Cancer in Firefighters: Recent Research

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National Institute for Occupational Safety and Health (NIOSH)
Outline

• Why study firefighters?
• How to conduct EPI Studies
• Recent EPI Studies
  – U.S. firefighters
  – Nordic firefighters
  – Australian firefighters
• Exposure Assessment
• Future research needs
Why study firefighters?

Toxic Exposures

- Many and varied exposures
- Multiple known carcinogens
- Change in 1960’s with introduction of synthetic materials
- “Overhaul” phase of fire presents high exposure risk
- SCBA has greatly reduced exposure: use issues
- Multiple routes of entry
Why study firefighters?
Affected Population

Large population at risk:
• 1.1 M U.S. firefighters
  – 31% career firefighters
  – 30,000 fire departments nationwide
• 1.4 million fires per year
  – 0.5 million structure fires
  – ~1-5% of time is spent at structure fires (20-100 hrs/yr)

Significant public concern:
• Fire Service (IAFF, IAFC)
• Recommending bodies and advocacy groups (IARC, NLC, and FCSN)
• U.S and State Governments (U.S. Fire Administration, U.S. Congress, Pennsylvania State Legislature)
Existing Research

- 1\textsuperscript{st} Generation (1950s – 2000s): Mostly mortality in single municipal fire departments (see Table 2.1 of IARC Monograph Vol. 98).

- 2\textsuperscript{nd} Generation (2006 - 2010): Systematic reviews and meta-analyses of first generation studies (LeMasters et al., 2006; Guidotti, 2007; IARC, 2010)

- 3\textsuperscript{rd} Generation (2013-present): Pooled studies (U.S. Firefighters, Nordic Firefighters, Australian Firefighters)
Meta Analysis, LeMasters et al. (2006)

- Reviewed 32 previous studies
- Classified cancers as either probable, possible, or unlikely related to firefighting
- 4 probable cancers (right panel)
- 8 possible:
  - skin
  - malignant melanoma
  - brain
  - rectum
  - buccal cavity and pharynx
  - stomach
  - colon
  - leukemia

<table>
<thead>
<tr>
<th>Probable Cancers</th>
<th>SRE (95% CI)</th>
<th>n=number of studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testes</td>
<td>2.02 (1.30-3.13), n=4</td>
<td></td>
</tr>
<tr>
<td>Mult. Myeloma</td>
<td>1.53 (1.21-1.94), n=10</td>
<td></td>
</tr>
<tr>
<td>NHL</td>
<td>1.51 (1.31-1.73), n=8</td>
<td></td>
</tr>
<tr>
<td>Prostate</td>
<td>1.28 (1.15-1.43), n=13</td>
<td></td>
</tr>
</tbody>
</table>

Lit Review, Guidotti (2007)

- Causality of occupational cancers in firefighters; the weight of evidence.
- Presumption is justified for:
  - Genitourinary cancers (bladder, kidney, and testes)
  - Brain
  - Lung cancer in non-smokers
  - NHL
  - Leukemia
  - Myeloma

Guidotti, TL, Occup Med 2007;57:466–471
National League of Cities (2009)

The NLC (TriData) Report:

• “...a lack of substantive scientific evidence currently available to confirm or deny linkages between firefighting and an elevated incidence of cancer.”
Why Study Firefighters?
Gaps in Current Knowledge

- Elevated cancer risk at many different sites but few consistently observed
- IARC reviewed 42 Epi studies and identified 3 potential sites (right panel)
- Studies at best used indirect (poor) measurements of exposure.

<table>
<thead>
<tr>
<th>Cancers</th>
<th>SRE (95% CI)</th>
<th>n=number of studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testes</td>
<td>1.47 (1.20-1.80),</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>n=6</td>
<td></td>
</tr>
<tr>
<td>NHL</td>
<td>1.21 (1.31-1.73),</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>n=7</td>
<td></td>
</tr>
<tr>
<td>Prostate</td>
<td>1.30 (1.08-1.36),</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>n=16</td>
<td></td>
</tr>
</tbody>
</table>

IARC’s conclusions “limited evidence in humans for the carcinogenicity of occupational exposure as a fire fighter” (Group 2B, possibly carcinogenic to humans)

Cancer

- A group of diseases characterized by uncontrolled growth and spread of abnormal cells.
- Multifactorial etiology: genetic, environmental, medical, lifestyle, and chance.
  - 1/3 variation due to environmental and genetic factors
  - 2/3 stochastic effects (Tomasetti and Vogelstein, 2014)
- Risks tend to increase with age. About 77% of all cancers are diagnosed in persons 55 years of age and older.
- Early diagnosis and treatment are vital; identifying persons at increased risk is an important objective of cancer research.
U.S. Cancer Facts

• About 1.7 million new cancer cases each year.

• Men have about a 1 in 2 lifetime risk of developing cancer; for women, the risk is a little more than 1 in 3.

• Cancer accounts for 1 in 4 deaths; 2nd most common cause.

• Direct costs of cancer are about $124 billion per year.

• About 33 million disability days per year; $7.5 billion in lost work productivity.

• Occupational cancer comprises about 4 to 10% of cases.
# U.S. Cancer Stats

<table>
<thead>
<tr>
<th>Cancer</th>
<th>New Cases per 100,000 PYAR</th>
<th>Deaths per 100,000 PYAR</th>
<th>Lifetime Risk (%)</th>
<th>5-year Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Cancer</td>
<td>460.4</td>
<td>173.8</td>
<td>40.4</td>
<td>66.1</td>
</tr>
<tr>
<td>Prostate</td>
<td>147.8</td>
<td>22.3</td>
<td>15.0</td>
<td>98.9</td>
</tr>
<tr>
<td>Testis</td>
<td>5.6</td>
<td>0.2</td>
<td>0.4</td>
<td>95.3</td>
</tr>
<tr>
<td>NHL</td>
<td>19.7</td>
<td>6.3</td>
<td>2.1</td>
<td>69.3</td>
</tr>
<tr>
<td>Lung &amp; Bronchus</td>
<td>60.1</td>
<td>48.4</td>
<td>6.9</td>
<td>16.8</td>
</tr>
<tr>
<td>Female Breast</td>
<td>124.6</td>
<td>22.2</td>
<td>12.3</td>
<td>89.2</td>
</tr>
<tr>
<td>Colorectal</td>
<td>43.7</td>
<td>15.9</td>
<td>4.7</td>
<td>64.7</td>
</tr>
<tr>
<td>Leukemia</td>
<td>13.0</td>
<td>7.1</td>
<td>1.4</td>
<td>57.2</td>
</tr>
</tbody>
</table>

Rates based on 2007-2011 cases and deaths. Lifetime risk based on 2009-2011 data. 5-year survival based on 2004-2010 data.

http://seer.cancer.gov/
Some definitions

Scientific certainty is seldom attainable; *causality* is based on the *weight of evidence*.

- **Causality**: relating causes (e.g., smoking habits) to the effects they produce (e.g., lung cancer).

- **Association**: statistical dependence between two or more quantities (common measures: RR, SMR, and OR). *The presence of a statistical association alone is not “proof” of causality.*

- **Probabilistic Causality**: the causal factor is neither necessary nor sufficient. *Having cancer (effect) does not imply exposure (cause) and exposures do not always result in cancer.*
What is evidence of causality?

<table>
<thead>
<tr>
<th>Guideline</th>
<th>Explanation or example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength of Association</td>
<td>The larger the association, the more likely the exposure is causing the disease.</td>
</tr>
<tr>
<td>Consistency</td>
<td>The association is observed repeatedly in different persons, places, times, and circumstances.</td>
</tr>
<tr>
<td>Temporality</td>
<td>The exposure must precede the disease in time.</td>
</tr>
<tr>
<td>Biologic Gradient (dose-response)</td>
<td>Persons who have increasingly higher exposure levels have increasingly higher risks of disease.</td>
</tr>
<tr>
<td>Plausibility</td>
<td>The relationship does not conflict with current knowledge of natural history and biology of disease.</td>
</tr>
<tr>
<td>Experiment</td>
<td>Intervention that lowers exposure should result in less disease</td>
</tr>
</tbody>
</table>
Cancer Epidemiology

Investigates the frequency and distribution of cancers in a defined population to determine causes, discover ways to alleviate them, and to prevent their reoccurrences
Cancer Epi Studies

• Uncover disease etiology
  – Describe cancer in populations over time.
  – Determine whether an agent is carcinogenic
  – Quantify risk per unit exposure.
  – Identify population at risk.

• Mitigation/Prevention
  – Develop preventive measures
  – Assess efficacy of preventive measures
Hierarchy of Epidemiologic studies

- **Descriptive**
  - Case report
  - Case series
  - Survey

- **Analytic**
  - **Observational**
    - Cross sectional
    - Longitudinal (e.g. Cohort study)

- **Experimental**
  - Randomized controlled trials

Strength of evidence for causality between a risk factor and outcome
Longitudinal studies

Figure 2: Schematic diagram of concurrent, retrospective, and ambidirectional cohort studies
What’s needed for a longitudinal (cohort) study?

• Large number of subjects and cases.
• Long length of time for follow-up.
  - Disease latency
  - Modification by age and time since exposure
• Information on exposure
  - Quantity and distribution
• Information on factors that can modify risk
  - Age, sex, race, lifestyle, etc.
Something to Consider

- No study is error-free.
- Small associations are more affected by errors.
- Relative effect measures (RR, HR, SMR, SIR, and OR) < 2.0 are generally considered “weak” or “small”.
- Statistical “significance” does not imply “trueness”.

Narrow confidence intervals imply very high precision but do not guarantee a lack of bias.
Recent Epidemiologic Studies

• NIOSH Firefighter Study (2013)

• Nordic Firefighter Study (2014)

• Australian Firefighter Study (2014)
  – Final Report Australian Firefighters’ Health Study. Monash Centre for Occupational and Environmental Health (MonCOEH), School of Public Health & Preventive Medicine, Department of Epidemiology & Preventive Medicine. December 2014, 175 p.
NIOSH Study

• **Phase I (published):** Is cancer associated with firefighting?
  – Recruit study group of career firefighters
  – Determine mortality and cancer incidence among group
  – Compare cancer risk to the general population


• **Phase II (submitted):** Are higher-exposed firefighters more at risk?
  – Estimate the exposure potential of each study participant
  – Examine the relation between exposure and cancer risk
NIOSH Study Population

<table>
<thead>
<tr>
<th></th>
<th>ALL</th>
<th>SFFD</th>
<th>CFD</th>
<th>PFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persons</td>
<td>29,993</td>
<td>5,313</td>
<td>15,185</td>
<td>9,495</td>
</tr>
<tr>
<td>White</td>
<td>80.8%</td>
<td>80.1%</td>
<td>77.3%</td>
<td>86.9%</td>
</tr>
<tr>
<td>male</td>
<td>96.7%</td>
<td>94.3%</td>
<td>96.8%</td>
<td>97.9%</td>
</tr>
<tr>
<td>Deaths</td>
<td>12,028 (40%)</td>
<td>2,074</td>
<td>5,944</td>
<td>4,010</td>
</tr>
<tr>
<td>Cancer Deaths</td>
<td>3,285 (27%)</td>
<td>578</td>
<td>1,670</td>
<td>1,037</td>
</tr>
<tr>
<td>Diagnoses</td>
<td>4,461</td>
<td>855</td>
<td>2,186</td>
<td>1,420</td>
</tr>
</tbody>
</table>

**Career firefighters** employed for at least one day in fire departments serving San Francisco, Chicago, or Philadelphia, from 1950 through 2009.
NIOSH External Comparisons:  
All Causes and All Cancer

Overall mortality was not elevated:

<table>
<thead>
<tr>
<th>Outcome*</th>
<th>Obs</th>
<th>Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Causes</td>
<td>12,028</td>
<td>0.99 (0.97 to 1.01)</td>
</tr>
<tr>
<td>IHD</td>
<td>3,619</td>
<td>1.01 (0.98 to 1.04)</td>
</tr>
<tr>
<td>COPD</td>
<td>367</td>
<td>0.72 (0.65 to 0.80)</td>
</tr>
</tbody>
</table>

However, there was excess cancer:

<table>
<thead>
<tr>
<th>Risk Measure</th>
<th>Obs</th>
<th>All Cancers</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMR (95% CI)</td>
<td>3,285</td>
<td>1.14 (1.10 to 1.18)</td>
</tr>
<tr>
<td>SIR (95% CI)</td>
<td>4,461</td>
<td>1.09 (1.06 to 1.12)</td>
</tr>
</tbody>
</table>

Mortality: 1950-2009; n=29,993; 858,938 person-years at risk.
Incidence: 1985-2009; n=24,453; 403,152 person-years at risk.
NIOSH External Comparisons: Excess Cancers*

Excess cancer was limited to solid cancers, primarily of the respiratory, digestive, oral, and urinary organs.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Mortality</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Obs</td>
<td>SMR (95% CI)</td>
</tr>
<tr>
<td>Esophagus</td>
<td>113</td>
<td>1.39 (1.14 to 1.67)</td>
</tr>
<tr>
<td>Intestine</td>
<td>326</td>
<td>1.30 (1.16 to 1.44)</td>
</tr>
<tr>
<td>Lung</td>
<td>1046</td>
<td>1.10 (1.04 to 1.17)</td>
</tr>
<tr>
<td>Kidney</td>
<td>94</td>
<td>1.29 (1.05 to 1.58)</td>
</tr>
<tr>
<td>Oral cavity†</td>
<td>94</td>
<td>1.40 (1.13 to 1.72)</td>
</tr>
<tr>
<td>Mesothelioma</td>
<td>12</td>
<td>2.00 (1.03 to 3.49)</td>
</tr>
</tbody>
</table>

*Cancers with statistically significant excesses in mortality and incidence.
†Oral cavity includes lip (excluding skin of the lip), tongue, salivary glands, gum, mouth, pharynx, oropharynx, nasopharynx, and hypopharynx
### NIOSH External Comparisons: Minority Firefighters (n=4,657 males, 15.5%)

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Obs</th>
<th>Mortality SMR (95% CI)</th>
<th>Incidence SIR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All causes</td>
<td>453</td>
<td>0.68 (0.62 to 0.74)</td>
<td>NA</td>
</tr>
<tr>
<td>All cancers</td>
<td>104</td>
<td>0.80 (0.65 to 0.97)</td>
<td>240</td>
</tr>
<tr>
<td>Prostate</td>
<td>17</td>
<td>1.64 (0.95 to 2.63)</td>
<td>94</td>
</tr>
<tr>
<td>Leukemia</td>
<td>5</td>
<td>1.28 (0.41 to 2.98)</td>
<td>11</td>
</tr>
</tbody>
</table>

Minority firefighter risks were generally decreased; however, prostate cancer and leukemia appeared elevated.
TABLE 3

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Obs</th>
<th>SMR (95% CI)</th>
<th>Obs</th>
<th>SIR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All causes</td>
<td>26</td>
<td>0.91 (0.59 to 1.33)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>All cancers</td>
<td>6</td>
<td>0.74 (0.27 to 1.61)</td>
<td>40</td>
<td>1.24 (0.89 to 1.69)</td>
</tr>
<tr>
<td>Breast</td>
<td>&lt;5</td>
<td>1.46 (0.30 to 4.26)</td>
<td>18</td>
<td>1.45 (0.88 to 2.29)</td>
</tr>
<tr>
<td>Bladder</td>
<td>&lt;5</td>
<td>33.51 (4.06 to 121.1)</td>
<td>&lt;5</td>
<td>12.53 (3.41 to 32.1)</td>
</tr>
</tbody>
</table>

Bladder cancer was significantly elevated; however, the small sample and the lack of confirmatory results suggest cautious interpretation.
NIOSH External Comparisons: Risk differences by age

Significant age-at-risk differences observed in bladder and prostate cancer incidence:

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Age Group</th>
<th>Obs</th>
<th>Incidence SIR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bladder</td>
<td>All ages</td>
<td>316</td>
<td>1.12 (1.00 to 1.25)</td>
</tr>
<tr>
<td></td>
<td>17-64</td>
<td>97</td>
<td>1.33 (1.08 to 1.62)</td>
</tr>
<tr>
<td>Prostate</td>
<td>All ages</td>
<td>1261</td>
<td>1.03 (0.98 to 1.09)</td>
</tr>
<tr>
<td></td>
<td>17-64</td>
<td>426</td>
<td>1.21 (1.10 to 1.33)</td>
</tr>
<tr>
<td></td>
<td>45-59</td>
<td>249</td>
<td>1.45 (1.28 to 1.64)</td>
</tr>
<tr>
<td></td>
<td>45-49</td>
<td>31</td>
<td>2.14 (1.46 to 3.04)</td>
</tr>
</tbody>
</table>
Key findings from external comparisons

• The NIOSH study found excess solid cancers in firefighters:
  – Digestive (colon, esophagus)
  – Genitourinary
    • Kidney
    • Bladder in women and in men at younger ages (<65y)
    • Prostate at younger ages (<65y)
  – Oral sites (mouth, throat, tongue)
  – Respiratory (larynx, lung)
  – Mesothelioma

• The results add to the weight of evidence that firefighters are at risk for a variety of specific cancer outcomes.
NIOSH Study Internal Comparisons

- Estimate exposures for each firefighter:
  - Identify all jobs held and duration
  - Define exposure potentials by job
    - # fire runs (CFD & PFD)
    - # exposed days (All)
    - # fire run-hours (CFD only)

- Compare cancer risks in higher-exposed to lower-exposed by conditional logistic regression.

- Publish exposure-response modeling results (Early 2015).
Regression modeling methods

- Eight cancer and four non-cancer endpoints examined
- Three exposure measures: exposed-days, fire-runs, and fire-hours.
- General relative risk models used to calculate hazard ratios comparing 75th- and 25th-percentiles of lagged cumulative exposure.
- Model fits to loglinear, linear, log-quadratic, power, and restricted cubic splines were examined.
- Piecewise constant models were used to examine risk differences by time since exposure, age at exposure, and calendar period.
Exposure by cumulative fire runs

<table>
<thead>
<tr>
<th>Assignment</th>
<th>Job Title</th>
<th>Start Date</th>
<th>End Date</th>
<th>Years at Assignment</th>
<th>Fire Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTS</td>
<td>Firefighter</td>
<td>10/19/1959</td>
<td>12/20/1959</td>
<td>0.17</td>
<td>0</td>
</tr>
<tr>
<td>E 60</td>
<td>Firefighter</td>
<td>12/21/1959</td>
<td>10/15/1967</td>
<td>7.82</td>
<td>5730</td>
</tr>
<tr>
<td>L 28</td>
<td>Firefighter</td>
<td>10/16/1967</td>
<td>8/26/1973</td>
<td>5.87</td>
<td>3905</td>
</tr>
<tr>
<td>FH</td>
<td>Firefighter</td>
<td>8/27/1973</td>
<td>11/30/1973</td>
<td>0.26</td>
<td>0</td>
</tr>
</tbody>
</table>

Cumulative Runs = 17715
Lung cancer dose-response model (Loglinear)
25th percentile is referent (95% CI shown as shaded area)
Leukemia dose-response model (power)
25th-percentile is referent (95% CI shown as shaded area)
Key findings from internal comparisons

• Metrics in order of preference were: 1) run-hours, 2) number of runs, and 3) exposed days. All were improvements to using simple employment duration.

• A positive exposure-response observed for lung cancer mortality and incidence and leukemia mortality, suggesting increased occupational cancer risk.

• A negative exposure-response observed for colorectal and prostate cancers, suggesting a healthy worker survivor effect or possible screening bias.
Strengths

- Large cohort (~30,000 career firefighters) under long observation (~850,000 person-years).
  - Includes firefighters of all races and gender
  - Includes multiple fire departments from the East, Midwest, and West regions
  - Includes both historical and recent firefighting experience (1950-2009)
- Cancer mortality and incidence examined.
- Framework for future studies (e.g. in-depth studies of single outcomes).
Limitations

• Low statistical power (difficulty observing causal effect)
  – Long latency of disease
  – Small effect size (most < 2-fold excess)
• Lacking direct information on exposure
• Few women and minority firefighters
• Estimates could be influenced by other factors:
  – Healthy worker and/or survivor effects
  – Case ascertainment errors
  – Information on other risk factors (e.g., tobacco use, alcohol consumption, diet, obesity) is lacking.
Criticism: National League of Cities

• Not representative of typical exposures
  – “old-line cities where the firefighters would be expected to fight more fires and encounter asbestos and chemicals...”

• Does not identify the strength of association criteria used to evaluate the causal relationships
  – “finds only small to moderate increases in risk...”

• Inconsistent with current knowledge:
  – “numerous cancers already targeted by state presumption statutes do not have a significant excess incidence or mortality...”

• Lack evaluation of “other risk factors”
Nordic Firefighter Study (2014)

• Longitudinal cancer incidence study; part of the Nordic Occupational Cancer (NOCCA) project
• Firefighters selected from five Nordic countries
• Data from census and cancer registries for the period 1961–2005.
• 16,422 male firefighters providing 412,991 person-years.
• External comparisons (SMRs and SIRs)

Key Findings

• Modest excess risk of all cancers combined.
• Cause specific excess risk was observed for:
  – Prostate cancer and melanoma at ages 30-49,
  – Multiple myeloma, lung adenocarcinoma, and mesothelioma at ages 70+

## NIOSH Study vs. Nordic Study (2014)

<table>
<thead>
<tr>
<th>Cancer Site</th>
<th>Daniels et al. (2013)</th>
<th></th>
<th></th>
<th>Pukkala et al. (2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Obs.</td>
<td>SIR (95% CI)</td>
<td></td>
<td>Obs.</td>
</tr>
<tr>
<td>All cancers</td>
<td>4461</td>
<td>1.09 (1.06 to 1.12)</td>
<td>2536</td>
<td>1.06 (1.02 to 1.11)</td>
</tr>
<tr>
<td>Testes</td>
<td>15</td>
<td>0.75 (0.42 to 1.24)</td>
<td>9</td>
<td>0.51 (0.23 to 0.98)</td>
</tr>
<tr>
<td><strong>Age group 30-49</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prostate</td>
<td>36</td>
<td>2.04 (1.43 to 2.82)</td>
<td>12</td>
<td>2.59 (1.34 to 4.52)</td>
</tr>
<tr>
<td>Melanoma</td>
<td>11</td>
<td>0.44 (0.22 to 0.79)</td>
<td>37</td>
<td>1.62 (1.14 to 2.23)</td>
</tr>
<tr>
<td><strong>Age group 70+</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-melanoma skin</td>
<td>NA</td>
<td>NA</td>
<td>75</td>
<td>1.40 (1.10 to 1.76)</td>
</tr>
<tr>
<td>Multiple myeloma</td>
<td>24</td>
<td>0.93 (0.60 to 1.39)</td>
<td>24</td>
<td>1.69 (1.08 to 2.51)</td>
</tr>
<tr>
<td>Lung</td>
<td>359</td>
<td>1.11 (1.00 to 1.23)</td>
<td>141</td>
<td>1.28 (1.08 to 1.52)</td>
</tr>
<tr>
<td>mesothelioma</td>
<td>23</td>
<td>2.44 (1.55 to 3.67)</td>
<td>10</td>
<td>2.59 (1.24 to 4.77)</td>
</tr>
</tbody>
</table>

Strengths and Limitations

• **Strengths:**
  – Large cohort from multiple countries
  – Relatively long followup (45 years)
  – Incidence data available (histology)

• **Limitations:**
  – Lacking direct information on exposure
  – Few women and minority firefighters
  – Estimates could be influenced by other factors (e.g., lifestyle, other employment, etc.)
Australian Firefighters Health Study (December 2014)

- Longitudinal study of firefighters employed at one of eight agencies between 1976-2011
  - Mortality (1980-2011)
  - Cancer incidence (1982-2010)
- Results by full-time (career), part-time, and volunteer firefighters
- External comparisons (SMRs and SIRs)
- Internal comparisons (RMRs, RIRs): employment, incidents

Cohort Definition: firefighters who ever attended fires to undertake firefighting tasks, including prescribed burning, as part of their employment or volunteer membership with participating agencies

http://www.coeh.monash.org/ausfireftr.html
## Study population (males only)

<table>
<thead>
<tr>
<th></th>
<th>Full-time</th>
<th>Part-time</th>
<th>Volunteer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firefighters</td>
<td>17394</td>
<td>12663</td>
<td>163159</td>
</tr>
<tr>
<td>Avg. age at risk start</td>
<td>34.3</td>
<td>33.1</td>
<td>39.4</td>
</tr>
<tr>
<td>Avg. age of alive at end of study</td>
<td>49.4</td>
<td>44.2</td>
<td>48.3</td>
</tr>
<tr>
<td>Employed prior to 1986</td>
<td>549</td>
<td>0</td>
<td>73</td>
</tr>
<tr>
<td>Deaths</td>
<td>780 (4.5%)</td>
<td>286 (2.3%)</td>
<td>4647 (2.8%)</td>
</tr>
<tr>
<td>Cancer deaths</td>
<td>329</td>
<td>124</td>
<td>1900</td>
</tr>
<tr>
<td>Cancer cases</td>
<td>1208</td>
<td>485</td>
<td>7057</td>
</tr>
</tbody>
</table>

Final Report Australian Firefighters’ Health Study (2014)
# Excess cancer incidence

## Males:

<table>
<thead>
<tr>
<th>Cancer Site</th>
<th>Career SIR (95% CI)</th>
<th>Part-time SIR (95% CI)</th>
<th>Volunteer SIR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cancers</td>
<td>1.08 (1.02 to 1.14)</td>
<td>1.11 (1.01 to 1.21)</td>
<td>0.86 (0.84 to 0.88)</td>
</tr>
<tr>
<td>Prostate</td>
<td>1.23 (1.10 to 1.37)</td>
<td>1.51 (1.28 to 1.77)</td>
<td>1.12 (1.08 to 1.16)</td>
</tr>
<tr>
<td>Melanoma</td>
<td>1.45 (1.26 to 1.66)</td>
<td>1.43 (1.15 to 1.76)</td>
<td>1.00 (0.93 to 1.06)</td>
</tr>
</tbody>
</table>

## Females:

<table>
<thead>
<tr>
<th>Cancer Site</th>
<th>Career SIR (95% CI)</th>
<th>Part-time SIR (95% CI)</th>
<th>Volunteer SIR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cancers</td>
<td>0.82 (0.35 to 1.61)</td>
<td>1.38 (0.84 to 2.13)</td>
<td>0.97 (0.91 to 1.03)</td>
</tr>
<tr>
<td>Brain</td>
<td>NR</td>
<td>11.75 (2.42 to 34.35)*</td>
<td>1.00 (0.56 to 1.65)</td>
</tr>
<tr>
<td>Melanoma</td>
<td>NR</td>
<td>2.10 (0.68 to 4.90)</td>
<td>1.25 (1.05 to 1.46)</td>
</tr>
</tbody>
</table>

*Based on only 3 cases

---

Final Report Australian Firefighters’ Health Study (2014)
# NIOSH Study vs. Australian Study for career firefighters

<table>
<thead>
<tr>
<th>Cancer Site</th>
<th>Daniels et al. (2013)</th>
<th>Australian Study (2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Obs</td>
<td>SIR (95% CI)</td>
</tr>
<tr>
<td>All cancers</td>
<td>4461</td>
<td>1.09 (1.06 to 1.12)</td>
</tr>
<tr>
<td>Esophagus</td>
<td>90</td>
<td>1.62 (1.31 to 2.00)</td>
</tr>
<tr>
<td>Intestine</td>
<td>398</td>
<td>1.21 (1.09 to 1.33)</td>
</tr>
<tr>
<td>Lung</td>
<td>716</td>
<td>1.12 (1.04 to 1.21)</td>
</tr>
<tr>
<td>Kidney</td>
<td>166</td>
<td>1.27 (1.09 to 1.48)</td>
</tr>
<tr>
<td>Oral cavity†</td>
<td>174</td>
<td>1.39 (1.19 to 1.62)</td>
</tr>
<tr>
<td>Mesothelioma</td>
<td>35</td>
<td>2.29 (1.60 to 3.19)</td>
</tr>
<tr>
<td>Prostate</td>
<td>1261</td>
<td>1.03 (0.98 to 1.09)</td>
</tr>
<tr>
<td>Prostate (&lt;65 years)</td>
<td>36</td>
<td>1.21 (1.10 to 1.33)</td>
</tr>
<tr>
<td>Melanoma</td>
<td>141</td>
<td>0.87 (0.73 to 1.03)</td>
</tr>
</tbody>
</table>

Final Report Australian Firefighters' Health Study (2014)
Key findings

• Modest overall cancer risk compared to general population.
• Site-specific increased risk of:
  – prostate cancer, (trend with incidents in internal analyses)
  – melanoma,
  – male breast cancer among those employed 20+ years (SIR =3.44; 95%CI: 1.12 to 8.04; n=5).
  – brain cancer in women part-time firefighters, but few cases.
• Limited evidence of excess mesothelioma and testicular cancer, but numbers were small.
• Significant trends in urinary and Lymphohematopoietic cancers with years of service.
Strengths and Limitations

• Strengths:
  – Large cohort
  – Mortality and cancer incidence
  – Examines health risks in career, part-time, and volunteers

• Limitations:
  – Narrow observation period
    • <5% of the cohort was deceased, few incidence cases
  – Strong healthy worker bias (SMR= 0.67; 95%CI: 0.62 to 0.72)
  – Lacking direct information on exposure
  – Few women and minority firefighters
  – Estimates could be influenced by other factors (e.g., lifestyle, other employment, etc.)
Esposure Assessment Research
Exposome: Characterize Everything!

- Occupational Exposures
- Environmental and lifestyle factors (e.g., chemicals, infectious agents, diet, tobacco, alcohol), and the internal exposures
- Endogenous processes (e.g., metabolism, hormones, inflammation)
- “omic” profiles (e.g., genomics, transcriptomics, epigenomics, etc.)

Environ and Molecular Mutagenesis 54:480-499 (2013)
Occupational exposure: Characterize fire composition

- **Most fires**: aromatic hydrocarbons, PAHs, nitro-PAHs, aldehydes, cyanides, acids, particulate, oxides of carbon, nitrogen, and sulfur
- **Synthetic materials**: vinyl chloride, PCBs, plasticizers, phthalates, isocyanates, flame retardants, dioxins and furans
- **Inorganics**: asbestos, metals
- **The unknown?**

Fabian et al. (2014) Fire Technol 50, 993-1019
Shaw et al. (2014) Chemosphere Vol. 91(10): 1386-1394
Exposure pathways: dermal absorption

• Neck is vulnerable to exposure (Fent et al., 2014, Baxter et al., 2014)
  – Particles/soot that contact the skin can be absorbed
    • PAHs
    • What else? Nitro-PAHs, dioxins, furans (Shaw et al., 2013; Hsu et al. 2011)?
  – Some vapors can also be absorbed through skin
    • Aromatic hydrocarbons
    • What else? HCN?

• How does the extreme environment affect dermal absorption?
  – Ambient temperatures, skin temperatures, humidity, and sweat

• Transfer of contaminants to skin during doffing and handling gear
  – UL identified various compounds on contaminated gear (e.g., PAHs, phthalates, metals)
Exposure pathways: Inhalation

- Respiratory Protection Use?
  - Overhaul
  - Scene investigation
  - Automobile fires
  - vegetation fires
  - roof ventilation
  - training exercises
Other exposure factors

• Synergistic effects
  – Combine effects of multiple exposures are greater than separate effects

• Intensity vs duration
  – The effects of short duration high intensity exposures compared to long duration low intensity exposures

• Exposure fractionation: time between exposures

• Physical stressors
  – Go from rest (low HR/low BP) to physically demanding work (high HR/high BP/physical stress/heat stress)
Recent Exposure Assessment Research

Future Research Needs
Areas for future EPI research

• Studies to assess causality
  – Strength of association:
    • Increased size and length of followup
    • Account for healthy worker selection and survivor biases
    • Account for important risk factors, such as tobacco use and diet
    • Cause-specific analyses to account for risk dilution from disease heterogeneity. (e.g., examine leukemia subtypes)
  – Investigate dose-response characteristics with improved metrics
    • Complete exposure histories
    • Account for varying employment policies, firefighting tactics, and the use of personal protective equipment.
    • Integrate measurement data when available
Areas for future EPI research

• Studies to identify populations at risk:
  – Assess risk difference by employment type (e.g., career vs volunteer) and fire type (wildland vs structural)
  – Investigate spatial and temporal effect modifiers (i.e., location, age at exposure, time since exposure, calendar period)
  – Examination of cancer risk in minority groups (non-whites and women)

• Studies to assess risk management
  – Intervention studies: Did the mitigation strategy reduce the cancer risk?
Areas for future exposure research

• Characterize exposures to lesser known compounds
  – Nitro-PAHs, flame retardants, plasticizers (DEHP), dioxins/furans

• Elucidate multiple routes and pathways of exposure
  – Inhalation vs. dermal vs. ingestion
  – Downwind of fire, overhaul, post-fire environment, cross contamination
  – Different types of fire and attack methods

• Develop better protection for neck skin and other technological advancements that can reduce exposure

• Study effectiveness of gross decon of PPE
Acknowledgements

**Investigators**

NIOSH:
Robert D. Daniels, Travis L. Kubale, James H. Yiin, Matthew M. Dahm, Thomas R. Hales, Kathleen M. Waters, and Lynne E. Pinkerton

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U.S. Fire Administration:
William Troup and Glenn Gaines
Questions?
Firefighter exposures:
Groups 1, 2A, and 2B agents have been detected at fires in one or more studies:
- 11 Group 1 substances:
  - e.g., polycyclic aromatic hydrocarbons (PAHs), formaldehyde, benzene, asbestos, diesel exhaust, and arsenic
- 5 Group 2A substances
- 18 Group 2B substances

IARC agent classifications:

<table>
<thead>
<tr>
<th>Group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Carcinogenic to humans</td>
</tr>
<tr>
<td>2A</td>
<td>Probably carcinogenic to humans</td>
</tr>
<tr>
<td>2B</td>
<td>Possibly carcinogenic to humans</td>
</tr>
<tr>
<td>3</td>
<td>Not classifiable as to its carcinogenicity to humans</td>
</tr>
<tr>
<td>4</td>
<td>Probably not carcinogenic to humans</td>
</tr>
</tbody>
</table>

http://monographs.iarc.fr/ENG/Classification/