Firefighters and the Evaluation of Cancer Causation
Disclosure

- *Health Risk and Fair Compensation in the Fire Service*
- Springer, anticipated November 2015
- Forthcoming book, with colleagues, on this topic:
  - Tee Guidotti
  - Alex Forrest
  - Sara Jahnke and colleagues
  - Nancy Lightfoot
  - Stephan Kales and Epidoforos Soteriades
  - Michel Lariviere and colleagues
Firefighting is exacting and highly demanding.
Ff’s are in excellent shape, generally low lifestyle risk factors for mortality.
Healthy worker effect, competing mortality
Low smoking prevalence
- But, mortality not much better than population
- Cancer risks are selectively elevated.
Years of svc a poor metric for risk
- Covaries with age, latency, change in ff-ing
WTC responders are a special group: different risks.
Toxic Exposures

- Many and varied exposures
- Multiple IARC carcinogens
- Change in 1960’s: introduction of synthetic materials
- “Overhaul” phase of fire presents high exposure risk
- SCBA has greatly reduced exposure: use issues
- Skin exposure, absorption
- \( \uparrow \) Mesothelioma rate confirms significant asbestos exposure
- Nitroarenes: fire combustion and diesel exhaust
Documented Exposures

NOT ASSOCIATED WITH FIRE COMBUSTION

- Antimony (constituent of flame retardant on turn-out gear)
- Asbestos
- Diesel exhaust (inc. PAHs, nitroarenes)
- Cadmium
- Lead
- PFOA (perfluorooctanoic acid and its product polytetrafluoroethylene)
- Pesticides (few)
- Polybrominated biphenyl compounds (mixed, low)
- Polychlorinated biphenyl compounds (mixed)
- Shiftwork
- Silica dust

ASSOCIATED WITH FIRE COMBUSTION

- Acetaldehyde
- Acrolein
- Aldehydes (mixed)
- Alkanes, straight chain (inc. propane*)
- Alkenes, straight chain (inc. propene*, 1-butene*/2-methylpropene)
- Benzene*
- Benzaldehyde
- Brominated hydrocarbons (low)
- 1,3-Butadiene*
- Carbon dioxide*
- Carbon monoxide*
- Chlorinated alkanes (low)
- Chlorobenzenes (low)
- Cycloalkanes
- Cyclopentenes
- Dioxins and furans (including 2,3,7,8-dibenzodioxin and –furan*)
- Dichlorofluoromethane
- Ethylbenzene
- Formaldehyde

- Glutaraldehyde*
- Hydrogen chloride
- Hydrogen fluoride
- Hydrogen cyanide
- Hydrogen fluoride
- Isopropylbenzene
- Isovaleraldehyde
- Methylene chloride
- Naphthalene (a PAH)
- Nitriles (mixed)
- Nitroarenes (nitroso-substituted analogues of PAHs)
- Nitrogen dioxide
- Particulate matter (fine)
- Phosgene
- Polycyclic aromatic hydrocarbons (mixture, including naphthalene*)
- Sulfur dioxide
- Styrene*
- Tetrachloroethylene
- Toluene*
- Trichloroethylene*
- Vinyl chloride
- Xylenes (including o-xylene*)

IARC-category I carcinogens are in red.

* Predominate in nonspecific urban structural fires.
## Cancer hazard among ff’s

<table>
<thead>
<tr>
<th>Relevant exposures (hazard)</th>
<th>Characteristic cancers</th>
<th>Evidence for ca among ff’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbestos</td>
<td>Mesothelioma</td>
<td>Definite</td>
</tr>
<tr>
<td>Benzene</td>
<td>AML</td>
<td>Weight of evidence</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>Lung, NHL</td>
<td>Weight of evidence</td>
</tr>
<tr>
<td>PAHs</td>
<td>Lung, GU, other</td>
<td>Weight of evidence</td>
</tr>
<tr>
<td>Nitroarenes</td>
<td>(Same as PAHs)</td>
<td>Weight of evidence</td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
<td>NHL (DLBCL)</td>
<td>Weight of evidence</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>NHL, kidney</td>
<td>Weight of evidence</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>Lung</td>
<td>Weight of evidence</td>
</tr>
</tbody>
</table>
New interest!

- Renewed interest in first responders
- Legislative activity on presumption
- IARC reports on tetrachloroethylene, shiftwork, ff
- NIOSH Study, published late 2013
  - Demonstrated elevation in ca risk
  - Surprise finding of mesothelioma excess
- Followed by new studies from Nordic countries, Australia, Scotland
- WTC/9-11 forced a rethink of ff health, but turns out WTC responders are different
Questions Remaining

- Many unresolved issues becoming clearer
- Increased cancer risk confirmed but specific ca’s still a contentious issue
- Need to examine problems structurally
  - Aggregation of outcomes into illogical groups: dilution
  - Interpretation of epidemiological studies
    - Bias
    - Power
    - Confounding
  - ↑risk estimates with better exposure metrics, corrects confounding and misclassification bias
- Still in need of a prospective cohort study for the modern era
Pushing the limits of epidemiology.
Association: a condition arises more frequently in the occupation, for any reason
Causation: a condition arises because of a work-related hazard or risk factor
Presumption: all other things being equal, most outcomes in this group are caused by exposure
Rebuttable presumption: presumption can be disputed in case on basis of evidence
## NIOSH Study (Daniels et al., 2013)

<table>
<thead>
<tr>
<th></th>
<th>LeMasters</th>
<th>NIOSH Study</th>
<th>Contrary evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kidney</td>
<td>1.07 (0.78 – 1.46)</td>
<td>1.29 (1.05 – 1.58) M</td>
<td>CC-study OR 4.89 in NZ (Firth); more often &gt;2</td>
</tr>
<tr>
<td>Bladder</td>
<td>1.20 (0.97 – 1.48)</td>
<td>1.12 (1.00 – 1.25)</td>
<td>ExpR in subgroups (Baris)</td>
</tr>
<tr>
<td>Testes cases</td>
<td>2.02 (1.30 – 3.13)</td>
<td>0.75 (0/42 – 1.24; &lt;5</td>
<td>RR of &gt;3 in literature</td>
</tr>
<tr>
<td>Brain</td>
<td>1.32 (1.12 – 1.54)</td>
<td>1.01 (0.79 – 1.27) M</td>
<td>RR ≈ 3 in some studies</td>
</tr>
<tr>
<td>NHL</td>
<td>1.51 (1.31 – 1.79)</td>
<td>1.17 (0.97 – 1.40) M</td>
<td>MOR 5.6 (Figgs)</td>
</tr>
<tr>
<td>Leukemia</td>
<td>1.14 (0.98 – 1.31)</td>
<td>1.10 (0.91 – 1.21) M</td>
<td>1.71 ff &lt;65 (Burnet); ExpR (Baris)</td>
</tr>
<tr>
<td>Myeloma</td>
<td>1.53 (1.21 – 1.94)</td>
<td>0.72 (9).50 – 0.99</td>
<td>1.71, ExpR (Baris)</td>
</tr>
<tr>
<td>Lung</td>
<td>1.03 (0.97 – 1.08)</td>
<td>1.12 (1.04 – 1.21)</td>
<td>SMR 317 (Hansen); usually ≈ 1.5</td>
</tr>
<tr>
<td>Mesothelioma</td>
<td>N.A.</td>
<td>2.00 (1.03 – 3.49) M</td>
<td>N.A.</td>
</tr>
</tbody>
</table>
Only Chicago is an entirely new population: SF and Philadelphia have been studied before, Philadelphia with overlapping cohort.

NIOSH Study often has results that differ from related studies on same ff population, different cohort, e.g. Baris, Beaumont.

Compared to world literature, generally lower risk estimates (except for Australia).

Even so, patterns of elevations overall are consistent with sites of concern, but show anomalies.

Less extensive subgroup analyses: FD, length of service, age 65 cutoff.
Multiple studies ≠ replication.

- Every new study brings some degree of replication, but:
  - No studies are exactly alike
  - Populations change over time
  - Exposures change over time
- Also differences:
  - Populations and eras
  - Methodological differences
- Available studies have power problems, even NIOSH study.
- Meta-analysis [LeMasters (2006)] has not solved the problem, but has clarified trends.
  - Well-conducted and useful but not definitive.
  - Algorithm threw out some outcomes that may be causal associations.
Three key issues

- Coding problems, aggregation
- Dilution
- Confounding
## Predictable Problems

<table>
<thead>
<tr>
<th>Situation</th>
<th>Methodological Problem</th>
<th>Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Uncommon, many confounders</td>
<td>Power, bias, and confounding</td>
</tr>
<tr>
<td>II</td>
<td>Aggregation of tumor types by site for main type</td>
<td>Dilutes risk estimate</td>
</tr>
<tr>
<td>III</td>
<td>Aggregation of uncommon tumor types</td>
<td>Obscures risk signal</td>
</tr>
<tr>
<td>IV</td>
<td>Confounder overwhelms risk factor</td>
<td>Confounding (smoking)</td>
</tr>
</tbody>
</table>
Different standards of certainty are applied to adjudication

- Scientific certainty is not reasonable
  - Seldom attainable, even in ideal situations
  - Burden on individual claimant, repeatedly
  - Contrary to civil standard of certainty > 50%
- In science, >95% (p < 0.05, Type I error)
- In workers’ compensation, ≥ 50% certainty
- Meta-analysis, while useful does not solve interpretation problem, esp. for rare outcomes in etiological studies
Most states, provinces have established a rebuttable presumption for certain outcomes:

- Brain
- Bladder
- Kidney
- “Non-Hodgkin lymphoma”
- Leukemia
- Testicular
- Lung cancer in non-smokers
- ?Other: melanoma, prostate
Firefighters are at risk for specific cancers.
Studies of ff require interpretation.
Individual cases always require individual review.
Scientific certainty is not fair in adjudication.
We need a new generation of studies for a new generation of ff.s!
Is Firefighting Carcinogenic? An Update

Susan D. Shaw, DrPH

Director, Marine & Environmental Research Institute
Professor, School of Public Health, Dept. of Environmental Health Sciences, SUNY-Albany

IAFF Redmond Symposium
Gaylord National Resort
National Harbor, MD 25-28 August 2015
Fire fighting is dangerous... it is also toxic
Does Firefighting Cause Cancer?

Recent epidemiological studies and meta-analyses have documented increased risk for several site-specific cancers in fire fighters.

In 2007, the International Agency for Research on Cancer (IARC) classified firefighting as possibly carcinogenic to humans (Group 2B).

In 2015, IARC considering upgrade of classification to probably carcinogenic to humans (Group 2A).
Line of Duty Deaths 2002-2012

- Heart Disease: 22%
- Cancer: 56%
- Trauma: 8%
- Stroke: 2%
- Respiratory Arrest: 1%
- Infectious Disease: 2%
- Asphyxiation: 5%
- Burn: 3%
- Unknown-Other: 1%

http://www.iaff.org/
Rise in Fire Fighter Cancer Deaths
1950-2014

Source: IAFF Line of Duty Deaths Database: http://www.iaff.org
Fire Fighter Cancer Deaths vs Other Causes

1950-2014

Source: IAFF Line of Duty Deaths Database: http://www.iaff.org
“Because of the multiple exposures and the multiple routes of exposure—they inhale carcinogens and absorb them through the skin—it is also highly unlikely for firefighters to get only one type of cancer.”

– LeMasters et al. (2006)
“Young fire fighters are developing far more aggressive types of cancers, such as brain cancers, at an earlier age than the general population...”

Routes of Exposure

- Inhalation
- Ingestion
- Skin Absorption
Exposure During Structural Fire Suppression

Knockdown & Overhaul Phases
Search & Rescue Operations
Outside Fires (Vehicles, Dumpsters, Garages)
Post-Fire Investigations
Exposure During Overhaul

– SCBA typically not used during overhaul and smaller structure fires
– Concentrations of residual gases and particulates can exceed safety limits even if there is little visible smoke (Bolstad-Johnson et al 2000; Fabian et al. 2011)
Fire fighters are present day chimney sweeps covered in carcinogens.”

– Alex Forrest, B.A., L.L.B.
IAFF Canadian Trustee and United Firefighters of Winnipeg President

Known Hazards of Combustion Residue
Heat Increases Skin Absorption

“Skin’s permeability increases with temperature and for every 5° increase in skin temperature, absorption increases 400%.”

(Romonchuk and Bunge 2004; Danon et al. 1986)
Extended Exposure (Inhalation and Dermal) from Contaminated PPE

"Bunker gear can go unwashed for months at a time, even after significant fires."

Inhalation (off-gassing) and transdermal exposure during and after fires

Smoke and soot on gloves 100X higher than hoods

Fire Fighter Cancer Support Network 2013; Fabian et al. 2011)
Contaminated Hoods After One Fire

Worn next to most permeable skin areas – jaw, forehead, scalp
Cleaning infrequent after fire suppression
Chemicals Most Studied: Gases and Particulates

Asphyxiants
• Carbon monoxide (CO)
• Hydrogen cyanide (HCN)
• Hydrogen sulfide (H₂S)

Irritants
• Ammonia (NH₃)
• Hydrogen chloride (HCl)
• Nitrogen oxides (NO₂)
• Sulfur dioxide (SO₂)
• Particulates/dust — carry airborne toxicants, carcinogens (metals, PAHs, phthalate esters)
Extensively Studied Chemicals: PAHs, VOCs

New controlled burn study shows off-gassing VOCs (benzene, toluene, etc) from used PPE correlated with FFs exhaled breath; potential for inhalation exposure from PPE in vehicles or while doffing PPE (Fent et al. 2015)

Single ring aromatics and PAHs elevated in post-firefighting exhaled breath samples from FFs wearing full PPE; suggests gear allows dermal exposure to airborne contaminants (Pleil et al 2014)

Study shows FFs wearing full PPE absorbed combustion products (PAHs, benzene) in their bodies; most likely via skin of neck as primary site due to low level of protection provided by hoods. Aromatic hydrocarbons can also be inhaled during doffing of contaminated gear (off-gassing) (Fent et al 2014)
Also Studied: PCBs, Chlorinated Dioxins/Furans
After Catastrophic Fire Events


New Chemical Hazards in Today’s Fire Environment

Halogenated flame retardants, per- and polyfluorinated alkyl substances in household materials

Foam furniture, carpets, mattresses, plastics, TVs, computers, electronics building insulation
Known or Presumed Carcinogens

- **Flame retardants**: foam furniture, electronics, plastics, insulation. NTP Report (2015) agrees pentaBDE mixtures exhibit carcinogenic activity
- **Chlorinated & brominated dioxins/furans**: combustion by-products of PBDEs, PCBs
- **Polychlorinated biphenyls (PCBs)**: di-electric fluids in electrical transformers, capacitors, hydraulics
- **Perfluorinated alkyl substances (PFAS)**: PFOA or C8 stain-resistant, non-stick coatings, firefighting foams (AFFFs)
- **Polycyclic aromatic hydrocarbons (PAHs, benzo(a)pyrene)**: incomplete combustion of organic matter
- **Volatile organic compounds (VOCs)**: e.g. benzene, toluene, ethylbenzene, xylene, styrene
- **Aldehydes**: formaldehyde
- **Phthalate diesters (DEHP)**: plasticizers in PVC polymers, HH products
- **Heavy metals**: e.g. antimony, arsenic, cadmium, lead, chromium, nickel
- **Asbestos**: insulation material, older buildings
Phthalate Esters: FFs Exposed to DEHP on Used PPE at Levels Much Higher than PAHs

**Phthalate diesters:** plasticizers in polyvinyl plastic materials – flooring, wall coverings, wiring, vinyl siding

DEHP (di-2-ethylhexylphthalate) – EPA Group B2, **probable human carcinogen** (assoc with testicular cancer in animals)

Phthalate diester contamination of gear is cumulative (Fabian et al 2011)

New study found DEHP 52-872 times higher on used gloves and hoods than any PAH (Alexander and Baxter 2015)

Presence on inner layer of gloves suggests dermal exposure a major route of exposure
Common Plasticizer (DEHP) Much Higher than PAHs on FF Gear
DEHP levels 52-875 times higher than PAHs

Alexander and Baxter 2014, JOEH
Halogenated Flame Retardants
(PBDEs, HBCDs, PBDE Alternative FRs)
In foam furniture, textiles, upholstery, TVs, computers, plastics, electronics, housing insulation: dust (80%)

Endocrine disruptors, developmental neurotoxins, cancer
Flame Retardants Increase Fire Toxicity

<table>
<thead>
<tr>
<th></th>
<th>No Retardant</th>
<th>PentaBDE Retardant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seconds to Ignition</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>Smoke m²/kg</td>
<td>413</td>
<td>833</td>
</tr>
<tr>
<td>Carbon Monoxide kg/kg</td>
<td>.02</td>
<td>.13</td>
</tr>
<tr>
<td>Soot kg/kg</td>
<td>.01</td>
<td>.88</td>
</tr>
</tbody>
</table>

Combustion By-Products of FRs

- Brominated and chlorinated dioxins and furans (PCDD/Fs, PBDD/Fs)
- Large amounts of PBDD/Fs can be formed during fires in presence of substrate e.g., PBDEs
- Toxic, carcinogenic, few human studies
Less Studied FRs High Volume Use: PBDE Replacements
(Post 2005 Penta and OctaPBDE Phase-Out)

Phosphate FRs (Chlorinated Tris)*
TDCPP (tris(1,3-dichloro-2-propyl)phosphate)
TCEP (tris(2-chloroethyl)phosphate)
TCPP (tris(1-chloro-2-propyl)phosphate)

New BFRs (Firemaster 550)
TBPH (tetrabromo phthalate)
TBB (tetrabromo benzoate)

*mutagenic, carcinogenic potential, removed from children’s pajamas in 1970s
Biomonitoring Studies

Flame Retardants (BFRs), Polyfluorinated Alkyl Substances (PFAS), Combustion Products of FRs in FF Blood

Northern California Study

Persistent organic pollutants including polychlorinated and polybrominated dibenzo-\(p\)-dioxins and dibenzofurans in firefighters from Northern California

Susan D. Shaw\(^{a,c,*}\), Michelle L. Berger\(^a\), Jennifer H. Harris\(^a\), Se Hun Yun\(^b\), Qian Wu\(^{b,c}\), Chunyang Liao\(^b\), Arlene Blum\(^d\), Anthony Stefani\(^e\), Kurunthachalam Kannan\(^{b,c}\)

Extensive exposure assessment high levels of flame retardants, combustion by-products, PFAS

– Shaw et al 2013
PBDE Levels in Fire Fighters, Workers, and General Population

- General Population Levels
  - Gen Pop, US
  - Gen Pop, MA
  - Gen Pop, CA
  - Gen Pop, CA

- Occupational Levels
  - Firefighters, No. CA
  - Firefighters, So. CA
  - Foam Recyclers
  - Carpet Layers
  - E-waste Recyclers
  - Rubber Mixers

Hormonal changes seen in men with PBDE levels at and above this concentration (Turyk, 2008)
Deca (BDE209) “Signature” in Fire Fighters (red bars)
High Levels of DecaBDE in E Waste Recyclers Exposed to Burning Plastics*

Guiyu, South China

*Continuous exposure to burning plastic, no protection
PBDEs in Fire Station Dust

High PBDE levels found in California fire station dust, much higher than PAHs or PCBs (Shen, M. Petreas et al 2015)

Extremely high BDE 209 dust levels in fire stations (med 47 000 ng/g) - higher than any previously found in homes or occupational setting (e waste sites, planes)

Hypotheses: Sources to Fire Station?
- Exposure during fire response back-tracked on used PPE
- Possible that PPE and vehicle interiors treated with PBDEs

High levels BDE 209 in blood of San Francisco FFs after fire response (Shaw et al 2013) – median 32 ppb; predominant PBDE in FF blood

BDE 209 produced by burning plastics; levels in humans imply continuous exposure
PBDD/Fs (TEQ) in Fire Fighters, Foam Workers, and General Population

Shaw et al 2013

- Japan Fat tissue
- Various Milk
- Sweden Fat tissue
- German Foam workers blood
- California Fire fighters serum

TEQ pg/g low

113 →

103 →

Marine & Environmental Research Institute
PBDD/Fs Elevated in 2 California Fire Fighters

Shaw et al 2013

TEQ pg/g lw

WHITE MALE (40)
15 YEARS FIREFIGHTING
BROKE INTO ROOF AND
OVERHAULED
DID NOT WEAR SCBA

WHITE MALE (59)
28 YEARS FFTNG
FIRE ATTACK
DID WEAR SCBA
SMOKER
LIVER CONDITION

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Perfluorinated Alkyl Substances (PFAS)

Stain-resistant coating on upholstery, carpets, performance clothing, non-stick coatings on cookware, food wrapping, surfactants in firefighting foams
Endocrine disruptors, liver, heart disease, cancer (PFOA)
Teflon Chemical Might Be Unsafe at Any Level

New study shows EPA drinking water standards 100X too high
(Grandjean and Clapp 2015)
PFOA (C8) Levels in Fire Fighters vs General Population

- **General Population Levels**
  - Gen Pop, US
  - Gen Pop, US
  - Gen Pop, MI
  - Gen Pop, TX

- **Occupational Levels**
  - Firefighters, No. CA
  - Firefighters, So. CA
  - Firefighters, WTC
  - GM plant retirees
  - Live near PFOA plant

<table>
<thead>
<tr>
<th>Occupation</th>
<th>PFOA ng/ml ww</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM plant retirees</td>
<td>691</td>
</tr>
<tr>
<td>Live near PFOA plant</td>
<td>84</td>
</tr>
<tr>
<td>Grand Total</td>
<td>775</td>
</tr>
</tbody>
</table>

PFOA ng/ml ww: PFOA nanograms per milliliter of whole blood.
PFOS Levels in Fire Fighters vs General Population

- General Population Levels
  - Gen Pop, US
  - Gen Pop, US
  - Gen Pop, MI
  - Gen Pop, TX
- Occupational Levels
  - Firefighters, No. CA
  - Firefighters, So. CA
  - Firefighters, WTC
  - GM plant retirees

PFOS levels range from 0 to 40 ng/ml WW.
PFNA and PFDA Levels in Fire Fighters vs General Population

General Population Levels
- Gen Pop, US
- Gen Pop, MI
- Gen Pop, TX

Occupational Levels
- Firefighters, No. CA
- Firefighters, So. CA
- Firefighters, WTC

PFNA ng/ml ww

PFDA ng/ml ww
Carcinogenic Chemicals Elevated in Fire Fighter Blood

- Flame retardants (PBDEs, DecaBDE) 2-3 X higher vs population levels
- Combustion by-products (PBDD/Fs, dioxins and furans) 100 X higher in 2 fire fighters
- Perfluorochemicals (PFOA, longer chain PFCs) higher in fire fighters
Health Risks from Exposure

Cancers

Exposure to known or presumed carcinogens - PBDEs, PBDD/Fs, PCDD/Fs, PFCs (PFOA)

Neurotoxicity

Chronic high exposure to DecaBDE

Cardiovascular effects, stroke

Exposure to PFCs (PFOA) in smoke and dust

Thyroid, reproductive, immune effects

Exposure to PBDEs, PFCs in smoke and dust
Does Fire Fighter Exposure Cause Cancer?

Not proven
Causal evidence lacking
Efforts underway to close research gaps
Planned: National Fire Fighter Cancer Biomarker Study

- Aim: examine relationships between exposure and early indicators of cancer risk in US fire fighters
- Comprehensive exposure assessment in blood and urine, also in soot wipes from gear
- Panel of molecular oncology biomarkers in fire fighter serum
Recommendations for FF Safety

- Frequent changing and cleaning of gear, especially hoods and gloves; frequent showering
- Use of cotton glove liners to reduce dermal exposure
- Decontamination at scene of structural fires
- Use of skin wipes to remove soot immediately
- Careful removal of turnout gear to avoid skin contact with soot
- Bagging of contaminated gear to avoid contamination of vehicle, living spaces
- Air drying of cleaned gear; open lockers
- Backup sets of gear to wear while gear is decontaminated