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Cancer Risk Among Firefighters: A Review and Meta-analysis of 32 Studies

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Objective: *The objective of this study was to review 32 studies on firefighters and to quantitatively and qualitatively determine the cancer risk using a meta-analysis.* ***Methods:*** *A comprehensive search of computerized databases and bibliographies from identified articles was performed. Three criteria used to assess the probable, possible, or unlikely risk for 21 cancers included pattern of meta-relative risks, study type, and heterogeneity testing.* ***Results:*** *The findings indicated that firefighters had a probable cancer risk for multiple myeloma with a summary risk estimate (SRE) of 1.53 and 95% confidence interval (CI) of 1.21–1.94, non-Hodgkin lymphoma (SRE = 1.51, 95% CI = 1.31–1.73), and prostate (SRE = 1.28; 95% CI = 1.15–1.43). Testicular cancer was upgraded to probable because it had the highest summary risk estimate (SRE = 2.02; 95% CI = 1.30–3.13). Eight additional cancers were listed as having a "possible" association with firefighting.* ***Conclusions:*** *Our results confirm previous findings of an elevated metarelative risk for multiple myeloma among firefighters. In addition, a probable association with non-Hodgkin lymphoma, prostate, and testicular cancer was demonstrated.* (J Occup Environ Med. *2006;48:1189–1202*)

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During the course of their work, firefighters are exposed to harmful substances at the fire scene as well as at the firehouse. At the fire scene, firefighters are potentially exposed to various mixtures of particulates, gases, mists, fumes of an organic and/or inorganic nature, and the resultant pyrolysis products.[1,2] Specific potential exposures include metals such as lead, antimony, cadmium, uranium, chemical substances, including acrolein, benzene, methylene chloride, polyaromatic hydrocarbons, perchlorethylene, toluene, trichloroethylene, trichlorophenol, xylene, formaldehydes, minerals such as asbestos, crystalline, and noncrystalline silica, silicates, and various gases that may have acute, toxic effects.[1,2] In some situations, respiratory protection equipment may be inadequate or not felt to be needed resulting in unrecognized exposure.[3] At the firehouse where firefighters spend long hours, exposures may occur to complex mixtures that comprise diesel exhaust, particularly if trucks are run in closed houses without adequate outside venting. In light of the World Trade Center disaster, concerns have reemerged and heightened related to building debris particle exposures from pulverized cement and glass, fiberglass, asbestos, silica, heavy metals, soot, and/or organic products of combustion.[3]

To date, only one meta-analysis conducted by Howe and Burch in 1990 examined the extent of cancer risk among firefighters in 11 mortality studies.[4] They reported that there was an increased association with the occurrence of brain tumors, malignant melanoma, and multiple myeloma with the evidence in favor of causality somewhat greater for brain tumors and multiple myeloma. Since then, there have been numerous mortality and incidence studies. Hence, the purpose of this study was twofold. The first purpose was to update the Howe and Burch findings by reviewing the methodologic characteristics of these studies and determining the probability of cancer by assessing the weight of evidence, including the calculated metarisk estimates. The second purpose was to describe a methodology for use in a meta-analysis when diverse investigations are being evaluated and summarized.

Materials and Methods

Search Strategy and Inclusion Criteria

Standardized mortality ratio (SMR), proportional mortality ratio (PMR), relative risk (RR), standardized incidence ratio (SIR), and case–control/mortality odds ratio (OR) studies related to firefighters and cancer risk were evaluated. For publication selection, at least 1 year in service as firefighters was required except for those studies basing employment on death certificates. Publications were retrieved by a search of computerized databases, including Medline (1966–December 2003), Health and Safety Science Abstracts (since 1980–December 2003), Cancerlit (1963–December 2003), NIOSHTIC and NIOSHTIC2 (up to December 2003), BIOSIS Previews (1980–December 2003), and PubMed (up to December 2003) using the following key words: firefighters, fire fighters, cancer. In addition to the computerized search, bibliographies in identified papers were reviewed for additional studies.

The search was restricted to reports published in English; abstracts and reviews were not included. Studies were excluded without basic data (eg, confidence intervals) that are necessary in the derivation of the meta-analysis risk estimate. If there was more than one article with the same or overlapping population, preference was given to the article providing more comprehensive information. The data were extracted from each article by one reviewer and was verified by another. Discrepancies identified by the second reviewer were resolved in a consensus meeting.

Likelihood of Cancer Risk. Statistically significant increases in cancer risks among firefighters were evaluated as the likelihood for cancer risk given a three-criteria assessment. The three criteria included "pattern of meta-relative risk association," "study type," and "consistency" among studies. These criteria were particularly important given the different methodologies used for evaluating cancer risk (ie, SMR, PMR, RR, SIR, and OR). These criteria were used in a forward approach as illustrated in Figure 1 in which at each stage, a new criterion was applied, and the probability of cancer risk was reassessed. The likelihood for cancer risk was given an assignment of "probable," "possible," or "not likely" patterned after the International Agency for Research on Cancer (IARC) risk assessment of human carcinogenicity in terms of weight of the evidence.[5]

The "pattern of metarelative risk associations" was the first criterion and included a two-step evaluation. For the

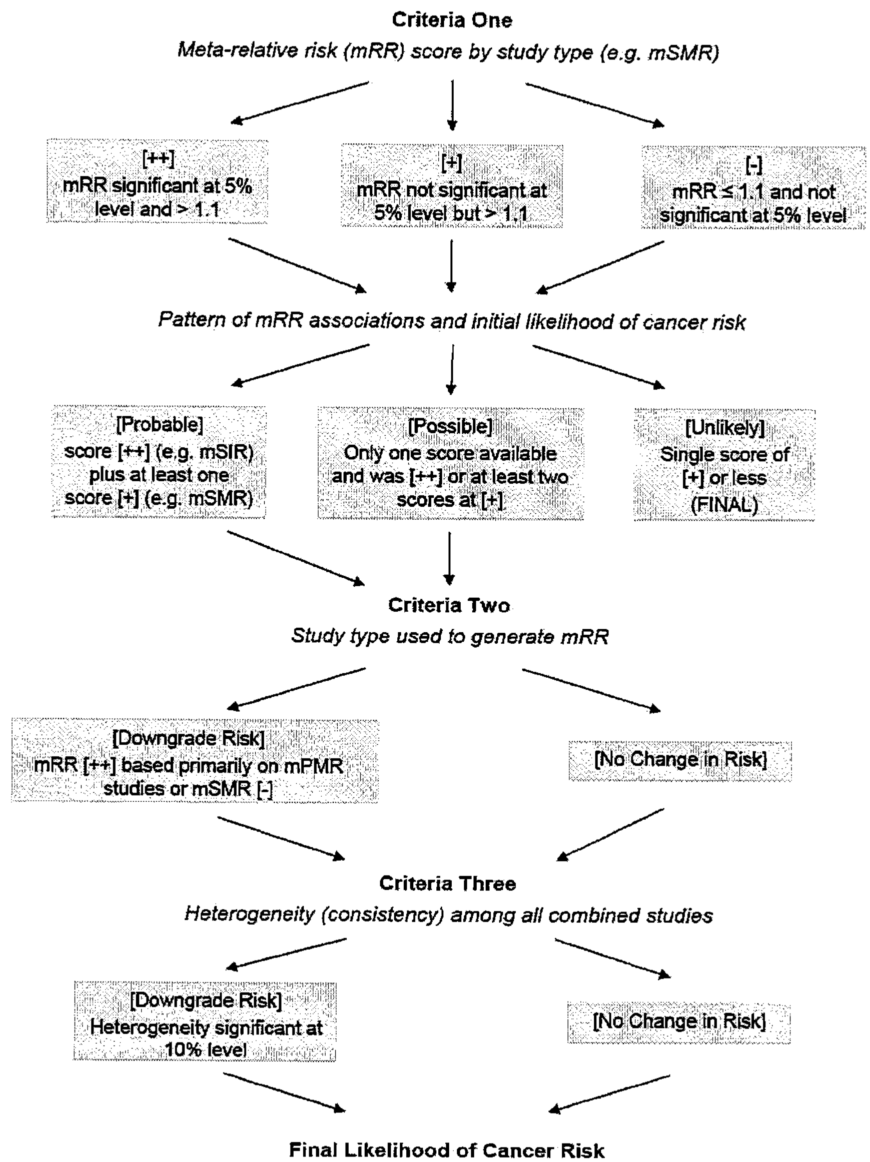

Fig. 1. Likelihood of cancer risk.

first step, the strength of the meta-analysis by each study type (eg, SMR, PMR) was assigned a score. The score of "++" was assigned if the metarelative risk was statistically significant and greater than 1.1. The score of "+" was assigned if the metarelative risk was not statistically significant, but the point risk estimate was greater than 1.1. The score of "−" was assigned if the metarelative risk was not statistically significant, and the point risk estimate was equal to or less than 1.1. At the second step, these scores were used to assign a probable, possible, or unlikely designation for the pattern of metarelative risk association. A "probable" was assigned to the cancer-specific site if one metarelative risk (ie, mSMR, mPMR, mSMR and PMR, mRR, mSIR, mOR) was statistically significant (score of ++) and at least another was greater than 1.1 (score of +). A "possible" assignment was given if only one metarelative risk was available and was statistically significant (score of ++) or if at least two metarelative risks were greater than 1.1 but were not statistically significant (score of +). "Not likely" was assigned if the cancer-specific site did not meet the probable or possible criteria.

The second criterion examined the "study type" used to generate metarelative risks. If the metarelative risk estimate reached statistical significance (score of ++), based primarily on PMR studies, the level was downgraded. PMR studies do not measure the risk of death or death rates but rather the relative frequency of that particular cause among all causes of death. Hence, the limitation of a PMR study is that the estimate may be abnormally low or high based on the overall increase or decrease in mortality and not due to the cause of interest.[6] Also, if the mSMR point risk estimate was not significant and ≤1.1 (−), the level was downgraded. The third criterion used for generating the likelihood of cancer risk was an assessment of "inconsistency" among studies. Heterogeneity testing as described in statistical methods was used to evaluate inconsistency. The level was downgraded if heterogeneity (inconsistency) testing among all combined studies had an $\alpha \leq 0.10$.

Statistical Methods

For all cancer outcomes having two or more studies, the observed and expected values from each study were summed and a metarelative risk estimate (mRR) was calculated. An mRR was calculated for each cancer by each study type, eg, SMR studies and as a summary metarelative risk across all study types. The mRR was defined as the ratio of the total number of observed deaths or incident cases to the total number of expected deaths or incident cases as follows:

$$mRR = \frac{\sum_{i=1}^{n} O_i}{\sum_{i=1}^{n} E_i}$$

where O_i denotes observed deaths (cases) in each individual study, E_i denotes expected deaths (cases), and n is the total number of studies.[7] The 95% confidence interval (CI) of mRR may be computed using the Poisson probability distribution as described by Breslow and Day.[8] The standard error (SE) for the metarelative risk is calculated as $SE = \frac{1}{\sqrt{\sum W_i}}$ where W_i is the statistical weight for a given study defined as $1/SE_i^2$ and SE_i is the standard error for a given study.

In the absence of heterogeneity, the fixed-effect model was applied for deriving the metarelative risk estimate; otherwise, the random-effects model was used. A test for heterogeneity for the fixed-effect approach is given by $Q = \Sigma_{i=1}^{n} W_i * \{\log(RR_i) - \log(mRR)\}^2$ where RR_i and mRR are the relative risk and the metarelative risk, respectively. The hypothesis of homogeneity among studies would be rejected if Q exceeds $\chi^2_{n-1,\alpha}$. Then the random-effects model was used with a different study weight (W_i*) that further accounts for the interstudy variation in effect size.[8] The weighing factor W_i* in the DerSimonian and Laird random-effects model is

$$W_i* = \frac{1}{\left[D + \left(\frac{1}{w_i}\right)\right]}$$

where W_i is the statistical weight for a given study for the fixed-effect model and is equal to $1/SE_i^2$ with SE_i being the standard error for a given study according to Chen and Seaton[9]

$$D = \frac{[Q - (n-1)] * \sum_{i=1}^{n} W_i}{\left(\sum_{i=1}^{n} W_i\right)^2 - \sum_{i=1}^{n} W_i^2}$$

It should be noted that D is set to 0 if $Q < n - 1$. The random-effects model was validated against data provided in Petitti,[10] which after application using our equations gave identical results. For this study, an $\alpha \leq 10\%$ or less for declaring heterogeneity was adopted.[11]

The SAS software was used to perform the calculations and validated our program for the fixed-effect model using data from different studies compiled by Howe and Burch[4] on standardized mortality ratios and proportional mortality ratios among firefighters. Where there were no observed deaths or incident cases, the lower confidence interval for an individual study was set at 0.1 as suggested in the method used by Collins and Acquavella.[12] This method was compared with the data excluding studies with a zero relative risk, and the results were similar.

Results

Identification and Characteristics of Studies

The computerized literature search identified 21 U.S. and 14 non-U.S. articles.[13–47] It was determined that three studies were not eligible for the meta-analysis because of either insufficient data,[41] data were combined for firefighters and other personnel,[42] or the text was not published in English.[43] In addition, four studies[44–47] were excluded because of overlapping populations with other reports.[18,30] For example, in 1992, Demers et al[18] reported more observed and expected cancers than in the 1994 article.[46] Four additional studies[48–51] were identified in the review by Howe and Burch[4] and used in the meta-analysis. These latter four studies are not presented in Table 1. Hence, a total of 28 studies received a detailed review as shown in Table 1, which describes the study design characteristics, exposure, and outcome definitions. Sixteen were U.S. studies and 12 were non-U.S. investigations. Five studies had an internal comparison group with the remaining using regional or national comparison groups. Fourteen ascertained exposures from employment records and defined exposure as a dichotomous (yes/no) variable. The majority of the studies relied on death certificates for assessing a cancer diagnosis. Of a total of 32 articles, 26 are included in the meta-analysis as shown in Table 2. The six additional articles are case–control/mortality odds ratio studies and presented in Table 3 with one meta-analysis for non-Hodgkin's lymphoma.

Overview of Meta-analysis

Table 2 summarizes the meta-analysis results by study type. Studies were mostly mortality and were analyzed using SMRs and PMRs. All-cause mortality had an SMR 10% less than general population rates. Mortality from all cancers was similar to the general population using SMR and RR indices, but PMR studies showed a 10% significantly higher rate (Table 2). For individual cancers, there were statistically significant elevated meta-SMR estimates for colon cancer (1.34) and multiple myeloma (1.69). PMR studies demonstrated three significantly elevated meta-PMR values that included skin (1.69), malignant melanoma (2.25), and multiple myeloma (1.42). There was one significantly elevated metarelative risk for esophageal cancer (2.03). Incidence studies showed significant meta-SIR for cancers of the stomach (1.58), prostate (1.29), and testis (1.83).

As shown in Table 3, only one cancer type, non-Hodgkin lymphoma, had two mortality OR analyses, and both were significant. The estimated mOR was essentially based on Ma et al[14] due to the much larger sample size of firefighters (n = 4800) compared with 23 for Figgs et al.[15] Odds ratios were significantly higher for buccal cavity/pharynx (5.90) and Hodgkin's disease (2.4)[14] as well as the single incidence study related to bladder cancer (2.11) and non-Hodgkin's lymphoma (3.27).[22]

The next step was to determine the likelihood of cancer risk based on the three criteria assessment. Cancers receiving "probable" and "possible" designations are shown in Table 4. Based on evaluating the first criterion "pattern of metarelative risk" for the 20 cancer sites, eight were designated as "probable," four as "possible," and eight as an unlikely risk. Based on the second criteria "study type" stomach, rectum, skin cancer, and malignant melanoma risk were downgraded because of reliance on PMR studies for statistical significance or the mSMR point risk estimate was not significant and ≤1.1.

For the third criterion, "inconsistency" among all studies caused a downgrading for only colon cancer to "possible." This inconsistency may have been related to several factors, including study type and a cohort effect. There were 14 SMR and PMR colon cancer studies with elevated meta-risk estimates of 1.34 and 1.25, respectively (Table 2). Of these 14 studies, there were 11 (78.6%) with firefighters employed on or before 1950. In contrast, there were six mRR and SIR studies with meta-risk estimates of 0.91 and 0.90, respectively, with half employed on or before 1950. It is possible that the older cohorts had higher exposures due to a lack of awareness of the hazards or use of protective equipment.

A final check on the three criteria assessment presented in Table 4 was made by calculating an overall summary of cancer risk across all studies (ie, SMR, PMR, RR, SIR, OR). There was agreement that cancer was unlikely between the criteria assessment and the not significant summary risk estimates for esophagus, liver, pancreas, larynx, lung, bladder, kidney, and Hodgkin's disease and all cancers (Table 5). Differences between the two approaches were found for cancers of the buccal cavity/pharynx and leukemia because these were designated as possible by the criteria assessment but as not significant in the summary risk estimate. The remaining cancers were all rated as probable or possible and all had significant summary risk estimates. Of note, testicular cancer received the highest summary risk estimate (OR = 2.02; 95% CI = 1.30–3.13) related to the SIR studies compared with the "possible" designation by the three criteria assessment.

Discussion

The meta-analysis and criteria assessment designate the likelihood of cancer among firefighters as probable for multiple myeloma and prostate cancer. Thus, the findings related to multiple myeloma are in agreement with Howe and Burch.[4] The Philadelphia firefighter study[13] was the largest cohort study reported to date investigating exposure–response relationships. For Philadelphia firefighters, the SMR results for multiple myeloma demonstrated an increasing trend with duration of employment as a firefighter: 0.73 (95% CI = 0.10–5.17) for under 9 years, 1.50 (95% CI = 0.48–4.66) for 10 to 19 years, and 2.31 (95% CI = 1.04–5.16) with six observed deaths for greater than 20 years. Except for race, there are essentially no known risk factors for multiple myeloma other than occupational exposures (eg, paints, herbicides, insecticides,

TABLE 1
Characteristics of Studies From Electronic Search

Reference	Company Location	Design/Analysis	Study Period	Number of Workers	Comparison Group	Exposure Variable	Exposure Source	Cancer Source	Cofactors
Baris, 2001[13]	Philadelphia	Cohort mortality (SMR)	1925–1986	7789	INT/NGP/NED	1, 3, 5	ER	DC	Age
Ma, 1998[14]	24 US states	Case–control (MOR)	1984–1993	6607	INT	4	DC	DC	Age/race
Figgs, 1995[15]	24 US states	Case–control (MOR)	1984–1989	23890 (cases) 119,450 (controls)	RGP	4	DC	DC	Age
Burnett, 1994[16]	27 US states	PMR	1984–1990	5744	INT	4	DC	DC	Age
Demers, 1993[17]	4 US states	Case–control (OR)	1977–1981	692 (cases) 1683 (controls)	LGP	4	TRV	TRV	Age
Demers, 1992a[18]	Seattle, Tacoma (WA)	Cohort mortality (SMR) Incidence (SIR)	1944–1979	4528	LGP INT/LW/NGP	4	ER	DCN, TRV	Age
Demers, 1992b[19]	Seattle, Tacoma, WA Portland	Cohort mortality (SMR)	1944–1979	4546	INT/LW/NGP	2, 3	ER	DCN	Age
Beaumont, 1991[20]	San Francisco	Cohort mortality (RR)	1940–1970	3066	NGP	3, 6	ER	DCN	Age/yr
Grimes, 1991[21]	Honolulu	PMR, RR	1969–1988	205	RGP	3, 4	ER	DC	Race
Sama, 1990[22]	Massachusetts	Case–control (MOR)	1982–1986	315	LW/RGP	4, 7	TRV	TR	Age/smoke
Vena, 1987[23]	Buffalo	Cohort mortality (SMR)	1950–1979	1867	NGP	3	ER	DCN	Age/yr
Feuer, 1986[24]	New Jersey	PMR	1974–1980	263	LW/RGP/NGP	3, 8	ER	DCN	Age
Morton, 1984[25]	Portland, Vancouver	Incidence (SIR)	1963–1977	1678	RGP	4	TR	TRV	Age
Dubrow, 1983[26]	British & USA	Cohort mortality (SMR)	1950–1977	—	—	4	AR	DC	None
Musk, 1978[27]	US	Cohort mortality (SMR)	1915–1975	5655	RGP, NGP	4	ER	DC	Age
Berg 1975[28]	US, Great Britain	Cohort mortality (SMR) PMR	1949–1953 and 1959–1963	—	NGP	4	DC	DC	Age
Stang, 2003[29]	Germany	Case–control OR)	1995–1997	269 (cases) 797 (controls)	RGP	4	ER	MR	Age
Bates, 2001[30]	New Zealand	Cohort mortality (SMR) Incidence (SIR)	1977–1995	4221	NGP	3	AR	DC, TR	Age/yr
Firth, 1996[31]	New Zealand	Incidence (SIR)	1972–1984	26207	NED	4	TR	TR	Age
Deschamps 1995[32]	France	Cohort mortality (SMR)	1977–1991	830	NGP	2	ER	DCN	Age
Delahunt, 1995[33]	New Zealand	Case–control (RR)	1978–1986	710 (cases) 12,756 (controls)	NGP	4	TR	TR	Age/smoke
Aronson, 1994[34]	Canada	Cohort mortality (SMR)	1950–1989	5414	RGP	3, 6, 7	ER	DCN	Age/yr
Tornling, 1994[35]	Sweden	Cohort mortality (SMR) Incidence (SIR)	1931–1983	1153	LGP	1, 3, 7	ER	DC, TR	Age/yr
Giles, 1993[36]	Australia	Incidence (SIR)	1980–1989	2865	RGP	3, 6, 7	TRV	TR	Age
Guidotti, 1993[37]	Canada	Cohort mortality (SMR)	1927–1987	3328	RGP	2	ER	DCN	Age/yr
Hansen, 1990[38]	Denmark	Cohort mortality (SMR)	1970–1980	886	NED	4	OTH	DC	Age

(Continued)

TABLE 1
Continued

Reference	Company Location	Design/Analysis	Study Period	Number of Workers	Comparison Group	Exposure Variable	Exposure Source	Cancer Source	Cofactors
Eliopulos, 1984[39]	Australia	Cohort mortality (SMR) PMR	1939–1978	990	RGP	3	ER	DC	Age/yr
Mastromatteo, 1959[40]	Canada	Cohort mortality (SMR)	1921–1953	1039	RGP	4	DC	DC	Age

Exposure Variables
1. Number of firefighter runs
2. Duration of "active" duty
3. Duration of employment overall as a firefighter
4. Occupation (based on death certificate or tumor registry)
5. Company type engine, ladder
6. Time since first employment
7. Age-specific
8. Employment status

Exposure or Cancer Source
ER, employment records
MR, medical records
AR, association records
DC, death certificate
DCN, death certificate nosologist
TR, tumor registry with no validation
TRV, tumor registry (occupation) with validation from external sources
OTH, other

Design/Analysis
RR, rate ratio
SMR, standardized mortality/morbidity ratio
MOR, mortality odds ratio
OR, odds ratio
PMR, proportional mortality ratio
SIR, standardized incidence mortality

Comparison Group:
INT = internal
LW = local workers
LGP = local general population
RGP = regional general population
NGP = national general population
NED = national employment database

engine exhausts, and organic solvents).[52–57] Benjamin et al[58] reported that blacks compared with whites have at least double the risk of being diagnosed with multiple myeloma and twice the mortality rate. Race may be ruled out as a potential factor among firefighters, because cancer risk was investigated primarily for whites.

The analyses for non-Hodgkin's lymphoma were consistent across a diversity of study designs, including SMR, PMR, SIR, and OR incident/mortality studies. All showed elevated meta-risk or point estimates. The overall summary risk estimate was significantly elevated at 1.51 (95% CI = 1.31–1.73). Hence, non-Hodgkin's lymphoma is considered a probable cancer risk for firefighters. Non-Hodgkin's lymphoma is, however, several cancer types with five International Classification of Disease (ICD) codes (200, 202.0, 202.1, 202.8, 202.9). Of importance is how the definition of non-Hodgkin's lymphoma by ICD code may contribute to the variability in study findings. For example, in a study by Demers et al[19] comparing firefighters with police, the mortality incidence density ratio for "lymphosarcoma and reticulosarcoma" (ICD 200) was not elevated (0.81)[19] but was (1.40) for "other lymphatic/hematopoietic" (ICD 202, 203). Subsequent to the time period covered in this review, Ma et al[59] examined Florida firefighters but evaluated only one of two cancers for ICD code 200, ie, lymphosarcoma but not reticular sarcoma and found nonsignificance (SMR = 0.94). Hence, these studies demonstrate the importance of being cognizant that differences in cancer risk estimates and interpretation of risk may be influenced by outcome definition.

Results showing a probable association for prostate cancer is curious. Prostate cancer is the most common malignancy affecting men and is the second leading cause of cancer.[60] Risk of developing prostate cancer is associated with advancing age, black

TABLE 2
Metarelative Risk Estimates and Test for Inconsistency for Mortality and Incidence*

Disease	Number of Studies	Reference	Observed	Expected	Metarelative Risk	95% Confidence Interval	*P* Value Inconsistency
Mortality studies							
Standardized mortality ratio (SMR)							
All causes (001–999)	12	13, 19, 23, 27, 30, 32, 34 35, 37–40	8384	9273.8	0.90	0.85–0.97	<0.00
All cancers (140–209)	13	13, 19, 23, 27, 30, 32, 34 35, 37–40, 51	1801	1799.9	1.00	0.93–1.08	0.02
Buccal cavity and pharynx (140–149)	5	13, 19, 32, 34, 37	34	29.8	1.14	0.79–1.60	0.84
Esophagus (150)	4	13, 19, 23, 34	17	25.1	0.68	0.39–1.08	0.62
Stomach (151)	7	13, 19, 23, 30, 34, 35, 37	75	81.3	0.92	0.73–1.16	0.72
Colon (153)	10	13, 19, 23, 26, 28, 30, 34, 35, 37, 51	252	188.3	1.34	1.01–1.79	<0.00
Rectum (154)	6	13, 19, 23, 30, 34, 35	54	40.7	1.33	1.00–1.73	0.43
Liver/gallbladder (155–156)	5	13, 19, 23, 34, 35	22	21.9	1.00	0.63–1.52	0.92
Pancreas (157)	6	13, 19, 23, 34, 35, 37	63	64.2	0.98	0.75–1.26	0.58
Larynx (161)	3	13, 19, 34	8	13.7	0.58	0.25–1.15	0.82
Lung (162)	8	13, 19, 30, 34, 35, 37, 38, 51	378	359.2	1.05	0.95–1.16	0.50
Skin (173)	3	13, 19, 37	16	15.7	1.02	0.58–1.66	0.68
Malignant melanoma (172)	2	30, 34	4	5.9	0.67	0.18–1.70	0.23
Prostate (185)	6	13, 19, 23, 34, 35, 37	104	91	1.14	0.93–1.39	0.67
Testis (186)	1	34	3	1.2	2.50	0.50–7.30	—
Bladder (188)	6	13, 19, 23, 30, 34, 37	41	33.0	1.24	0.68–2.26	0.03
Kidney (189)	6	13, 19, 23, 34, 35, 37	30	30.9	0.97	0.44–2.13	0.01
Brain and nervous system (191–192)	8	13, 19, 23, 27, 30, 34, 35, 37	64	46.1	1.39	0.94–2.06	0.07
Non-Hodgkin's lymphoma (200, 202)	3	13, 19, 34	30	20.6	1.46	0.98–2.08	0.92
Hodgkin's disease (201)	2	19, 34	4	5.1	0.78	0.21–2.01	0.59
Multiple myeloma (203)	4	13, 26, 34, 51	24	14.2	1.69	1.08–2.51	0.15
Leukemia (204–208)	2	13, 19	30	29.9	1.00	0.68–1.43	0.27
Proportional mortality ratio (PMR)							
All cancers (140–209)	6	16, 24, 39, 48, 49, 50	2443	2215.7	1.10	1.06–1.15	0.64
Buccal cavity and pharynx (140–149)	—		—	—	—	—	—
Esophagus (150)	—		—	—	—	—	—
Stomach (151)	—		—	—	—	—	—
Colon (153)	4	28, 48, 49, 50	99	79.2	1.25	0.90–1.74	0.08
Rectum (154)	1	16	37	25	1.48	1.05–2.05	—
Liver/gallbladder (155–156)	—		—	—	—	—	—
Pancreas (157)	—		—	—	—	—	—
Larynx (161)	—		—	—	—	—	—
Lung (162)	4	16, 48, 49, 50	773	742.1	1.04	0.88–1.23	0.04
Skin (172–173)	2	16, 24	42	24.8	1.69	1.22–2.29	0.41
Malignant melanoma (172)	2	48, 49	9	4	2.25	1.03–4.27	0.49
Prostate (185)	—		—	—	—	—	—

(*Continued*)

TABLE 2
Continued

Disease	Number of Studies	Reference	Observed	Expected	Metarelative Risk	95% Confidence Interval	*P* Value Inconsistency
Testis (186)	—		—	—	—	—	—
Bladder (188)	1	16	37	37.4	0.99	0.70–1.37	—
Kidney (189)	1	16	53	36.8	1.44	1.08–1.89	—
Brain and nervous system (191–192)	4	16, 48, 49, 50	64	54.9	1.17	0.90–1.49	0.27
Non-Hodgkin's lymphoma (200, 202)	1	16	66	50	1.32	1.02–1.67	—
Hodgkin's disease (201)	—		—	—	—	—	—
Multiple myeloma (203)	4	16, 48, 49, 50	46	32.5	1.42	1.04–1.89	0.88
Leukemia (204–208)	2	16, 24	65	53.5	1.21	0.94–1.55	0.47
Relative risk (RR)							
All causes (001–999)	—	—	—	—	—	—	—
All cancers (140–209)	2	20, 21	291	295.6	0.98	0.87–1.10	0.17
Buccal cavity and Pharynx (140–149)	1	20	11	7.7	1.43	0.71–2.57	—
Esophagus (150)	1	20	12	5.9	2.03	1.05–3.57	—
Stomach (151)	2	20, 21	25	20.6	1.21	0.80–1.81	0.55
Colon (153)	2	20, 21	25	27.5	0.91	0.60–1.36	0.92
Rectum (154)	1	20	13	9	1.44	0.77–2.49	—
Liver (155–156)	—	—	—	—	—	—	—
Pancreas (157)	1	20	17	13.6	1.25	0.73–2.00	—
Larynx (161)	1	20	3	3.8	0.79	0.17–2.35	—
Lung (162)	1	20	60	71.4	0.84	0.64–1.08	—
Skin (172–173)	1	20	7	4.1	1.71	0.68–3.49	—
Malignant melanoma (172)	—	—	—	—	—	—	—
Prostate (185)	2	20, 21	19	24.3	0.78	0.13–4.82	<0.00
Testis (186)	—	—	—	—	—	—	—
Bladder (188)	—	—	—	—	—	—	—
Kidney (189)	1	20	4	5.9	0.68	0.19–1.74	—
Brain and nervous system (191–192)	2	20, 21	9	7.1	1.26	0.55–2.34	0.14
Non-Hodgkin's lymphoma (200, 202)	—	—	—	—	—	—	—
Hodgkin's disease (201)	—	—	—	—	—	—	—
Multiple myeloma (203)	—	—	—	—	—	—	—
Leukemia (204–208)	1	20	6	9.8	0.61	0.22–1.33	—
Incidence studies (SIR)							
All cancers (140–209)	3	30, 35, 36	367	366.6	1.00	0.90–1.11	0.61
Buccal cavity and pharynx (140–149)	2	18, 36	25	19.6	1.28	0.83–1.88	0.73
Esophagus (150)	2	18, 30	10	7.6	1.32	0.63–2.42	0.51
Stomach (151)	3	18, 30, 35	38	24.1	1.58	1.12–2.16	0.33
Colon (153)	4	18, 30, 35, 36†	59	65.3	0.9	0.69–1.17	0.37
Rectum (154)	3	18, 30, 35	41	36.1	1.14	0.81–1.54	0.4
Liver (155–156)	1	35	4	4.7	0.85	0.23–2.18	—
Pancreas (157)	4	18, 30, 35, 36	22	18.2	1.21	0.76–1.83	0.83
Larynx (161)	2	18, 31	13	8.3	1.57	0.17–14.51	<0.00
Lung (162)	4	18, 30, 35, 36	111	120.0	0.93	0.76–1.11	0.83
Skin (172–173)	1	35	5	3.3	1.52	0.49–3.54	—
Malignant melanoma (172)	4	18, 30, 35, 36	60	47.9	1.25	0.96–1.61	0.87
Prostate (185)	4	18, 30, 35, 36	147	114.1	1.29	1.09–1.51	0.56

(Continued)

TABLE 2
Continued

Disease	Number of Studies	Reference	Observed	Expected	Metarelative Risk	95% Confidence Interval	*P* Value Inconsistency
Testis (186)	2	30, 36	21	11.5	1.83	1.13–2.79	0.15
Bladder (188)	2	18, 30	31	29.9	1.04	0.70–1.47	0.67
Kidney (189)	3	18, 30, 35	11	18	0.61	0.30–1.09	0.69
Brain and nervous system (191–192)	3	18, 30, 35	19	15.4	1.23	0.74–1.93	0.84
Non-Hodgkin's lymphoma (200–202)	1	36	4	2.2	1.82	0.49–4.65	—
Hodgkin's disease (201)	—		—	—	—	—	—
Multiple myeloma (203)	—		—	—	—	—	—
Leukemia (204–208)	4	18, 25, 30, 36	18	12.9	1.4	0.82–2.21	0.36

Note. Codes of the International Classification of Causes of Death (9th Revision) in parentheses; published data for references 48–50 in Howe and Birch.[4]

*Meta analysis completed only for two or more studies.

†Reference 36 is a combination of colon and rectum cancers.

TABLE 3
Mortality and Incidence Studies for Case–Control/Mortality Odds Ratio Studies

	Outcome	References	Odds Ratio	95% Confidence Interval
All cancers (140–209)	Mortality	14	1.10	1.10–1.20
Buccal cavity and pharynx (140–149)	Mortality	14	5.90	1.90–18.30
Esophagus (150)	Mortality	14	0.90	0.70–1.30
Stomach (151)	Mortality	14	1.20	0.90–1.60
Colon (153)	Mortality	14	1.00	0.90–1.20
	Incidence	22*	1.04	0.59–1.82
Rectum (154)	Mortality	14	1.10	0.80–1.60
	Incidence	22*	0.97	0.50–1.88
Liver/gallbladder (155–156)	Mortality	14	1.20	0.90–1.70
Pancrease (157)	Mortality	14	1.20	1.00–1.50
	Incidence	22*	3.19	0.72–14.15
Larynx (161)	Mortality	14	0.80	0.40–1.30
Lung (162)	Mortality	14	1.10	1.00–1.20
	Incidence	22*	1.30	0.84–2.03
Skin (172–173)	Mortality	14	1.00	0.50–1.90
Malignant melanoma (172)	Mortality	14	1.40	1.00–1.90
	Incidence	22*	1.38	0.60–3.19
Prostate (185)	Mortality	14	1.20	1.00–1.30
Testis (186)	Incidence	29	4.00	0.70–27.40
Bladder (188)	Mortality	14	1.20	0.90–1.60
	Incidence	22*	2.11	1.07–4.14
Kidney (189)	Mortality	14	1.30	1.00–1.70
	Incidence	33	4.89	2.47–8.93
Brain and nervous system (191–192)	Mortality	14	1.00	0.80–1.40
	Incidence	22*	1.52	0.39–5.92
Non-Hodgkin's lymphoma (200, 202)	Mortality	14,15†	1.41	1.10–1.70
	Incidence	22*	3.27	1.19–8.98
Hodgkin's disease (201)	Mortality	14	2.40	1.40–4.10
Multiple myeloma (203)	Mortality	14	1.10	0.80–1.60
	Incidence	17	1.90	0.50–9.40
Leukemia (204–208)	Mortality	14	1.10	0.80–1.40
	Incidence	22*	2.67	0.62–11.54

*Two control groups available; police rather than state employees selected as most comparable. Significance difference only for malignant melanoma when using state employees odds ratio and 95% confidence interval was 2.92 (1.70–5.03).

†Mortality odds ratio (mOR) calculated only for non-Hodgkin lymphoma as only case–control study with at least two studies. mOR estimated based primarily on larger sample in Ma et al.[14]

TABLE 4
Likelihood of Cancer Risk Among Firefighters After Employing Pattern of Metarelative Risk Association, Study Type, and Inconsistency Among Studies

	Criteria 1							Criteria 2		Criteria 3	
	Pattern of Metarelative Risk Association										
Cancer Site	mSMR	mPMR	mSMR and PMR	mRR	mSIR	mOR	Likelihood of Cancer Risk	Study Type	Likelihood of Cancer Risk	Inconsistency	Likelihood of Cancer Risk
Buccal	+	NA	NC	NC	+	–	Possible	No change	Possible	No change	Possible
Stomach	–	NA	NC	+	++	–	Probable	Down one	Possible	No change	Possible
Colon	++	+	++	–	–	–	Probable	No change	Probable	Down one	Possible
Rectum	+	NC	++	NC	+	–	Probable	Down one	Possible	No change	Possible
Skin	–	++	++	NC	NC	–	Probable	Down one	Possible	No change	Possible
Malignant melanoma	–	++	–	NA	+	–	Probable	Down one	Possible	No change	Possible
Prostate	+	NA	NC	–	++	–	Probable	No change	Probable	No change	Probable
Testis	NC	NA	NC	NA	++	–	Possible	No change	Possible	No change	Possible
Brain	+	+	+	+	+	–	Possible	No change	Possible	No change	Possible
Non–Hodgkin's lymphoma	+	NC	++	NA	NC	++	Probable	No change	Probable	No change	Probable
Multiple myeloma	++	++	++	NA	NA	–	Probable	No change	Probable	No change	Probable
Leukemia	–	+	+	NC	+	–	Possible	No change	Possible	No change	Possible

Pattern of meta-relative risk: "++" meta-relative risk is significant at the 5% level and >1.1; "+" meta-relative risk is not significant at the 5% level but <1.1; "–" meta-relative risk is ≤1.1 and not significant at the 5% level.

NA indicates no available studies; NC, not able to calculate because only one study of that type available.

Study type: down one level, the metarelative risk (++) is based primarily on mPMR studies and/or negative (–) mSMR studies.

Inconsistency among studies: down one level heterogeneity significant among all combined studies at the 10% level.

ethnicity, a positive family history, and may be influenced by diet. Although the positive association with prostate cancer may be due to some of these factors, it is unlikely that these entirely explain the findings; most studies analyzed white men adjusting for age. The summary risk estimate was 1.28 (95% CI = 1.15–1.43). The mSIR was significantly elevated, and all individual studies showed excess SIR values. Parent and Siemiatycki,[61] in a review article, concluded that there was suggestive epidemiologic evidence for prostate cancer associated with exposure to pesticides and herbicides, metallic dusts, metal working fluids, polycyclic aromatic hydrocarbon, and diesel engine emissions. Certainly firefighters are exposed to these latter two agents. Recently, exposure to complex mixture in the semiconductor industry also has been associated with an increase in prostate cancer.[62] Thus, it is possible that some of the mixed exposures experienced by firefighters may be prostate carcinogens. Ross and Schottenfeld[63] have cautioned, however, against associating occupational exposures with prostate cancer.

Although there were only four studies evaluating testicular cancer, we propose upgrading the likelihood of cancer risk from possible to probable. This upgrade is suggested because testicular cancer had the largest summary point estimate (2.02, 95% CI = 1.30–3.13) as well as consistency among the one SMR study, two incidence studies, and one case–control study showing elevated risk estimates between 1.15 and 4.30. Testicular cancer is the most common malignancy between the ages of 20 and 34. Except for cryptorchism, no risk factor has been clearly demonstrated.[64] Because testicular cancer occurs among younger men with high survival, mortality studies are less germane. Bates et al[30] showed an increase in the incident cases of testicular cancer with firefighter exposure duration as follows: 10 years:

TABLE 5
Summary of Likelihood of Cancer Risk and Summary Risk Estimate (95% CI) Across All Types of Studies for All Cancers

Cancer Site	Likelihood of Cancer Risk by Criteria	Summary Risk Estimate (95% CI)	Comments
Multiple myeloma	Probable	1.53 (1.21–1.94)	Consistent with mSMR and PMR (1.50, 95% CI = 1.17–1.89) Based on 10 analyses Heterogeneity—not significant at the 10% level
Non-Hodgkin lymphoma	Probable	1.51 (1.31–1.73)	Only two SMR and another PMR studies Slightly higher than mSMR and PMR (1.36, 95% CI = 1.10–1.67) Based on eight analyses Heterogeneity—not significant at the 10% level
Prostate	Probable	1.28 (1.15–1.43)	Consistent with mSIR (1.29, 95% CI = 1.09–1.51) Based on 13 analyses Heterogeneity—not significant at the 10% level
Testis	Possible	2.02 (1.30–3.13)	Slightly higher than mSIR (1.83, 95% CI = 1.13–2.79) Based on four analyses Heterogeneity—not significant at the 10% level
Skin	Possible	1.39 (1.10–1.73)	Slightly lower than mSMR and PMR (1.44, 95% CI = 1.10–1.87) – derived on basis of PMR studies Based on eight analyses Heterogeneity—not significant at the 10% level
Malignant melanoma	Possible	1.32 (1.10–1.57)	Slightly higher than mSMR and PMR (1.29, 95% CI = 0.68–2.20) Based on 10 analyses Heterogeneity—not significant at the 10% level
Brain	Possible	1.32 (1.12–1.54)	Slightly higher than mSMR and PMR (1.27, 95% CI = 0.98–1.63) Based on 19 analyses Heterogeneity—not significant at the 10% level; there was heterogeneity among SMR studies
Rectum	Possible	1.29 (1.10–1.51)	Slightly lower than mSMR and PMR (1.39, 95% CI = 1.12–1.70) Based on 13 analyses Heterogeneity—not significant at the 10% level
Buccal cavity and pharynx	Possible	1.23 (0.96–1.55)	Slightly higher than mSMR (1.18, 95% CI = 0.81–1.66) Based on nine analyses Heterogeneity—not significant at the 10% level
Stomach	Possible	1.22 (1.04–1.44)	Lower than mSIR (1.58, 95% CI = 1.12–2.16); Based on 13 analyses Heterogeneity—not significant at the 10% level
Colon	Possible	1.21 (1.03–1.41)	Slightly lower than mSMR and PMR (1.31, 95% CI = 1.08–1.59) Based on 25 analyses Heterogeneity—significant at the 10% level; there were heterogeneity among SMR and PMR studies
Leukemia	Possible	1.14 (0.98–1.31)	Similar to mSMR and PMR (1.14, 95% CI = 0.92–1.39) Based on eight analyses Heterogeneity—not significant at the 10% level
Larynx	Unlikely	1.22 (0.87–1.70)	Higher than mSMR (0.58, 95% CI = 0.25–1.15) Based on seven analyses Heterogeneity—not significant at the 10% level
Bladder	Unlikely	1.20 (0.97–1.48)	Similar to mSMR and PMR (1.24, 95% CI = 0.83,1.49) Based on 11 analyses Heterogeneity—significant at the 10% level; there was heterogeneity among SMR studies
Esophagus	Unlikely	1.16 (0.86–1.57)	Higher than mSMR (0.68, 95% CI = 0.39–1.08) Based on eight analyses Heterogeneity—not significant at the 10% level
Pancreas	Unlikely	1.10 (0.91–1.34)	Slightly higher than mSMR (0.98, 95% CI = 0.75–1.26) Based on 13 analyses Heterogeneity—not significant at the 10% level
Kidney	Unlikely	1.07 (0.78–1.46)	Similar to mSMR and PMR (1.23, 95% CI = 0.94–1.59) Based on 12 analyses Heterogeneity—significant at the 10% level; there was heterogeneity among SMR studies

(*Continued*)

TABLE 5
Continued

Cancer Site	Likelihood of Cancer Risk by Criteria	Summary Risk Estimate (95% CI)	Comments
Hodgkin's disease	Unlikely	1.07 (0.59–1.92)	Higher than mSMR (0.78, 95% CI = 0.21–2.01) Based on three analyses Heterogeneity—not significant at the 10% level
Liver	Unlikely	1.04 (0.72–1.49)	Similar to mSMR (1.00, 95% CI = 0.63–1.52) Based on seven analyses Heterogeneity—not significant at the 10% level
Lung	Unlikely	1.03 (0.97–1.08)	Similar to mSMR and PMR (1.05, 95% CI = 0.96–1.14) Based on 19 analyses Heterogeneity—not significant at the 10% level; there was heterogeneity among PMR studies
All cancers	Unlikely	1.05 (1.00–1.09)	Similar to mSMR and PMR (1.06, 95% CI = 1.02–1.10 Based on 25 analyses Heterogeneity—significant at the 10% level; there was heterogeneity among SMR studies

CI indicates confidence interval; SMR, standardized mortality ratio; PMR, proportional mortality ratio; SIR, standardized incidence ratio.

SIR = 1.39, 95% CI = 0.2–5.0; 11 to 20 years: SIR = 4.03, 95% CI = 1.3–9.4. In those exposed greater than 20 years, the risk estimate remained elevated but declined (SIR = 2.65, 95% CI = 0.3–9.6), possibly because testicular cancer generally occurs at a younger age. Bates et al[30] argued that, although the reason for the excess risk of testicular cancer remained obscure, the possibility that this is a chance finding was low because incident studies are likely the most appropriate methodology for a cancer that can be successfully treated.

The 1990 findings of Howe and Burch[4] showing a positive association with brain cancer and malignant melanoma are compatible with our results because both had significant summary risk estimates. Brain cancers were initially scored as probable but then downgraded to possible (Table 5). There was inconsistency among the SMR studies, which resulted in the use of the random-effects model, yielding confidence limits that were not significant (SMR = 1.39, 95% CI = 0.94–2.06) (Table 2). This inconsistency primarily resulted from the Baris et al study,[13] a 61-year follow up of 7789 firefighters demonstrating a marked reduction in brain cancer (SMR = 0.61, 95% CI = 0.31–1.22). As noted in Table 4, however, there were elevated, but not significant, risk estimates across all studies, ie, mSMR, mPMR, mRR, and mSIR. This consistency is all the more remarkable given the diversity of rare cancers included in the category "brain and nervous system." Furthermore, there was a 2003 study by Krishnan et al[65] published after our search that examined adult gliomas in the San Francisco Bay area of men in 35 occupational groups. This study showed that male firefighters (six cases and one control) had the highest risk with an odds ratio of 5.93, although the confidence intervals were wide and not significant. In addition, malignant melanoma was also initially scored as probable but was downgraded to "possible" due to study type. This study downgrade was related to the negative SMR (−) and reliance primarily on a PMR study. Thus, in conclusion, our study supports a probable risk for multiple myeloma, similar to Howe and Burch's[4] findings, and a possible association with malignant melanoma and brain cancer.

Summary

We implemented a qualitative three-criteria assessment in addition to the quantitative meta-analyses. Based on the more traditional quantitative summary risk estimates shown in Table 5, 10 cancers, or half, were significantly associated with firefighting after the three cancers were designated as a probable risk based on the quantitative meta-risk estimates and our three criteria assessment. These cancers included multiple myeloma, non-Hodgkin's lymphoma, and prostate. A recommendation is also made, however, for upgrading testicular cancer to "probable" based on the twofold excess summary risk estimate and the consistency among the studies. Thus, firefighter risk for these four cancers may be related to the direct effect associated with exposures to complex mixtures, the routes of delivery to target organs, and the indirect effects associated with modulation of biochemical or physiologic pathways. In anecdotal conversations with firefighters, they report that their skin, including the groin area, is frequently covered with "black soot." It is noteworthy that testicular cancer had the highest summary risk estimate (2.02) and skin cancer had a summary risk estimate (1.39) higher than prostate (1.28). Certainly, Edelman et al[3] at the World Trade Center, although under extreme conditions, revealed the hazards that firefighters may encounter only because air monitoring was performed.

As noted in Table 1, approximately half of the studies used local, regional, or national general population rates as the comparison group. These general population comparison groups raise concern that the actual risk of cancer may be underestimated due to the healthy worker effect related to the strict physical entry requirements, maintenance of better physical fitness, and good health benefits. The healthy worker bias may be less pronounced, however, for cancer than for conditions such as coronary heart disease. Furthermore, tobacco is unlikely a contributing factor because cancers known to be associated with smoking such as lung, bladder, and larynx were designated as unlikely and corresponding summary risk estimates were not statistically significant.

These findings of an association of firefighting with significant increased risk for specific types of cancer raise red flags and should encourage further development of innovative comfortable protective equipment allowing firefighters to do their jobs without compromising their health. Studies are especially needed that better characterize the type and extent of exposures to firefighters.

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THEORETICAL & EXPERIMENTAL STUDIES

Characterization of Firefighter Exposures During Fire Overhaul

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Previous studies have characterized firefighter exposures during fire suppression. However, minimal information is available regarding firefighter exposures during overhaul, when firefighters look for hidden fire inside attics, ceilings, and walls, often without respiratory protection. A comprehensive air monitoring study was conducted to characterize City of Phoenix firefighter exposures during the overhaul phase of 25 structure fires. Personal samples were collected for aldehydes; benzene; toluene; ethyl benzene; xylene; hydrochloric acid; polynuclear aromatic hydrocarbons (PNA); respirable dust; and hydrogen cyanide (HCN). Gas analyzers were employed to continuously monitor carbon monoxide (CO), HCN, nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). Area samples were collected for asbestos, metals (Cd, Cr, Pb), and total dust. During overhaul the following exceeded published ceiling values: acrolein (American Conference of Governmental Industrial Hygienists [ACGIH®] 0.1 ppm) at 1 fire; CO (National Institute for Occupational Safety and Health [NIOSH] 200 ppm) at 5 fires; formaldehyde (NIOSH 0.1 ppm) at 22 fires; and glutaraldehyde (ACGIH 0.05 ppm) at 5 fires. In addition, the following exceeded published short-term exposure limit values: benzene (NIOSH 1 ppm) at two fires, NO_2 (NIOSH 1 ppm) at two fires, and SO_2 (ACGIH 5 ppm) at five fires. On an additive effects basis, PNA concentrations exceeded the NIOSH recommended exposure limits (0.1 mg/M^3) for coal tar pitch volatiles at two fires. Maximum concentrations of other sampled substances were below their respective permissible exposure limits. Initial 10-min average CO concentrations did not predict concentrations of other products of combustion. The results indicate that firefighters should use respiratory protection during overhaul. In addition, these findings suggest that CO should not be used as an indicator gas for other contaminants found in this atmosphere.

Keywords: characterization of hazards during fire overhaul, fire overhaul, fire overhaul contaminants, recommended respiratory protection

A number of studies have identified toxic chemicals in fire smoke,[1–3] but there are few that classify the fire overhaul environment.[4] Fire overhaul is the firefighting stage in which fire suppression is complete and firefighters are searching the structure for hidden fire or hot embers, which may be found above ceilings, in between walls, or in other obscure areas. The overhaul phase of a fire lasts an average of 30 min.[5] It is during this phase of a fire, when there is little or no smoke in the environment, that a firefighter is most likely to remove his or her respirator facepiece and work in this environment without respiratory protection.[6]

Removal of respiratory protection during fire overhaul could expose firefighters to a variety of toxic gases. A typical structure fire may involve destruction of plastics, foams, fabrics, carpets, asbestos-containing materials, and wood products. Gases, vapors, and airborne particulates are liberated when these materials are compromised by fire, and may remain in the overhaul environment for extended periods of time. In addition, organic vapors as well as halogenated compounds may use airborne respirable size particulates as a vehicle for entry into the firefighters' lungs. The purpose of this study was to characterize exposures that firefighters may encounter during the overhaul phase of fire incidents.

This study was supported by the City of Phoenix Fire Department.

METHODS

Twelve firefighters with hazardous materials experience were trained on the sampling strategy, set-up, and pre- and postcalibration of all sampling equipment. Training was conducted over several days and included several hours of hands-on experience with the sampling equipment, followed by a competency test to allow an opportunity for these individuals to demonstrate their knowledge as well as expose any areas that needed additional attention. These 12 individuals worked rotating 12-hour shifts and were assigned to a single fire station. For this study these firefighters will be referred to as industrial hygiene assistants. Additional firefighters, identified as participating firefighters, wore the sampling media during fire overhaul.

The participating firefighters were positioned at a single fire station, and all sampling equipment was staged on a hazardous materials (HM) response truck. The study team was dispatched to all working structural fires within a reasonable logistical area, requiring two additional fire engines and one ladder as a back-up team to relieve the first firefighting team if necessary. The participating firefighters did not directly perform overhaul activities, but instead shadowed working firefighters or positioned themselves in rooms with active overhaul activities. This configuration allowed monitoring of four firefighters at each fire incident without compromising the integrity of firefighting operations already in place. In addition, this method allowed for the personnel and monitoring equipment to be delivered to a fire scene in a simple, efficient manner.

The sampling strategy involved the collection of both personal and area samples. Personal sampling trains consisted of three personal sampling pumps and one 4-gas meter (Metrosonics, West Henrietta, N.Y.) for each of the four individuals monitored. The sampling pumps were held in a custom-made sleeve that fit over the air tank of the firefighter's self-contained breathing apparatus (SCBA) unit. The configuration of the sampling train included one pump dedicated to the collection of respirable dust, one pump dedicated to the collection of polynuclear aromatic hydrocarbons (PNAs), and one pump equipped with a low-flow adapter with adjustable flow rates for aldehydes and BTEX (benzene, toluene, ethyl benzene, and xylene), and a t-adapter to a hydrochloric acid sampling tube.

The area sampling train consisted of two area sampling pumps for the area of origin and another area adjacent to the fire origin where overhaul activities occurred within the structure. The configuration of the area sampling train included one pump dedicated to the collection of airborne asbestos fibers and the other pump dedicated to the collection of total dust and metals (Cd, Cr, Pb). A t-adapter was used to connect the different types of media utilized for the collection of total dust and airborne metals samples. Preweighed 5.0 μm polyvinyl chloride and 0.8 μm mixed cellulose ester filters were used to collect total dust and metal samples, respectively. Flow rates were set for total dust near 4.0 L/min and ranged between 1.0 and 2.0 L/min for the metals samples.

To ensure the validity and integrity of sample collection for this study, the industrial hygiene assistants were directed to calibrate all of the pumps daily and record the results. The industrial hygiene assistants were provided with a reference document regarding their responsibilities and target flow rates for collection of each sample on the sampling train. The four gas meters were calibrated weekly.

Prior to arrival at a scene, sampling media were preloaded. At the scene, firefighters removed filter plugs, broke sampling tubes, and the industrial hygiene assistant initiated sampling. Set-up time averaged 7 min. After collection, all sample media were placed in their respective prelabeled bags and stored in a refrigerator located on the HM truck. Other documentation requirements of the industrial hygiene assistant included a record of unusual events, a schematic diagram indicating area of fire origin and other area, the location of stationary ventilation fans, and a brief description of the fire and the stage of the fire at the time of their arrival.

During the study, it was noted that the hydrogen cyanide (HCN) direct-read instruments were reporting HCN concentrations at least 10 times higher than anticipated based on information from previous studies.[4,7,8] To resolve the apparent disparity, a sorbent tube was added to at least one of the personal sampling trains to sample for HCN utilizing NIOSH Method 6010.[9] This change in the sampling train occurred prior to Fire 11 and continued through the remainder of the study.

A minimum sampling time of 20 min was required to accommodate the various limits of detection for the analytical methods. All samples were submitted to an American Industrial Hygiene Association-accredited laboratory for analysis. Table I provides a description of the analytical methods and limits of detection for each analyte.[9–12]

In addition to evaluating average concentrations for the four gas readings per fire incident, these data also were evaluated based on the first 10 min of data logging (the first 10 min began 4 min after the data logger was turned on to allow for firefighter travel time to get into the structure from the set-up point). The purpose of this additional data evaluation was to test the data for correlations to see if the direct read instrumentation could predict concentrations of other contaminants in the fire overhaul environment.

A logistic regression (SPSS version 7.5) was performed to test the hypothesis that CO was an indicator or a predictor of other contaminants present in the overhaul environment. Specifically, initial 10 min average concentrations of CO, SO_2, and NO_2 were compared with averages over the entire overhaul period for acetaldehyde, benzene, formaldehyde, and hydrochloric acid.

RESULTS

Twenty-six fires were evaluated from June 13–September 25, 1998. However, all results from 1 fire were eliminated because there were essentially no overhaul activities at this fire scene, leaving 25 fires for complete analysis. Monitoring activities occurred at 14 houses, 6 apartments, and 5 commercial buildings. Not all analytes were collected at all fires due to equipment and sampling difficulties. Sampling results are provided in Tables III–VI.

During overhaul, the following analytes exceeded published ceiling values: acrolein (American Conference of Governmental Industrial Hygienists [ACGIH®] 0.1 ppm) at 1 fire; CO (National Institute for Occupational Safety and Health [NIOSH] 200 ppm) at 5 fires; formaldehyde (NIOSH 0.1 ppm) at 22 fires; and glutaraldehyde (ACGIH 0.05 ppm) at 5 fires. In addition, the following analytes exceeded published short-term exposure limit (STEL) values: benzene (NIOSH 1 ppm) at two fires; NO_2 (NIOSH 1 ppm) at two fires; and SO_2 (ACGIH 5 ppm) at five fires. Table II summarizes published exposure standards and guidelines used for the interpretation of firefighter exposure data. The following analytes were not measured in concentrations above the limit of detection (LOD): ethyl benzene, toluene, and xylene. A limited number of PNA samples resulted in concentrations above the LODs. Laboratory analysis of the PNA samples identified 17 separate chemicals (Table V). Reviewing the data on a chemical-by-chemical basis revealed low concentrations of PNAs. However, reviewing the data on an additive effects basis revealed concentrations that exceeded the NIOSH recommended exposure

TABLE I. Analytical Limits of Detection

Analyte	NIOSH Method	Analytical Detection Limit	Sample Media[B]	Flow Rate	Calculated Sensitivity per Sample[A]
Area Samples					
Asbestos	7400	7 fibers/field	0.8 μm, 25 mm MCE filter	11 L/min	0.03 f/cc
Cadmium (Cd)	7300	0.005 μg	0.8 μm, 37 mm MCE filter	2.0 L/min	0.000125 mg/M³
Chromium (Cr)	7300	0.05 μg	0.8 μm, 37 mm MCE filter	2.0 L/min	0.00125 mg/M³
Lead (Pb)	7300	0.025 μg	0.8 μm, 37 mm MCE filter	2.0 L/min	0.00625 mg/M³
Total dust	0500	0.05 mg	5 μm, 37 mm PVC filter	4.0 L/min	0.00625 mg/M³
Personal Samples					
Acetaldehyde	2532	2 μg	DNPH tube (SKC 226-118)	0.5 L/min	0.2 mg/M³
Acrolein	2532	0.4 μg	DNPH tube (SKC 226-118)	0.5 L/min	0.04 mg/M³
Benzaldehyde	2532	2 μg	DNPH tube (SKC 226-118)	0.5 L/min	0.2 mg/M³
Benzene	1501	2 μg/tube	small charcoal tube (SKC 226-01)	0.2 L/min	0.5 mg/M³
Ethyl benzene	1501	20 μg/tube	small charcoal tube (SKC 226-01)	0.2 L/min	5.0 mg/M³
Formaldehyde	2532	0.4 μg	DNPH tube (SKC 226-118)	0.5 L/min	0.04 mg/M³
Glutaraldehyde	2532	0.2 μg	DNPH tube (SKC 226-118)	0.5 L/min	0.02 mg/M³
Hydrochloric acid	7903	2 μg/tube	ORBO 53 tube	0.5 L/min	0.2 mg/M³
Hydrogen cyanide	6010	2 μg/tube	soda lime tube (SKC 226-28)	0.18 L/min	1 mg/M³
PNAs	5515	2 μg/tube	PTFE filter/ ORBO 43 tube	2.0 L/min	0.05 mg/M³
Respirable dust	0600	0.05 mg	preweighed PVC filter	1.8 L/min	3.0 mg/M³
Toluene	1501	20 μg/tube	small charcoal tube (SKC 226-01)	0.2 L/min	5.0 mg/M³
Xylene	1501	20 μg/tube	small charcoal tube (SKC 226-01)	0.2 L/min	5.0 mg/M³

[A]Based on a 20-min sample.
[B]SKC West, Fullerton, Calif.

limit (REL; 0.1 mg/M³) for coal tar pitch volatiles at two fires and exceeded the OSHA permissible exposure limit (PEL) and ACGIH threshold limit value (TLV®; 0.2 mg/M³) at one fire.

Of the 16 fires in which NIOSH method 6010 was used to sample HCN, only 4 samples resulted in concentrations above the LOD. None of these four samples had concentrations of HCN above 10 μg, hence, the concentrations could not be quantified, but were all well below 1 mg/M³.

Initial 10-min average CO and NO_2 concentrations did not correlate by logistic regression with other products of combustion (POCs). However, by regression analysis 54.9% of the acetaldehyde variation and 48.4% of the formaldehyde variation was explained ($p = 0.000$) by initial SO_2 average concentration readings obtained within the first 10 min of fire overhaul activities. Evaluation of the data on a fire-by-fire basis revealed that even low concentrations of CO (4–5 ppm) did not predict ($p>0.05$) the presence of other contaminants, as concentrations of formaldehyde that exceeded the NIOSH ceiling of 0.1 ppm were determined at the same scene. Further, this analysis revealed that as the formaldehyde concentration approached 1.0 ppm, glutaraldehyde was present in concentrations above the ACGIH ceiling value of 0.05 ppm.

DISCUSSION

This study demonstrated that maximum concentrations of selected contaminants in the overhaul atmosphere exceeded occupational exposure limits and could therefore result in adverse health effects in firefighters without respiratory protection. In a variable number of fires, concentrations of acrolein, CO, formaldehyde, and glutaraldehyde exceeded their respective ceiling values; concentrations of sulfur dioxide exceeded the STEL value; and concentrations of coal tar pitch volatiles (PNAs) exceeded the OSHA PEL, ACGIH TLV, and NIOSH REL. The other POCs sampled occurred at concentrations below published occupational exposure limits. Among fires there was tremendous variation in concentrations of the sampled contaminants. This variation may be explained by the diverse nature of each fire, including contents, number of rooms, commercial building versus residential, etc. However, certain contaminants, such as formaldehyde, were found at elevated concentrations at a majority of fires.

PNAs consist of POCs that are present in smoke. Most of the 17 identified and quantifiable compounds within the PNA family

TABLE II. Exposure Standards and Guidelines for the Interpretation of Firefighter Exposure Data

Chemical	OSHA PEL	ACGIH TLV	NIOSH REL	STEL[A]	IDLH[A]
Acetaldehyde	200 ppm	—	LF[A]	25 ppm (C)[B]	2000 ppm
Acrolein	0.1 ppm	—	0.1 ppm	0.1 ppm (C)[B] 0.3 ppm[C]	2 ppm
Asbestos	0.1 f/cc	0.1 f/cc	LF	—	—
Benzene	1 ppm	0.5 ppm	0.1 ppm	2.5 ppm[B] 1 ppm[C]	3000 ppm
Benzaldehyde	—	—	—	—	—
Carbon monoxide	50 ppm	25 ppm	35 ppm	200 ppm (C)[C]	1200 ppm
Formaldehyde	0.75 ppm	—	0.016 ppm	2 ppm[D] 0.3 ppm (C)[B] 0.1 ppm (C)[C]	20 ppm
Glutaraldehyde	—	—	—	0.05 ppm (C)[B] 0.2 ppm (C)[C]	—
Hydrogen chloride	—	—	—	5 ppm (C)[B–D]	50 ppm
Hydrogen cyanide	10 ppm	—	—	4.7 ppm[C] 4.7 ppm (C)[B]	50 ppm
Isovaleraldehyde	—	—	—	—	—
Nitrogen dioxide	—	3 ppm	—	5 ppm (C)[B,D] 1 ppm[C]	20 ppm
Particulates, respirable	5 mg/M³	3 mg/M³	—	—	—
Particulates, total	15 mg/M³	10 mg/M³	—	—	—
Sulfur dioxide	5 ppm	2 ppm	2 ppm	5 ppm[B,C]	100 ppm

[A]IDLH = immediately dangerous to life or health; LF = lowest feasible concentration; C = ceiling (not to be exceeded).
[B]American Conference of Governmental Industrial Hygienists (ACGIH).
[C]National Institute for Occupational Safety and Health (NIOSH).
[D]Occupational Safety and Health Administration.

are considered to be carcinogens. Because during overhaul activities there is little or no smoke, the presence of PNAs was not expected. Although the OSHA PEL (0.2 mg/M³) was exceeded for coal tar pitch volatiles at one fire, this may be the result of fire suppression activities that were continuing on the roof when the monitoring commenced inside the structure.

Due to suspected interference from extreme temperature and humid environments, invalid results were experienced on the direct-read instrument for HCN. Samples collected using NIOSH Method 6010 were either below the LOD or too low to quantify. As a result of these findings and in consideration of other published studies[4,7,8] that have quantified HCN at extremely low concentrations, the readings obtained from the four-gas meters were eliminated from further analysis.

The chemicals found to exceed occupational exposure limits in this study have the potential to cause adverse health effects in firefighters. Acrolein produces intense irritation to the eye and mucous membranes of the respiratory tract. Acute exposures may result in bronchial inflammation, resulting in bronchitis or pulmonary edema. Carbon monoxide is present in all fire environments as a product of incomplete combustion and decreases the oxygen transport of the blood, which results in an inadequate supply of oxygen to the tissues. Adverse health effects due to formaldehyde may occur after exposure by inhalation, ingestion, or skin contact. Eye irritation can occur at concentrations of 0.01–2.0 ppm, irritation of the nose and throat at 1.0–3.0 ppm, and severe respiratory symptoms at 10–20 ppm.[13] Formaldehyde is classified as a probable carcinogen.[10,12,14] Glutaraldehyde is a potent sensory irritant with the capability to cross-link, or fix proteins. SO_2 is irritating to mucous membranes of the upper respiratory tract. Chronic exposures may result in fatigue, altered sense of smell, and symptoms

TABLE III. Summary of Data on CO, NO_2, and SO_2 Obtained from Direct-Read Four-Gas Meter

Gas	Number of Samples	Average Sample Time (min)	Average Sample Conc.	STD DEV	MAX	Average Calculated 8-hour TWA[A]	MAX TWA
CO	65	42.2	52.6 ppm	66	260[B] ppm	3.95 ppm	26.9 ppm
CO[C]	65	10	89.5 ppm	134	671[B] ppm	—	—
NO_2	65	42.2	0.24 ppm	0.64	3.6 ppm	0.017 ppm	0.31 ppm
NO_2[C]	65	10	0.13 ppm	0.21	0.89 ppm	—	—
SO_2	65	42.2	1.60 ppm	2.06	8.69[D] ppm	0.114 ppm	0.71 ppm
SO_2[C]	65	10	2.95 ppm	4.91	21.7[D] ppm	—	—

[A]TWA = time-weighted average.
[B]Exceeded NIOSH ceiling—200 ppm.
[C]Average of first 10 min of readings.
[D]Exceeded ACGIH/NIOSH STEL—5 ppm.

TABLE IV. Summary Data for Nonparticulate Samples

Analyte	Number of Samples Collected	Number of Samples Above LOD	Average Sample Conc.	STD DEV	MIN	MAX
Acetaldehyde	96	71	0.34[A] ppm	0.41	0.041 ppm	1.75[A] ppm
Acrolein	96	7	0.123[B] ppm	0.133	0.013 ppm	0.3[B] ppm
Benzaldehyde	96	18	0.057 ppm	0.031	0.016 ppm	0.13 ppm
Formaldehyde	96	86	0.25[C] ppm	0.252	0.016 ppm	1.18[C] ppm
Glutaraldehyde	96	24	0.046 ppm	0.04	0.005 ppm	0.15[D] ppm
Isovaleraldehyde	96	18	0.07 ppm	0.038	0.02 ppm	0.16 ppm
Benzene	95	53	0.383 ppm	0.425	0.07 ppm	1.99[E] ppm
Hydrochloric acid	95	34	0.99 mg/M³	1.10	0.1 mg/M³	3.96 mg/M³
Hydrogen cyanide	25	4[F]	—	—	—	—

[A]Exceeded NIOSH lowest feasible concentration.
[B]Exceeded ACGIH ceiling 0.1 ppm.
[C]Exceeded NIOSH ceiling 0.1 ppm; exceeded ACGIH ceiling 0.3 ppm.
[D]Exceeded ACGIH ceiling 0.05 ppm.
[E]Exceeded NIOSH STEL 1 ppm.
[F]Above analytical limit of detection but below quantification limit all samples were less than 1.0 mg/M³.

representing chronic bronchitis (i.e., dyspnea on exertion and cough).

In addition to the contaminants evaluated in this study, fire scenes include a diverse mix of chemicals that are not easily characterized. Published health effects often are not available for many of these chemical contaminants, and in addition there are inadequate health effects data available on the combined effects of multiple low-level exposures. Adverse health effects may occur from exposure to a mixture of products of combustion, even if individual components do not exceed occupational exposure limits.

One of the challenges of this study involved getting to the fire scene in time to conduct environmental air monitoring during overhaul activities. Training the hazardous materials firefighters to function as industrial hygiene assistants played a key role in meeting this challenge. In addition, the ability to station all supplies, equipment, and personnel at one fire station minimized response time to a particular incident. Finally, the ability to simplify a complicated sampling train through color coding all of the instruments and sample media collection bags minimized human errors.

TABLE V. Summary Data for PNA Samples*

Analyte	Number Samples Above LOD	Avg. Sample Conc. (μg/M³)	STD DEV	MIN (μg/M³)	MAX (μg/M³)
Acenaphthene	2	77.7	15.8	66.5	88.8
Acenaphthylene	34	415.0	536	88	2,440
Anthracene	1	22.2	—	—	—
Benz(a) anthracene	3	24.9	4.90	19.3	27.9
Benzo(a)pyrene	5	33.2	13.6	18.7	50
Benzo(b)fluoranthene	4	22.3	10.6	9.5	34
Benzo(ghi)perylene	2	29.0	23.3	12.5	45.4
Benzo(k)fluoranthene	2	23.8	1.67	22.6	25
Chrysene	1	12.9	—	—	—
Dibenz(a,h)anthracene	2	45.5	31.6	23.2	67.9
Fluoranthene	4	120	39.9	79.1	169
Fluorene	0	—	—	—	—
Indeno(1,2,3-cd)pyrene	3	19.5	8.35	14.3	29.1
Naphthalene	28	223.0	101	73	540
Phenanthrene	13	24.3	9.19	10.8	40.5
Pyrene	4	93.1	83.8	13.8	211

*Total = 88 PNA samples collected.

Limitations of this study included inconsistencies in recording observational information regarding details of the fire scene and definitions of when overhaul phase begins and fire suppression ends. Due to logistical challenges, it was not possible to begin monitoring within a uniform number of minutes after fire suppression at each incident. Finally, it was discovered late in the study that the gas-powered ventilation fans may have confounded the CO readings obtained during overhaul monitoring. During the study, firefighters discovered that the ventilation fans used to purge the environment of smoke generate CO in concentrations up to 39 ppm.

Although many studies have discussed the protective value of SCBA during fire suppression activities, few suggest the need for respiratory protection during fire overhaul activities.[4] Based on the findings of this study, it is apparent that firefighters should use respiratory protection during fire overhaul. SCBA units provide optimum respiratory protection with a given protection factor of approximately 10,000, but they are heavy, and for this reason may not be used by firefighters during fire overhaul. Full-face air purifying respirators (APRs) equipped with appropriate cartridges would provide a protection factor of approximately 50, and their use during fire overhaul would reduce the physical burden of carrying the extra weight associated with the SCBA unit. Overhaul activities could therefore occur more quickly and more efficiently. Currently, the City of Phoenix is utilizing Scott Air Products. Scott Air has a t-bar assembly that can be easily interchanged with the regulator of the Scott SCBA unit. Replacement of the regulator with a t-bar assembly modifies the respirator from a full-face, pressure demand SCBA to a negative pressure, full-face APR in seconds.

Currently, NIOSH approved cartridges for APRs do not provide protection for CO. In consideration of the NIOSH ceiling value for CO as well as OSHA PEL (50 ppm), NIOSH REL (35 ppm), and ACGIH TLV (25 ppm), the study findings support the use of SCBA during overhaul activities for CO concentrations in excess of 150 ppm, and the use of APRs equipped with combination cartridges appropriate for particulates, aldehydes, acid gases, and organic vapors for CO concentrations less than 150 ppm. The 150 ppm concentration is based on a 60-min exposure during 8 working hours, which results in an average

TABLE VI. Summary Data for Particulate and Metals (Cd, Cr, Pb) Samples

Analyte	Number of Samples	Number of Samples above LOD	Ave. Sample Conc.	STD DEV	MIN	MAX
Personal Samples						
Respirable dust	93	29	8.01 mg/M³	8.02	0.71 mg/M³	25.7 mg/M³
Total chlorides	93	16	0.232 mg/M³	0.18	0.038 mg/M³	0.68 mg/M³
Total sulfates	93	8	0.232 mg/M³	0.20	0.062 mg/M³	0.53 mg/M³
Area Samples						
Asbestos	46	15	0.073 f/cc	0.063	0	0.2 f/cc
Total dust	46	22	1.82 mg/M³	8.73	0.364 mg/M³	30.79 mg/M³
Cadmium	46	0	—	—		
Chromium	46	0	—	—		
Lead	46	2	0.03 mg/M³	—	0.03 mg/M³	0.033 mg/M³

CO exposure of 18.75 ppm (150 ppm × 60 min/480 min), which is 25% below the most stringent published concentration (ACGIH TLV 25 ppm). However, additional health-based studies on the use of APRs during overhaul should be used to confirm their effectiveness.

CONCLUSION

Concentrations of air contaminants during fire overhaul exceed occupational exposure limits. Without the use of respiratory protection, firefighters are overexposed to irritants, chemical asphyxiants and carcinogens. Therefore, respiratory protection is recommended during fire overhaul. SCBA should be used in atmospheres with CO concentrations above 150 ppm, and APRs may be used when CO concentrations are below 150 ppm. Finally, CO concentrations should not be used to predict the presence of other contaminants found in the overhaul environment.

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A Study on Chemicals found in the Overhaul Phase of Structure Fires using Advanced Portable Air Monitoring available for Chemical Speciation

Regional Hazardous Materials Team HM09-Tualatin Valley Fire & Rescue
Office of State Fire Marshal
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ABSTRACT

During the overhaul phase of a structure fire, firefighters commonly doff their self contained breathing apparatus SCBA protection for easier working conditions and traditionally rely upon carbon monoxide (CO) detection as the determinate for this action. A CO level of below 35 ppm has traditionally been the acceptable limit for firefighters to wear this lesser level of respiratory protection. Removal of respiratory protection during fire overhaul activities or in the general area can expose firefighters and fire investigators to an unknown variety of toxic chemicals and particulates. Typical structure fires involve high temperature destruction of many types of plastics, foams, various species of wood, fabrics and other materials.

Gases and particulates liberated from these burning materials often contain toxic, reactive and otherwise unhealthy chemicals that are both inhalation hazards and skin absorptive hazards. This study focused on the direct reading of gases present during overhaul, measurement of these gases over an extended period of time in comparison to CO, and on the compilation of data to support and continue the understanding of post-fire event airborne hazards to firefighters and fire investigators.

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INTRODUCTION

Fire departments across the country use carbon monoxide detection equipment to determine when it is safe to enter and work in a structure without the use of a SCBA. A growing number of studies [1,2,4,5] have concluded that there are many other chemicals and known carcinogens produced in a structure fire that should be monitored after the fire is knocked down, yet the fire service continues to utilize carbon monoxide detectors for establishing SCBA guidelines. The purpose was to demonstrate that the fire service could improve on respiratory protection guidelines and establish procedures to reduce dermal exposure. Emerging technology provides a means to sample several gases in a mixture after a fire is knocked down and presents some of the data necessary to establish best practices for firefighters and fire investigators.

Previous studies[1,2,4] concluded that SCBA should be worn continually during the overhaul phase unless the fire department had the ability to purchase detection equipment to speciate the airborne hazards. This study demonstrates that firefighter protection and best practices should not be limited to carbon monoxide detection and SCBA use. There are several other practices that will limit the exposure to firefighters and fire investigators after the fire has been knocked down and after the crews have returned to their stations.

This report outlines an eight month study and presents the data collected in the overhaul phase of thirty-eight structure fires of varying types. Real time portable gas analyzers were tested and validated against known standards. Particulate measurements were taken throughout the study and carbon monoxide levels were compared to the other toxicants found. Conclusions were drawn and recommendations made based on the data collected as well as toxicologist, industrial hygienist, and medical toxicologist/EMS medical director review.

Although this study followed guidelines for calibration, sampling, and data collection, it was performed in the field with unpredictable conditions and circumstances. This was compounded by the fact that structure fires present a mixture of chemicals with synergistic effects. Concentrations and even chemicals present may depend on what is burning.

"This report will be presented to the Oregon Fire Chiefs Association, Safety Committee. The Safety Committee will use this report to write recommendations for the Fire Service."

METHODS

Thirty two hazmat technicians were trained on the chemical detection equipment, including calibration, time synchronization, troubleshooting, post clean-up and re-calibration, and sampling strategy. Training was conducted with and under the direction of the Hazmat Team Monitoring Specialist. Training recommendations and observations were made by a technical review committee. Members of this committee were made up of the Oregon Occupational Safety and Health Administration (OR-OSHA) and Oregon Department of Environmental Quality (DEQ) lab managers and the State of Oregon Health Authority's (OHA) toxicologist. The training was conducted over six days, providing each crewmember experience in handling and performing all of the equipment checks and functions. A final controlled training burn was completed and evaluated to ensure that all personnel utilized consistent response, set-up, and monitoring techniques throughout the study. Four technicians responded to every structure fire in Tualatin Valley Fire & Rescue's 210 square miles; however, a majority of the fires occurred within an area approximately 1/3 that size.

The participating technicians were located at a central fire station in Tualatin, Oregon which housed Tualatin Valley Fire & Rescue's hazmat team (Oregon State Fire Marshal Team HM09). This team used a fire response apparatus, either a hazmat truck or suppression engine, to travel to each fire in a code three (lights and sirens) response status. The response started immediately when a 911 situation was confirmed to be a working structure fire. The participating technicians were primarily tasked with fire-gas monitoring duties unless the fire was in the immediate area surrounding their station (first-due area). For first due area fires the technicians, who were also responding firefighters, would first perform suppression duties and then quickly transition to fire-gas monitoring. Three of the documented fires were in this first due area. Response times to fires were calculated as the time after knock-down until monitoring for chemicals had commenced. Knock down is generally defined as the point where the majority of fire has been extinguished; however, overhaul operations can reveal areas that continue to smolder. The times were taken from dispatch records and monitoring data log times (Figure 1).

Upon reaching a scene, the hazmat technicians were allowed to monitor any areas where fire personnel were working including nearby rooms, outside the structure, at the fire apparatus, and at rehabilitation areas where firefighters traditionally rest, rehydrate and cool down. The monitoring period established generally lasted a minimum of 5 minutes at each point and increased if specific positive detections were being collected. Additionally, if levels obtained exceeded safe OR-OSHA established levels for crews in the overhaul areas, monitoring continued until safe levels could be reported to the Command Officer present. The sampling team dictated when SCBA use was no longer necessary.

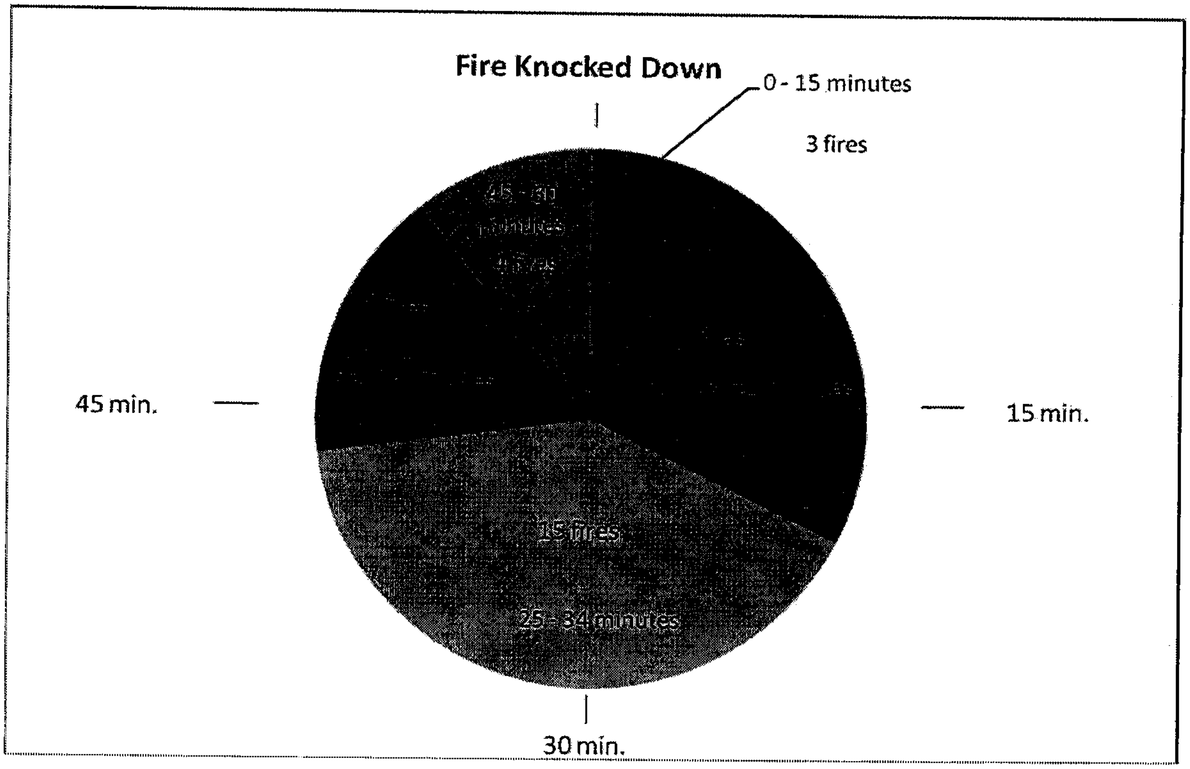

Figure 1 - Elapsed time after knock-down to commencement of monitoring

The sampling procedure relied on a trained four person crew responding to each fire. The crew would turn on all equipment at sufficient distance from the fire scene to obtain a clean background sample prior to entering. One firefighter was charged with taking digital pictures and documenting temperature, humidity and other pertinent information for all locations. A second firefighter utilized the primary instrument and ensured that it was placed at the prescribed locations and in "breathing zones" (4 to 5 feet off the ground). A third firefighter carried a "monitor board" which held a photo-ionization detector (PID) and two electrochemical sensor detectors (e-c detectors). The board also held two colorimetric devices, a pull tube device, and a colorimetric chip system for benzene, formaldehyde, hydrogen chloride, nitrogen dioxide and sulfur dioxide. A fourth firefighter carried a particulate meter set at 10 µmor less. This fourth firefighter also placed badge style mercury (Hg) packets adjacent to the UV spectrometer device for Hg confirmation and carried a portable quadrupole GC-MS device on the last 3 fires.

Minimum sampling time at each event was thirty minutes. Data was extracted from the instruments and sent to the Oregon OSHA lab manager, Hazmat Team Monitoring Specialist, and OHA Toxicologist for review and compilation. When data collected indicated a potential health concern for responders, TVFR's medical director was contacted for opinion and recommendations.