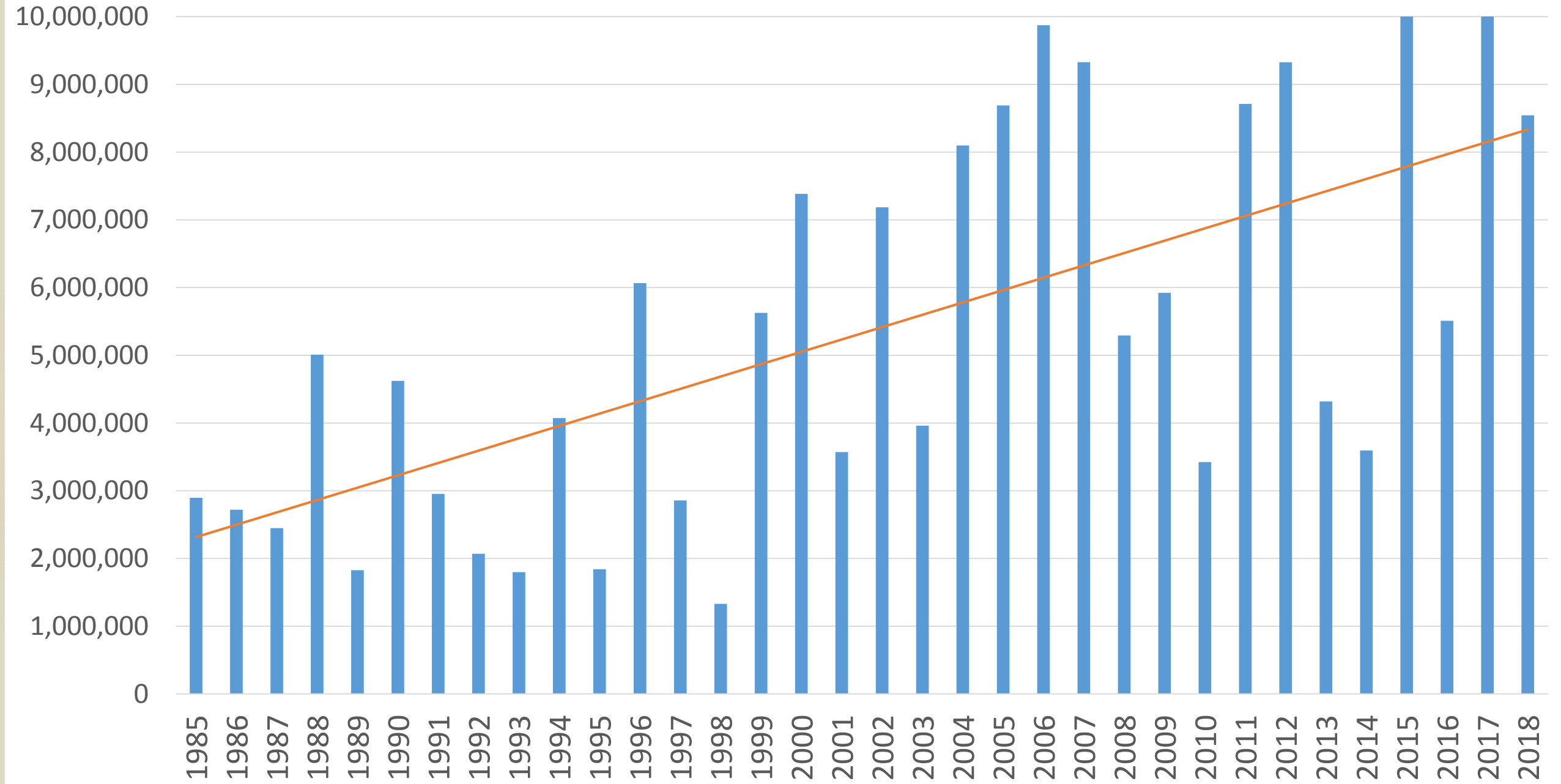


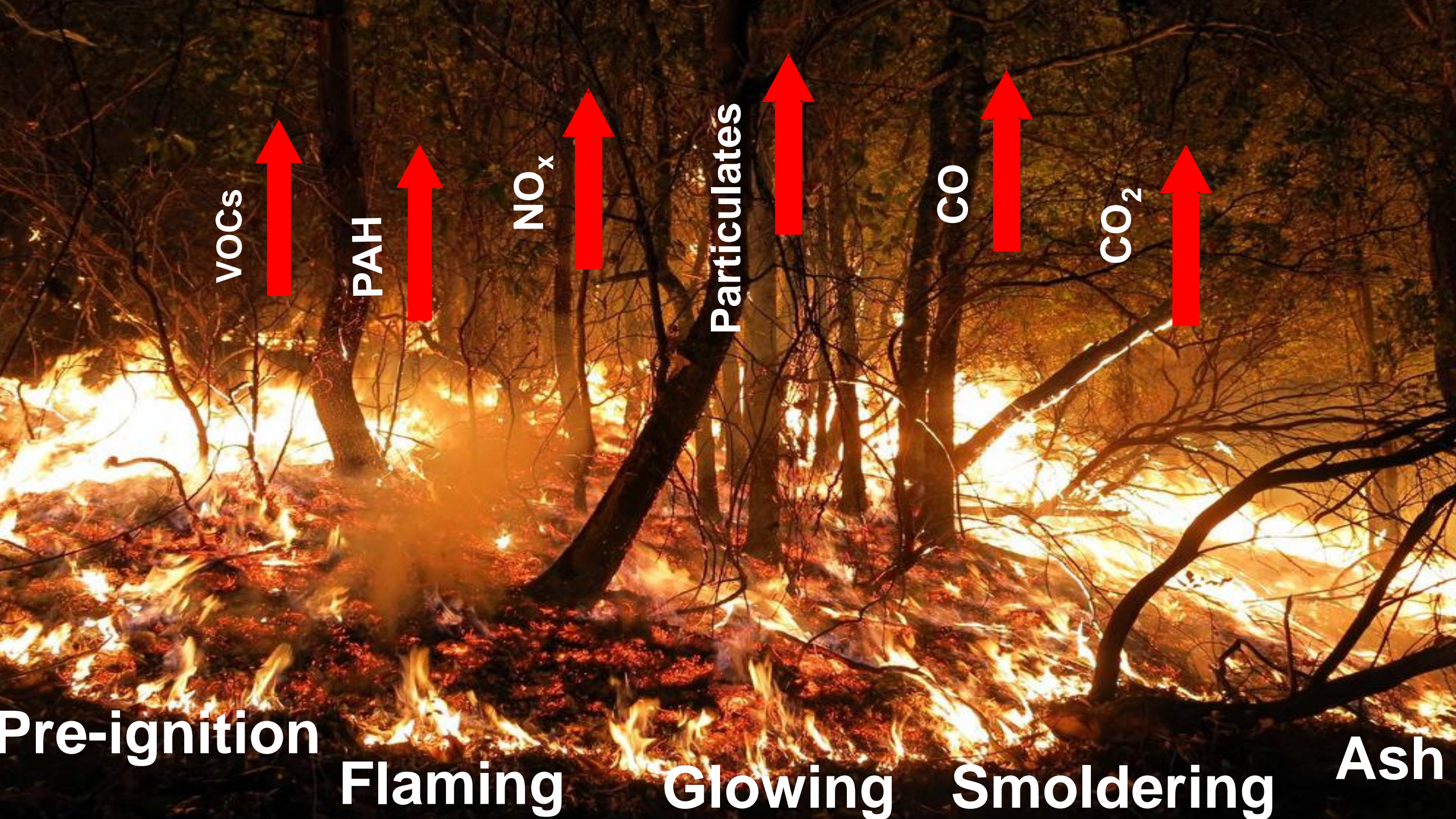


Exposure and Health Impacts of Smoke for Wildland Firefighters



Acres Burned in Wildland Fires 1985-2018





VOCS



PAH



NO_x



Particulates



CO



CO₂



Pre-ignition

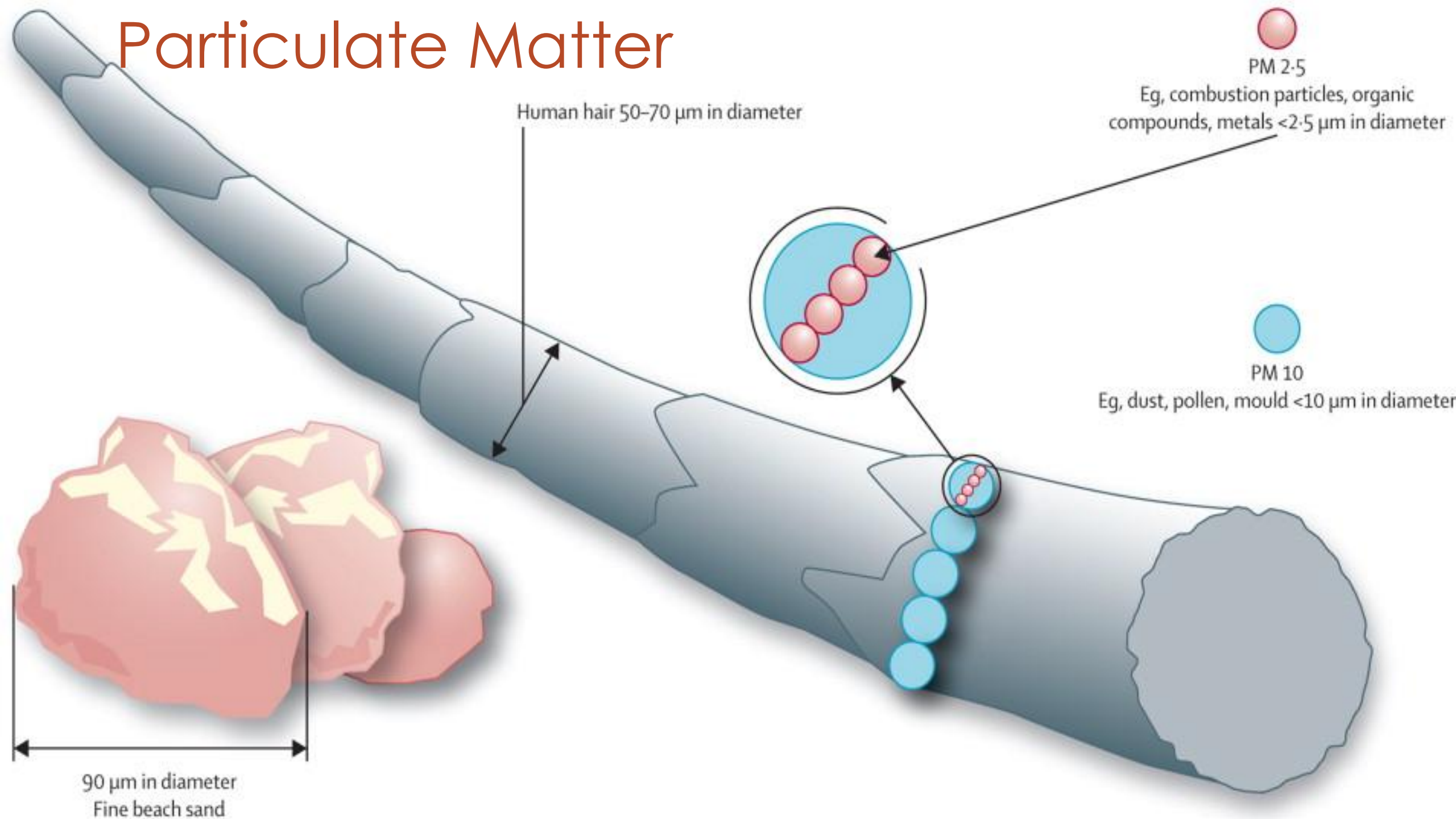
Flaming

Glowing

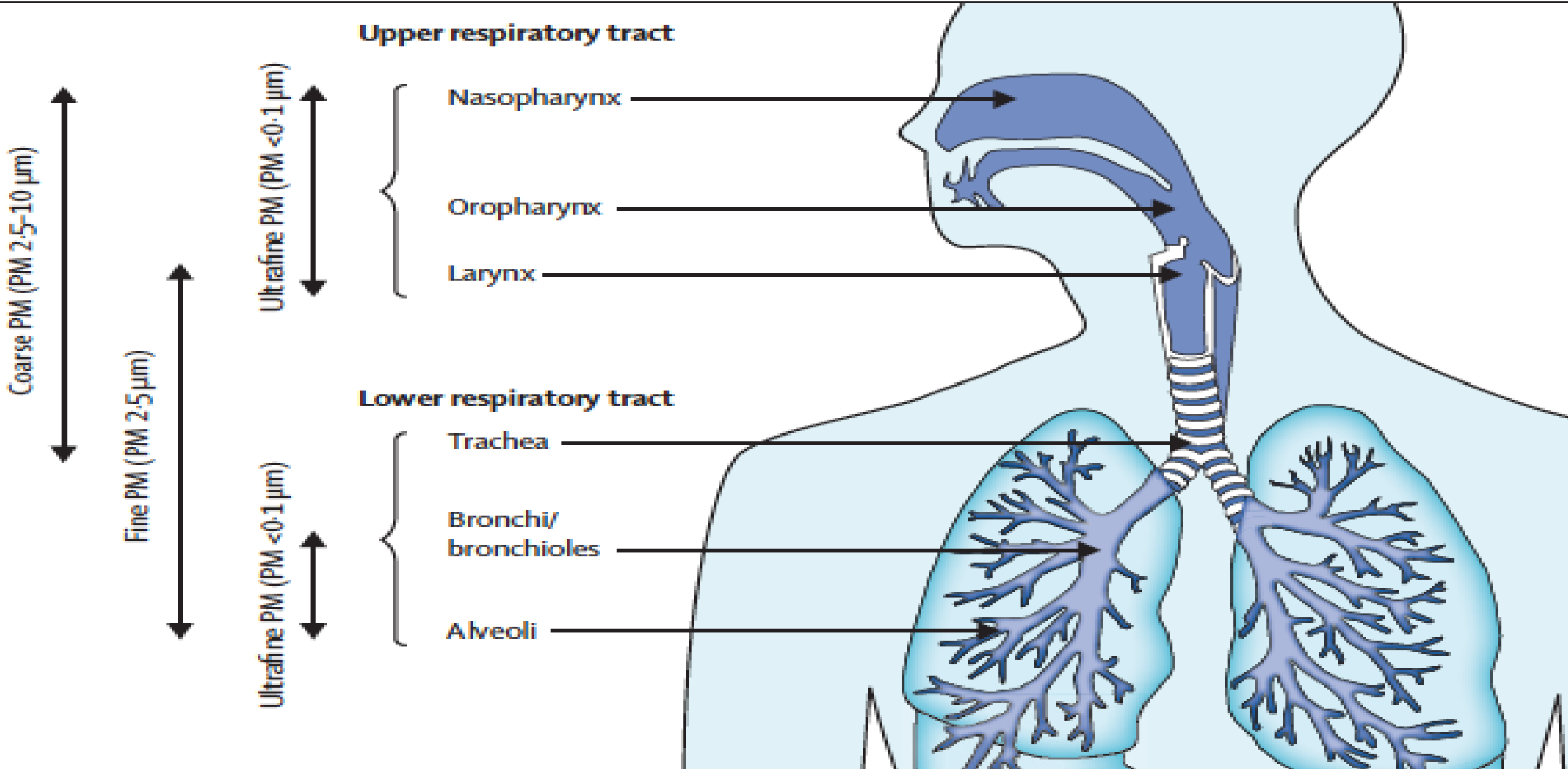
Smoldering

Ash

Particulate Matter



Respiratory System





Wildfire



Prescribed Fire (Rx)



- 2018 - 27,400 wildland firefighters
- Arduous Work Conditions
- Personal Protection Equipment
 - No respirator
- Off – duty Exposures

Background - Human Risks

Yellowstone Wildfires 1988

- 30,000 medical visits
- 12,000 included respiratory complaints
- 600 required subsequent medical attention

Short-Term Health Effects



- ▶ Eye irritation
- ▶ Upper Respiratory Irritation
- ▶ Headache
- ▶ Nausea
- ▶ Lung function

Potential Long-Term Health Effects

A photograph of a volcanic eruption. In the background, a mountain range is visible under a sky filled with thick, dark grey and brown ash clouds. A large plume of white smoke or steam rises from the volcano, partially obscuring the sky. In the foreground, there is a lush green landscape with rolling hills and tall, golden-brown grasses in the immediate foreground. The overall scene is dramatic and powerful.

- ▶ Chronic obstructive pulmonary disease
- ▶ Bronchitis
- ▶ Emphysema
- ▶ Heart disease
- ▶ Cancer

	Exposure (mean)	Outcome	Study Details
Hejl et al 2013 S. Carolina Prescribed Burn	PM _{2.5} 0.65 mg/m ³ CO 3.6 ppm	↑ Inflammation Markers	Cross-shift change
Slaughter et al 2005 Northwest Prescribed Burn	PM _{3.5} 0.88 mg/m ³ CO 7.19 ppm	↓ Lung Function	Cross-shift change Not assoc. with exposure
Gaughan et al 2014 Colorado Fire Hotshot Crew	PM _{2.5} 1.04 mg/m ³ CO 6.64 ppm	↓ Lung Function	High levoglucosan exposure
Semmens et al 2016 Survey of Firefighters	Years of Wildland firefighting	↑ High Blood Pressure ↑ Heart Arrhythmia ↑ Knee Surgery	Self-reported health outcomes

Pre/Post Season Assessments

▶ Liu et al. 1992

▶ Airway response ↑

▶ Lung Function

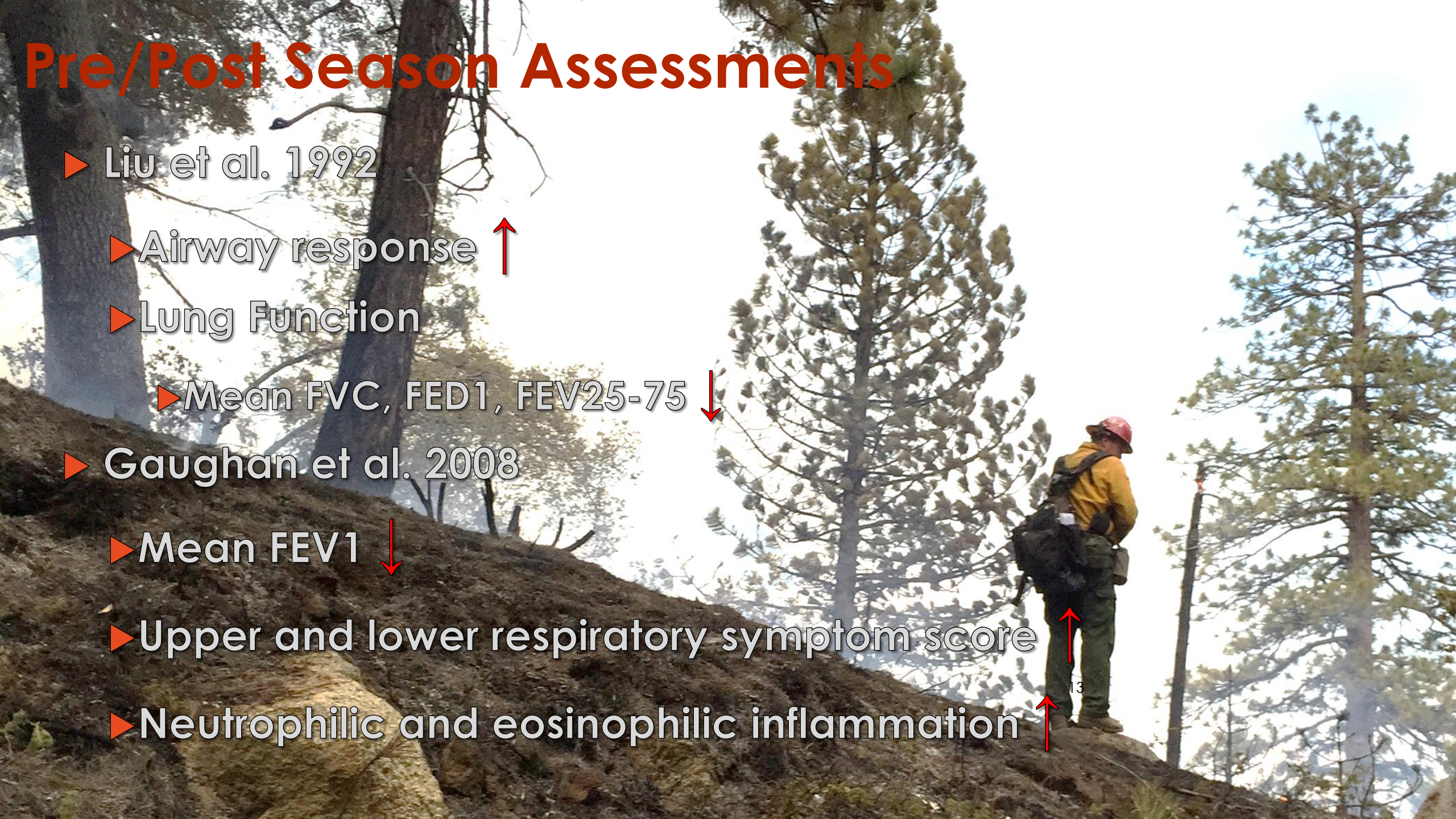
▶ Mean FVC, FED1, FEV25-75 ↓

▶ Gaughan et al. 2008

▶ Mean FEV1 ↓

▶ Upper and lower respiratory symptom score ↑

▶ Neutrophilic and eosinophilic inflammation ↑



Overview

- Introduction to Wildland Firefighting
 - Incident Command System
 - Job Tasks
- Firefighter Research Projects
 - Polycyclic Aromatic Hydrocarbon Exposure across Job Tasks and at Fire Camp
 - Particulate Matter Exposure and Disease Risk

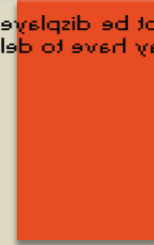
Incident Command System

- ▶ Incident – Emergency Response Situation
- ▶ Command - Overall responsibility and decision-making for the incident
 - ▶ Incident Commander
- ▶ Operations - Develops and implements the strategy and tactics.



Resource Types

- ▶ Type 1/2 resources
- ▶ Hand crews
- ▶ Engines
- ▶ Aviation



Suppression Strategies

A group of firefighters in full gear, including helmets and large air tanks, are walking through a grassy field. In the background, there are mountains and a large plume of smoke rising into the sky under a blue sky with scattered clouds.

▶ Direct/Indirect Attack

▶ Initial/Extended Attack



Fire Line Construction



Holding



Mop-Up



Engine Operator



Firing



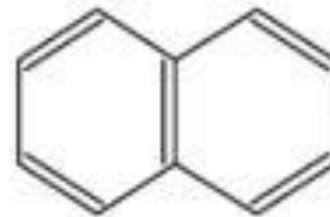
Characterization of Polycyclic Aromatic Hydrocarbon Exposure for Wildland Firefighters



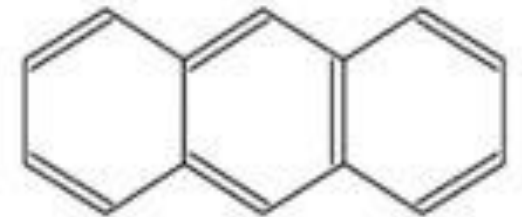
Objective - characterize exposures of wildland firefighters performing various job tasks to PAHs and examine off-duty PAH and $PM_{2.5}$ concentrations associated with wildland fires.

Polycyclic Aromatic Hydrocarbons

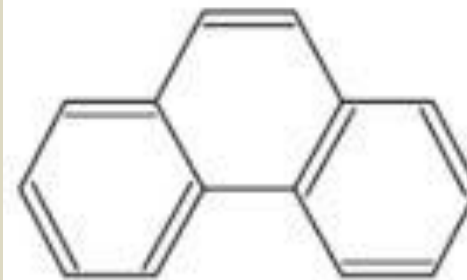
- ▶ Incomplete combustion by-product
 - ▶ Gas and Particle - Inhalable
- ▶ Health Effects
 - ▶ Carcinogens
 - ▶ Immune dysfunction
 - ▶ Cardiopulmonary



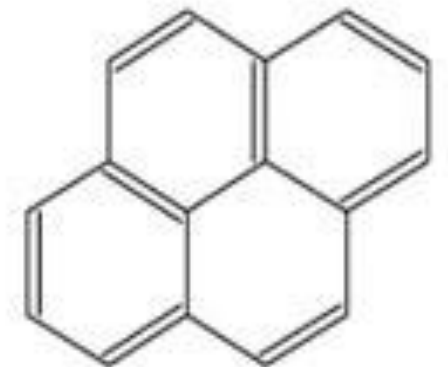
Naphthalene



Anthracene



Phenanthrene



Pyrene

Methods – Exposure Assessment

- ▶ Personal Samples – various job tasks
- ▶ Wildfire (N=21)
 - ▶ Willow – 5,700 acres
 - ▶ Rough – 151,623 acres
- ▶ Prescribed Fire (N=4)
 - ▶ Klamath Rx Fire - 30 acres



Exposure Assessment

- ▶ XAD2 Coated Filters
- ▶ Sorbent tubes
- ▶ Sampling pumps
 - ▶ 200 ml/min
 - ▶ 1.5 – 2 L/min
- ▶ 17 PAHs measured

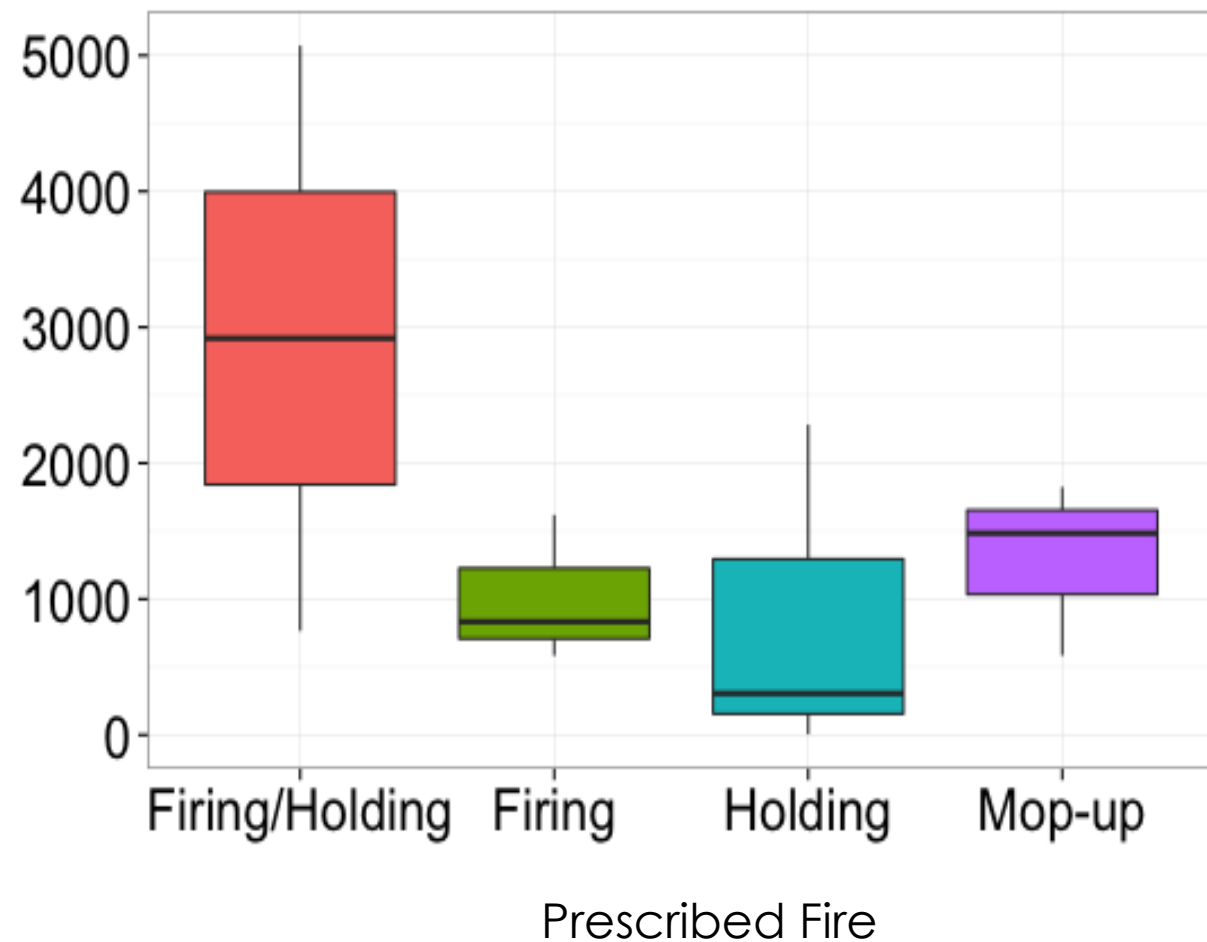
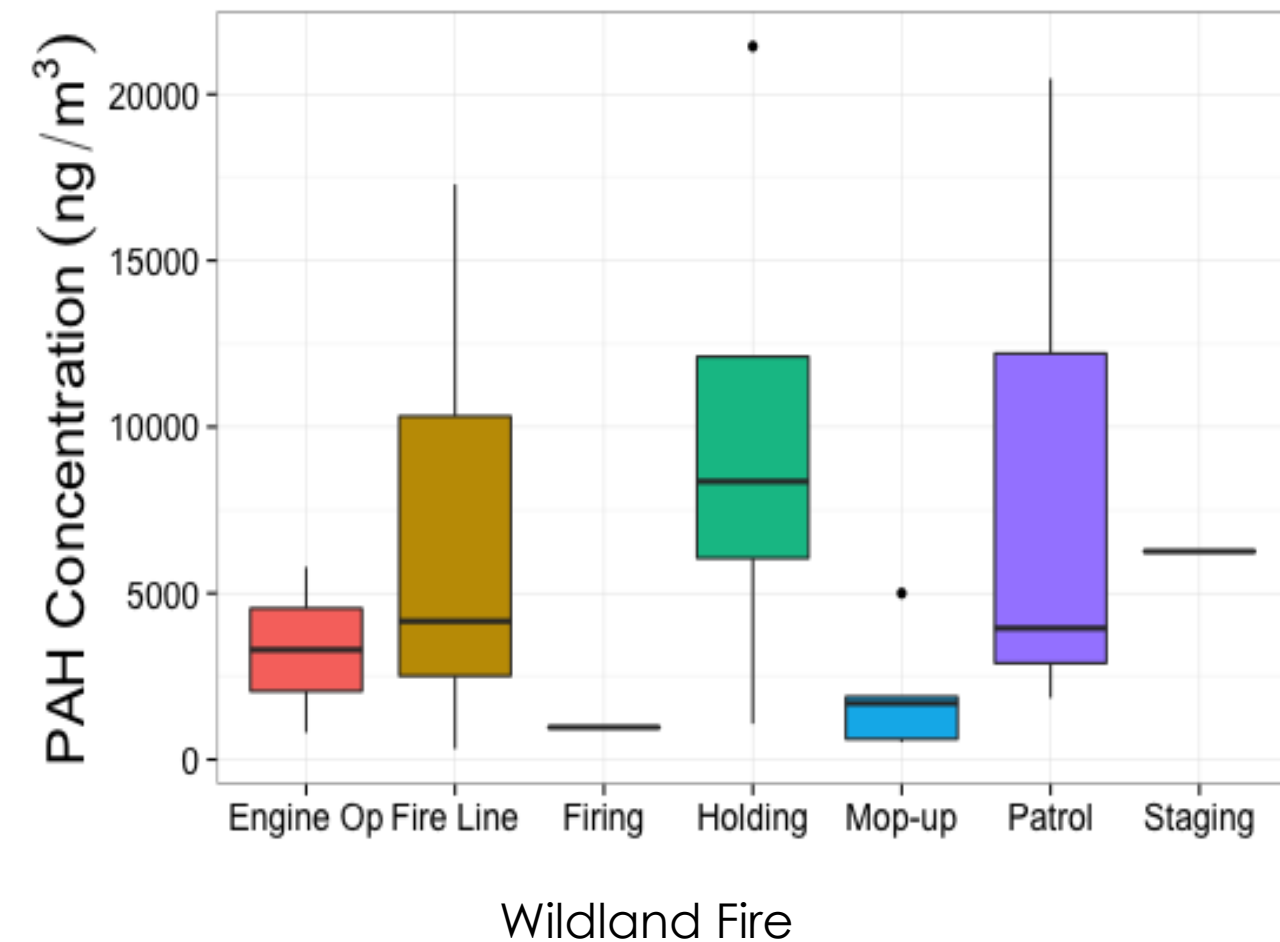


Results - Participants

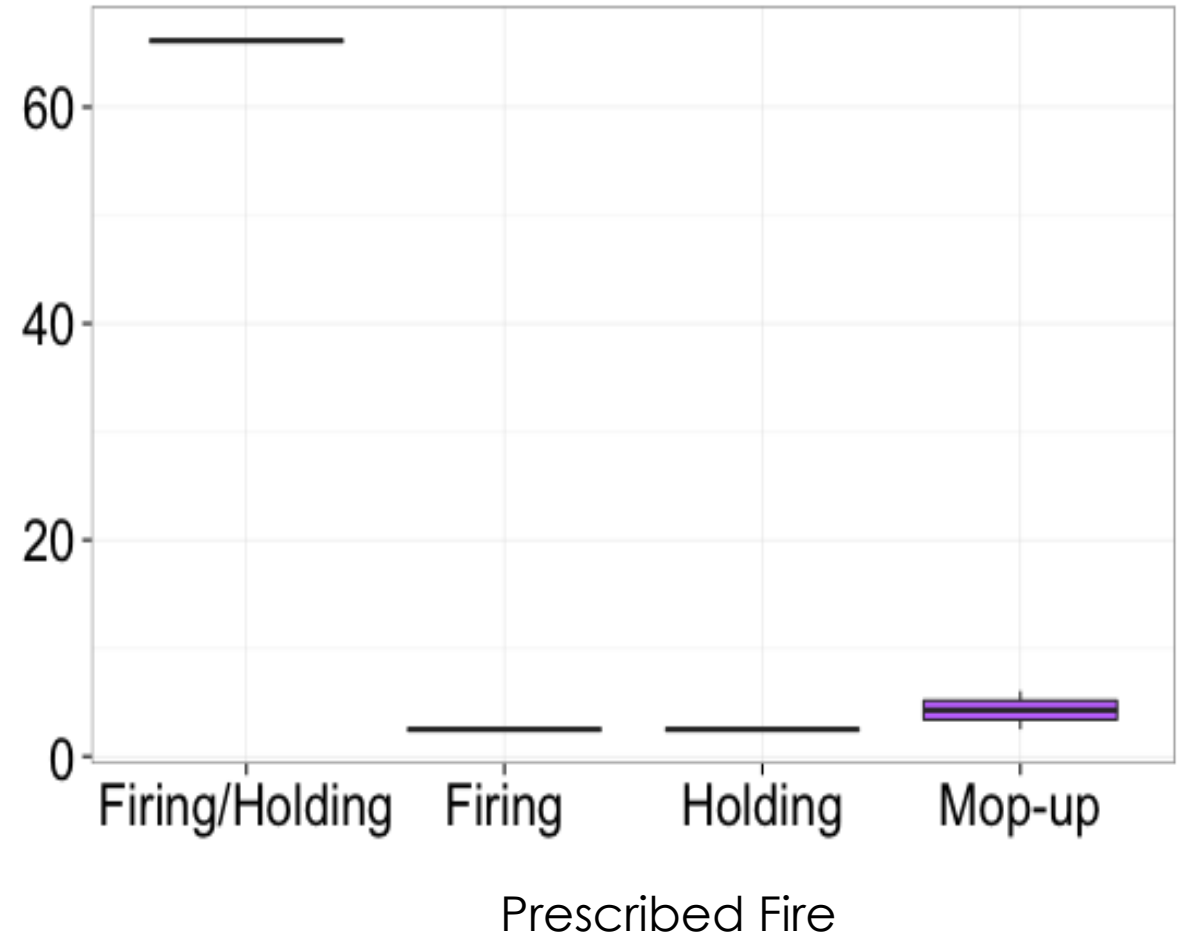
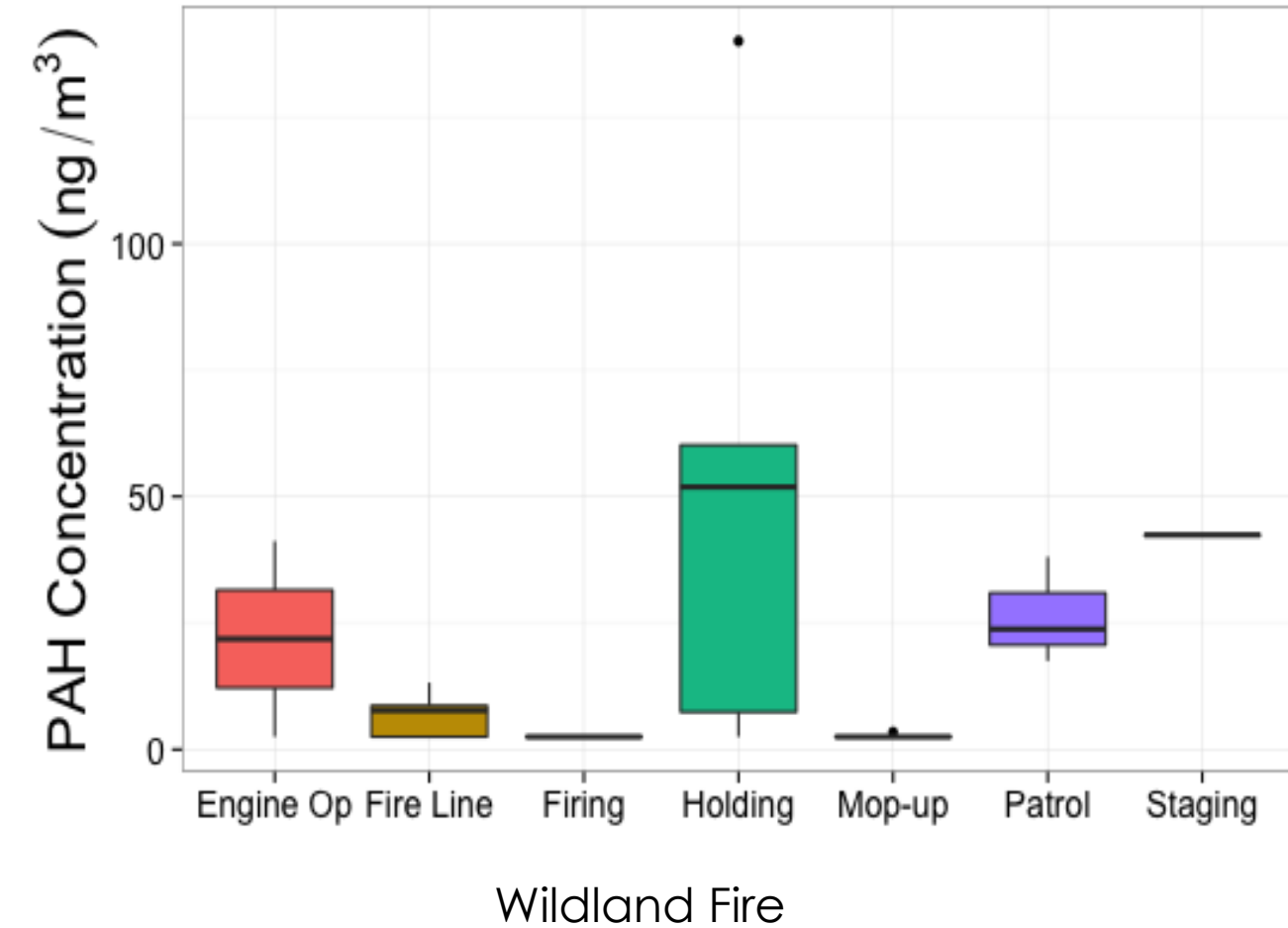
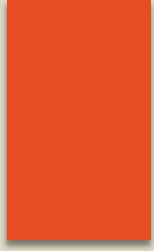
Variable		Response
Wildland Fire		N = 21
Male		18 (86%)
Crew Type		
	IHC	15 (71%)
	Engine	6 (29%)
Day Shift		20 (95%)
Chainsaw Use		3 (10%)
Smoke Rating		
	None	2 (7%)
	Mild	13 (46%)
	Mild/Moderate	3 (11 %)
	Moderate	5 (18%)
	Moderate/Severe	1 (4%)
	Severe	4 (14%)

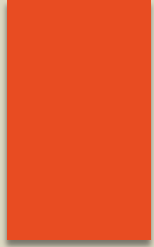
Prescribed Fire		N = 4
Male		2 (50%)
Smoke Rating		
	None	1 (9%)
	Mild	5 (45.5%)
	Moderate	5 (45.5%)
	Severe	0

Results - Naphthalene



Results – Benzo[a]pyrene





Discussion – Personal Exposures

- Past Exposure Assessments
 - Similar to Materna et al. - 12 particle-phase PAHs (4 – 257 ng m⁻³)
 - Lower than Reh et. al. (Yosemite)
- Occupational Exposures
 - Lower than Structural Firefighters
 - Higher than Forest Workers using chainsaws

Materna, B. L.; Jones, J. R.; Sutton, P. M.; Rothman, N.; Harrison, R. J. Occupational exposures in California wildland fire fighting. *Am. Ind. Hyg. Assoc. J.* **1992**, 53 (1), 69–76.

Reh, C. M.; Letts, D.; Scott Deitchman. NIOSH Health Hazard Evaluation Report - HETA 90-0365-2415. US Department of Interior, National Park Service, Yosemite National Park, California.; 90-0365-2415; 1994.

Robinson, M. S.; Anthony, T. R.; Littau, S. R.; Herckes, P.; Nelson, X.; Poplin, G. S.; Burgess, J. L. Occupational PAH exposures during prescribed pile burns. *Ann. Occup. Hyg.* **2008**, 52 (6), 497–508.

Baxter, C. S.; Hoffman, J. D.; Knipp, M. J.; Reponen, T.; Haynes, E. N. Exposure of Firefighters to Particulates and Polycyclic Aromatic Hydrocarbons. *J. Occup. Environ. Hyg.* 2014, 11 (7), D85–D91.

Neri, F.; Foderi, C.; Laschi, A.; Fabiano, F.; Cambi, M.; Sciarra, G.; Aprea, M. C.; Cenni, A.; Marchi, E. Determining exhaust fumes exposure in chainsaw operations. *Environ. Pollut.* 2016, 218, 1162–

Conclusions

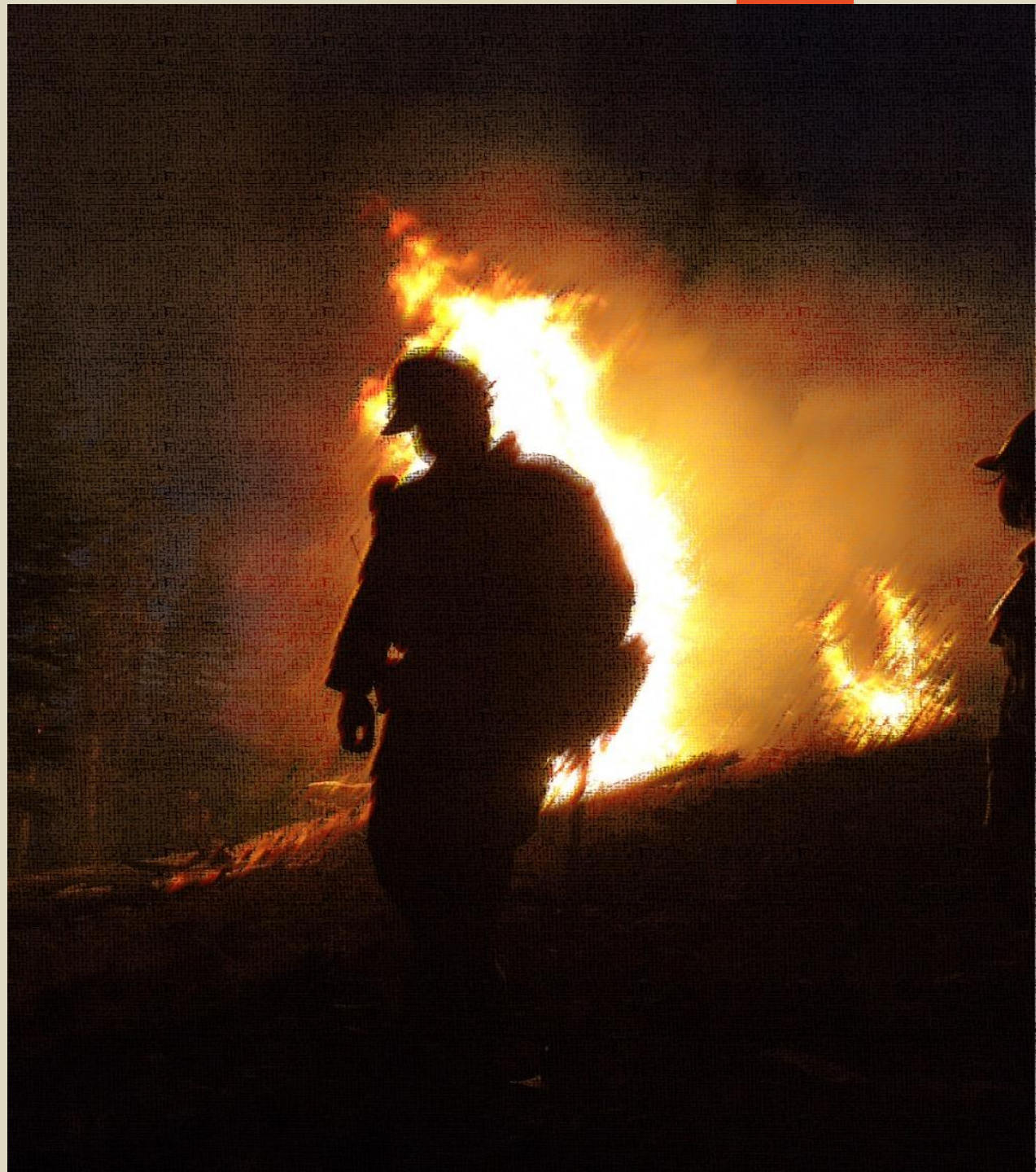
- Naphthalene had highest measured concentrations
- Low molecular weight PAHs contributed most to Total PAH
- Wildland Fire – Holding had highest concentrations of many PAHs
- Rx – Firing/Holding had highest concentrations of many PAHs
- Lower than other highly PAH exposed occupations
- Limitations
 - Small sample size
 - Convenience sampling

Wildland Firefighter Smoke Exposure and Risk of Lung Cancer and Cardiovascular Disease Mortality

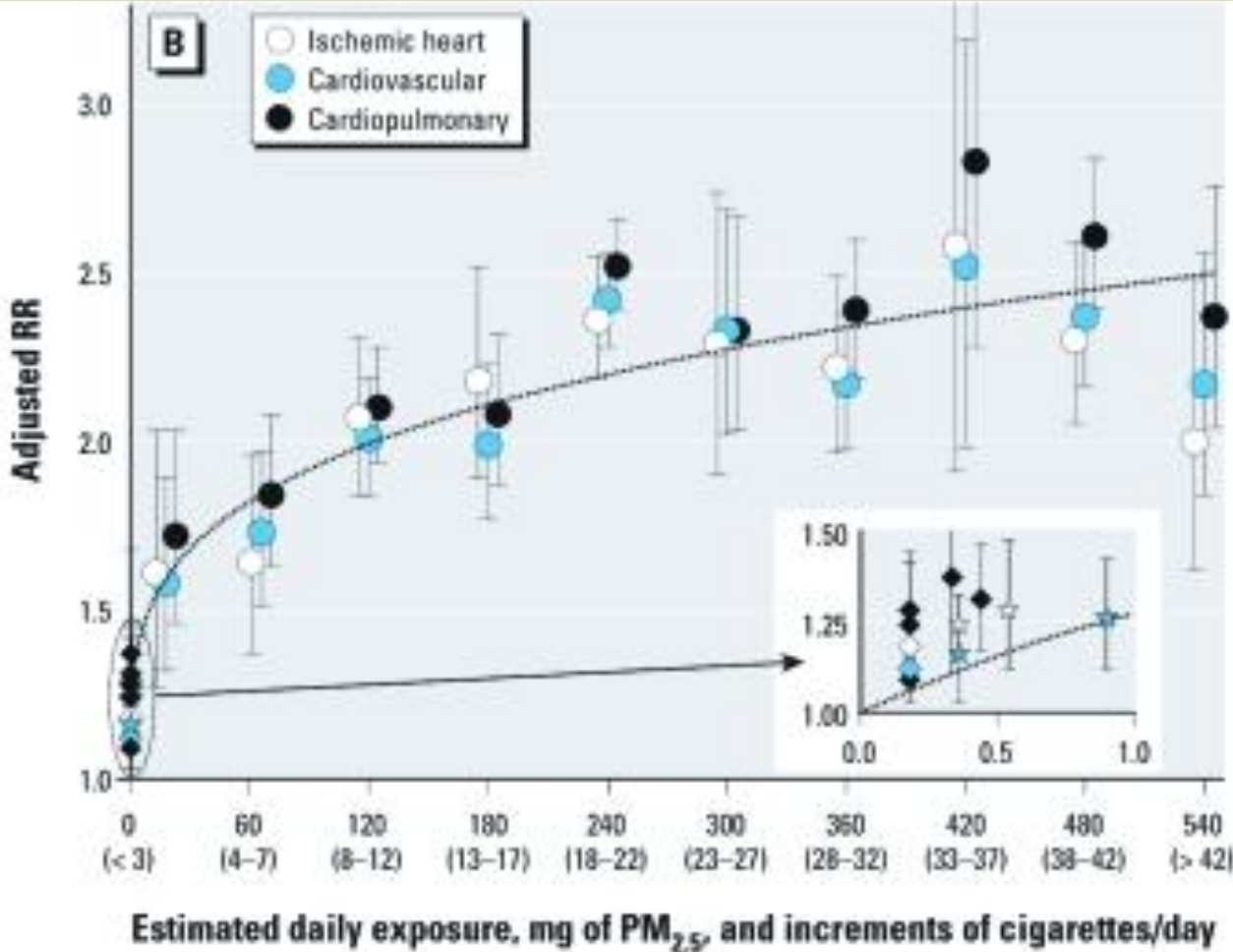
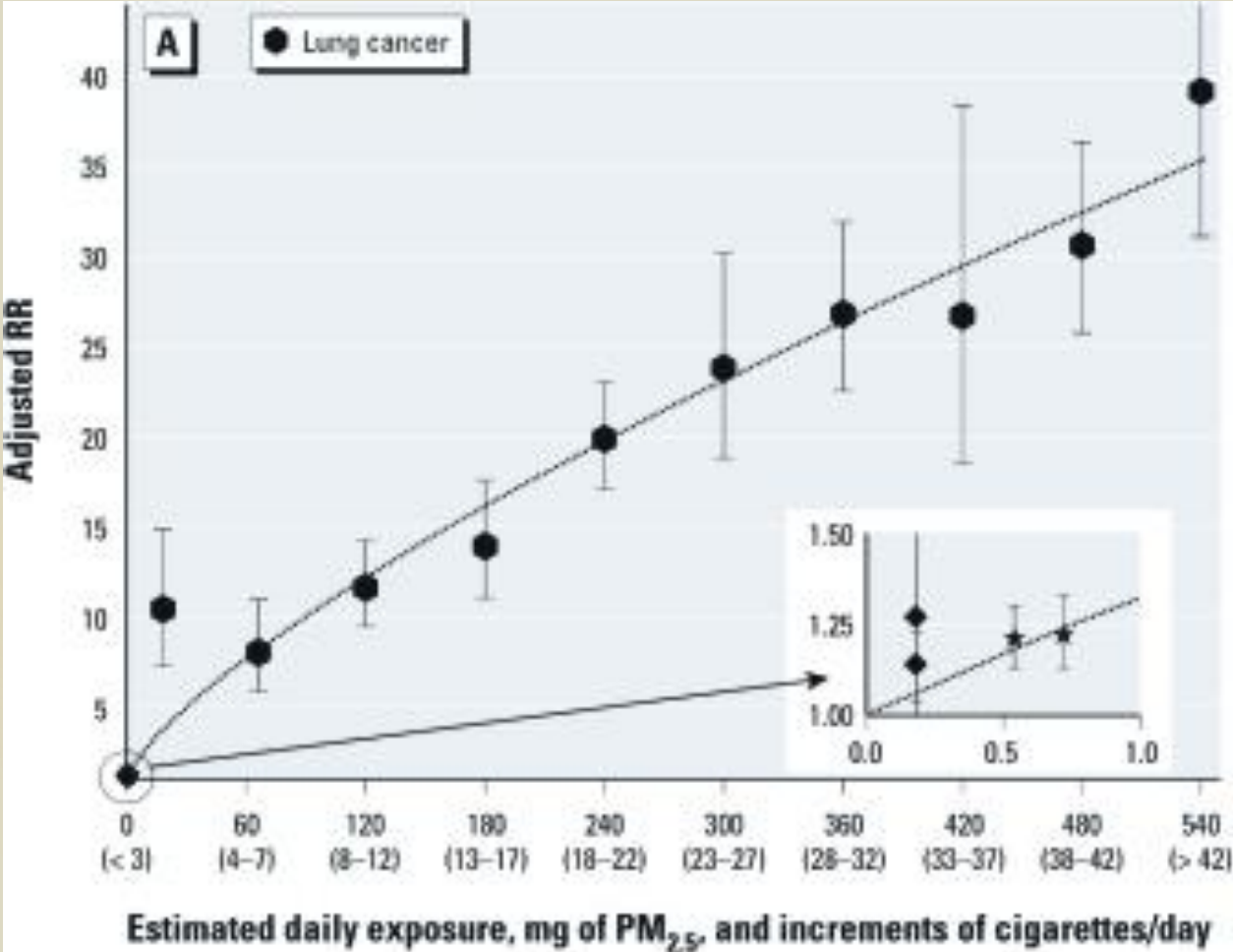


Objective

Estimate lifetime risk of lung cancer (LC) and cardiovascular disease (CVD) from relative exposure to particulate matter (PM) from smoke.



Exposure – Response – Pope III et al. 2011



Methods

Estimation of Mortality Risk (Pope et al., 2011)

▶
$$RR = 1 + \alpha(dose)^\beta$$

Daily dose PM₄(mg)

$$= \text{Exposure Concentration} \left(\frac{mg}{m^3} \right) \times \text{Breathing Rate} \left(\frac{L}{min} \right) \times \text{Daily Shift Duration} \left(\frac{hrs}{shift} \right) \times F \times CF$$

$$F - \text{Frequency of exposure} = \left(\frac{\text{shift days per year}}{365 \text{ days per year}} \times \frac{\text{years of firefighting career}}{45 \text{ years}} \right)$$

$$CF - \text{Conversion Factors} \left(\frac{60 \text{ min}}{hr} \right) \text{ and } \left(\frac{m^3}{1000 \text{ liters}} \right)$$

Wildland Fire Personnel Smoke Exposure

GEORGE BROYLES AND JOE DOMITROVICH PHD
FOREST SERVICE NATIONAL T&D PROGRAM



Sample size, shift duration and fireline duration

		Prescribed Fire	Wildfire	Prescribed Natural Fire	Initial Attack
		n=83	n=417	n=83	n=60
Average shift duration	(hh:mm)	10:27	13:38	13:33	12:24
Maximum shift duration	(hh:mm)	17:00	17:00	16:30	16:30
Minimum shift duration	(hh:mm)	4:08	7:30	6:24	3:30
Average fireline duration	(hh:mm)	6:03	9:57	10:14	4:13
Maximum fireline duration	(hh:mm)	12:00	16:00	14:00	10:18
Minimum fireline duration	(hh:mm)	1:25	1:10	4:00	0:51

M 6:57 AUG/12/2014

Exposure Study 2009-2012, 2015-2017



Data Sheet

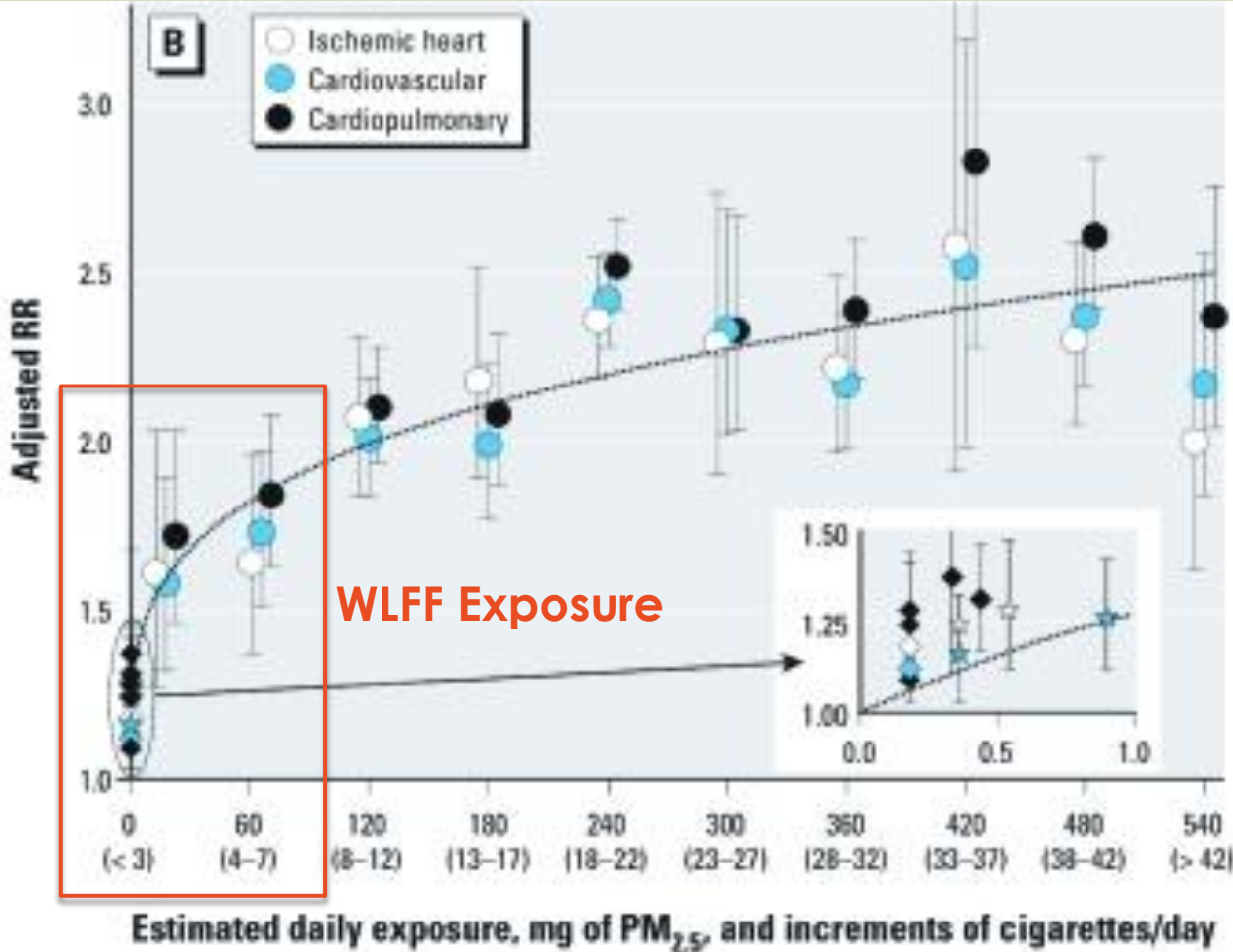
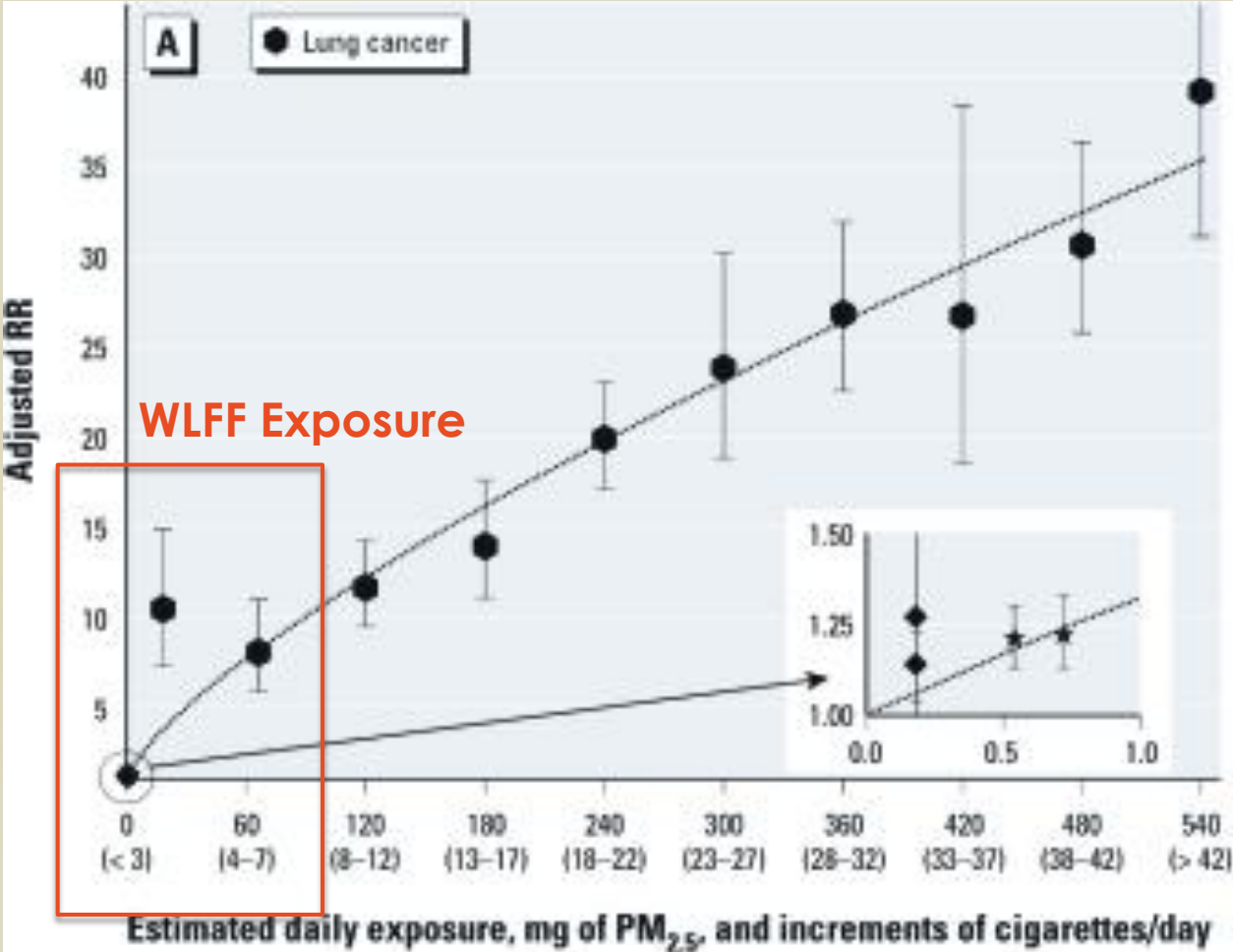
Fire Name:		Record # _____ of _____	
Crew Name:		Fire Behavior:	Slash:
Member Name		<input type="checkbox"/> Crowning	<input type="checkbox"/> Heavy
Date:		<input type="checkbox"/> Torching	<input type="checkbox"/> Moderate
Day # on Fire:		<input type="checkbox"/> Spotting	<input type="checkbox"/> Light
Start Time:		<input type="checkbox"/> Ground	
Lat:			Flame Height:
Long:		Brush Height:	<input type="checkbox"/> 0-1 FT
Fuel Model:		<input type="checkbox"/> 0-2 FT	<input type="checkbox"/> 2-4 FT
Slope %:		<input type="checkbox"/> 2-4 FT	<input type="checkbox"/> >4 FT
Temp:		<input type="checkbox"/> 4-6 FT	
RH:		<input type="checkbox"/> >6 FT	Canopy:
Wind Speed:			<input type="checkbox"/> Open
Wind Dir:		Fire Activity:	<input type="checkbox"/> Closed
Slope Aspect:		<input type="checkbox"/> Backing	
Elevations:		<input type="checkbox"/> Head	Fuel Loading:
End Time:		<input type="checkbox"/> Flank	<input type="checkbox"/> Continuous
Imaging Reference #s:			
Fireline Specifications:			
Direct:	Indirect:	Width:	Felling:
<input type="checkbox"/> Scratch	<input type="checkbox"/> Scratch	<input type="checkbox"/> 0-12 IN	# Sawyers:
<input type="checkbox"/> Under Slung	<input type="checkbox"/> Under Slung	<input type="checkbox"/> 1-2 FT	
<input type="checkbox"/> Cup Trench	<input type="checkbox"/> Cup Trench	<input type="checkbox"/> 2-3 FT	# Brushers:
		<input type="checkbox"/> >3 FT	
Removal Width: (each side of line)	Removal Height: (each side of line)	Offline - Non Working	Other Operations:
<input type="checkbox"/> Brush	<input type="checkbox"/> Brush	<input type="checkbox"/> Driving	<input type="checkbox"/> Firing
<input type="checkbox"/> Ladder Fuel	<input type="checkbox"/> Ladder Fuel	<input type="checkbox"/> Hiking	
<input type="checkbox"/> 1-2 FT	<input type="checkbox"/> 1-2 FT		<input type="checkbox"/> Holding
<input type="checkbox"/> 2-3 FT	<input type="checkbox"/> 2-3 FT		
<input type="checkbox"/> 3-5 FT	<input type="checkbox"/> 3-5 FT		<input type="checkbox"/> Improving
<input type="checkbox"/> >5 FT	<input type="checkbox"/> >5 FT		
Offline:		Offline:	
Start:	End:	Start:	End:
<input type="checkbox"/> Operational	<input type="checkbox"/> Safety	<input type="checkbox"/> Operational	<input type="checkbox"/> Safety
<input type="checkbox"/> Air Support	<input type="checkbox"/> Relocation	<input type="checkbox"/> Air Support	<input type="checkbox"/> Relocation
<input type="checkbox"/> Other:		<input type="checkbox"/> Other:	

Fire Activity Codes			
1.1	Handline Direct Scratch	2.1	Handline Indirect Scratch
1.5	Handline Direct Sawyer	2.5	Handline Indirect Sawyer
1.7	Handline Direct Swamper	2.7	Handline Indirect Swamper
1.8	Handline Direct Engine	2.8	Handline Indirect Engine
1.9	Handline Direct Pump	2.9	Handline Indirect Pump
1.10	Handline Direct Squad	2.1	Handline Indirect Squad
1.11	Handline Direct Firefighter	2.11	Handline Indirect Firefighter
1.12	Handline Direct Mop Up		
1.13	Handline Direct Dozer Boss	2.13	Handline Indirect Dozer Boss
Non-Fire Activity Types			
3.1	Dozer Line Direct	7	Line Preparation
3.2	Dozer Line Indirect	7.1	Initial Attack
4	Cold Trailing	8.1	ICP Stationary
		8.2	ICP Supply
5.1	Improving Direct	8.3	ICP Ground
5.2	Improving Indirect	8.4	ICP Other
6.1	Holding Direct	9.1	Rx Lighter
6.2	Holding Indirect	9.2	Rx Holder
6.3	Holding Firefighter	9.3	Rx Burn Boss
6.4	Holding Squad	9.4	Suppression Lighter
6.5	Holding Engine	9.5	Suppression Holder
6.6	Engine Pump Operator	9.6	Suppression Burn Boss
6.7	Holding Pump	0	Smoke Mitigation
Crew Types			
1	I - Force Account		
2.1	II - Force Account	3.1	II(A) - Force Account
2.2	II - Contract	3.2	II(A) - Contract

Study Results

Exposure Time	Occupational Exposure Limit	Geo. Mean (SD)	% above OEL	
CO	1-minute	NIOSH IDLH 1200 ppm	60 ppm (3.7)	1
	5-minute	STEL NIOSH/States 200 ppm	29 ppm (4.0)	9
	8-hour TWA	OSHA PEL 50 ppm	2.2 ppm (5.8)	6
	Fireline	NWCG 25 ppm	1.8 ppm (6.1)	11
	Shift	NWCG 16 ppm	1.4 ppm (5.9)	8
PM₄	Shift	NWCG 0.7 mg/m³	0.32 mg/m³ (2.7)	22
Silica	Shift	Adjusted PEL 0.057 mg/m ³	0.007 mg/m ³ (6.9)	10

Exposure – Response – Pope III et al. 2011



Methods

Estimation of Mortality Risk (Pope et al., 2011)

▶
$$RR = 1 + \alpha(dose)^\beta$$

Daily dose PM₄(mg)

$$= \text{Exposure Concentration} \left(\frac{mg}{m^3} \right) \times \text{Breathing Rate} \left(\frac{L}{min} \right) \times \text{Daily Shift Duration} \left(\frac{hrs}{shift} \right) \times F \times CF$$

$$F - \text{Frequency of exposure} = \left(\frac{\text{shift days per year}}{365 \text{ days per year}} \times \frac{\text{years of firefighting career}}{45 \text{ years}} \right)$$

$$CF - \text{Conversion Factors} \left(\frac{60 \text{ min}}{hr} \right) \text{ and } \left(\frac{m^3}{1000 \text{ liters}} \right)$$

Breathing Rate (liters/min)

- ▶ Field measured heart rates
- ▶ Job Tasks
- ▶ Valli et al., 2013
 - ▶ Six participants performed exercise testing
 - ▶ $V_e = 3(\text{HR}) + 16.2$
- ▶ BR – 25 liters min^{-1}



Methods

Estimation of Mortality Risk (Pope et al., 2011)

▶
$$RR = 1 + \alpha(dose)^\beta$$

Daily dose PM₄(mg)

$$= \text{Exposure Concentration} \left(\frac{\text{mg}}{\text{m}^3} \right) \times \text{Breathing Rate} \left(\frac{\text{L}}{\text{min}} \right) \times \text{Daily Shift Duration} \left(\frac{\text{hrs}}{\text{shift}} \right) \times F \times CF$$

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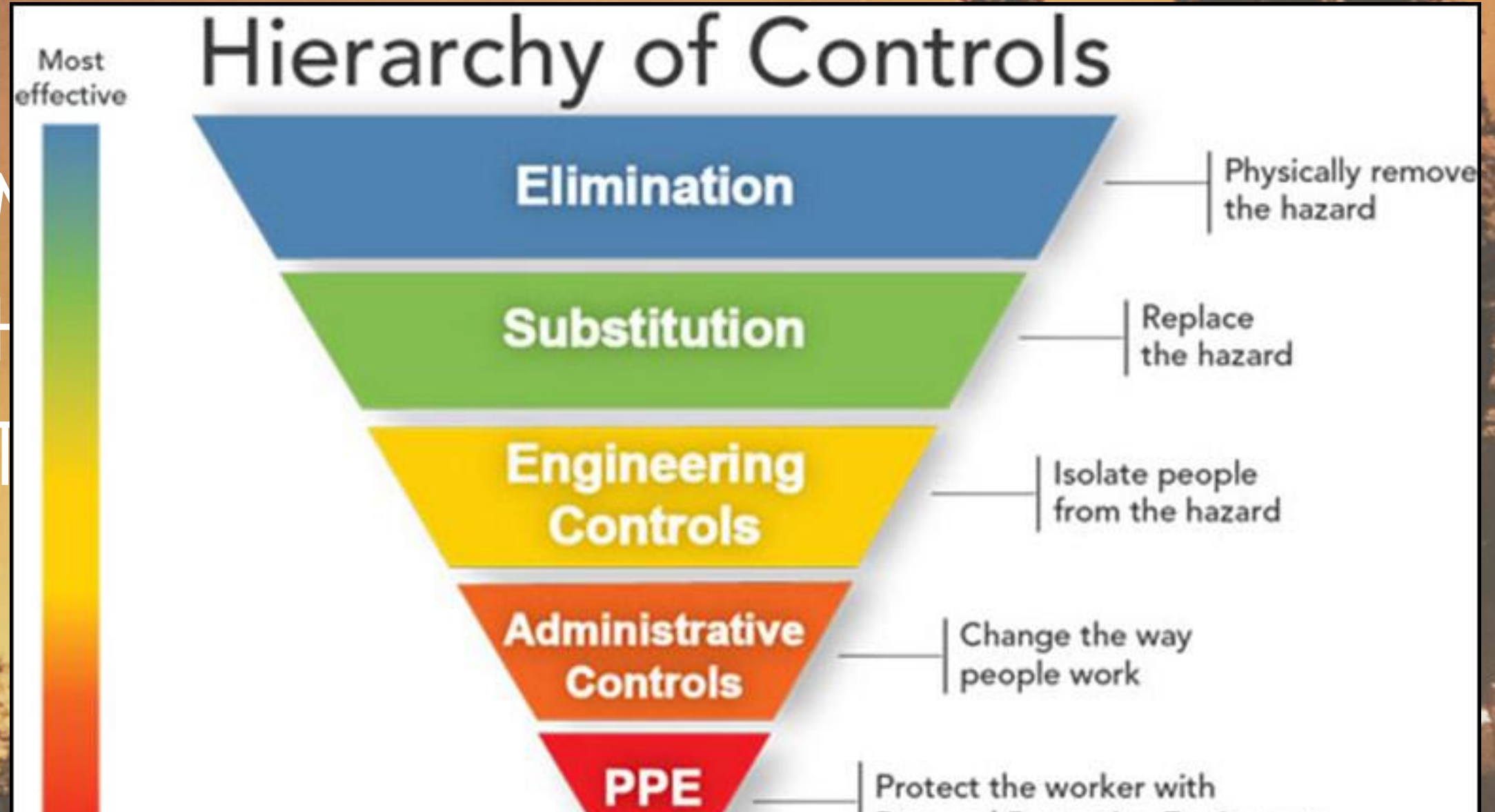
WLFF Risk Assessment – Methods

Exposure Scenario	Shift Exposure (mg/m ³)		Breathing Rate (LPM)	Shift Duration (hours)	Fire Days (Days/Year)	Career Duration	PM ₄ Daily Dose (mg)
	Mean	95th Percentile					Mean (95th PCTL)
Short Season	0.5	0.64	24	13.6	49	5	0.15 (0.19)
						10	0.30 (0.37)
						15	0.45 (0.56)
						20	0.60 (0.75)
						25	0.74 (0.93)
Long Season	0.5	0.64	24		98	5	0.30 (0.37)
						10	0.60 (0.75)
						15	0.89 (1.12)
						20	1.19 (1.50)
						25	1.49 (1.87)

WLFF Risk Assessment - Results

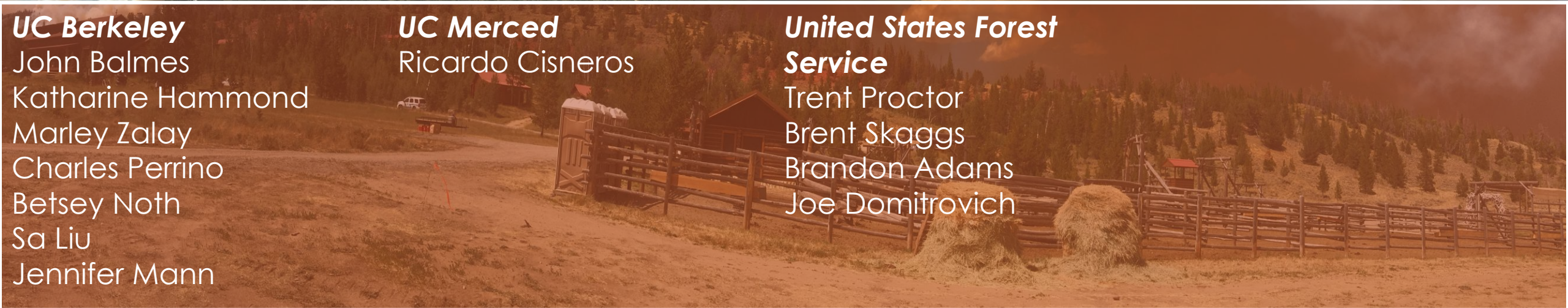
Exposure Scenario	Lung Cancer		CVD	
	Excess Risk (%)	95 th (%)	Excess Risk (%)	95 th (%)
Short Season	8	9	16	17
	13	15	19	21
	18	21	22	23
	22	26	23	25
	26	30	25	26
Long Season	13	15	19	21
	22	26	23	25
	29	35	26	28
	36	43	28	30
	43	51	30	32

Mitigation Strategies



Future Research Needs

- ▶ PPE - Respirator use
- ▶ Dermal Exposures
- ▶ Prospective cohort study
- ▶ Firefighter vs. Community Smoke Exposure



UC Berkeley

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Marley Zalay
Charles Perrino
Betsey Noth
Sa Liu
Jennifer Mann

UC Merced

Ricardo Cisneros

United States Forest Service

Trent Proctor
Brent Skaggs
Brandon Adams
Joe Domitrovich