Firefighters' unique exposure profiles

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LCDR Kenneth W. Fent, PhD
U.S. Public Health Service
National Institute for Occupational Safety and Health
Health Hazard Evaluation Program

Outline

- **Firefighter's exposure profiles**
  - Contaminants produced by fires
  - Exposure pathways and routes
  - Intensity and duration of exposures
- **Implications on health**
- **Implication on exposure assessments**
- **Conclusions**
- **Recommendations**

What is an exposure profile?

- **Characterization of an employee's exposures that includes the following:**
  - Source: where the chemicals originate
  - Composition: makeup and physical state of the chemicals
  - Pathway: how the employee comes into contact with the chemicals
  - Route: how the chemicals enter the employee's body (inhalation, dermal absorption, or ingestion)
  - Intensity: levels of the systemic exposure
  - Duration: length of the exposure time

Composition of fires

- **Hundreds of hazardous compounds**
  - Most fires: aromatic hydrocarbons, PAHs, nitro-PAHs, aldehydes, cyanides, acids, particulate, oxides of carbon, nitrogen, and sulfur*
  - Synthetic materials: vinyl chloride, PCBs, phthalates, isocyanates*

- **Many are carcinogenic, respiratory irritants, respiratory sensitizers, chemical asphyxiants, or have been implicated in adverse cardiovascular outcomes***

* UL (Underwriters Laboratories) 2010

Exposure pathways and routes

1. **When wearing full ensembles**
   - Dermal absorption
     - Particles/soot that contact the skin can be absorbed*
       - PAHs in air and on skin significantly correlated with PAHs in urine†
     - Some vapors can also be absorbed‡
       - Significantly higher benzene levels in breath after firefighting†
     - Neck is vulnerable to exposure
       - Significantly higher PAH levels on neck after firefighting†
     - Dermal absorption may increase with increasing:
       - Concentration, ambient temperatures, skin temperatures, humidity, and sweat§

* VanRooij et al. 1993
† NIOSH [In Review]
‡ Bader et al. 2008, Piotrowski 1967, 1971, Weschler and Nazaroff 2012
§ Franz 1984, Jones et al. 2003

Exposure pathways and routes

1. **When wearing full ensembles**
   - Inhalation during doffing of gear
     - Volatile compounds on contaminated gear will evaporate (e.g., benzene, toluene, styrene)
     - Likely < STELs or ceiling limits*
   - Transfer of contaminants to skin during doffing of gear and packing-up
     - Non- or semi-volatile compounds (e.g., PAHs, nitro-PAHs, phthalates)†

* NIOSH [In Review]
† UL (Underwriters Laboratories) 2010, Wobst et al. 1999

Exposure pathways and routes

2. **When at the fire scene but not wearing respirators**
   - <u>Inhalation exposures downwind of the fire</u>
     - Could be more exposed than firefighters involved in the attack
       - Higher air concentrations of isocyanates and benzene downwind of vehicle fires*
       - Toluene was higher in the personal breathing zones*

* NIOSH 2010

Exposure pathways and routes

3. **When performing overhaul or investigation and not wearing respirators**
   - The 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
   - Compounds > STELs or ceiling limits*:
     - Acrolein, CO, formaldehyde, glutaraldehyde, benzene, NO_2, SO_2

* Bolstad-Johnson et al. 2000

Exposure pathways and routes

4. **Other sources of exposures include:**
   - Automobile fires, vegetation fires, roof ventilation, and training exercises
   - Respirators are not always worn during these events

Intensity and duration of exposures

- **Many industrial exposures:**
  - Few compounds, inhalation or dermal route, low intensity (<OELs), long duration
- **Firefighters' exposures when well protected:**
  - Unknown number of compounds, mostly dermal route, probably low intensity, short duration
- **Firefighters' exposures when <u>not</u> well protected**
  - Multiple compounds, mostly inhalation route, high intensity (possibly >OELs), short duration

Implications on health

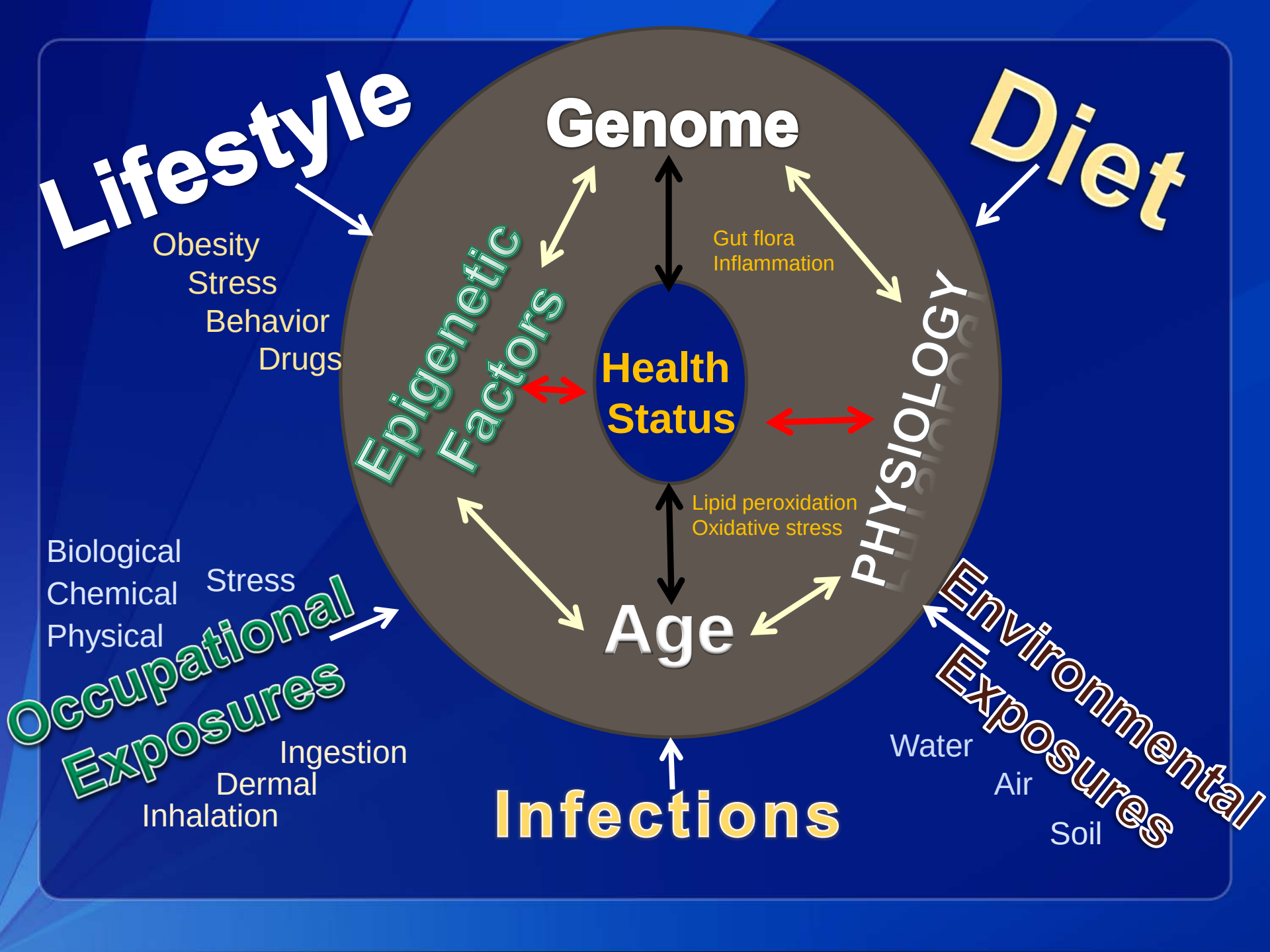
- **Multiple exposures could act synergistically**
- **Short duration high intensity exposures could be more toxic than long duration low intensity exposures**
  - Chemical asphyxiants, respiratory irritants, respiratory sensitizers
    - Large dose of exposure can quickly overwhelm the system
  - Carcinogens
    - Some animal studies suggest that there is a greater risk of cancer from short duration high intensity exposures than long duration low intensity exposures*
  - Particles
    - Short-term elevations in ambient particle levels have been associated with cardiovascular morbidity and mortality†

* Kodell et al. 1987, Chen et al. 1988, Murdoch et al. 1992, Halmes et al. 2000
† Brook et al. 2004

Implications on health

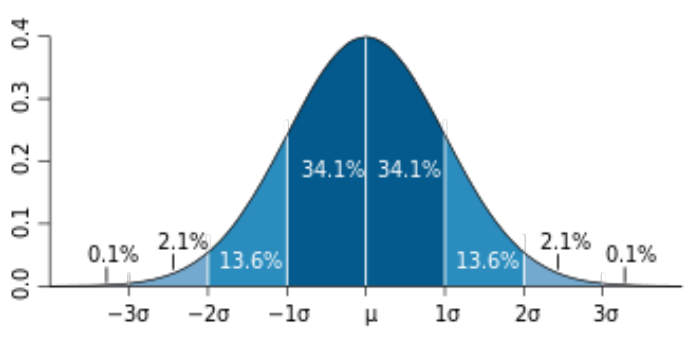
- **Other unique factors that could enhance the effect of chemical exposures**
  - Go from rest (low HR/low BP) to physically demanding work (high HR/high BP/physical stress/heat stress)
  - Puts stress on the cardiovascular system and lungs
  - Exposures to chemical asphyxiants and particulate could also put stress on these organs
    - *Risk of death from cardiovascular disease was 10 times greater during fire suppression than during other strenuous duties (e.g., physical training)**

* Kales et al. 2007


Lifestyle
Obesity
Stress
Behavior
Drugs
Genome
Diet
Gut flora
Inflammation
Epigenetic Factors
Health Status
PHYSIOLOGY
Lipid peroxidation
Oxidative stress
Age
Biological
Chemical
Physical
Stress
Occupational Exposures
Ingestion
Dermal
Inhalation
Infections
Water
Air
Soil
Environmental Exposures

Implications on doing exposure assessments

- **Comparing concentrations of individual compounds to OELs is inadequate**
- **Should consider additive effects of chemicals targeting the same organs**
  - ACGIH additive mixture formula*
    - Hazard index = sum of hazard quotients
    - Hazard quotient = Conc.$_1$/Exposure limit$_1$
    - Hazard index from vehicle fires > 9†



* ACGIH 2012
† Fent et al. 2011

Implications on doing exposure assessments

- **Biological monitoring can be useful**
  - Advantages:
    - Accounts for multiple routes of entry
    - Best estimate of systemic exposure
    - Blood, urine, breath
  - Disadvantages:
    - Few chemicals can be monitored
    - Metabolism varies
    - Expensive
    - Non-occupational sources may contribute
    - Few biological exposure limits

* ACGIH 2012

Conclusions

- **Firefighters' exposure profiles are unique and complex**
  - Consists of multiple chemicals
  - Usually short-duration
  - Intensity can range from low to high
  - Even when full ensembles are worn, dermal absorption is possible
- **Exposures and other factors may lead to higher health risk**
- **More research is needed**

Recommendations

- **Simple measures can be taken to minimize exposures**
  - Wearing SCBA during external suppression and overhaul
  - Doffing SCBA last after firefighting
  - Keeping contaminated gear segregated from firefighters during rehab
  - Airing out gear before return trip to station
  - Airing out structures before overhaul or investigation
  - Washing hands and showering ASAP after firefighting
  - Wearing clean station uniforms

Recommendations

- **Other measures may help reduce exposures, but require more research**
  - Deconning gear after firefighting
  - Redesigning hoods for better skin protection
  - Developing real-time monitors to determine when respiratory protection is no longer needed

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Thank you for your attention

Kenneth W. Fent, Ph.D.
LCDR, U.S. Public Health Service
Industrial Hygienist, CDC/NIOSH
4676 Columbia Parkway, MS R-11
Cincinnati, OH 45226
kfent@cdc.gov
(513) 841-4569
www.cdc.gov/niosh/hhe
http://www.facebook.com/health.hazard.evaluation.program

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Extra Slides

Exposure routes and pathways for firefighters

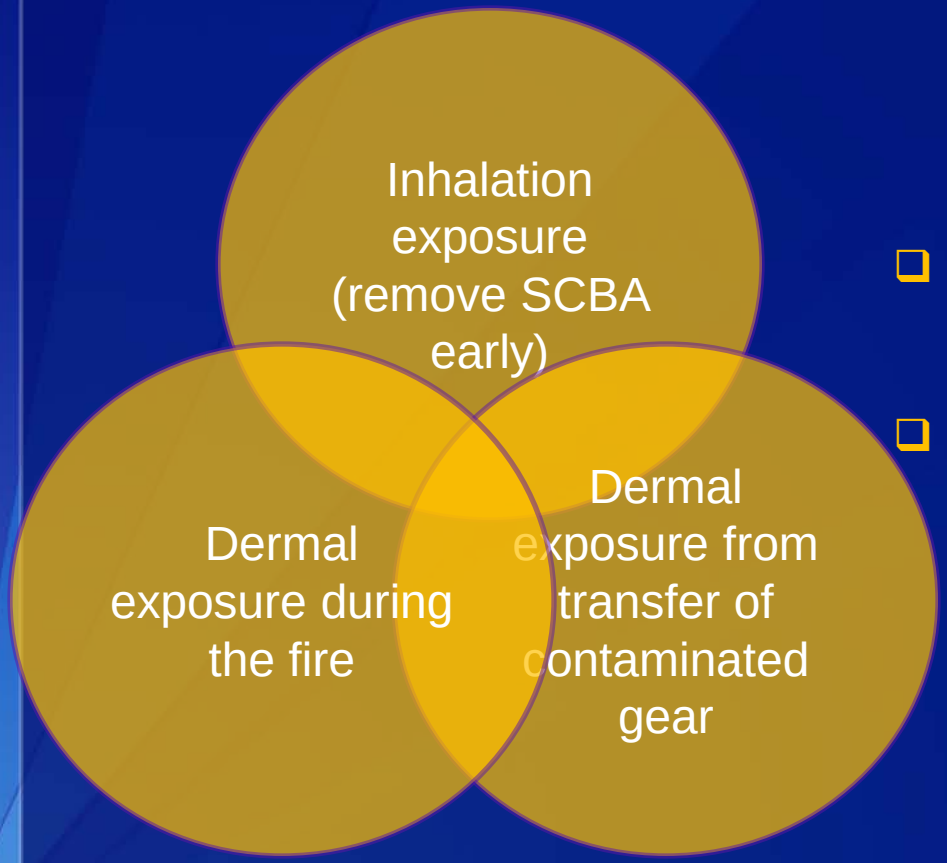
Only a few existing studies

- **Compared to external air concentrations, low levels of aromatic hydrocarbons were found under turnout gear***
  - Limitation: sampling pumps used under gear could have created a gradient that pulled in contaminants
- **Compared to pre-exposure levels, urinary biomarkers of PAHs and benzene were elevated following training exercises†**
  - Limitation: inhalation exposure and transfer of PAHs from gear to the skin were possible because:
    - Did not control when SCBA was removed
    - Did not use laundered gear

* Queensland Fire and Rescue Service 2011.
† Laitinen et al. 2009 and Caux et al. 2002.

Study design

Firefighter exposure routes



- **Firefighter participants suppressed controlled structural fires**
  - 20 to 30 minutes of exposure
- **Wore laundered turnout gear, gloves, and hoods**
- **Wore SCBA until completion of overhaul**
  - Did not remove until 30 meters from burn structure

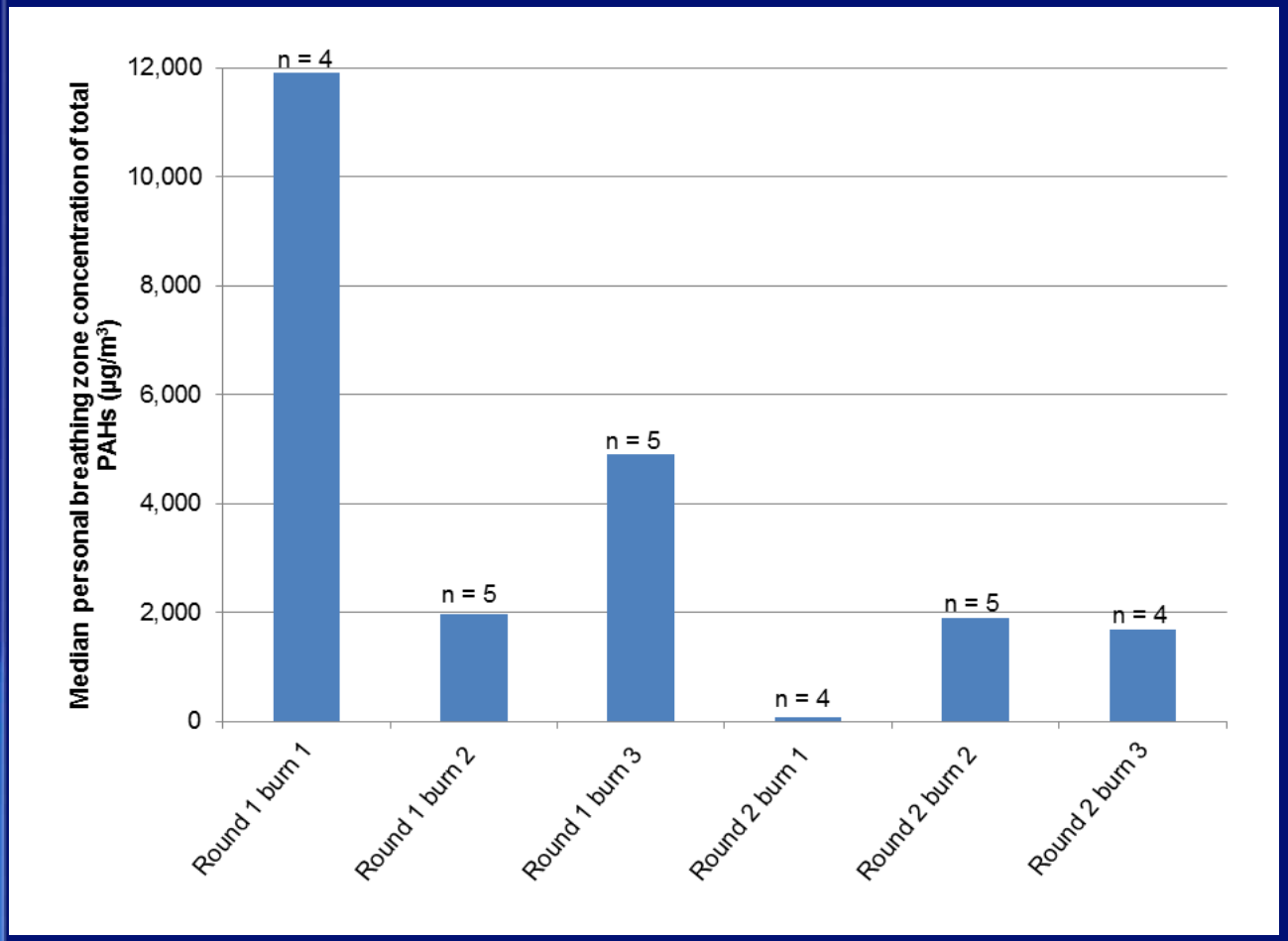
Study design

- **Pilot study (small sample size)**
- **2 rounds, 3 days per round, 1 burn evolution per day, 5 firefighters per burn**
  - 11 firefighters in round 1 also participated in round 2 (19 participants total)
- **Each burn took place in the morning with samples collected throughout the day:**
  - Pre exposure (~1 hour before the burn)
  - Exposure (during the burn)
  - Post exposure (10-40 minutes after the burn)
  - 3 hours post exposure
  - 6 hours post exposure

Fuel package before a burn

Fuel package after a burn

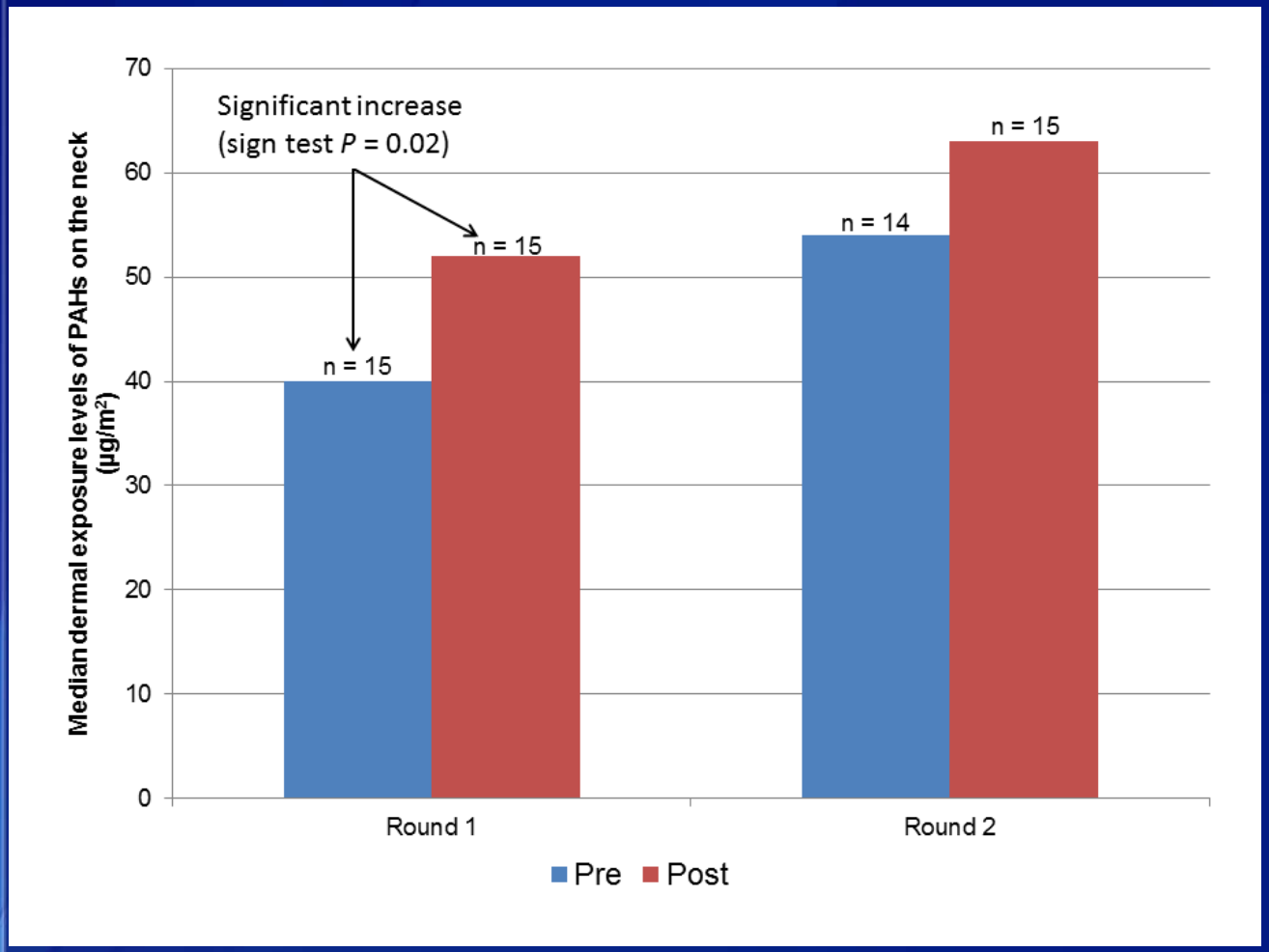
Personal breathing zone concentrations of total PAHs varied across burns



These personal air concentrations are comparable or higher than those measured in other firefighter studies*

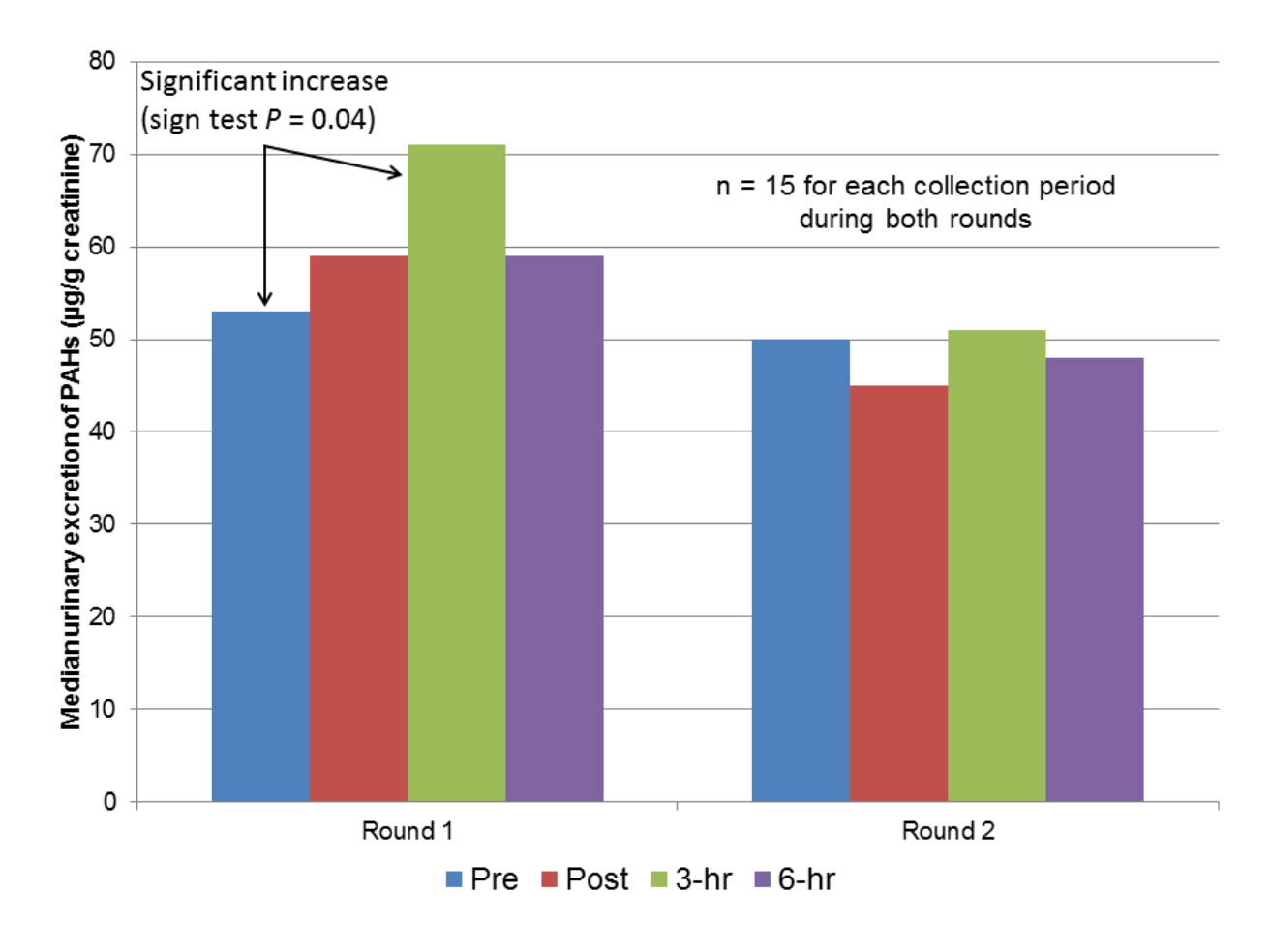
* Queensland Fire and Rescue Service 2011, Feunekes et al. 1997, and Jankovic et al. 1991.

Neck appears to be a primary site for dermal exposure to PAHs



Neck protected mainly by nomex hood

Urinary excretion of total PAHs appears to peak 3 hours after the exposure period



The 3-hour urine levels are comparable to the levels measured in unexposed or low-exposed workers*

* McClean at al. 2012, Osborn et al. 2011, and Smith et al. 2011

Correlations between urinary PAHs and external measures of exposure

Outcome variable	Explanatory variable	Round	No. of samples	Spearman r	Spearman P-value
3-hour change in urinary PAHs (from pre-exposure levels)	Personal breathing zone concentration of PAHs	1	14	0.70	< 0.01
		2	13	0.16	0.60
3-hour change in urinary PAHs (from pre-exposure levels)	Post-exposure change of PAHs on the neck	1	15	0.43	0.11
		2	14	0.62	0.02

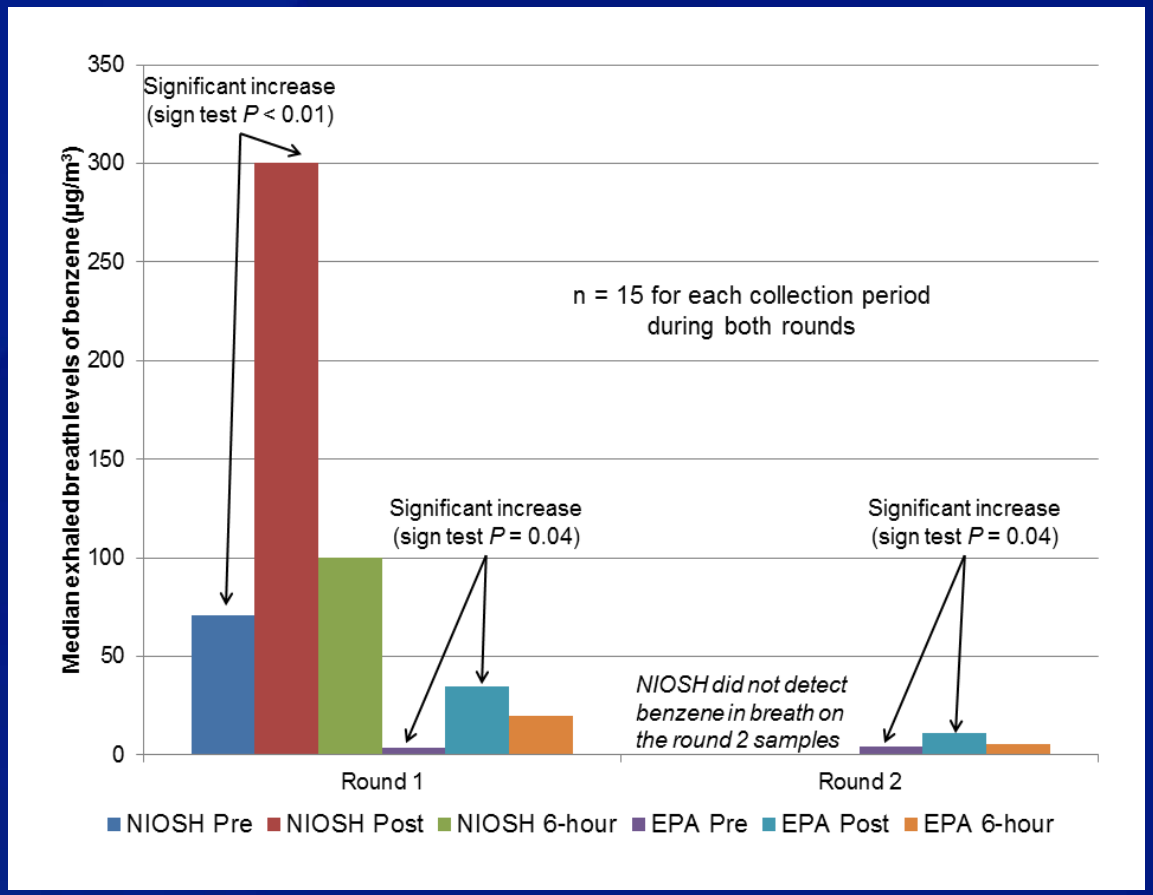
- **Two of these correlations suggest that PAHs in the fire atmosphere are entering the body**
- **Because firefighters wore SCBA, dermal absorption is the most plausible route of entry**
  - Measured elevated levels of PAHs on the neck
  - 20 to 56% of PAHs on skin can be absorbed into the body and, generally, thinner skin has faster absorption*

* Van Rooij et al. 1993

Exhaled breath levels of benzene appear to peak immediately after the exposure period

- NIOSH method had a much higher LOD than the method used by EPA
- EPA lab did not analyze the round 1 samples until 1 year after collection
- Benzene may have degraded during that time

Exhaled breath collection



The post-exposure benzene levels in breath are comparable or higher than the levels measured in low-exposed workers*

* Egeghy et al. 2002

Correlations between exhaled breath levels of benzene and external air concentrations of PAHs

Outcome variable	Explanatory variable	Round	No. of samples	Spearman	
				r	P-value*
Post-exposure change of benzene in breath (NIOSH data)	Personal breathing zone concentration of PAHs	1	14	0.49	0.08
Post-exposure change of benzene in breath (EPA data)	Personal breathing zone concentration of PAHs	2	13	0.74	< 0.01

- **As airborne levels of PAHs increased so might have levels of benzene**
- **This correlation suggest that benzene in the fire atmosphere is entering the body**
- **Dermal absorption is a possible route of entry**
  - <1% of benzene vapor may be absorbed through the skin*
  - High humidity, sweat, increased blood flow at the skin's surface, and other factors could increase absorption†
  - However, because benzene is volatile, some could evaporate from contaminated turnout gear and be inhaled during the doffing of SCBA

* Franz 1984
†Jones et al. 2003, Wester and Maibach 2000, and Franz 1984

Conclusions

- **Firefighters have evidence of systemic exposure to PAHs and benzene despite wearing:**
  - Freshly-laundered turnout gear, gloves, and hoods
  - SCBA throughout the entire burn evolution
- **Increases in PAHs and benzene levels after the fires appear to be related to external exposures**
  - Not all correlations were statistically significant, but these results may be due to weak statistical power
- **Dermal absorption may be the primary route of entry**
  - Neck appears to be one of the main sites of exposure
- **Overall, systemic exposures were comparable to low-exposed occupational groups**