United States Environmental Protection Agency

The Role of Composition and Particle Size on the Toxicity of Wildfire Emissions

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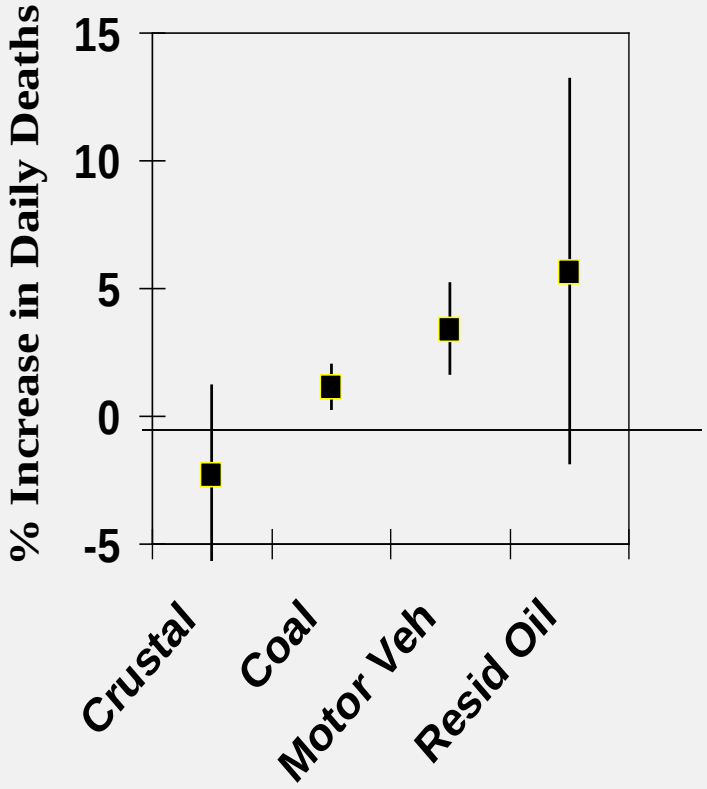
Source-Specific $PM_{2.5}$ and Daily Mortality in Six US Cities

Laden, Neas, Dockery, Schwartz, EHP 2000

- $PM_{2.5}$ associated with daily mortality in six cities (1980's)
- Factor analysis of elemental composition of $PM_{2.5}$ used to estimate source-specific concentrations
- Associations estimated with 4 source classes (10 $\mu g/m^3$)
  - Crustal (Si)
  - Coal (Se)
  - Motor Vehicle (Pb)
  - Residual Oil (Vn, Mn)



Toxicology Questions

Can we reproduce the epidemiological findings in the laboratory (biological plausibility)?

Which chemical components of air pollution (either singly or in combination) cause health effects?

What are the likely sources and do production conditions (e.g. engine type, combustion efficiency, fuel etc) and atmospheric transformation change toxicity?

Does air pollution enhance or potentiate particular diseases and if so how?

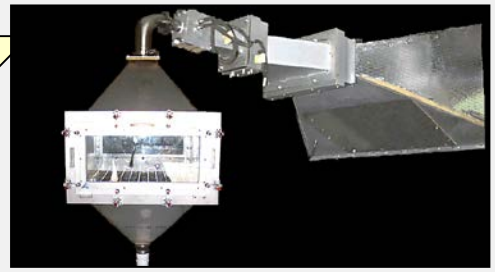
Toxicological Approach for Studying Health Impacts of Different Sizes of PM

Source PM

Inhaled coal, diesel, woodsmoke.

Instilled coal, diesel, ROFA, metals, etc

Ambient PM



Inhaled CAPs

Instilled ambient PM

Components

Size

Dose

Effects

Mechanisms

Health Effects of Combustion Emissions Program

Source

- Residual Oil Fly Ash
- Diesel Exhaust PM
- Coal Fly Ash
- Biofuels
- Fuel-Born Catalysts
- Wood Smoke
- Photochemical Aging

Size, Chemistry

Effect

NRMRL
Physicochemical Analyses

- PM size, mass, and morphology
- Inorganic elements
  : XRF, ICP-OES
- Organic components
  : Gravimetric analysis, GC-MS
- Carbonaceous components
  : Elemental and organic carbon, black carbon
- Reactive Oxygen Species
  : EPR, reduction-oxidation potential
- Real-time PM analysis
  : Aerosol Time-Of-Flight Mass Spectrometer (ATOF-MS)
- Continuous emission monitoring for gaseous components

NHEERL
Biological Assays

- Pulmonary inflammation
- Allergic potential
- Viral infectivity
- Cardiopulmonary function
- Fetal immune polarization
- Trans-generational alteration of gene expression
- Mutagenicity
- Cardiac/pulmonary gene expression

Collecting PM for Subsequent Cardiopulmonary Toxicity Testing

COARSE **FINE** **ULTRAFINE**

Comparative Toxicity of Size Fractionated Airborne Particulate Matter Obtained from Different Cities in the USA. Gilmour MI., McGee, J, Duvall, RM., Dailey, L., Daniels, M., Boykin E., Cho, SH., Doerfler, D., Gordon, T., & Devlin, RB. **(2007)** *Inhalation Toxicology.* 19 (S). 1-10.

Comparative toxicity of size-fractionated airborne particulate matter collected at different distances from an urban highway. Cho, SH., Tong, H., McGee, J., Baldauf, R., & Gilmour, MI. **(2009).** Env Hlth Perspect. 117 (11), 1682-1689

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Differential cardiopulmonary effects of size-fractionated ambient particulate matter in mice. Tong, HY, Cheng, WY, Samet, JM, Gilmour MI, Devlin RB**. (2010).** Cardiovascular Toxicology, 10 (4). 259-67.

Cookstove Statistics

- ~3 Billion people (~40% of the global population) cook with fire using solid biofuels (wood, dung, straw) [IARC, Vol 95, 2010]
- In the U.S., this is ~500,000 [Rogalsky et al. 2014]
- Household air pollution due largely to cookstoves causes ~4 million premature deaths/year [Smith 2014]
- Annual mortality from household air pollution > HIV/AIDS + TB + malaria

Attributable Mortality

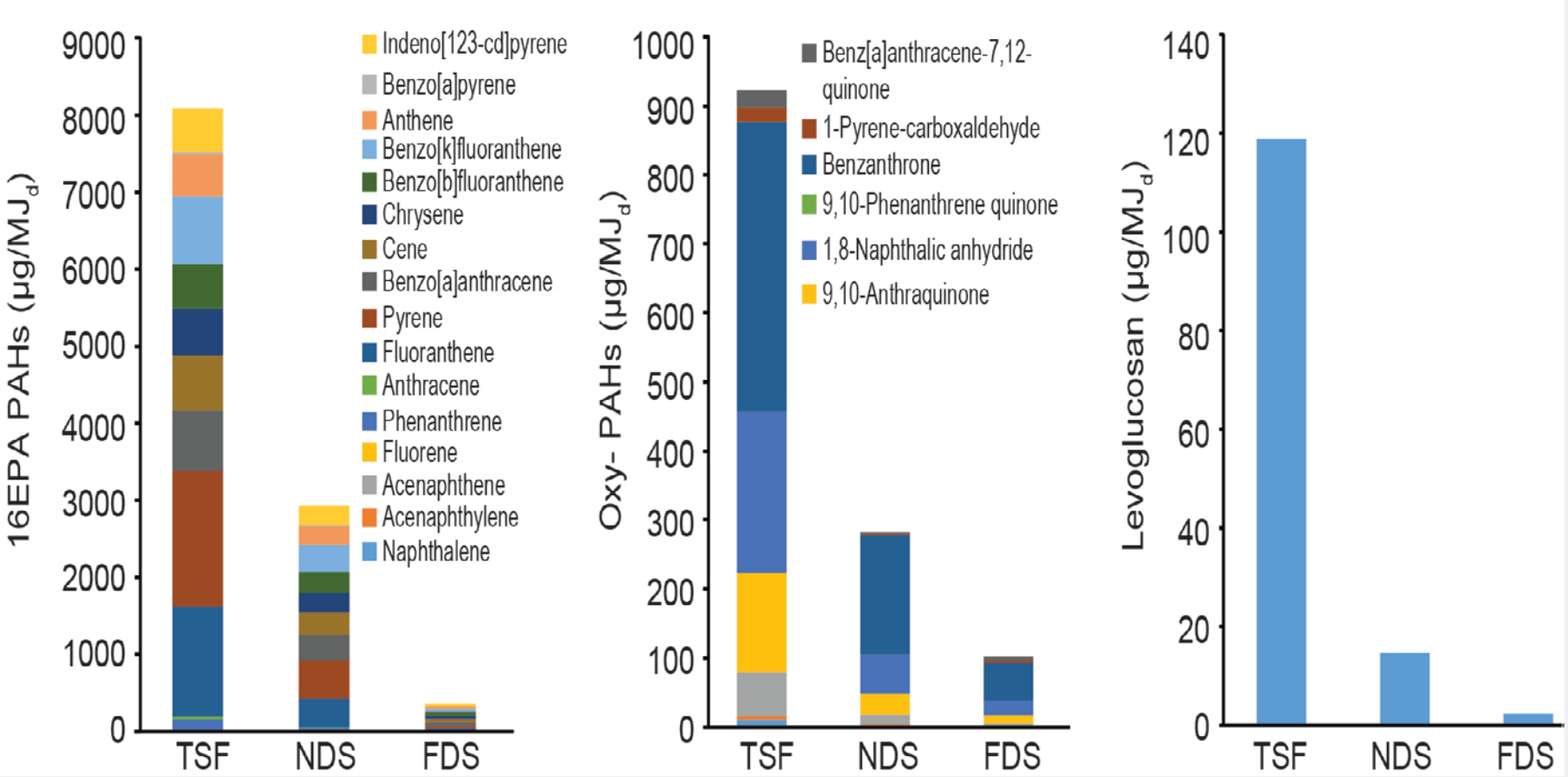
- Cardiovascular [Smith & Peel 2010]
- COPD [Kurmi et al. 2010]
- Low birth weight/stillbirth Pope et al. 2010]
- Upper-respiratory infections in children [Dherani et al. 2008]
- Lung cancer [IARC 2010]

Stoves

3-Stone Fire (TSF)
Natural-Draft Stove (NDS)
Forced-Draft Stove (FDS)
Type: Rocket
Brand: Envirofit
Type: Fan
Brand: Philips

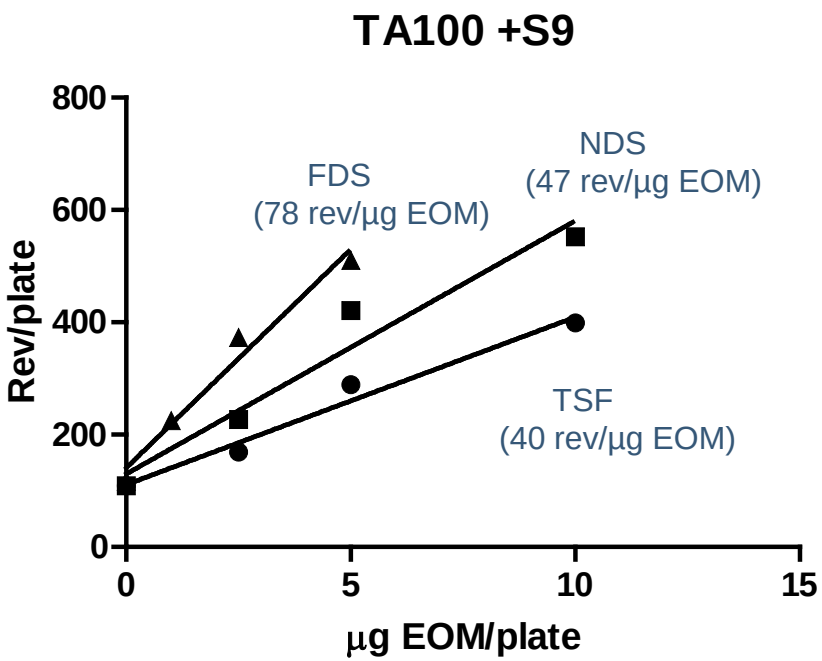
Pollutant-Emission Factors from DCM Extract of $PM_{2.5}$ Decrease with Improved Combustion

16 EPA Priority PAHs | 6 Oxy-PAHs | Levoglucosan

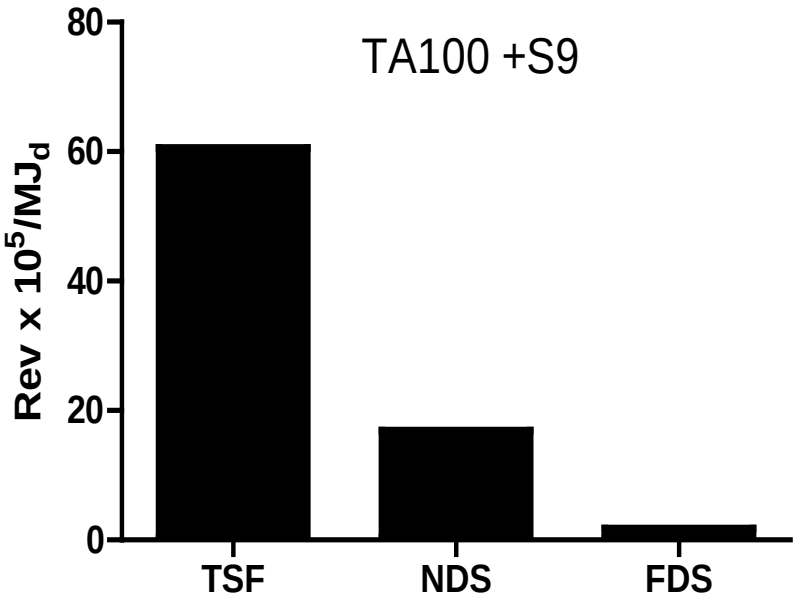


Mutagenicity Characteristics of Cookstove Emissions

Revertants/microgram EOM



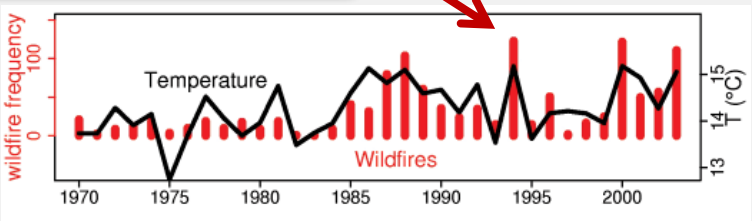
Revertants/Emission Factor



Incidence and Health Impact of Wildfires

Wildfire smoke
(PM, PAHs, CO, VOC, NOx, SOx, and free radicals)

Increase in wildfire frequency

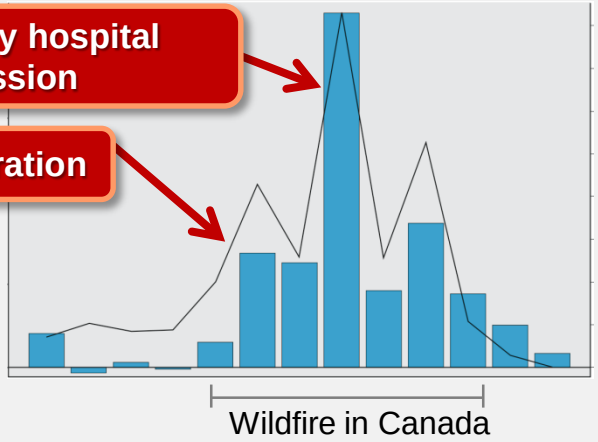


(Westerling et al. 2006, *Science*)

(Henderson et al. 2011, *Environ Health Perspect*)

Respiratory hospital admission

PM_{10} concentration



Toxicity of Wildfire Smoke

- While most studies cite epidemiological observations, few reports describe the toxicity of wildfire smoke.

Forest Wildfire vs. Peat Wildfire

- Forest fires spread quickly with extremely intense flame and high temperature.
- Peat fires propagate slowly without flame but emit huge amounts of smoke, and can last for months or even years.
- Most investigations have focused on forest fires, while peat fires have not been widely studied.

2008 Pocosin Lakes National Wildlife Refuge Peat Wildfire

Satellite image showing the location of Evans Road Fire in the Pocosin Lakes National Wildlife Refuge, NC

- ED visits reported to NC Disease Event Tracking and Epidemiologic Collection Tool (NCDETECT) – State surveillance program.

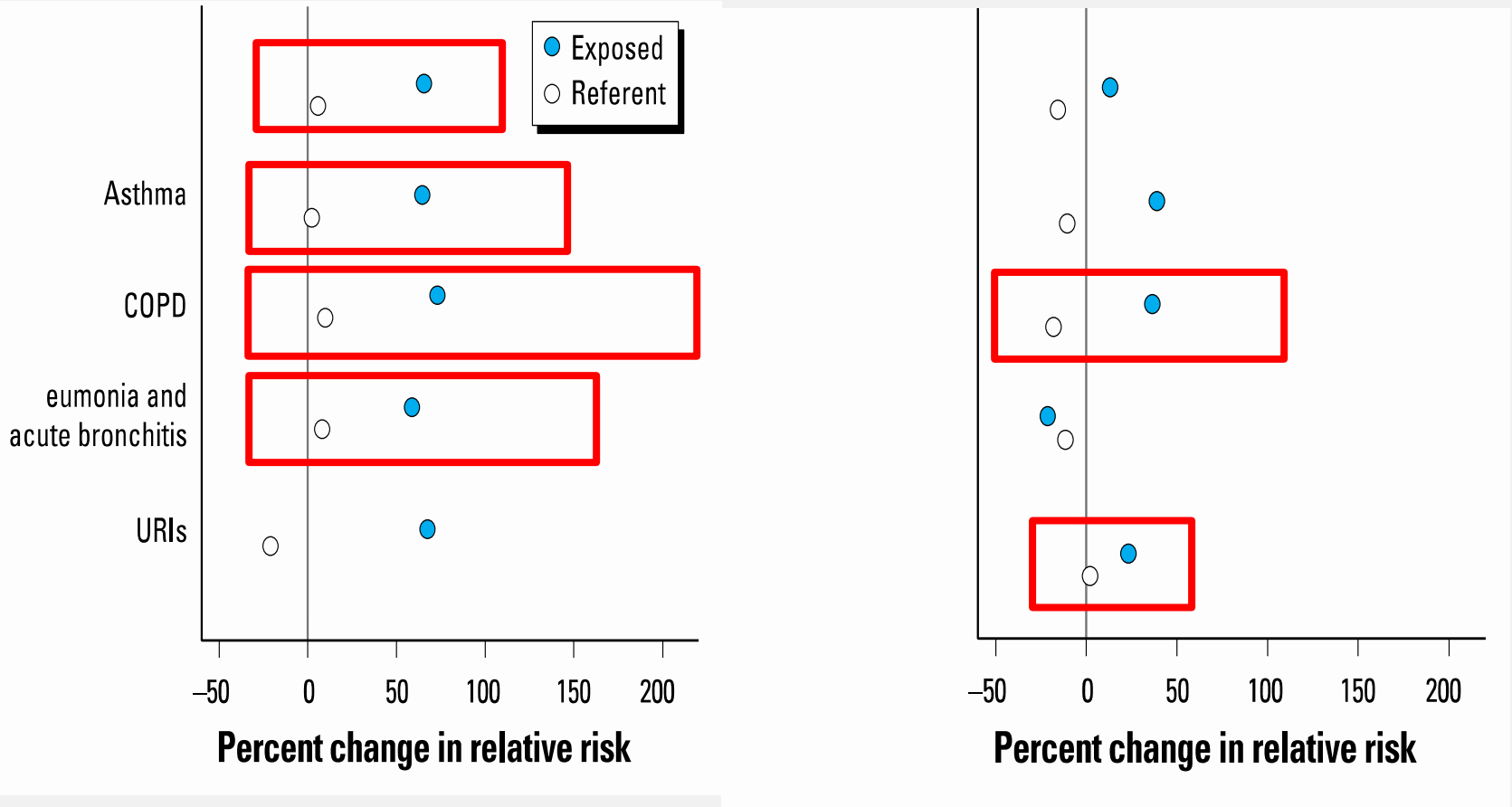
- Respiratory and cardiac outcomes in adults.

- Discharge ICD-9 codes, country of residence, gender, age, and date of admission.

- ICD-9 codes were grouped according to the outcomes of interest.

Rappold et al. Environ. Health Perspect. 2011

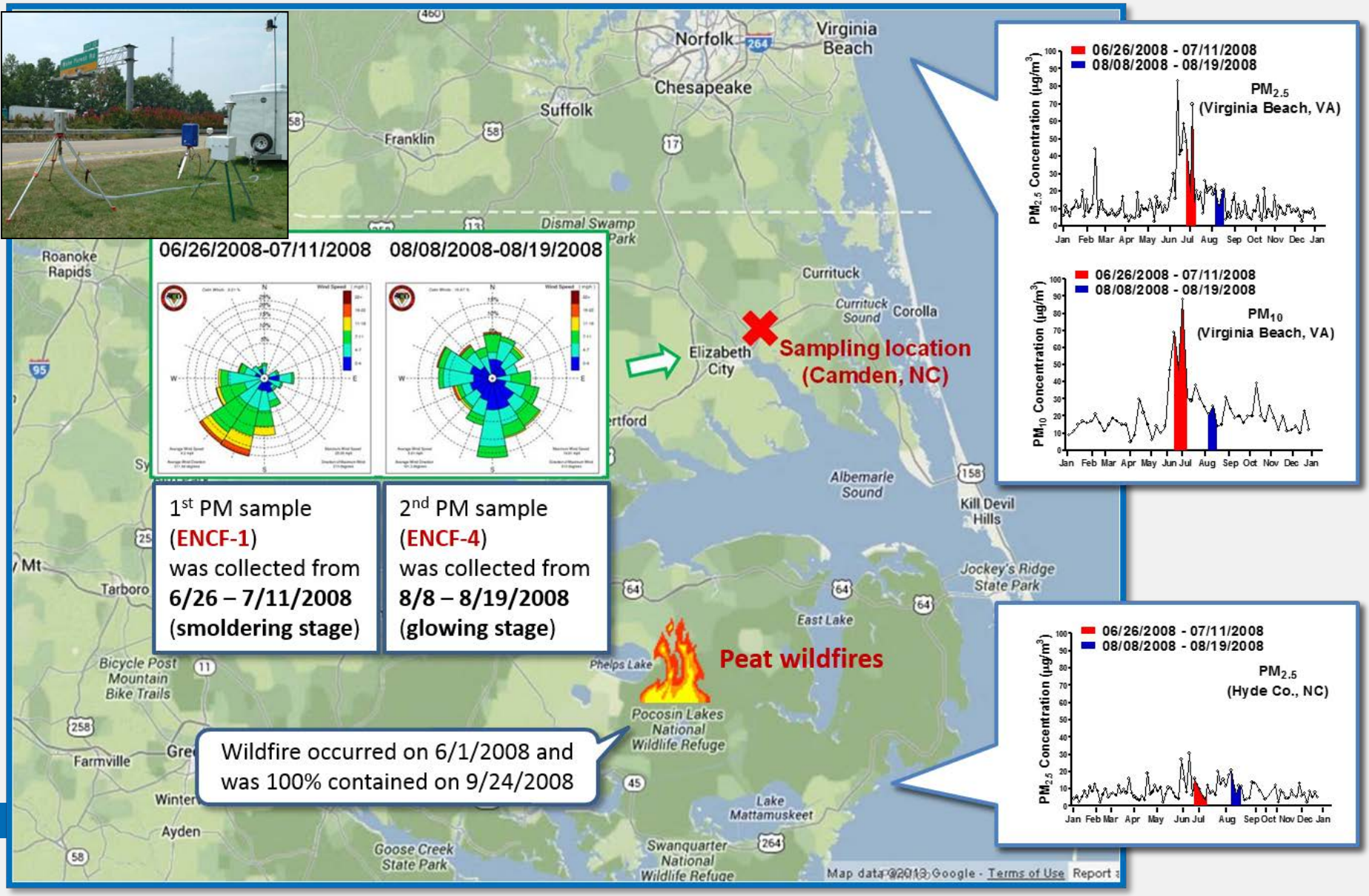
Peat Wildfire 2008 - Regional Health Effects



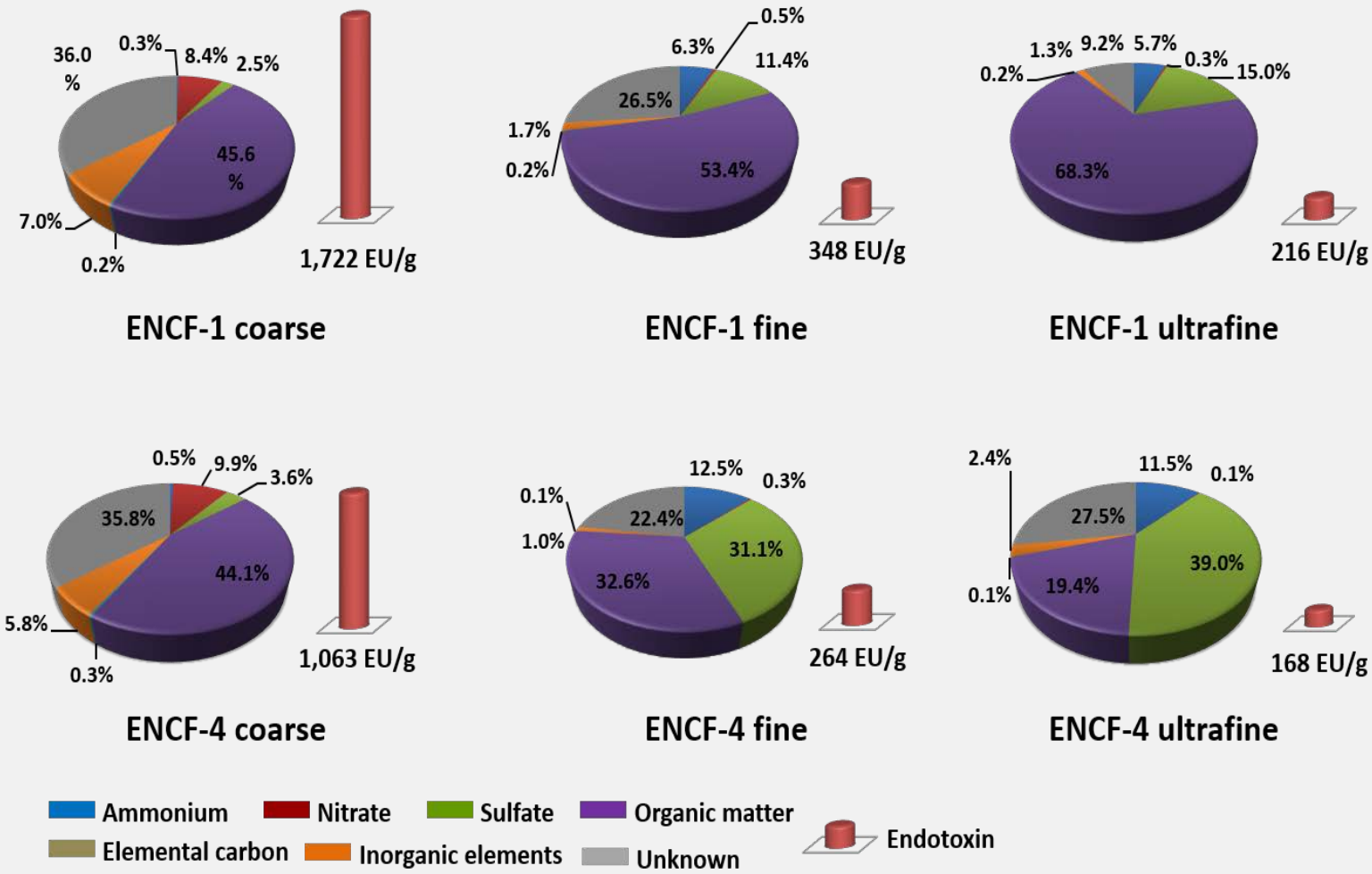
Percent change in cumulative RR by discharge diagnosis category for exposed and referent counties in NC during 3-day period of high exposure compared with the entire 6-week study period.

Rappold et al. Environ. Health Perspect. 2011

Location of Chemvol PM sampler and monitoring data for ENCF-1 and ENCF-4



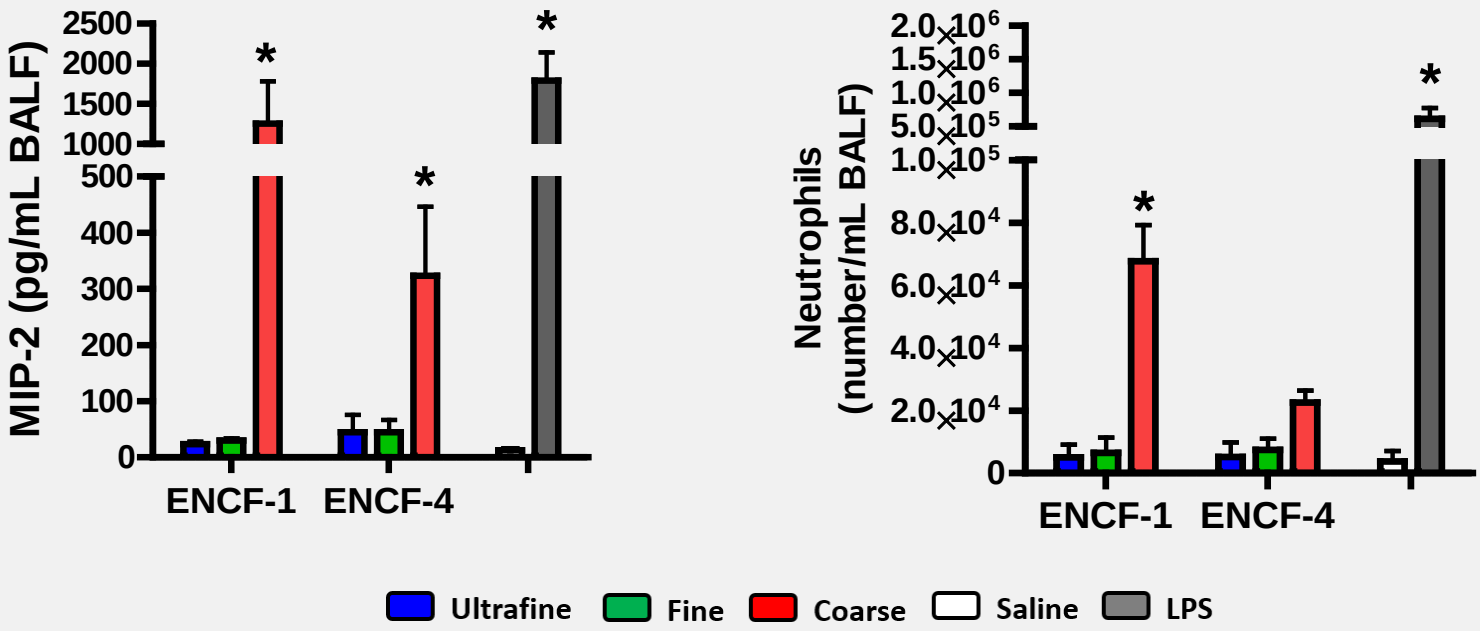
Mass Balance of Major Classes of Chemical Components



- Coarse ENCF-1 and ENCF-4 had greater endotoxin content than the fine and ultrafine PM.
- Coarse ENCF-1 had greater endotoxin content than ENCF-4.
- Fine and ultrafine ENCF-1 had a far greater abundance of organic material than ENCF-4.

Lung Toxicity Analysis of Peat Wildfire PM (in vivo test)

Lung inflammatory responses in BALF at 4 h post-exposure

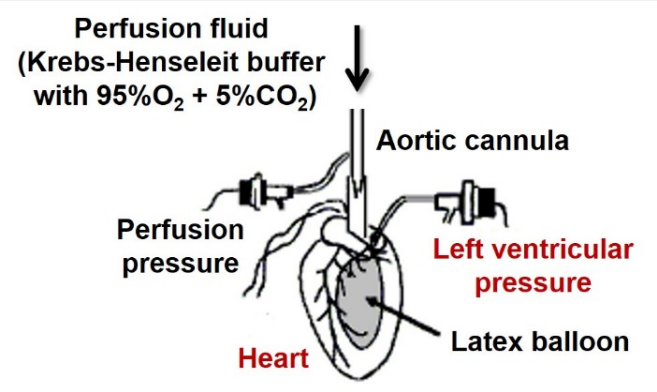


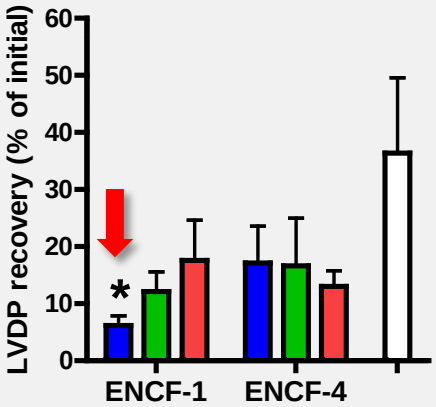
- Exposure to the wildfire PM did not cause severe cellular lung damage (not shown).
- Exposure to the coarse PM significantly increased the levels of cytokines (IL-6, TNF-a, and MIP-2) and neutrophils in BALF of mice and this was higher with ENCF-1.

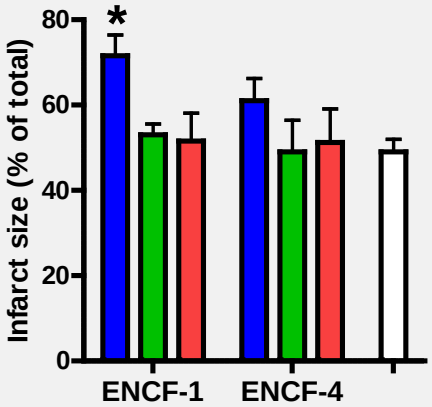
Kim et al. Part. Fibre Toxicol. 2014

Cardiac Toxicity Analysis of Peat Wildfire PM (ex vivo test)

Cardiac function in mice at 24 h post-exposure

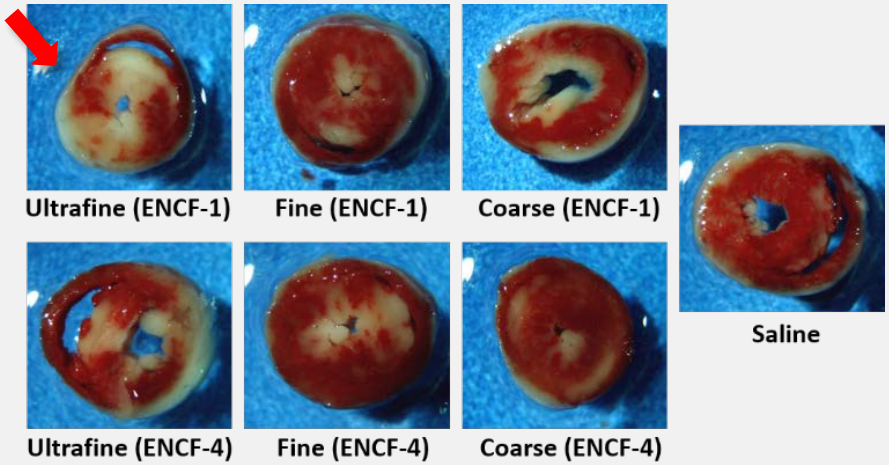






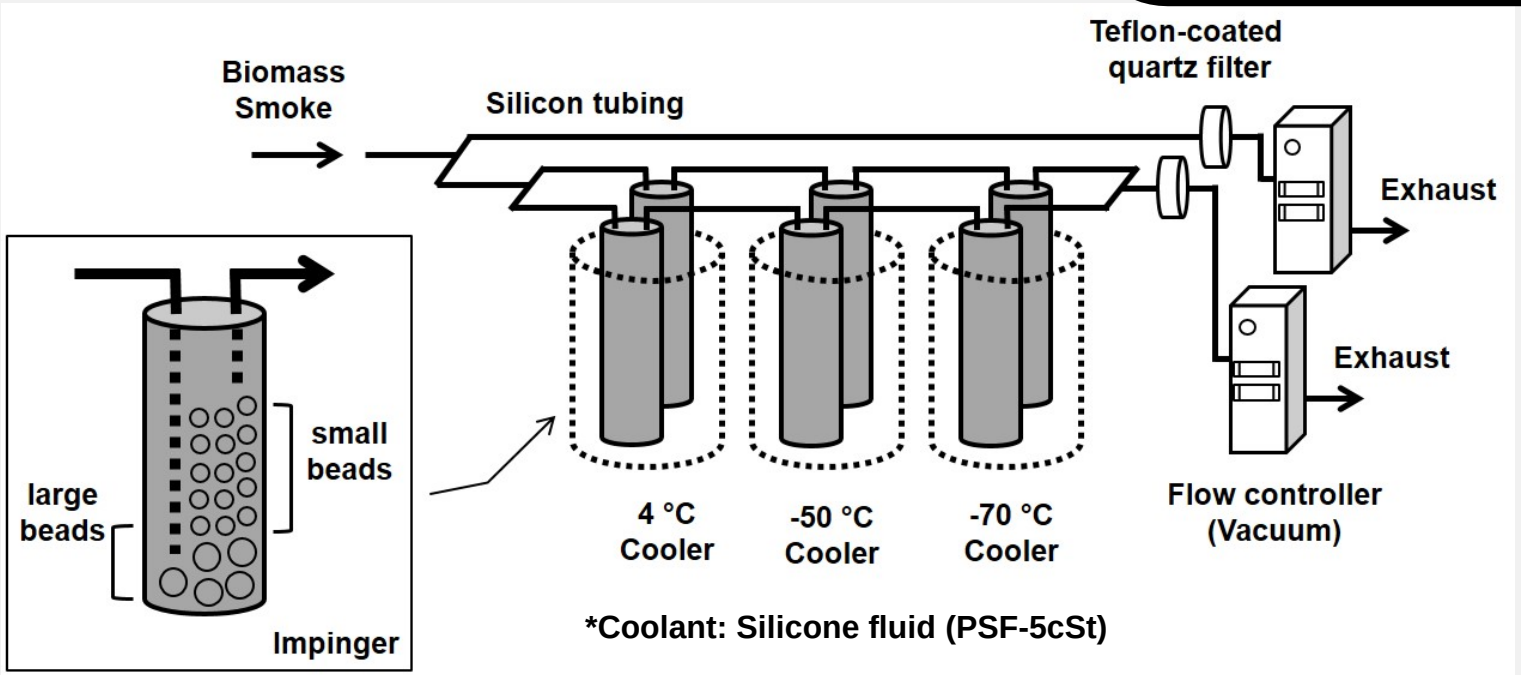
Ultrafine Fine Coarse Saline

- Recovery of left ventricular developed pressure (LVDP) and infarct size measured at 1 hr and 2 hrs of reflow after 20 min of ischemia, respectively.
- Exposure to only ultrafine ENCF-1 markedly decreased LVDP and increased the infarct size.



Kim et al. Part. Fibre Toxicol. 2014

Burn Hut and Cryotrap System for Collection of Smoke Constituents



JFSP Hypothesis and Research Plan FY 15-17

Agency

Hypothesis: Toxicity of smoke emissions from wildfires varies depending on the type of fuel, combustion conditions and resultant particle size and chemistry.

Objectives:

1. Compare the relative cardiopulmonary toxicity and mutagenicity of coarse and fine/ultrafine emissions from four distinct fuel types (pine, oak, peat, and a mixed pine and deciduous Southeastern forest biomass) obtained from both smoldering and active flame phases.

2. Provide a potency ranking and compare effects to size-fractionated ambient PM samples collected from urban and rural sites.

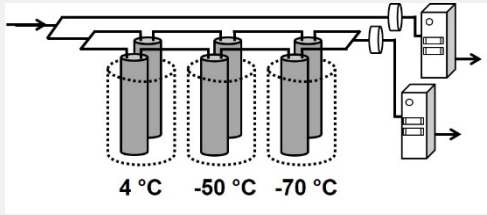
Combustion

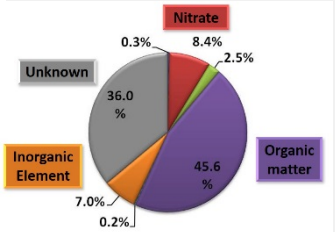
Fire enclosure (28 m^3)
Mixed fuels

Collection/ Analysis

Cyclone/Cryotrap system

Particle and gas phase chemistry and mass balance



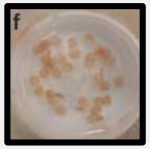


Toxicity Test

WT and K/O mice

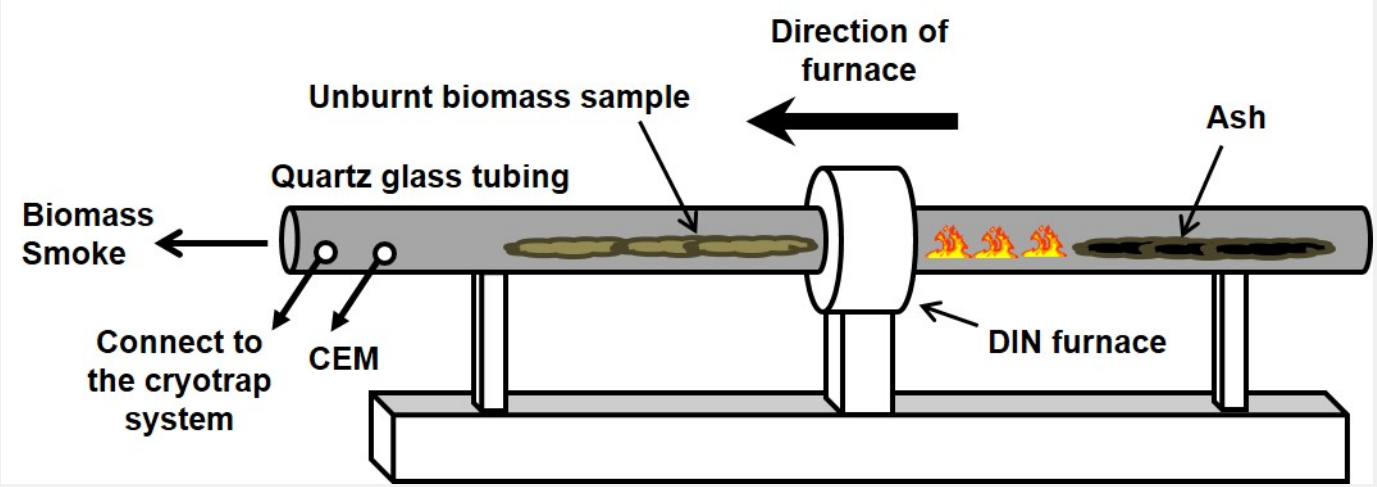
Toxicity Ranking matrix

Cells, Tissue slices

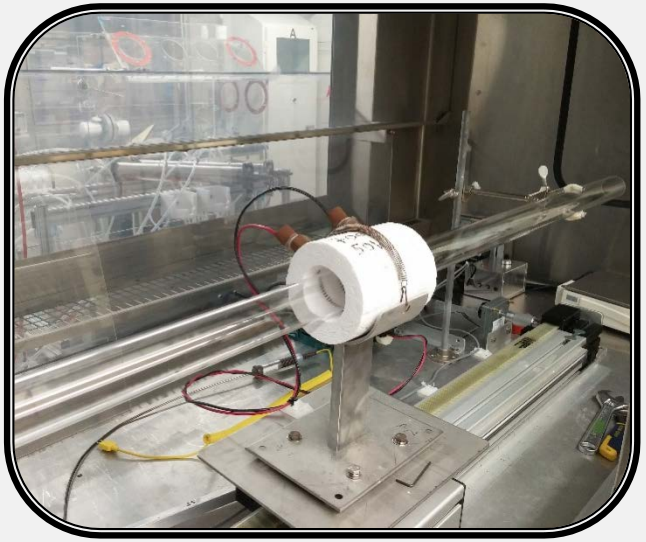


5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
	1	2	3	4	5

Quartz glass tube furnace system



*A quartz glass tube: 1000 mm long and 38 mm diameter
*Furnace speed: 2 cm/min
*Furnace temperature: ~450 – 700 C

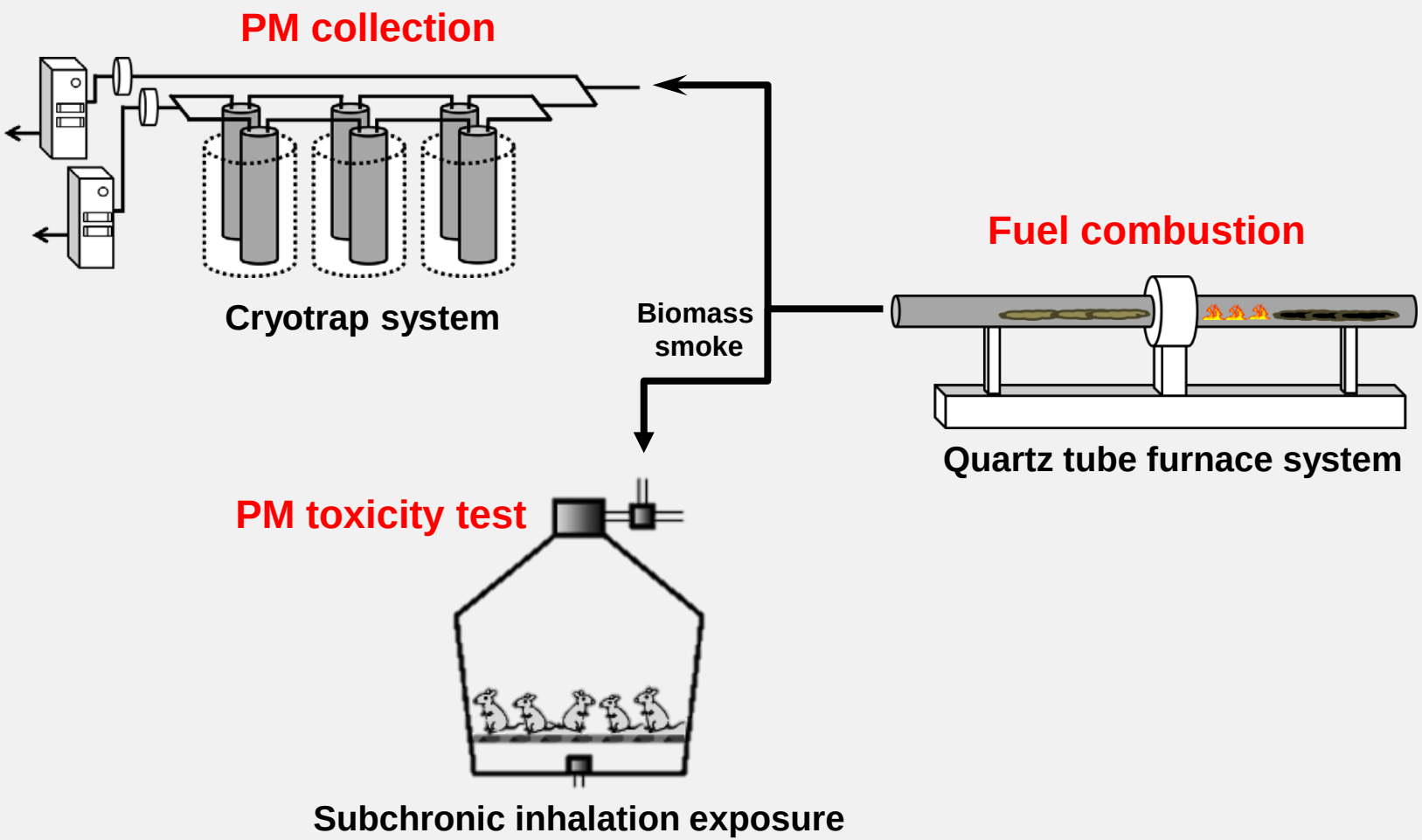


Biomass fuel types

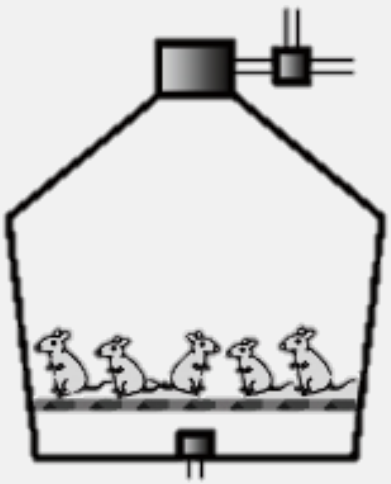
- Peat
- Pine
- Chaparral
- Mixed conifer

Quartz glass tube furnace system (Video)

Studies planned

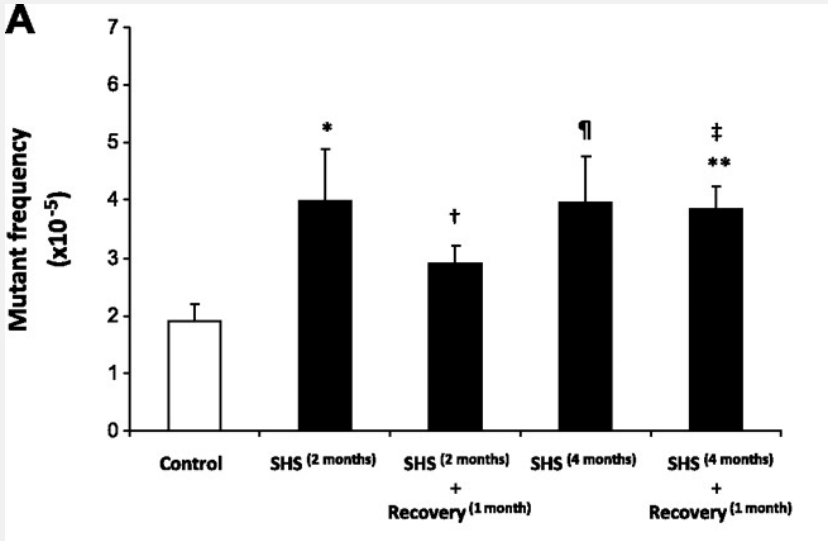


Subchronic Inhalation Exposure Protocols (28 days or 2 days x 14 weeks of exposure)



- Pulmonary function test: whole body plethysmography
- Neurobehavioral function test: functional observation battery
- Cardiopulmonary function test: radiotelemetry
- Pulmonary toxicity and mutagenicity assessments
  BALF analysis
  Histopathological analysis
  Mutant frequency analysis

cII mutant frequency in lungs of mice exposed to secondhand smoke (SHS) (2 or 4 months)



Big Blue mouse

- Big Blue mice accurately and efficiently predict mutagenicity and genotoxicity of exogenous compounds.
- Quantify mutations on chromosomal DNA in any organs (lung, liver, blood, bladder etc).

Acknowledgements

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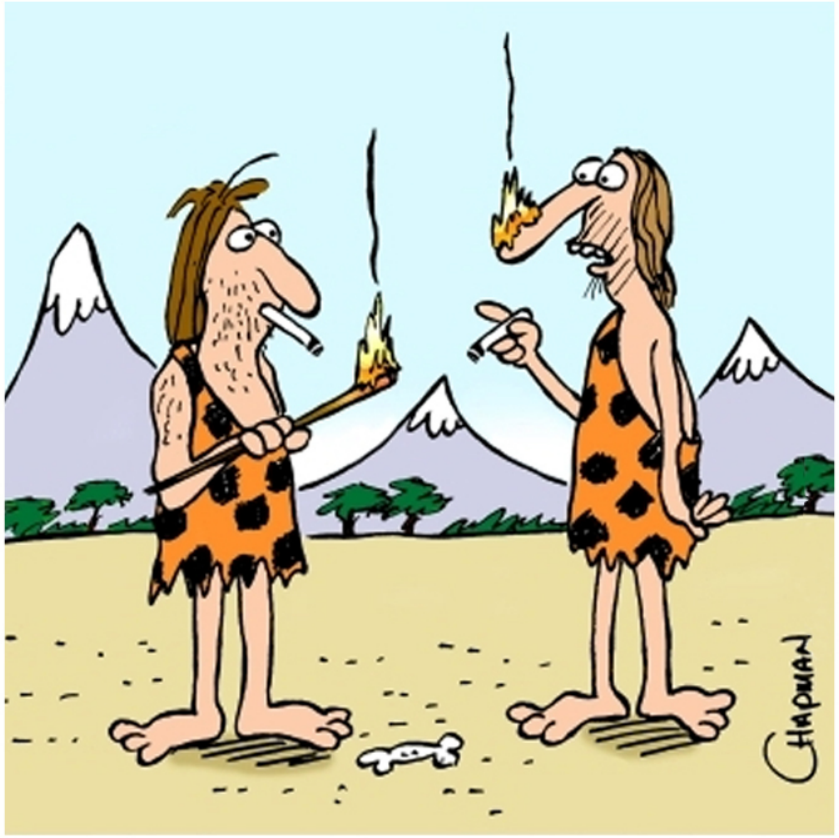

"I just can't keep up with all this modern technology."