehydes	**Carcinogenic** (formaldehyde), respiratory sensitizer (formaldehyde), pulmonary edema (acrolein)
Acid gases	Respiratory irritation, pulmonary edema, chemical asphyxiation (HCN)
Phthalates	Endocrine disruption, **liver tumors in animals** (DEHP)
Polybrominated diphenyl ethers (PBDEs)	Accumulates in the body, thyroid, liver, immune system effects, neurodevelopmental effects, **liver tumors in animals** (deca-BDE)
Dioxins and furans	Accumulates in the body, similar health effects as PBDEs, **carcinogenic** (TCDD)
Organophosphate flame retardants (OPFRs)	Neurotoxicity, cytotoxicity
Diesel exhaust	**Carcinogenic**

May be produced when organic materials are burned

May be produced when synthetic materials are burned

Source → Composition → Transport / contact → Intensity → Duration → Absorption route → Dose

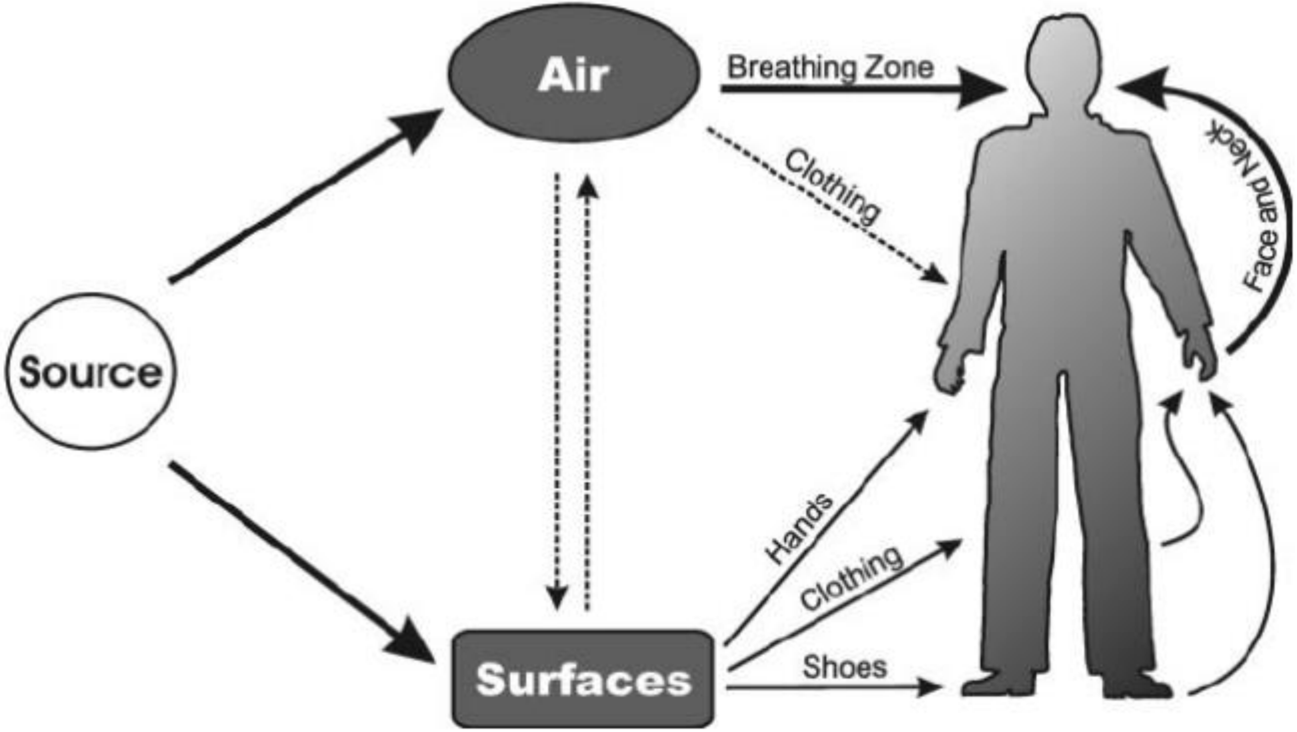
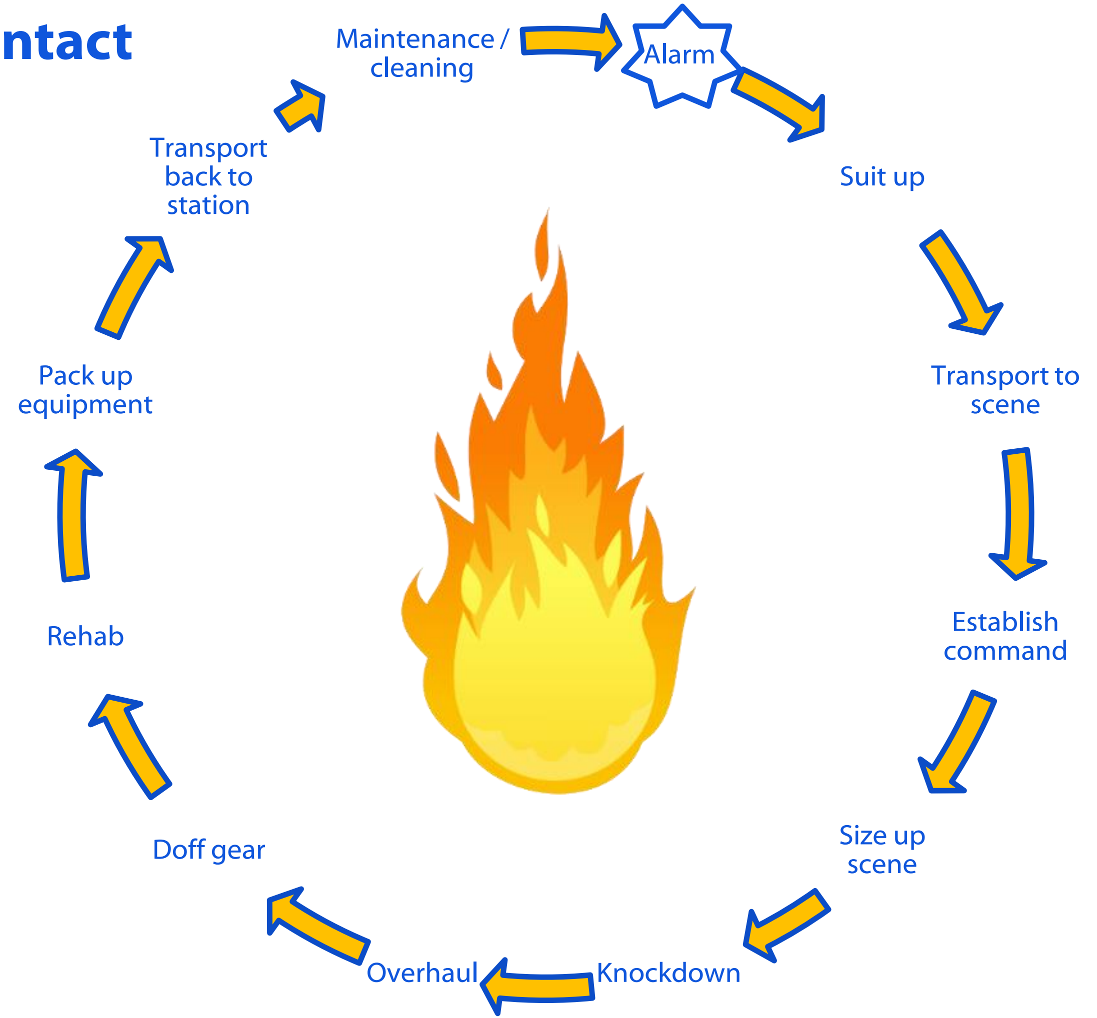


Figure by Day et al. 2007. Ann Occup Hyg. 51(1):67-80

Potential for Chemical Contact

* Also during live-fire and simulated smoke training



PPE Contamination

- PAHs, phthalates, flame retardants, and metals have been measured on turnout gear[1-4]
- PAHs and flame retardants have been measured on Nomex hoods[5]
- Hose and other equipment likely contaminated

1. UL Firefighter Exposure to Smoke Particulates (2010)
2. Fent et al. (2017)
3. Kirk et al. (2015)
4. Easter et al. (2016)
5. Alexander and Baxter (2016)

Tracking Contamination Back to Station?

- Higher levels of FRs have been measured in fire station dust than other occupational settings
  - Vacuum dust from 25 metro stations
  - Most abundant congeners in fire station dust have been found in high concentrations in the fire environment

THE APPARATUS BAY. PHOTO BY LARA SWIMMER, COURTESY OF SCHACHT ASLANI ARCHITECTS.

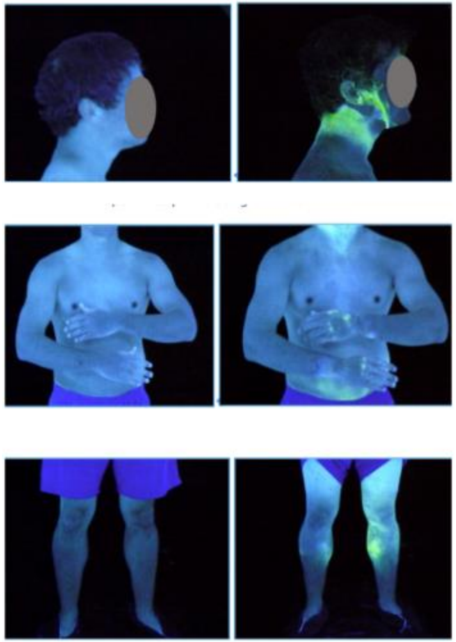
Presentation by Sharyle Patton (2017)

Source → Composition → Transport / contact → **Intensity** → **Duration** → Absorption route → Dose

Dermal Exposures during Knockdown

- **PAH contamination on wrist, neck, forehead, and back[1]**
- **Neck may be especially vulnerable**
  - Significantly higher PAH levels on neck after firefighting[2]

Before After



Jeff Stull, RTI study commissioned by IAFF

1. Presentation by Dr. McCarry, McMaster University (2013)
2. NIOSH Report 2010-0156 (2013), Fent et al. (2014)

PAH = polycyclic aromatic hydrocarbon

Exposures during Overhaul

- **Inhalation exposure possible if respiratory protection is not worn**
  - Compounds > short-term exposure or ceiling limits: Acrolein, CO, formaldehyde, glutaraldehyde, benzene, NO_2, SO_2, PAHs[1,2]
- **Levels of exposure will depend on:**
  - Time-lapse from suppression to the next activity
  - Amount of natural or mechanical ventilation
  - If materials are still smoldering
  - If there are any dead-air spaces
- **Dermal exposure possible if protective clothing is not worn**

1. Bolstad-Johnson et al. (2000)
2. NIOSH Report 2010-0156 (2013)

CO = carbon monoxide, NO_2 = nitrogen dioxide, SO_2 = sulfur dioxide, PAH = polycyclic aromatic hydrocarbons

Fireground Exposures

- Sizing up the fire without SCBA
- Exterior operations without SCBA
- Diesel exhaust exposure – Group 1 human carcinogen[1]

* Currently lacking reliable data on fireground exposure levels

1. IARC (2012)

Off-Gassing Gear

- **Volatile compounds will off-gas from gear and can be inhaled**
  - Benzene, toluene, ethylbenzene, xylenes, styrene, and HCN have been measured at elevated levels (compared to background)
  - Well below short-term exposure limits, but yet another source of exposure[1,2]

Photo Courtesy of Anderson Career and Technology Center

** Semi-volatile compounds can off-gas for weeks, months, or even years, but this exposure pathway has not been well characterized.*

1. Fent et al. (2015)
2. Kirk et al. (2015)

HCN = hydrogen cyanide

Training and Other Fires

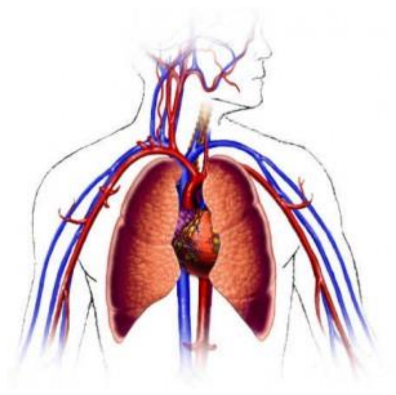
- **<u>Vehicle fires</u>:** High levels of formaldehyde, acrolein, carbon monoxide, and isocyanates[1]
- **<u>Class A fuels (e.g. pallet and straw):</u>** High levels of PAHs, aldehydes, HCN and CO[2-4]
- **<u>Simulated smoke</u>:** High levels (above short-term exposure limits) of mineral oil mist and/or glycols[5]
- **<u>Simulated smoke and propane burners</u>:** High levels of formaldehyde and acrolein[5]

Simulated smoke training

1. NIOSH Report 2008-0241 (2010)
2. UL Firefighter Exposure to Smoke Particulates (2010)
3. Kirk and Logan (2015)
4. Feunekes et al. (1997)
5. NIOSH Report 2012-0028 (2013)

Exposure Duration

- **Initial exposure period is typically short**
- **High intensity, short duration exposures may be more hazardous**
  - Respiratory irritants, sensitizers, and asphyxiants – can overwhelm the respiratory system
  - Carcinogens – may present greater risk of cancer[1]
  - Particles – can precipitate cardiovascular events[2]
- **Extends beyond the fireground (contaminated gear and equipment)**



1. Kodell et al. (1987), Chen et al. (1988), Murdoch et al. (1992), Halmes et al. (2000)
2. Brook et al. (2004)

Absorption Route

- Inhalation is the most direct route of entry and most important to control
- Particles/soot that contact the skin can be absorbed[1]
- Some vapors (e.g., benzene) can also be absorbed through skin[2]
- Chemicals absorb faster through thinner skin (e.g., neck)
- Dermal absorption may increase with increasing:
  - Concentration, ambient temperatures, skin temperatures, humidity, and sweat[3]

Hydrocortisone relative absorption[4]

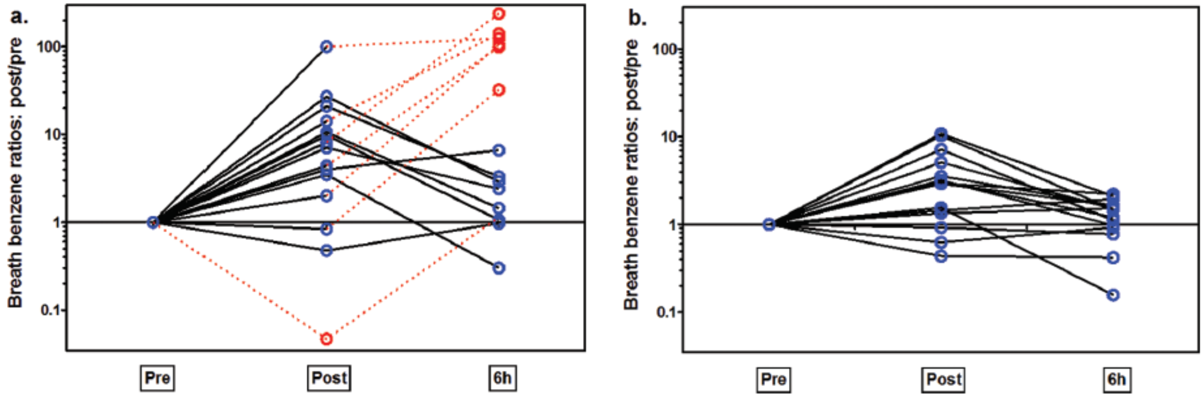
Plantar foot arch	1
Lateral ankle	3
Palm	6
Ventral forearm	7
Back	12
Scalp	25
Forehead	43
Jaw angle	93
Scrotum	**300**

1. VanRooij et al. (1993)
2. Bader et al. (2008), Piotrowski (1967, 1971), Weschler and Nazaroff (2012)
3. Franz (1984), Jones et al. (2003)
4. Feldmann & Maibach (1967)

Source → Composition → Transport / contact → Intensity → Duration → Absorption route → Dose

Biological Absorption

- **Elevated levels of contaminants (i.e., PAHs) in the body after firefighting[1-4]**
  - Recent studies show 2-fold to 8-fold increases in specific PAH metabolites
- **Increasing urinary PAHs and exhaled breath levels of benzene with increasing air concentrations of PAHs[5]**
  - Firefighters wore SCBA throughout the response
  - Dermal absorption was hypothesized as the primary route of entry
  - Systemic exposure levels generally similar to occupational groups with low exposures.
- **Elevated levels of flame retardants in California firefighters[6,7]**



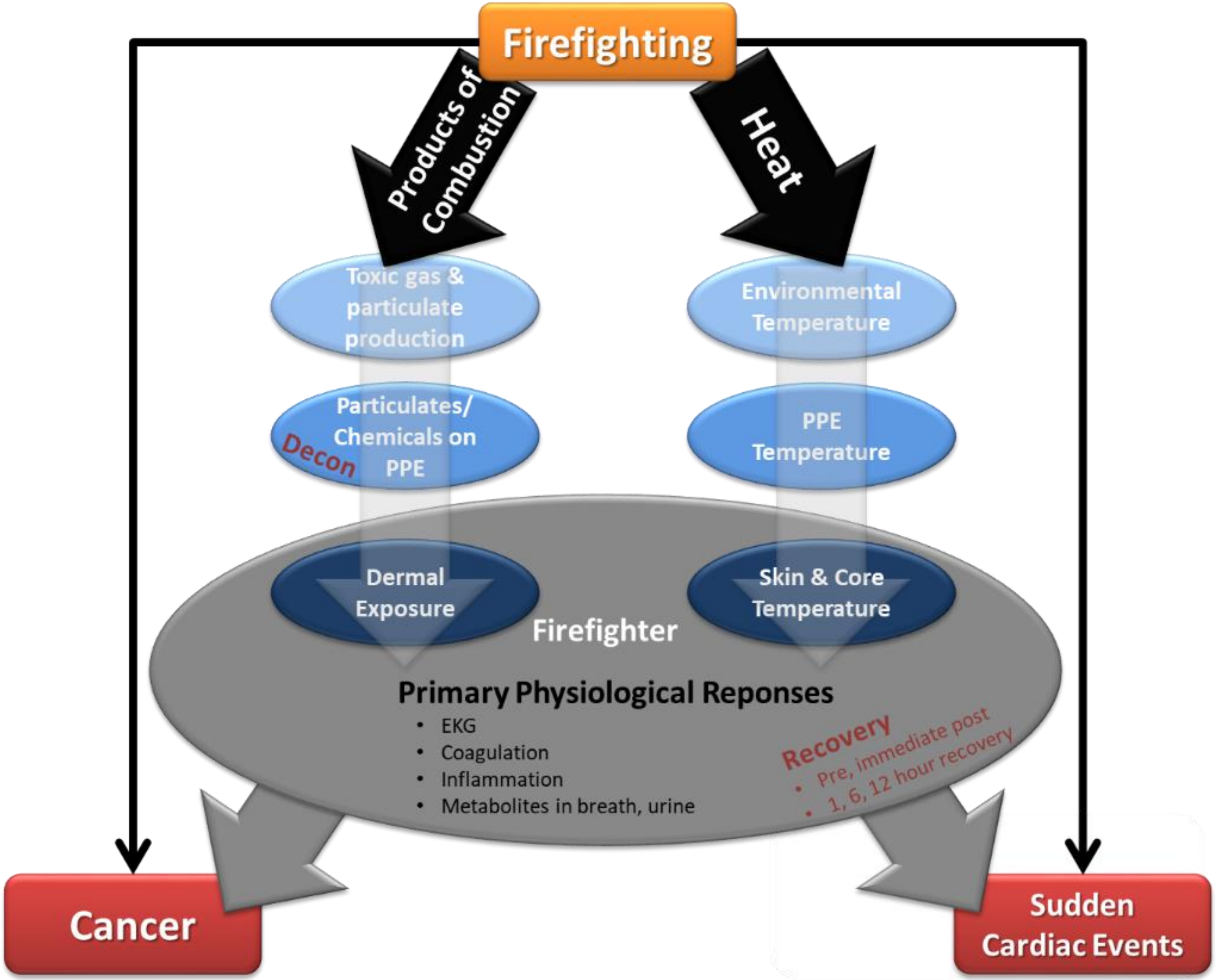
1. Caux et al. (2002)
2. Laitinen et al. (2009)
3. Keir et al. (2017)
4. Wingfors et al. (2017)
5. NIOSH Report 2010-0156 (2013), Fent et al. (2014)
6. Park et al. (2015)
7. Shaw et al. (2013)

Knowledge Gaps

- **How do the following factors affect exposure?**
  - Job assignment
  - Attack tactic (interior vs. transitional attack)
  - Environmental conditions
- **What is the effectiveness of the following control interventions?**
  - Gross on-scene decon of turnout gear
  - Laundering of turnout gear (hoods)
  - Use of skin cleansing wipes

IFSI/UL/NIOSH Modern Fire Study of 2015

VIDEO: **https://www.youtube.com/watch?v=uZO3GO1Nd-E**



Firefighting
Products of Combustion
Heat
Toxic gas & particulate production
Environmental Temperature
Particulates/ Chemicals on PPE
Decon
PPE Temperature
Dermal Exposure
Skin & Core Temperature
Firefighter
Primary Physiological Reponses
• EKG
• Coagulation
• Inflammation
• Metabolites in breath, urine
Recovery
• Pre, immediate post
• 1, 6, 12 hour recovery
Cancer
Sudden Cardiac Events

Participants

- **40 firefighters recruited from across the country**
  - Between the ages of 18 and 55 years old
  - Not a smoker or other tobacco user
  - Have no known cardiovascular diseases, history of any neurological disorders or digestive complications
  - Have completed an NFPA 1582 based physical in the past year

- Canton (IL)
- Cleveland (OH)
- Cobb County (GA)
- Corn Belt FPD (IL)
- Danville (IL)
- Decatur (IL)
- Hanover Park (IL)
- IAFF Local 4416 (IN)
- IAFF Local 1147 (IL)
- Kenosha (WI)
- Lafayette (IN)
- Milwaukee (WI)
- Mt Carmel (IL)
- Oakwood (IL)
- Savoy (IL)
- Sioux Falls (SD)
- Springfield (IL)
- Streamwood (IL)
- Wayne Township (IN)
- West Lafayette (IN)

Fireground Roles

- **The teams were separated into pairs that completed specific tasks.**
  - Compliment of 4 firefighters arriving every 1 minute
  - Engine 1 –
    - A - **Interior** firefighters responsible for the attack line and
    - B - **Exterior** based command and pump operator positions.
  - Truck –
    - A - **Interior** firefighters responsible for forcible entry into the structure as well as search and rescue
    - B - **Exterior** ventilation (horizontal and vertical).
  - Engine 2
    - A - Pulled a back-up line and supported the first-in engine prior to **overhaul** operations.
    - B - Initially set up as a rapid intervention team (RIT) then transitioned to **overhaul** operations after the fire was suppressed.

Fire Suppression Tactics

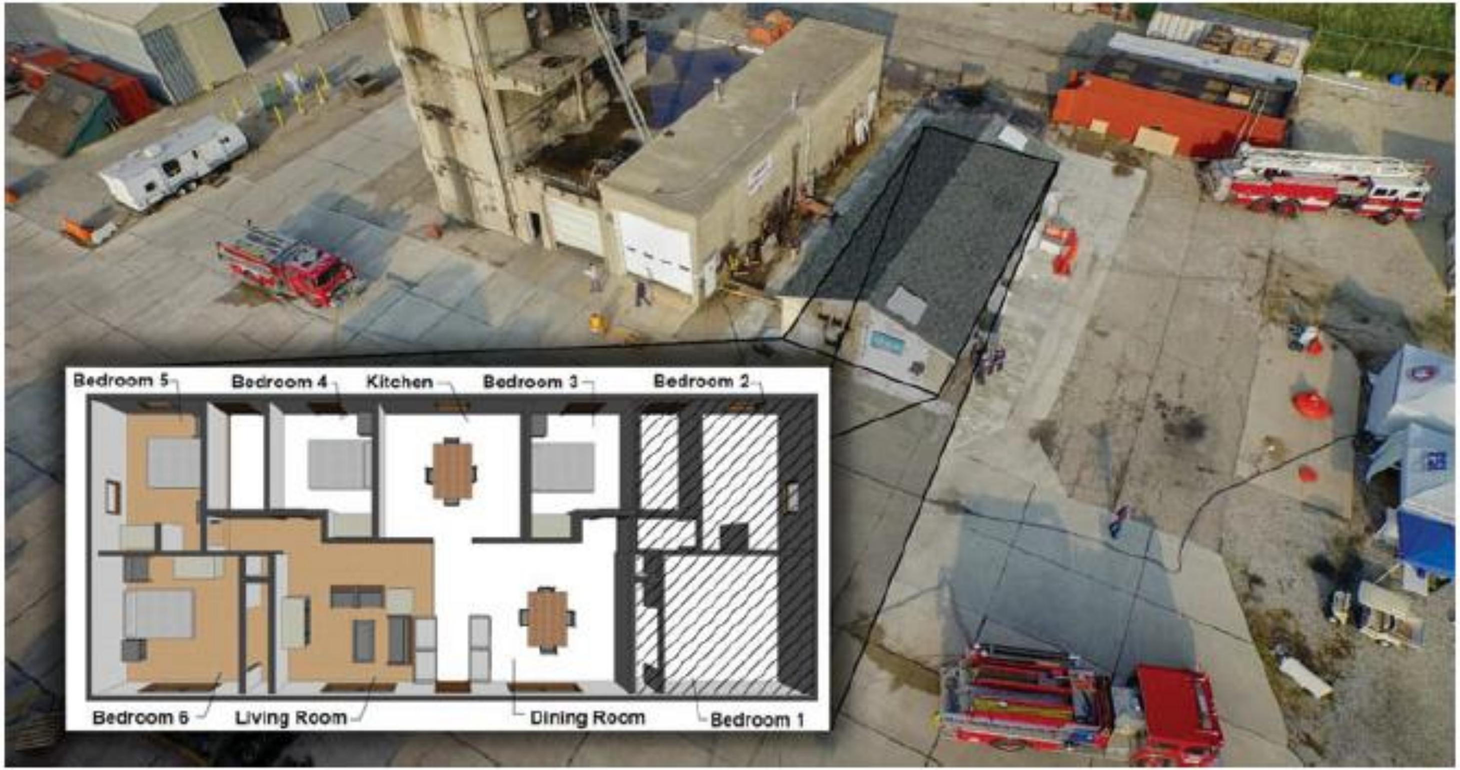
- First line through the front door

- Hit from exterior then transition through front door

Comprehensive Study

- **We sought to answer multiple questions: grouped by**
  - Temperature/gas exposure (for FF and victim)
  - Cardiovascular strain
  - Chemical exposure – especially related to carcinogenic risk (for FF and victim)

New Research Burn Structure



Fuel Load

- Fires set in two bedrooms
- Ventilation-limited fires

Living Room

Kitchen

Bedroom 1/6

Bedroom 2/5

Bedroom 3/4

Dining Room

Coordinated Attack

Conditions at dispatch

Attack Team deploying transitional attack

Attack Team transitions to front door as Search Team forced door prop

Attack Team makes entry followed by Search Team

Backup line is deployed as outside ventilation is taking place

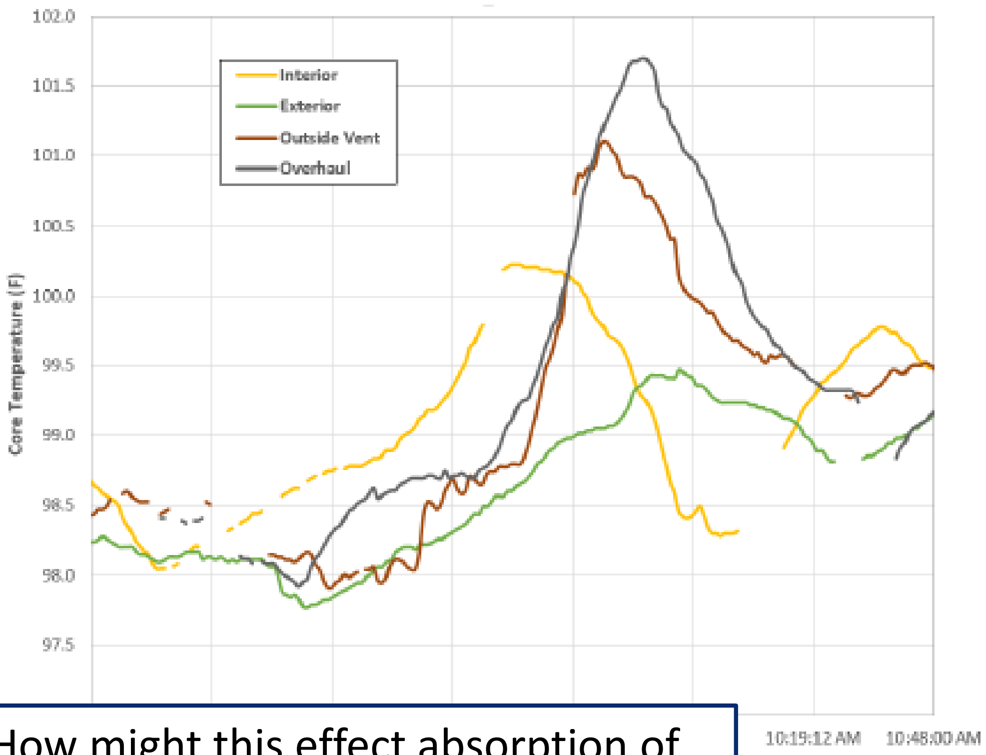
Roof is ventilated as fire is suppressed

Simulated occupant is rescued by Search Team

Overhaul Teams remove debris and drywall from fire rooms

Thermal Strain

- Neck skin temps were increased for all job assignments except for command
- Interior attack resulted in lower (~0.5°C) neck skin temps
- Significantly higher core temperatures were found for **outside vent** and **overhaul** firefighters than inside positions (~0.6-0.9°C difference)



How might this effect absorption of chemical contaminants?

More Information

- Full text freely available at https://www.tandfonline.com/doi/full/10.1080/00140139.2017.1355072

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Thermal response to firefighting activities in residential structure fires: impact of job assignment and suppression tactic

Gavin P. Horn[a], Richard M. Kesler[a], Steve Kerber[b], Kenneth W. Fent[c], Tad J. Schroeder[a], William S. Scott[d], Patricia C. Fehling[e], Bo Fernhall[f] and Denise L. Smith[a,e]

[a]Illinois Fire Service Institute, University of Illinois, Urbana, IL, USA; [b]UL Firefighter Safety Research Institute, Columbia, MD, USA; [c]National Institute for Occupational Safety & Health, Cincinnati, OH, USA; [d]Carle Physician Group, Urbana, IL, USA; [e]Skidmore College, Saratoga Springs, NY, USA; [f]Department of Kinesiology and Nutrition, University of Illinois at Chicago, Chicago, IL, USA

ABSTRACT

Firefighters' thermal burden is generally attributed to high heat loads from the fire and metabolic heat generation, which may vary between job assignments and suppression tactic employed. Utilising a full-sized residential structure, firefighters were deployed in six job assignments utilising two attack tactics (1. Water applied from the *interior*, or 2. Exterior water application before *transitioning* to the interior). Environmental temperatures decreased after water application, but more rapidly with transitional attack. Local ambient temperatures for inside operation firefighters were higher than other positions (average ~10–30 °C). Rapid elevations in skin temperature were found for all job assignments other than outside command. Neck skin temperatures for inside attack firefighters were ~0.5 °C lower when the transitional tactic was employed. Significantly higher core temperatures were measured for the outside ventilation and overhaul positions than the inside positions (~0.6–0.9 °C). Firefighters working at all fireground positions must be monitored and relieved based on intensity and duration.

Practitioner Summary: Testing was done to characterise the thermal burden experienced by firefighters in different job assignments who responded to controlled residential fires (with typical furnishings) using two tactics. Ambient, skin and core temperatures varied based on job assignment and tactic employed, with rapid elevations in core temperature in many roles.

ARTICLE HISTORY
Received 11 January 2017
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KEYWORDS
Firefighting; core temperature; heat stress; heat strain; body temperature

1. Introduction

Heat stress is one of the most common challenges that firefighters routinely encounter. Because firefighters perform strenuous work while wearing heavy, insulating personal protective equipment (PPE), a rise in body temperature almost always accompanies firefighting activity. High heat loads from the fire can also add to the heat stress experienced by firefighters. The physiological and thermal strain of firefighting activities have been documented based on simulated fireground work. The change in core temperature associated with firefighting activities has been reported by several research groups (Colburn et al. 2011; Horn et al. 2013; Hostler et al. 2010; Walker et al. 2015). Firefighting involves strenuous work that leads to maximal or near-maximal heart rates (HR) and, in some cases, rapid changes in core temperature (Tco) (Barr, Gregson, and Reilly 2010). Horn et al. (2011), reported average changes of 0.70 °C during short bouts of firefighting activity typical of residential 'room and contents' fires. The researchers noted that repeated bouts of firefighting or the use of multiple cylinders of air is associated with further increases in body temperature. It is important to note, however, the vast majority of work that has been done characterising the thermal stress of firefighting has occurred during training fires or in controlled laboratory conditions. Training fires differ considerably from residential fires in terms of the geometry of the structure, building materials and fuel loads. Because of these factors, firefighters may experience different thermal environments, as well as different chemical exposures, during actual fires in residential buildings than in a training burn. Recent measurement of ambient temperatures inside common structure fires have further detailed risks posed by firefighting activities in modern structure fires (Kerber 2013). However, these studies have not included human subjects. Portable thermal data acquisition systems carried by firefighters have

CONTACT Gavin P. Horn ghorn@illinois.edu

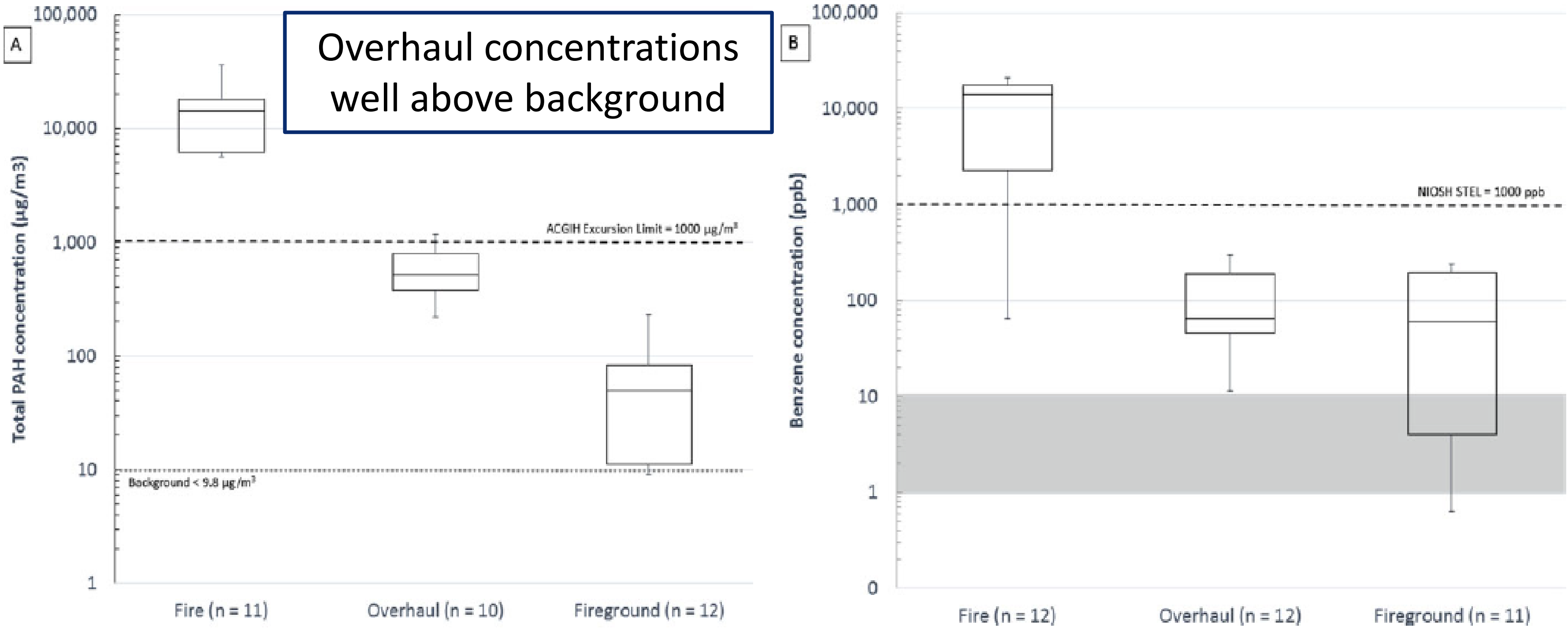
Personal Air Concentrations

Firefighters doing overhaul and outside vent should be on air

Analyte	Personal air concentrations					Most protective short-term occupational exposure limits[B]
	Assignment	n[A]	ND (%)	Median	Range	
HCN (ppb)	Attack	13	0	33,500	4,100 – 100,400	NIOSH STEL: 4,700 ppb
	Search	17	29	85	<60 – 106,000	NIOSH IDLH: 50,000 ppb
	Overhaul	39	2.6	249	<20 – 1,380	
	Outside vent	21	0	16,300	98 – 72,900	
	Command/Pump	24	0	379	50 – 3,560	
Total PAHs ($\mu g/m^3$)	Attack	19	0	23,800	7,460 – 78,200	ACGIH excursion limit (coal tar pitch volatiles): 1,000 $\mu g/m^3$
	Search	16	0	17,800	9,770 – 43,800	
	Overhaul	43	0	512	105 – 2,220	
	Outside vent	18	0	96	33 – 547	
	Command/Pump	23	48	<30	<30 – 220	
Benzene (ppb)	Attack	17	0	40,300	12,400 – 322,000	NIOSH STEL: 1,000 ppb
	Search	22	0	37,900	12,000 – 306,200	
	Overhaul	47	6.4	902	<6 – 2,970	
	Outside vent	22	14	204	<9 – 883	
	Command/Pump	24	58	<10	<10 – 297	

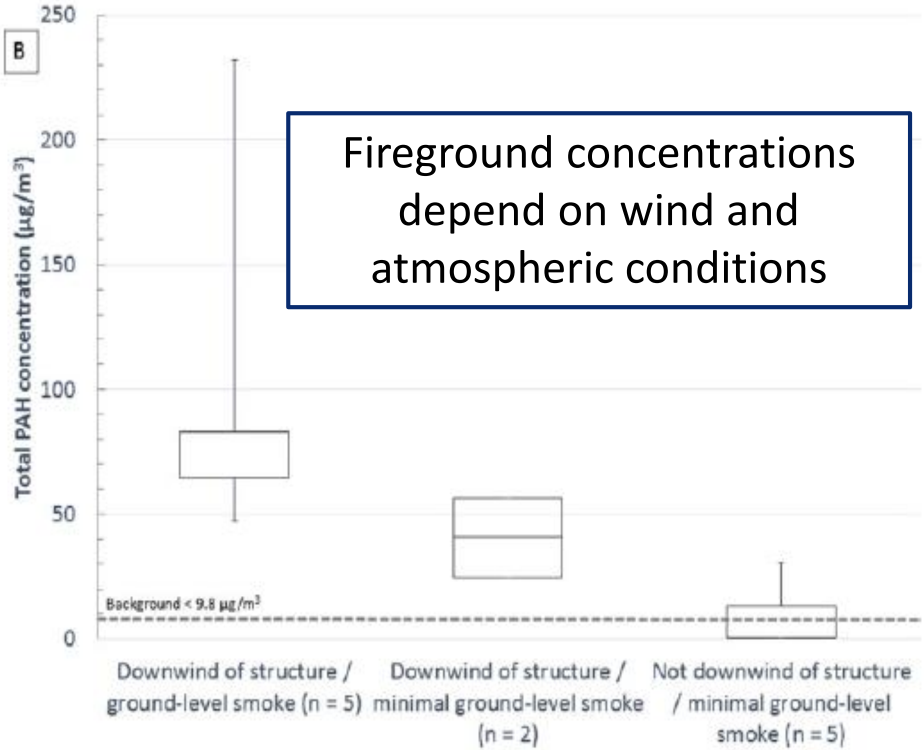
** Tactic did not appear to have an effect on the personal air concentrations*

Air Concentrations by Stage of Response

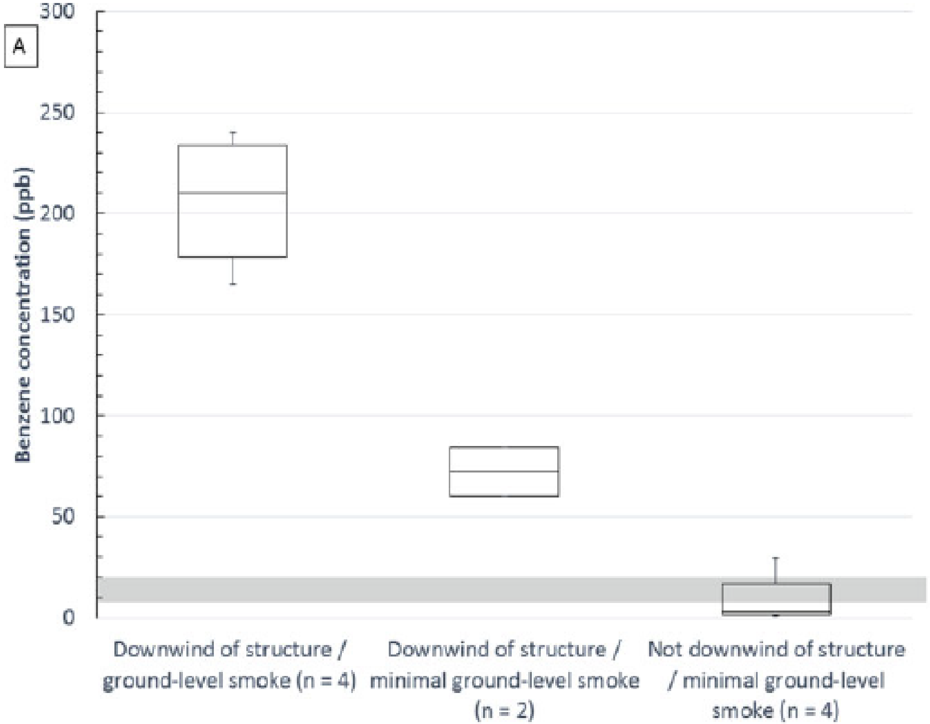


Overhaul concentrations well above background

Fireground Concentrations by Environmental Conditions



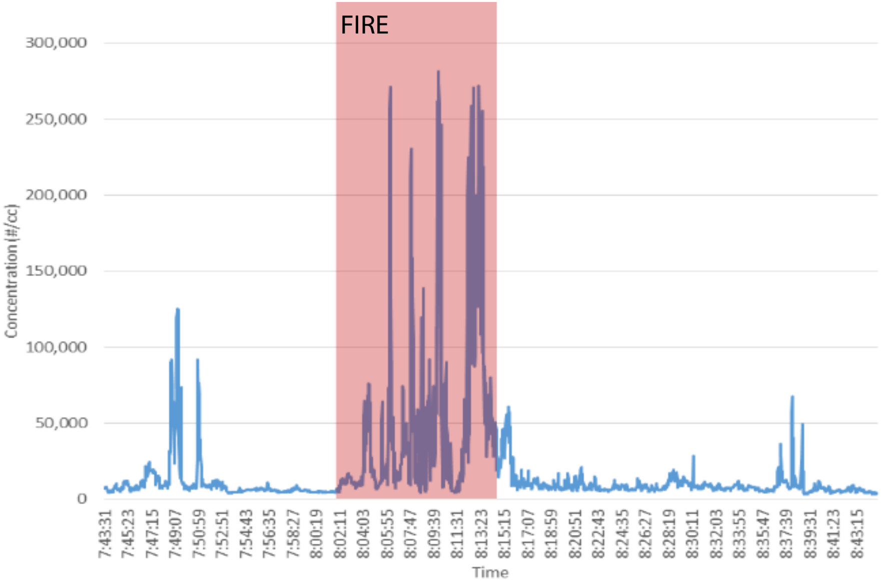
Fireground concentrations depend on wind and atmospheric conditions



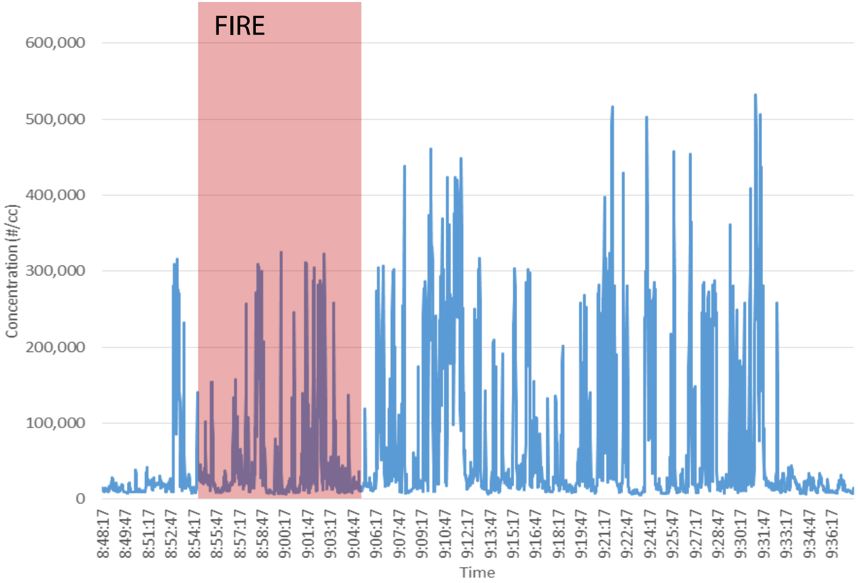
Diesel Exhaust Contribution

Diesel exhaust can contribute as much particulate to the air as the structure fire

Downwind of smoke plume



Downwind of diesel exhaust



More Information

- Full text freely available at https://www.tandfonline.com/doi/full/10.1080/15459624.2018.1445260

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Airborne contaminants during controlled residential fires

Kenneth W. Fent[a], Douglas E. Evans[b], Kelsey Babik[a], Cynthia Striley[b], Stephen Bertke[a], Steve Kerber[c], Denise Smith[d,e], and Gavin P. Horn[e]

[a]Division of Surveillance, Hazard Evaluations, and Field Studies, National Institute for Occupational Safety and Health (NIOSH), Cincinnati, Ohio; [b]Division of Applied Research and Technology, NIOSH, Cincinnati, Ohio; [c]Firefighter Safety Research Institute, Underwriters Laboratories, Columbia, Maryland; [d]Health and Exercise Sciences Department, Skidmore College, Saratoga Springs, New York; [e]Illinois Fire Service Institute, University of Illinois at Urbana-Champaign, Urbana-Champaign, Illinois

ABSTRACT

In this study, we characterize the area and personal air concentrations of combustion byproducts produced during controlled residential fires with furnishings common in 21st century single family structures. Area air measurements were collected from the structure during active fire and overhaul (post suppression) and on the fireground where personnel were operating without any respiratory protection. Personal air measurements were collected from firefighters assigned to fire attack, victim search, overhaul, outside ventilation, and command/pump operator positions. Two different fire attack tactics were conducted for the fires (6 interior and 6 transitional) and exposures were compared between the tactics. For each of the 12 fires, firefighters were paired up to conduct each job assignment, except for overhaul that was conducted by 4 firefighters. Sampled compounds included polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs, e.g., benzene), hydrogen cyanide (HCN), and particulate (area air sampling only). Median personal air concentrations for the attack and search firefighters were generally well above applicable short-term occupational exposure limits, with the exception of HCN measured from search firefighters. Area air concentrations of all measured compounds decreased after suppression. Personal air concentrations of total PAHs and benzene measured from some overhaul firefighters exceeded exposure limits. Median personal air concentrations of HCN (16,300 ppb) exceeded the exposure limit for outside vent firefighters, with maximum levels (72,900 ppb) higher than the immediately dangerous to life and health (IDLH) level. Median air concentrations on the fireground (including particle count) were above background levels and highest when collected downwind of the structure and when ground-level smoke was the heaviest. No statistically significant differences in personal air concentrations were found between the 2 attack tactics. The results underscore the importance of wearing self-contained breathing apparatus when conducting overhaul or outside ventilation activities. Firefighters should also try to establish command upwind of the structure fire, and if this cannot be done, respiratory protection should be considered.

KEYWORDS
Firefighters; HCN; overhaul; PAHs; particulate; VOCs

Introduction

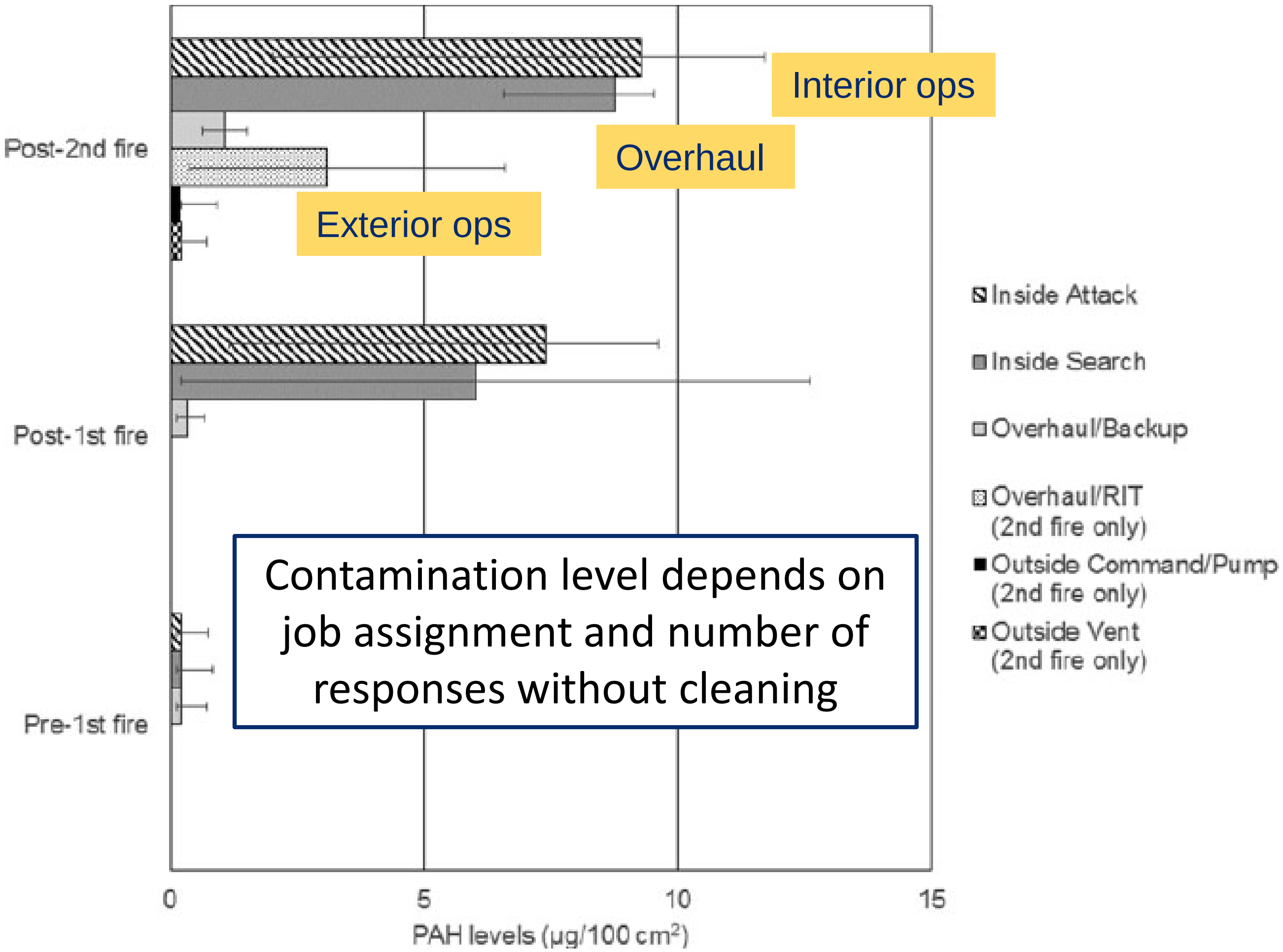
Two of the most pressing health concerns in the fire service are sudden cardiac events and cancer. Sudden cardiac events are the leading cause of on-duty deaths in the fire service, accounting for 42% of such fatalities in the last 10 years.[1] For every on-duty sudden cardiac death, almost 17 non-fatal cardiac events occur during or immediately after firefighting work.[2] The risk of sudden cardiac death is 10–100 times higher during fire suppression responses than non-emergency events, and this risk remains elevated (2- to 10-fold) during the recovery time after a response.[3,4]

A combination of factors increases the risk of a sudden cardiac event during fire suppression activities, including physical exertion, strenuous work, heat stress, dehydration, and emotional stress. These stressors when coupled with underlying morbidity, could result in pathological changes increasing the risk of thrombosis, plaque rupture, or arrhythmia.[2] This risk may be further compounded by exposure to pollutants on the fireground, such as

CONTACT Kenneth W. Fent kfent@cdc.gov Division of Surveillance, Hazard Evaluations, and Field Studies, National Institute for Occupational Safety and Health, 1090 Tusculum Ave., MS R-14 Cincinnati, OH 45226.
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uoeh.
Supplemental data for this article can be accessed on the publisher's website. AIHA and ACGIH members may also access supplementary material at http://oeh.tandfonline.com/.

Turnout Gear Contamination by Job Assignment

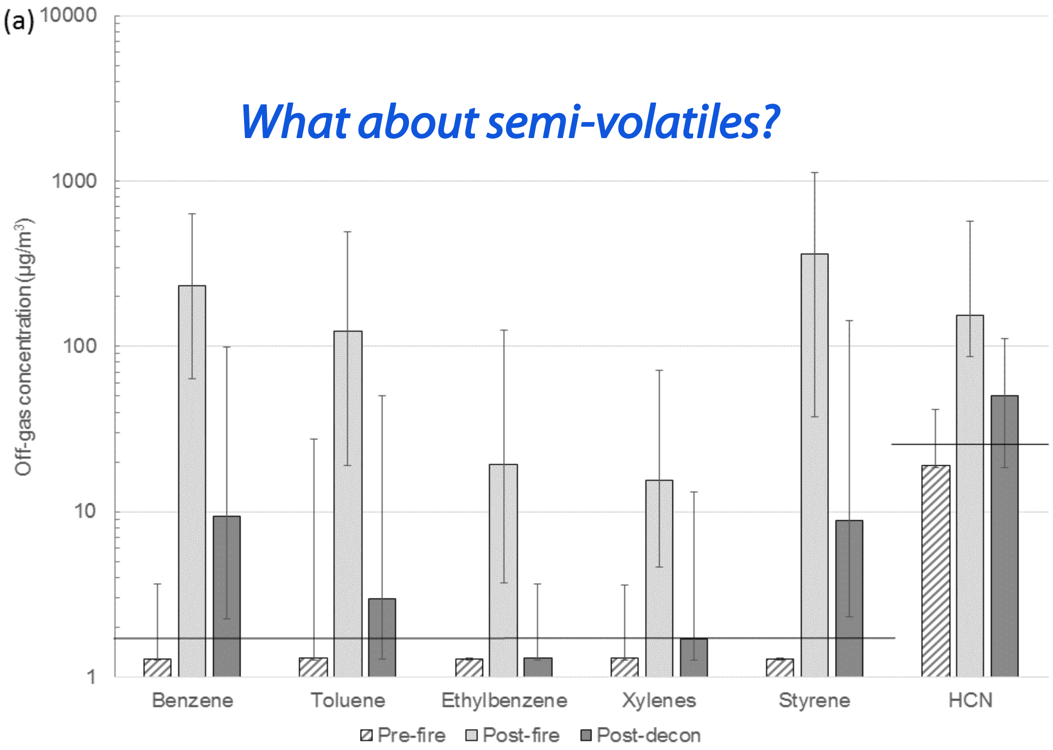
What if contaminated gear is worn for subsequent responses?



PAH contamination on turnout jackets

Turnout Gear Off-Gassing

- 6 sets of used gear inside an enclosure representative in volume to apparatus cabin
- Levels returned to near background 17-36 minutes after firefighting



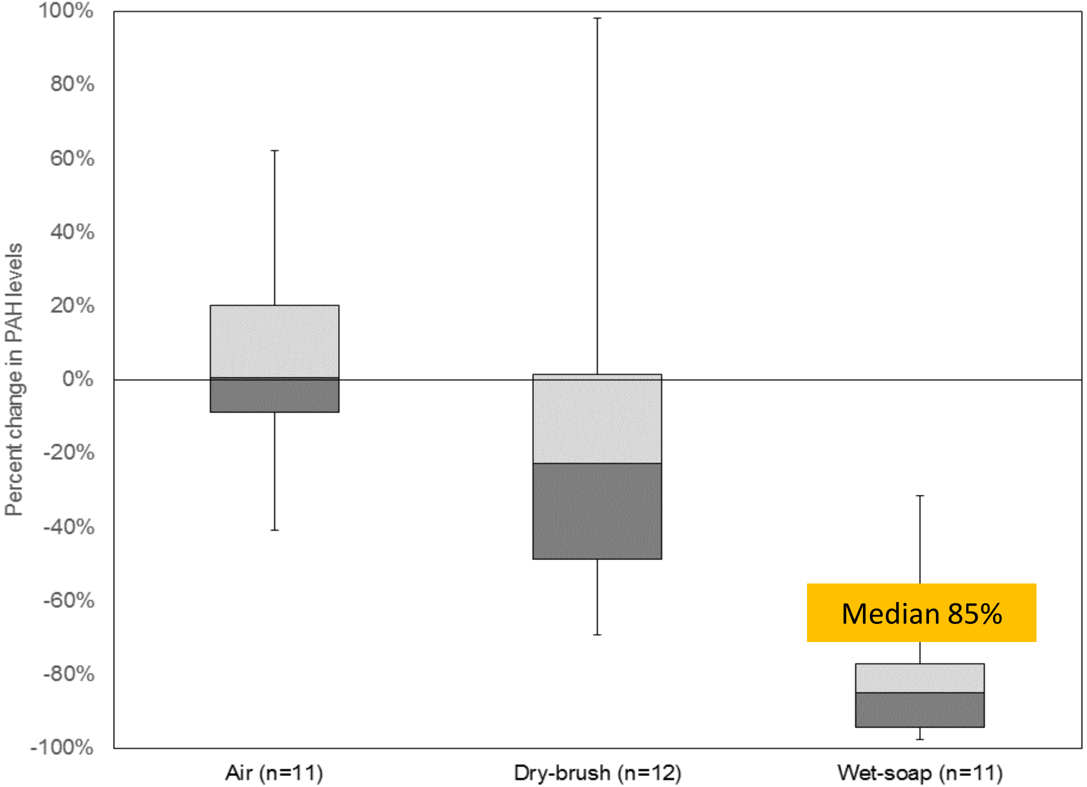
Levels well below short-term exposure limits

Effectiveness of Decon

Air-based

Dry-brush

Wet-soap



Change in PAH Levels on Outer Shell after On-Scene Decon

Dermal Exposures to PAHs

Job assignment	Skin site	Percent detection	Median (µg/m^2)	Interquartile range (µg/m^2)
Attack	Hands	96%	135	67 - 190
	Neck	50%	< 32	< 24 - 152
Search	Hands	100%		144 - 313
	Neck	50%		< 24 - 72
Overhaul/RIT	Hands	67%		6.1 - 31
	Neck	38%		< 24 - 34
Outside Vent	Hands	83%		6.2 - 23
	Neck	58%		< 24 - 39

** Tactic did not have statistically significant effect on dermal exposure; although median levels were lower for transitional attack*

Effectiveness of Skin Cleansing Wipes

- Sampled half of the neck
- Firefighters cleaned their neck using commercial baby wipes
- Sampled other half of the neck

54% reduction in PAHs (IQR = 18% – 100% reduction)

More Information

- Full text freely available at https://www.tandfonline.com/doi/full/10.1080/15459624.2017.1334904

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Contamination of firefighter personal protective equipment and skin and the effectiveness of decontamination procedures

Kenneth W. Fent[a], Barbara Alexander[b], Jennifer Roberts[b], Shirley Robertson[b], Christine Toennis[b], Deborah Sammons[b], Stephen Bertke[a], Steve Kerber[c], Denise Smith[d,e], and Gavin Horn[e]

[a]Division of Surveillance, Hazard Evaluations, and Field Studies, National Institute for Occupational Safety and Health (NIOSH), Cincinnati, Ohio; [b]Division of Applied Research and Technology (NIOSH), Cincinnati, Ohio; [c]Firefighter Safety Research Institute, Underwriters Laboratories, Northbrook, Illinois; [d]Health and Exercise Sciences Department, Skidmore College, Saratoga Springs, New York; [e]Illinois Fire Service Institute, University of Illinois at Urbana-Champaign, Champaign, Illinois

ABSTRACT
Firefighters' skin may be exposed to chemicals via permeation/penetration of combustion byproducts through or around personal protective equipment (PPE) or from the cross-transfer of contaminants on PPE to the skin. Additionally, volatile contaminants can evaporate from PPE following a response and be inhaled by firefighters. Using polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs) as respective markers for non-volatile and volatile substances, we investigated the contamination of firefighters' turnout gear and skin following controlled residential fire responses. Participants were grouped into three crews of twelve firefighters. Each crew was deployed to a fire scenario (one per day, four total) and then paired up to complete six fireground job assignments. Wipe sampling of the exterior of the turnout gear was conducted pre- and post-fire. Wipe samples were also collected from a subset of the gear after field decontamination. VOCs off-gassing from gear were also measured pre-fire, post-fire, and post-decon. Wipe sampling of the firefighters' hands and neck was conducted pre- and post-fire. Additional wipes were collected after cleaning neck skin. PAH levels on turnout gear increased after each response and were greatest for gear worn by firefighters assigned to fire attack and to search and rescue activities. Field decontamination using dish soap, water, and scrubbing was able to reduce PAH contamination on turnout jackets by a median of 85%. Off-gassing VOC levels increased post-fire and then decreased 17–36 min later regardless of whether field decontamination was performed. Median post-fire PAH levels on the neck were near or below the limit of detection (< 24 micrograms per square meter [$\mu g/m^2$]) for all positions. For firefighters assigned to attack, search, and outside ventilation, the 75[th] percentile values on the neck were 152, 71.7, and 39.3 $\mu g/m^2$, respectively. Firefighters assigned to attack and search had higher post-fire median hand contamination (135 and 226 $\mu g/m^2$, respectively) than other positions (< 10.5 $\mu g/m^2$). Cleansing wipes were able to reduce PAH contamination on neck skin by a median of 54%.

KEYWORDS
Contaminants; decontamination; evaporation; firefighters; PAHs; turnout gear

Introduction

The International Agency for Research on Cancer (IARC) classified occupational exposure as a firefighter as possibly carcinogenic to humans (Group 2B).[1] Since this determination was made in 2010, a number of epidemiology studies continue to find elevated risks of several cancers in firefighters. In the largest cohort mortality study to date (30,000 firefighters), Daniels et al.[2] found increased mortality and incidence risk for all cancers, mesothelioma, and cancers of the esophagus, intestine, lung, kidney, and oral cavity, as well as an elevated risk for prostate and bladder cancer among younger firefighters. In a follow-on study, Daniels et al.[3] found a dose-response relationship between fire-runs and leukemia mortality and fire-hours and lung cancer mortality and incidence. Other studies corroborate the elevated risk of a number of these cancers and provide evidence for the increased risk of other cancers, like melanoma and

CONTACT Kenneth W. Fent kfent@cdc.gov Division of Surveillance, Hazard Evaluations, and Field Studies, National Institute for Occupational Safety and Health, 1090 Tusculum Ave., MS R-14 Cincinnati, OH 45226.
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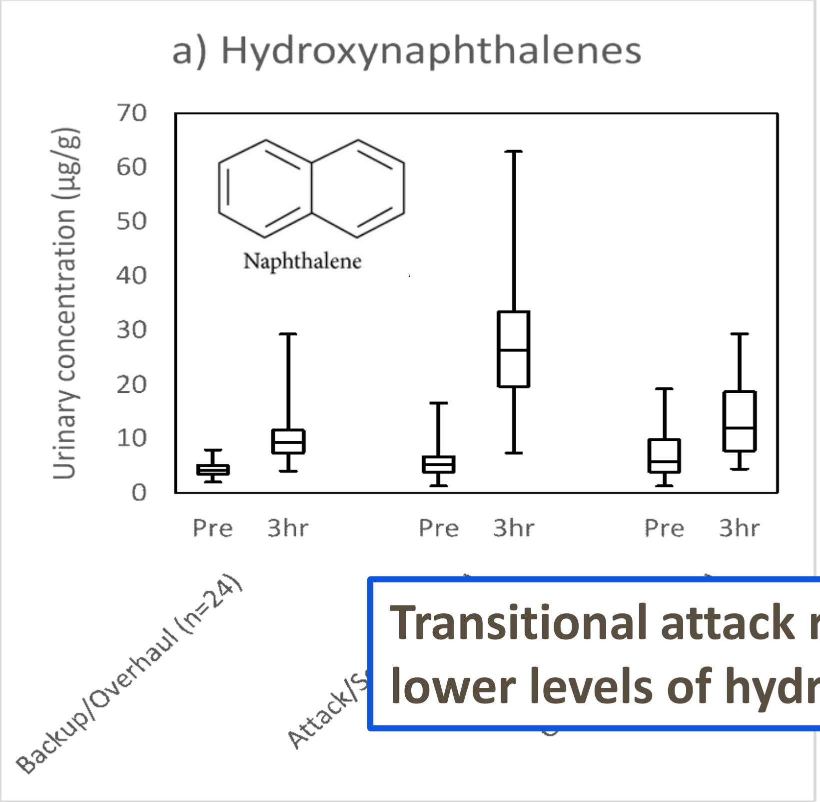
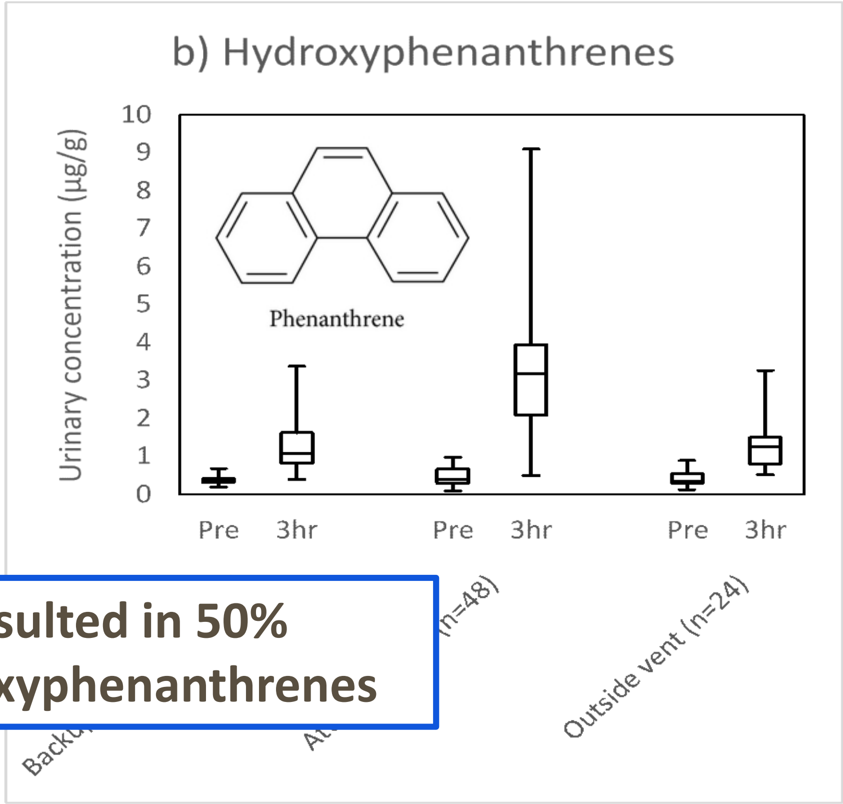
Biological Levels after Controlled-Residential Fires

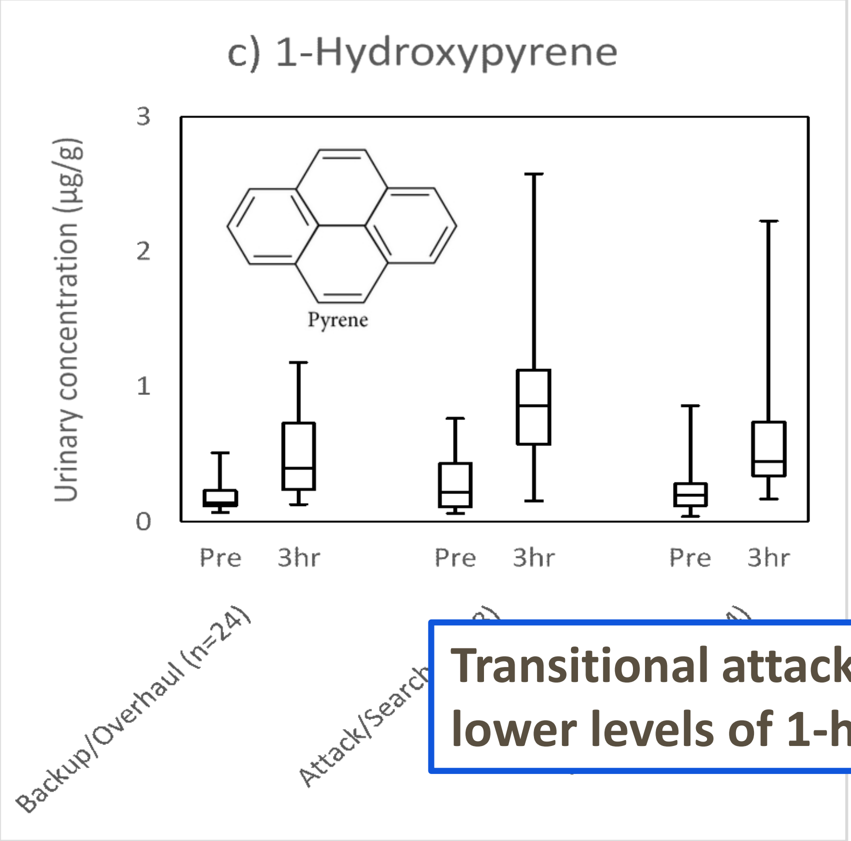
Urinary PAHs after Firefighting

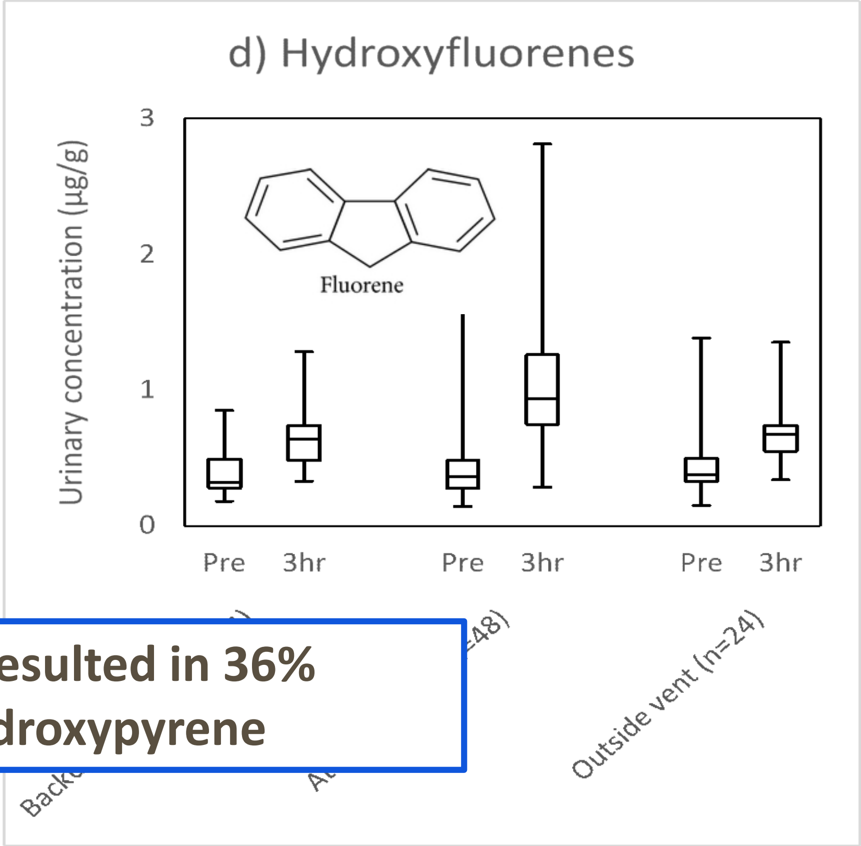




Transitional attack resulted in 50% lower levels of hydroxyphenanthrenes

Urinary PAHs after Firefighting





Transitional attack resulted in 36% lower levels of 1-hydroxypyrene

Table Comparison of 3-hr post-firefighting urinary OH-PAH metabolite concentrations to the non-smoking adult general population (µg/g)

OH-PAH compound	NHANES 2011-2012 survey data for 20-49 year old non-smokers[a]			Median 3-hr post exposure results by job assignment		
	n	Median	95th percentile	Attack/search (n = 48)	Outside vent (n = 24)	Backup/overhaul (n = 24)
				13.4	2.2	3
				13.7	7.7	5.9
				1.2	0.44	0.41
				1.9	0.71	0.66
1-Hydroxypyrene	638	0.10	0.33	$\boxed{0.86}$	0.45	0.4
2-Hydroxyfluorene	639	0.18	0.64	0.73	0.49	0.48
3-Hydroxyfluorene	638	0.07	0.25	0.24	0.18	0.14

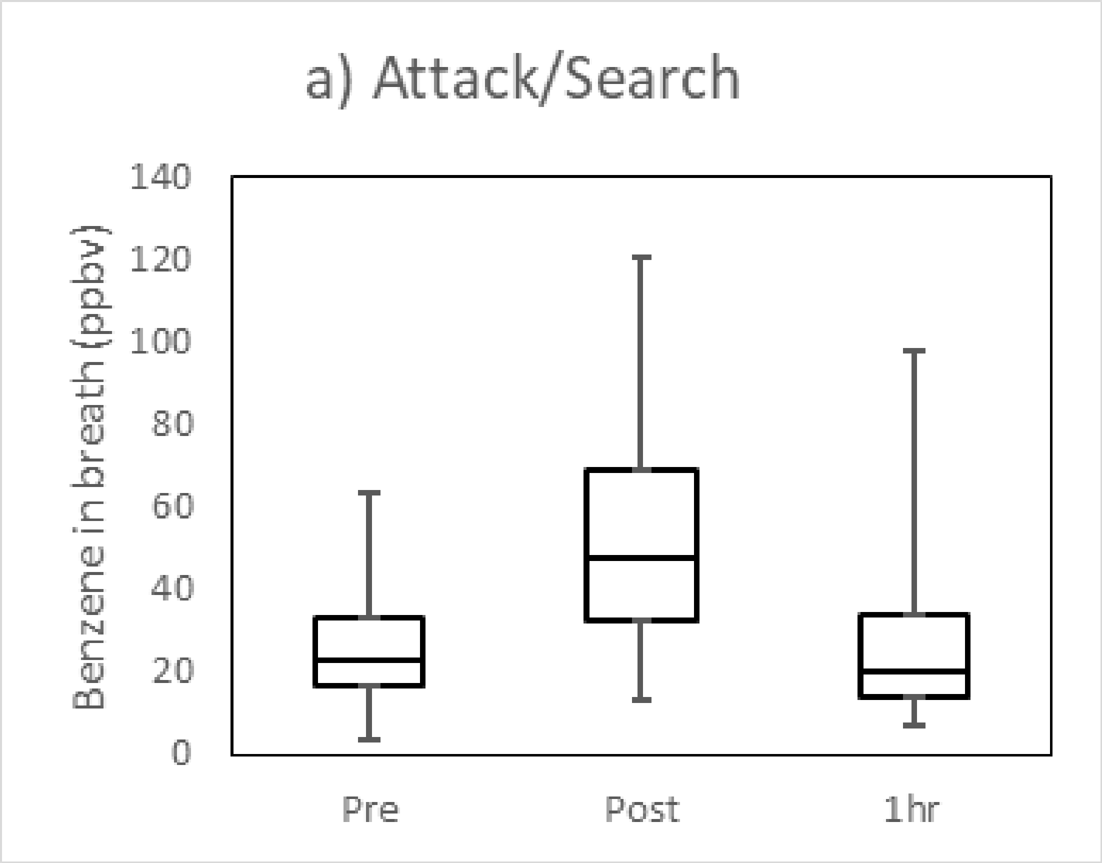
[a] Fourth National Report on Human Exposure to Environmental Chemicals, Updated Tables, March 2018, Volume Two [49].

[b] 2-Hydroxyphenanthrene and 3-hydroxyphenanthrene were reported separately for 2011-2012 NHANES data. For comparison purposes here, we estimated the 2- and 3-hydroxyphenanthrene (combined) summary statistics by summing the reported median values of the two compounds and 95th percentile values of the two compounds.

1-hydroxypyrene in other occupations

- 0.4 – 334 µg/g for coke oven operators
- 0.3 – 7.7 µg/g for gas workers
- 1.2-3.5 µg/g for road pavers

Exhaled Breath Concentrations of Benzene



Median increase of 24 ppb

Smokers, median = 5 ppb
Non-smokers, median = 0.8 ppb (Wallace 1986)

NIOSH short-term exposure limit (for air sampling) = 1000 ppb

Ongoing work

- Airborne and surface levels of flame retardants (FRs) and dioxins and furans
  - Are these compounds released into the fire environment?
  - Is gross on-scene decon effective at removing contamination?
- Biological levels of FRs and dioxins/furans
  - Are these compounds absorbed into the firefighters’ bodies?

Firefighter Hood Contamination Study

Alex Mayer, MPH
Contractor, NIOSH

Firefighter exposure

- Firefighters' occupational exposure to FRs and PAHs is of increasing concern
- PAHs are known carcinogens[1], some FRs alter hormone regulation[2,3]
- PAHs and FRs have been identified in firefighters' urine post firefighting[5-6]

1. International Agency for Research on Cancer. 2010
2. Linares et al. 2015
3. Saunders et al. 2013
4. Fent et al. 2013
5. Jayatilaka et al. 2017

Flame Retardants

- Used in foams, textiles, plastics, and insulation
- Polybrominated diphenyl ethers (**PBDEs**)
  - Phased out (2003-2013)
  - Still present in nearly all U.S. buildings
- Alternative FRs:
  - Non-PBDE (i.e. **NPBFRs**)
    - e.g., TBB, TBPH
  - Organophosphates (i.e. **OPFRs**)
    - e.g., TPP, TDCPP, TCPP

Concentrations of flame retardants (µg/g)* in bulk samples of the burn room furnishings

	Compound measured	Carpet padding (n = 3)	Curtain liner (n = 1)	Foam from inner spring mattress (n = 2)	Foam topper for bed (n = 2)	Head-board padding (n = 1)	Chair cushion (n = 2)	Liner for chair cushion (n = 1)	Flat screen TV plastic (n = 1)
	Polybrominated diphenyl ethers								
PBDEs	BDE 47	< 0.1 - 0.41	0.19	< 0.1	< 0.1 - 0.74	5,600	< 0.1 - 4.1	< 0.1	< 0.1
	BDE 85	< 0.1	< 0.1	< 0.1	< 0.1	840	< 0.1 - 1.6	< 0.1	< 0.1
	BDE 99	0.11 - 0.56	0.25	< 0.1 - 0.44	< 0.1 - 2.9	15,000	< 0.1 - 25	< 0.1	< 0.1
	BDE 100	< 0.1	< 0.1	< 0.1	< 0.1 - 0.6	2,500	< 0.1 - 3.8	< 0.1	< 0.1
	BDE 153	< 0.1 - 5.6	< 0.1	< 0.1	< 0.1 - 2.0	2,000	< 0.1 - 13	< 0.1	< 0.1
	BDE 154	< 0.1	< 0.1	< 0.1	< 0.1 - 0.69	1,400	< 0.1 - 5.0	< 0.1	< 0.1
	BDE 183	< 0.1 - 1.1	< 0.1	< 0.1	< 0.1 - 2.0	67	< 0.1	< 0.1	< 0.1
	BDE 206	< 0.1 - 14	2.8	< 0.1 - 6.3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	BDE 209	0.41 - 102	440	< 0.1 - 61	< 0.1	< 0.1	< 0.1 - 0.68	< 0.1	< 0.1
	Other brominated flame retardants								
NPBFRs	TBBPA	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	TBB	0.38 - 3.2	910	< 0.1 - 0.5	< 0.1 - 7.5	< 0.1	18,500 - 26,750	68.5	< 0.1
	TBPH	0.22 - 5.7	340	< 0.1 - 1.2	< 0.1 - 3.7	< 0.1	5,800 - 6,380	19.6	< 0.1
	DBDPE	< 0.1 - 0.53	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	Organophosphate flame retardants								
OPFRs	TCEP	< 0.1	1.4	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	TCPP	59 - 630	5.4	< 0.1	< 0.1	8.4	< 0.1 - 1.3	< 0.1	< 0.1
	TDCPP	240 - 9,100	1.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	TPP	0.43 - 3.8	4.0	0.16 - 0.23	< 0.1 - 1.3	1,690	1,400 - 7,380	22.6	19
	TCP	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

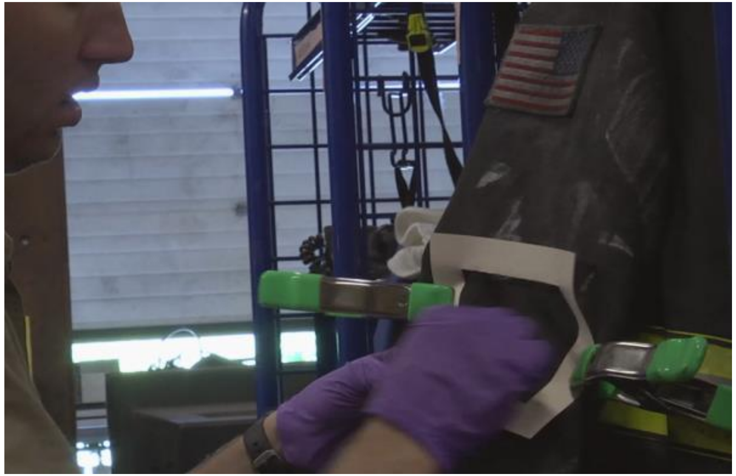
Flame retardant air concentrations (µg/m^3) measured from living room during active fire and from initial burn room (bedroom) during overhaul on one day of the study.

Preliminary Results (Interim report)

	Compound measured	Fire period	Overhaul period
PBDEs	BDE 47	9.6	< 0.04
	BDE 85	< 0.17	< 0.04
	BDE 99	7.4	< 0.04
	BDE 100	< 0.17	< 0.04
	BDE 153	< 0.17	< 0.04
	BDE 154	8.7	< 0.04
	BDE 183	< 0.17	< 0.04
	BDE 206	< 0.17	< 0.04
	BDE 209	14	< 0.04
NPBFRs	TBBPA	12	< 0.04
	TBB	9.2	< 0.04
	TBPH	1.2	< 0.04
	DBDPE	< 0.17	< 0.04
OPFRs	TCEP	< 0.25	< 0.06
	TCPP	< 0.25	< 0.06
	TDCPP	< 0.25	< 0.06
	TPP	2000	14
	TCP	220	1.9

Photo by NIST

Preliminary Results
(Interim report)



Surface contamination levels (ng/100 cm^2) of flame retardants from one set of turnout gear after use for search and rescue

Group	Compound Measured	Post-fire (jacket)*	Post fire (right glove)
PBDEs	BDE 47	48	35
	BDE 85	< 1	< 1
	BDE 99	< 1	40
	BDE 100	< 1	12
	BDE 153	< 1	< 1
	BDE 154	< 1	< 1
	BDE 183	< 1	< 1
	BDE 206	< 1	< 1
	BDE 209	1,200	1,200
NPBFRs	TBBPA	< 1	30
	TBB	22	30
	TBPH	11	14
	DBDPE	140	290
OPFRs	TCEP	5.5	< 1.5
	TCPP	< 1.5	200
	TDCPP	190	460
	TPP	2	3,100
	TCP	< 0.2	360

* Quality control samples were 60–80% less than expected, so measurements may be underestimated.

Current Understanding of PBDE Exposure

- Have been associated with altered hormone regulation[1]
- 12 San Francisco firefighters[2]
  - First study to document higher levels of certain PBDEs and dioxins in firefighters
- 100 California firefighters[3]
  - Found higher serum levels of PBDEs than general population (~ 2 times higher)
  - Cleaning gear after response associated with lower serum levels
- Fire station dust was found to have high PBDE levels

1. Linares et al. 2015
2. Shaw et al. 2013
3. Park et al. 2015

PBDEs = polybrominated diphenyl ethers

Current Understanding of OPFR/NPBFR Exposure

- OPFRs
  - Certain OPFRs (e.g., TPP) may be more neurotoxic than PBDEs[1,2]
  - Only one study to date[1]
  - Firefighters had higher urinary levels of OPFRs than general public
    - TCEP, TCPP, TDCPP (5x), TPP (3x)
- NPBFRs
  - Relatively few studies have examined NPBFRs
  - Thought to react similarly to PBDEs
  - Some, (TBB, TBPH) were observed to be endocrine disruptors[3]

1. Jayatilaka et al. 2017
2. Dishaw et al. 2011
3. Behl et al. 2016

OPFRs = organophosphate flame retardants
NPBFRs = non-polybrominated flame retardants

Contamination on Turnout Gear

- A variety of PBDEs have been measured on used turnout jackets, gloves, and hoods[1,2]
- Some FRs (e.g., BDE-209) have been measured on new "unused" gear[2]
- Other contaminants found on gear include PAHs, phthalates, metals, and volatile organic compounds (VOCs)[1-5]

1. Easter et al. 2016
2. Alexander and Baxter 2016
3. Fabian et al. (UL) 2010
4. Fent et al. 2015
5. Kirk et al. 2015

HYPOTHESIS

Our hypothesis was laundering will reduce PAH and FR contamination to normal background or non-detectable levels.

Initial Findings

- Tested contamination on hoods that had been laundered after each fire (4 fires) to hoods that had not been laundered
- Compared contamination levels by job assignment
- Found lower levels on routinely laundered hoods
    - PAHs 82% lower
    - NPBFRs 65% lower
    - OPFRs 56% lower
    - PBDEs were actually <u>higher</u> in the routinely laundered hoods. ***Why?***

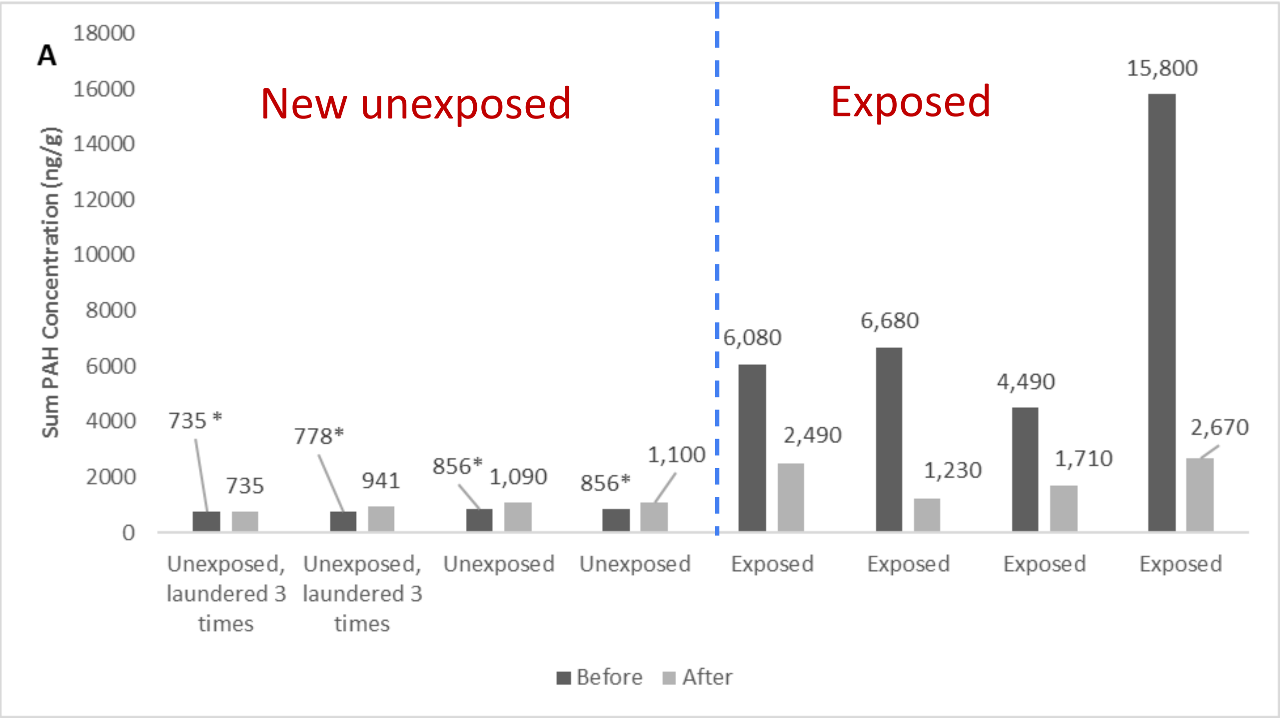
Follow-On: Post Hoc Study

- **Cross contamination appeared to be an area of concern**
  - 4 of the unlaundered <u>exposed</u> hoods were laundered once with:
    - 2 brand new hoods
    - 2 new hoods previously laundered 3 times
    - 4 hoods highly contaminated with PAHs and FRs
  - Samples were taken pre and post-laundering to assess for cross contamination

unexposed

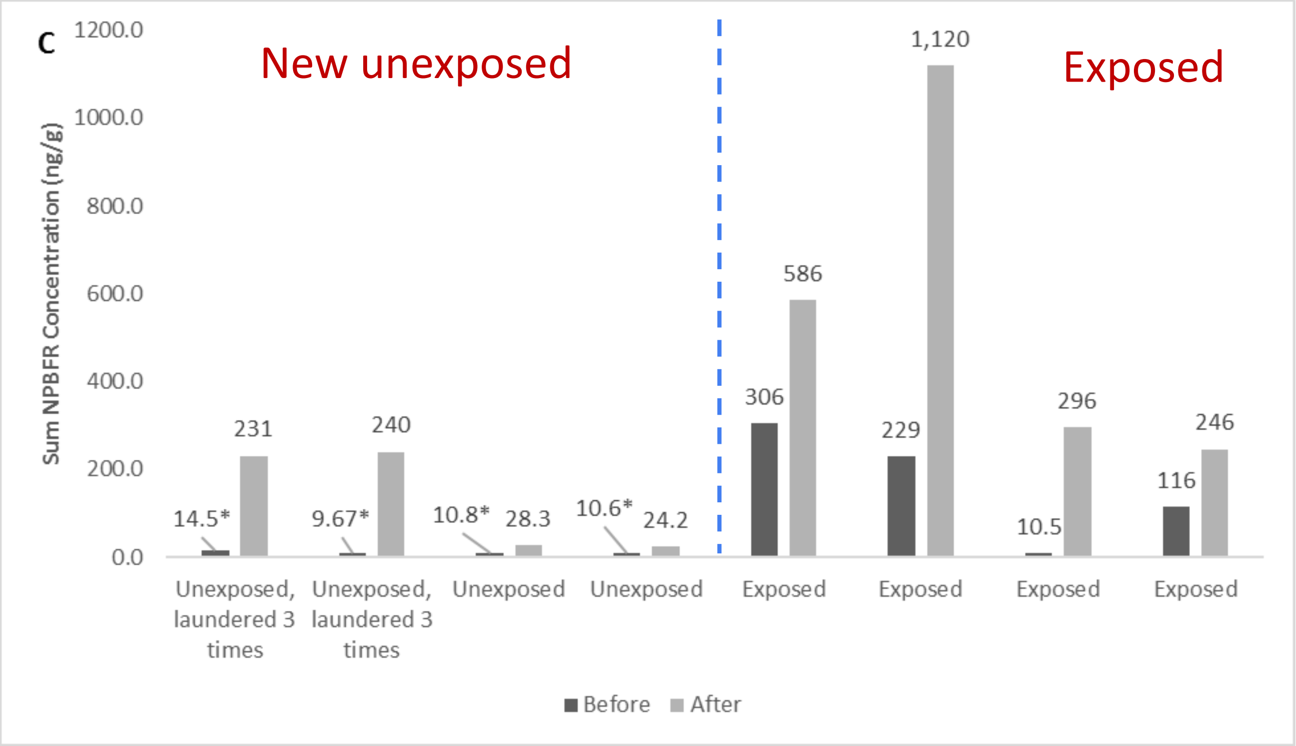
Results: PAHs

- Total PAHs were 76% lower on exposed hoods after laundering (P=0.001)
- Very minimal cross contamination on unexposed hoods
- PAHs appear to be effectively removed through laundering

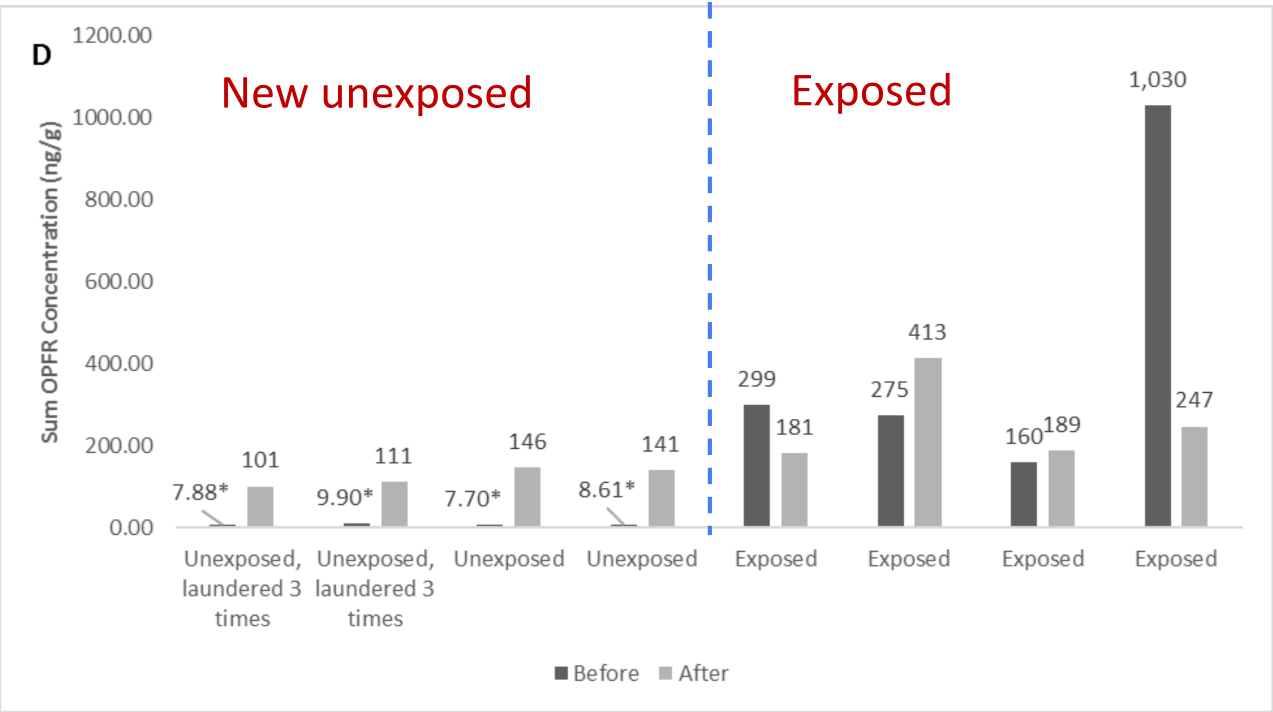


Results: NPBFRs

- NPBFR contamination increased on all hoods after laundering
- Evidence of cross-contamination
- Contradict our initial findings

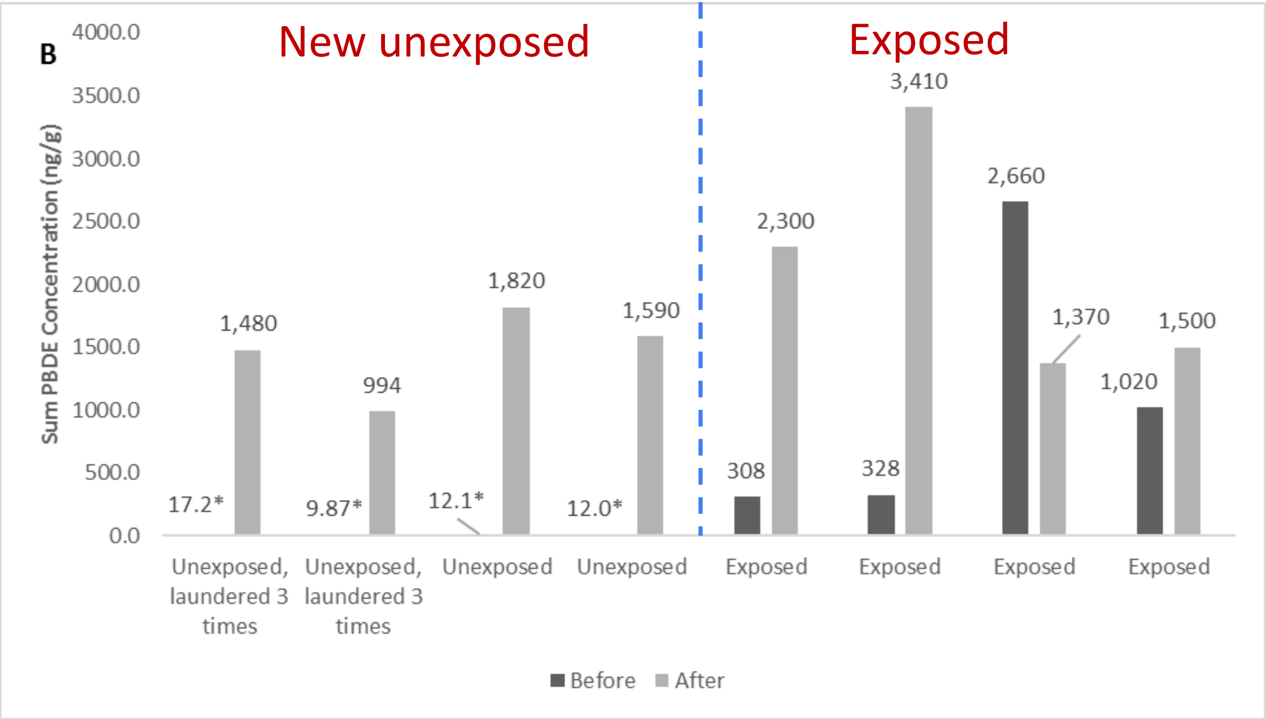


Results: OPFRs



- In total, 42% reduction after laundering on exposed hoods
- Evidence of cross-contamination

Results: PBDEs



- PBDEs were much higher on exposed hoods after laundering (98% increase)
- Evidence of cross-contamination
- PBDEs do not appear to be effectively removed through laundering

Results: PBDEs

- PBDE results were surprising
- Study found 90% of PBDEs were not removed during laundering[1]
- PBDEs have low water solubility, still doesn't explain why laundered hoods had higher contamination
- Cross contamination appears to be an area of concern

Saini et al. 2016

Conclusions

- **PAHs were effectively reduced in both studies**
  - The only known carcinogen in class of chemicals analyzed
- **OPFR and NPBFR contamination reduced, but residual levels**
- **PBDEs were not removed well**
- **Evidence of cross contamination for all but PAHs**
- **Currently working on a follow-up study**
  - Examining extraction of PBDEs through synthetic sweat
  - Identify what firefighters may be exposed to during responses

Wrapping Up

Summary, Future Work, and Recommendations

Summary of Main Findings (to date…)

- Contamination and exposure depends on job assignment
- Transitional attack resulted in less uptake of some PAHs
- Inhalation is most direct route, but skin absorption plays an important role
- HCN air concentrations can be very high for outside vent firefighters
- Exposure to fireground personnel depends on weather conditions and diesel exhaust
- Cleansing wipes are able to remove 50% or more of PAH contamination from skin
- Wet decon with dish soap is able to remove much of the PAH contamination on outer shell
- Laundering hoods effective for PAHs and OPFRs, but less effective for brominated FRs

Ongoing and Future Work

- **Training Fire Study**
  - Examine firefighter and instructors' exposures by fuel package: (1) pallet & straw, (2) OSB, and (3) simulated smoke
- **PPE Laundering Study**
  - What happens to the protective properties of turnout gear when exposed and laundered multiple times (40x)?
  - How effective are particle-blocking hoods?
- **PPE Interface Study**
  - Can tighter interfaces attenuate exposure and how does this vary between gases and particulate?

Ongoing and Future Work

- **Fire Fighter Cancer Cohort Study**
  - *Prospective* study of up to 10,000 firefighters
  - Exposure tracking (NFORS)
  - Biological monitoring (blood, urine, breath)
  - Epigenetic changes
    - How do exposures affect the transcription of genes?
    - Before development of tumor
  - Underrepresented groups
    - Volunteers, females, arson investigators, trainers, wildland urban interface

Victory! Fire Fighter Cancer Registry Act Signed Into Law

Culminating more than two years of intense lobbying and hard work by the IAFF and its leadership, President Donald Trump has signed the Firefighter Cancer Registry Act of 2018 (H.R. 931) into law. With this final action, the federal government takes the first steps towards establishing a one-of-a-kind national cancer registry specifically for fire fighters.

With President Trump's signature, the Centers for Disease Control (CDC) is now directed to undertake the collection of detailed data on the occurrence of cancer in fire fighters. The data will provide scientists with specialized information needed to research the relationship between the disease and the job, which will help strengthen our understanding of the link between firefighting and cancer and potentially lead to better prevention and safety protocols.

The bill, introduced in the House by Representatives Chris Collins (R-NY) and Bill Pascrell (D-NJ), and in the Senate by Senators Lisa Murkowski (R-AK) and Robert Menendez (D-NJ), passed the House unanimously in June for the second time after the Senate made slight modifications to the bill. H.R. 931 first passed the House last September.

This legislative victory was only possible with the dedication and hard work of IAFF members and a bipartisan cadre of elected federal officials. "I sincerely thank Representatives Collins and Pascrell, along with Senators Murkowski and Menendez, for working with the IAFF to pass the Firefighter Cancer Registry Act. Their superior leadership on this legislation has been invaluable. I also thank the entire House and Senate for their unanimous votes necessary to deliver this legislation to the president's desk for his signature," says General President Harold Schaitberger. "The strength of the vote in each chamber demonstrates the importance of this legislation and the need to better understand cancer within the fire service."

The bill requires the Trump administration partner with national fire service organizations, including the IAFF, to build out the registry. As this process begins, we will be working closely with the Centers for Disease Control to ensure the registry well represents our members and their interests.

Recommendations

To reduce inhalation exposures

- Wear SCBA
- Establish hazard zones at fire scene
- Set up command upwind (if possible)
- Rehab away from used gear
- Transport contaminated gear in encapsulated bag
- Diesel exhaust filtration (on scene) / capture (station)

Recommendations

<u>To reduce dermal exposure</u>

- Remove gear in a way to minimize cross-contamination
- Wash skin with soap and water or use skin-cleansing wipes (on scene)
- Decontaminate and/or launder turnout gear (including hoods and gloves)
  - Items to be laundered should be segregated by contamination
- Shower as soon as possible
- New particle blocking hoods??

Acknowledgements

IFSI RESEARCH

FIREFIGHTER SAFETY RESEARCH INSTITUTE — SCIENCE · KNOWLEDGE · EXPERIENCE — UL

SKIDMORE COLLEGE

CDC — CENTERS FOR DISEASE CONTROL AND PREVENTION

EPA — United States Environmental Protection Agency

GLOBE

UIC — UNIVERSITY OF ILLINOIS AT CHICAGO

THE UNIVERSITY OF ARIZONA — Mel & Enid Zuckerman College of Public Health

UHealth — UNIVERSITY OF MIAMI HEALTH SYSTEM — UNIVERSITY OF MIAMI MILLER SCHOOL of MEDICINE

U.S. Fire Administration — Working for a fire-safe America

NFPA — RESEARCH FOUNDATION — RESEARCH FOR THE NFPA MISSION

CDC Foundation — Together our impact is greater

U.S. DEPARTMENT OF HOMELAND SECURITY — FEMA

NTP — National Toxicology Program

Mention of any company name or product does not constitute endorsement by CDC / NIOSH

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All Participating Firefighters!

Thank You!

For more information on these studies:

https://www.cdc.gov/niosh/firefighters/

https://www.fsi.illinois.edu/CardioChemRisks

https://www.ffccs.org

Kenneth Fent, PhD, CIH
1090 Tusculum Ave, MS R-14
Cincinnati, OH 45226

kfent@cdc.gov

For more information, contact CDC
1-800-CDC-INFO (232-4636)
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