Cohort Mortality Study of Philadelphia Firefighters

Dalsu Baris, MD, PhD,[1]* Thomas J. Garrity,[2] Joel Leon Telles, PhD,[3] Ellen F. Heineman, PhD,[1] Andrew Olshan, PhD,[4] and Shelia Hoar Zahm, ScD[1]

Background *Fire fighters are exposed to a wide variety of toxic chemicals. Previous studies have reported excess risk of some cancers but have been limited by small numbers or little information on employment characteristics.*

Methods *We conducted a retrospective cohort mortality study among 7,789 Philadelphia firefighters employed between 1925 and 1986. For each cause of death, the standardized mortality ratios (SMRs) and 95% confidence intervals were estimated. We also compared mortality among groups of firefighters defined by the estimated number of career runs and potential for diesel exposure.*

Results *In comparison with U.S. white men, the firefighters had similar mortality from all causes of death combined (SMR = 0.96) and all cancers (SMR = 1.10). There were statistically significant deficits of deaths from nervous system diseases (SMR = 0.47), cerebrovascular diseases (SMR = 0.83), respiratory diseases (SMR = 0.67), genitourinary diseases (SMR = 0.54), all accidents (SMR = 0.72), and suicide (SMR = 0.66). Statistically significant excess risks were observed for colon cancer (SMR = 1.51) and ischemic heart disease (SMR = 1.09). The risks of mortality from colon cancer (SMR = 1.68), kidney cancer (SMR = 2.20), non-Hodgkin's lymphoma (SMR = 1.72), multiple myeloma (SMR = 2.31), and benign neoplasms (SMR = 2.54) were increased among firefighters with at least 20 years of service.*

Conclusions *Our study found no significant increase in overall mortality among Philadelphia firefighters. However, we observed increased mortality for cancers of the colon and kidney, non-Hodgkin's lymphoma and multiple myeloma. There was insufficient follow-up since the introduction of diesel equipment to adequately assess risk.* Am. J. Ind. Med. 39:463–476, 2001. *Published 2001 Wiley-Liss, Inc.*†

KEY WORDS: firefighters; mortality; cohort study

INTRODUCTION

Firefighters are exposed under uncontrolled conditions to a wide variety of toxic chemicals including known and suspected carcinogens, such as benzene and formaldehyde in wood smoke, polycylic aromatic hydrocarbons (PAHs) in soots and tars, arsenic in wood preservatives, asbestos in building insulation, diesel engine exhaust, and dioxins [Froines et al., 1987; IARC 1987; Jankovic et al., 1991; McDiarmid et al., 1991; Siemiyatcki, 1991]. The widespread introduction of synthetic building materials in the

[1]Division of Cancer Epidemiology and Genetics, National Cancer Institute, Rockville, Maryland.
[2]Local No. 22 City Firefighters Union, International Association of Fire Fighters (IAFF), Philadelphia, Pennsylvania.
[3]Delaware Valley Healthcare Council of HAP, Philadelphia, Pennsylvania.
[4]University of North Carolina, Department of Epidemiology at Chapel Hill, North Carolina.
*Correspondence to: Dalsu Baris, Occupational Epidemiology Branch, Division of Cancer Epidemiology and Genetics, 6120 Executive Blvd., EPS 8122, Bethesda, Maryland 20892. E-mail: barisd@mail.nih.gov

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late 1950s increased the complexity of the firefighters' exposure. The combustion of the common plastic polyvinyl chloride (PVC), for example, has been estimated to produce dozens of different chemicals including cyanide (Terill et al., 1978).

Previous studies of firefighters have reported excess risks of malignant melanoma, multiple myeloma, leukemia, and cancers of the bladder, kidney, brain, and colon [Golden et al., 1995; Guidotti, 1995; Landrigan et al., 1995]. However, despite the number of studies done over the past two decades, the risk estimates for specific cancer sites have been inconsistent and the extent of occupational cancer risk has not been fully understood. Most of the epidemiologic studies examined relatively small populations and had no information on exposures or surrogates of exposures except duration of employment in a few studies [Aronson et al., 1994; Guidotti, 1993; Heyer et al., 1990]. In addition, the studies had too few recent person-years to detect the effects of building material changes or the introduction of diesel equipment.

In response to health concerns of Philadelphia firefighters, the National Cancer Institute collaborated with the Local No. 22 City Firefighters Union, International Association of Firefighters, and the City of Philadelphia Fire Department (PFD) to conduct a retrospective cohort study to examine the mortality experience of firefighters employed by the City of Philadelphia.

METHODS

Cohort Identification

The PFD maintains a record of each employee's identification information and work history on a 5×7 in Employee Service Record (ESR) card. The cards are stored in the Personnel Office of the PFD and contain the firefighter's name, date of birth, address, badge number, phone number, Social Security Number (recent cards only), date of graduation from the Fire Academy, and dates of all fire company assignments.

Available firefighters' employment records dated back to 1898. After examining the number of firefighters by year hired, we did not feel confident that we had ESR cards for all employees hired in these early years. The cards were probably incomplete, with cards available only for firefighters who stayed with the Department for many years. To avoid a biased sample of "survivors," we restricted the cohort to firefighters employed between 1 January 1925 and 31 December 1986. A small number of women who were determined to be clerical workers in the PFD were excluded from the study. A total of 8,511 cards for all firefighters employed at any time after 1925 by the PFD were identified.

Vital Status Determination

Vital status as of 31 December 1986 was obtained through a variety of sources. The ESR cards of current firefighters and the City of Philadelphia Board of Pensions identified 2,627 firefighters as living at the end of 1986. The Board of Pensions also identified 2,000 deceased firefighters among the cohort members. We determined the vital status of the remaining subjects through the National Death Index, Veterans Affairs Beneficiary Information Record Locator System, credit bureaus, Union archives, the Pennsylvania Department of Transportation's driver's license records, and the personal knowledge of some long-term firefighters. These sources yielded an additional 220 deaths. We obtained death certificates from state bureaus of vital records. The underlying cause of death was abstracted from each death certificate and coded using the International Classification of Diseases, ninth revision (ICD-9). A total of 4,987 (58.6%) firefighters were confirmed as living, 2,220 (26.1%) deceased, and 582 (6.8%) lost to follow-up, with 722 (8.5%) excluded because of missing data, leaving 7,789 firefighters eligible for analysis.

Occupational Histories

The ESR cards provided a sequential occupational history for each firefighter based on company assignments (e.g., Engine Company 22, Ladder Company 16) and positions (e.g., firefighter, battalion chief).

Assignments and positions are crucial information because responsibilities vary by company type. Firefighters assigned to an engine company are responsible for locating, confining, and extinguishing the fire, and at most structure fires this requires aggressive interior tactics. At the initial phase of the fire attack, most firefighters assigned to a ladder company work outside the structure, making forcible entry, placing ladders, removing occupants, and ventilating the building of smoke and heat. In the later phases, the ladder company moves inside to continue the search for occupants and for any evidence of concealed fire, and to open walls, ceilings, and floors.

We abstracted the information for each individual's fire company assignments, including the company type, company number, position, and start and stop dates. The data were computerized to create a job history file with over 54,000 entries of work assignments. Fifty of the older ESR cards were missing names and 1,057 cards were missing information in one or more critical data fields. After extensive research using records from the Philadelphia Fire Academy, Fireman's Hall (Museum), Local 22, City Records Department, and interviewing retired firefighters we identified 49 of the 50 missing names and located over 90% of the missing data.

Runs Matrix

Ideally, we would have liked to characterize each firefighter by the number of fires he attended over his career with additional detail on type of fire and tasks performed, but the PFD does not keep records of fires attended by an individual firefighter. However, each year the PFD publishes an annual report of total emergency responses for each fire company. Each time a fire company (truck) leaves a fire station to respond to a call, this response is called a ‘‘run.’’ A run can be for a residential building fire, an automobile fire, a commercial/industrial fire, non-firefighting activity such as a chemical spill or for a false alarm. Firefighters believe that the number of annual fire company runs provides an indication of firefighting activity, i.e., fire companies that have a substantially higher number of runs are likely to fight more fires than companies with substantially fewer runs. The annual runs data permits public safety administrators to evaluate the relative demands of their fire stations, and permit the firefighters to compare their workloads with firefighters assigned to other fire stations. However, these runs data (1935–1986) do not distinguish between fires and non-fire runs such as medical responses, auto accidents and false alarms.

In 1969, the PFD started to publish another annual summary report and categorize the number of first-in fire company runs. First-in firefighting may be associated with the most frequent and acute type of exposure for firefighters because most structural fires in Philadelphia are extinguished by the first-in engine and ladder companies. However, there were no first-in data prior to 1969 and little first-in data for ladder companies even for the period after 1969. Since the fire company runs and first-in-fires were correlated, we used firefighters' company career runs as estimates of firefighting activity in the analysis. Using the information available at the PFD, Fireman's Hall and Union records, we created a matrix including the company type and number plus estimates of annual average number of runs for each fire company between 1935 and 1986. For the years after 1937 with missing summary reports (1943, 1944, 1949, 1951, 1957, 1958), we interpolated the data from the two nearest years. For the years 1935 and 1936, we factored runs from the closest known year (1937) by the increase or decrease in total city alarms for each of the two missing years (1935 and 1936). For a given company and calendar year, annual runs were divided by the number of shifts (platoons) to obtain the proportion of total runs per firefighter corrected for shift work.

Diesel Exposure

In 1969, the PFD began converting its fleet of fire trucks from gasoline to diesel. Anecdotal reports from firefighters indicate that the first diesel trucks produced exceedingly dirty exhaust. Firefighters reported that these trucks, particularly when started with cold engines, emitted dark clouds of smoke. The curator of Philadelphia Fireman's Hall, Mr. Jack Robrecht, maintained a log of trucks assignments dating back to the start of the career fire department in 1871. Using the log, we created a database of fire truck assignments to fire stations 1871–1986 that included information on the type of engine.

Philadelphia has a variety of station house designs which vary in the ability of diesel engine emissions to reach the firefighters' living quarters. Older stations were typically two or three stories with the apparatus floor, watch desk, and kitchen area on the first floor, and offices, bunkroom, bathroom, and dayroom(s) on the upper floor(s). Stairs and poles connected the upper floors to the apparatus floor. These openings permitted diesel emissions to migrate throughout the station. Firefighters have reported that diesel soot was deposited on the walls, ceiling, beds, and other surfaces throughout the older stations. The newest fire station design separates the apparatus area (garage) from the other areas of the stations. An intermediate station design, constructed during the fifties and early sixties, is one story with the living space on either side of the apparatus floor. In all three types of stations the only mechanical exhaust for gas and diesel engine emissions are wall-mounted exhaust fans. None of the stations have more sophisticated diesel emission control systems.

Every city fire station was classified by design: (1) ‘‘closed’’ with a compartmentalized apparatus area, separate from the rest of the station; (2) intermediate style; and (3) ‘‘open,’’ as described above. These design features and assigned fire apparatus engine type were added to the runs matrix.

Analysis

First, we compared mortality rates by cause of death between firefighters and the general population. Comparisons were made using expected numbers based on the U.S. white male population, since in this study the vast majority of the firefighters were white men (exact proportion is unknown because race information was not included on the ESR cards). Standardized mortality ratios (SMRs) and exact Poisson 95% confidence intervals (CI) were computed with the EPICURE program [Preston et al., 1992]. Observed and expected numbers were calculated by 5-year age and calendar periods. We calculated SMRs for subgroups of cohorts classified by position, duration of employment (<9, 10–19, ≥ 20 years), age at risk (16–39, 40–64, 65, and older), hire period (<1935, 1935–1944, ≥ 1945), and company type (ladder, engine or both). A 10-year lagging of duration of employment was incorporated into the duration analysis to allow for latency effects [Checkoway et al., 1989]. In the lagged analysis, firefighters' current person-years at risk were assigned to the exposure level calculated for 10 years earlier.

Second, we compared mortality between groups of firefighters by number of runs. A firefighter's cumulative lifetime runs and his total runs during the first five years of employment as a firefighter were calculated by multiplying the time (in years) spent at each fire company assignment by the average number of runs for each, adjusted by the number of shifts per day. Because the runs data were available only from 1935 and on, we excluded 1,312 firefighters who were hired prior to 1935 from these analyses, leaving 6,477 firefighters in the "restricted cohort." To evaluate if the full and restricted cohorts differed substantially in mortality experience, we calculated the cause-specific SMRs for the restricted cohort. For the internal comparisons between subgroups of the restricted cohort, categories of runs were defined as low, medium, and high based on the values below median, $\geq$ median and $<$ 75th percentile, or $\geq$ 75th percentile of the corresponding cutpoints among deceased firefighters. For additional analysis, we combined medium and high exposure groups and defined only two exposure groups as follows: (a) low: $<$ median; and (b) high: $\geq$ median. We incorporated a 10-year lagging of exposure into the analysis with runs to allow for latency effects. Rate ratios (RR) and 95% CIs in the high-exposure group relative to the low-exposure group were calculated by Poisson regression using the EPICURE program, adjusted for age (5-year groups) and calendar year (5-year groups). Duration of employment and number of runs were treated as time-dependent variables [Swaen, 1987]. This means that firefighters moved from one exposure category to another over their follow-up period instead of being assigned to a fixed category of exposure. This allowed firefighters to contribute their person-year experience at different ages and calendar years progressively through ordered categories of exposure.

For diesel exposure, we compared mortality between groups of firefighters categorized by the number of runs with potential diesel exposure. Similar to analysis with lifetime runs, we multiplied the time (in years) spent in various companies by the relevant proportion of annual number of diesel exposed runs at that company for that year. For cumulative exposure to diesel, four exposure groups were defined as follows: (a) unexposed; (b) low: $<$ median; (c) medium: $\geq$ median and $<$ 75th percentile; and (d) high: $\geq$ 75th percentile. We repeated these analyses after weighting the exposure by type of station-house design.

We also compared the Philadelphia firefighters to the National Cancer Institute/National Institute for Occupational Safety and Health Computerized Occupational Referent Population System (CORPS) [Thomas et al., 1986], a database of employed persons, in an effort to ameliorate possible healthy worker effect. The results were similar to those based on the U.S. general population, and because of the relatively small size of CORPS as compared to the U.S. general population, these less stable estimates are not presented.

RESULTS

Table I summarizes the descriptive characteristics of the cohort. The mean year of birth was 1925 and the mean year of hire was 1952. The average age at hire and the age at death or end of follow-up was 27 and 54 years, respectively. The mean duration of employment was 18 years and mean duration of follow-up was 26 years. From 1 January 1925 through 31 December 1986, a total of 204,821 person-years at risk were accumulated.

There were 2,220 deaths with known cause identified among the Philadelphia firefighters cohort. In comparison with the U.S. white men, the cohort had similar mortality from all causes of death combined (SMR = 0.96, 95% CI = 0.92–0.99) and all cancers (SMR = 1.10, 95% CI = 1.00–1.20) (Table II). Statistically significant excess risks were observed for colon cancer (SMR = 1.51, 95% CI = 1.18–1.93) and ischemic heart disease (SMR = 1.09, 95% CI = 1.02–1.16). Elevated, although not statistically significant, risks were found for cancers of buccal cavity and pharynx (SMR = 1.36, 95% CI = 0.87–2.14), bladder

TABLE I. Descriptive Characteristics of the Philadelphia Firefighters Cohort (N = 7,789)

	Deceased			Alive at the end of follow-up[a]			Entire cohort[a]		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Year of birth	1906	1874	1956	1932	1867	1967	1925	1867	1967
Year of hire	1936	1918	1977	1959	1918	1985	1952	1918	1985
Age at hire	29	19	55	26	16	63	27	16	63
Duration of employment (years)	21	<1	48	17	<1	43	18	<1	48
Age at death or end of follow-up	63	22	96	50	19	98	54	19	98
Years of follow-up	33	<1	62	24	<1	62	26	<1	62

[a]Includes firefighters who were lost to follow-up (N = 582).

TABLE II. Observed (Obs) Deaths, Standardized Mortality Ratios (SMR), and 95% Confidence Intervals (CI) Among Philadelphia Firefighters by Major Causes of Death (1925–1986) (N = 7,789)

Cause of death (ICD-9)	Obs[a]	SMR	95%CI
All causes (001–999)	2,220	**0.96**	0.92–0.99
All cancers (140–209)	500	**1.10**	1.00–1.20
Buccal cavity and pharynx (140–149)	19	**1.36**	0.87–2.14
Esophagus (150)	6	**0.56**	0.25–1.24
Stomach (151)	24	**0.90**	0.61–1.35
Colon (153)	64	**1.51**	1.18–1.93
Rectum (154)	14	**0.99**	0.59–1.68
Liver (155–156)	8	**0.82**	0.41–1.64
Pancreas (157)	23	**0.96**	0.64–1.44
Larynx (161)	5	**0.75**	0.31–1.81
Lung (162)	162	**1.13**	0.97–1.32
Skin (172–173)	10	**1.18**	0.64–2.20
Prostate (185)	31	**0.96**	0.68–1.37
Bladder (188)	17	**1.25**	0.77–2.00
Kidney (189)	12	**1.07**	0.61–1.88
Brain (191–192)	8	**0.61**	0.31–1.22
Non-Hodgkin's lymphoma (200,202)	20	**1.41**	0.91–2.19
Multiple myeloma (203)	10	**1.68**	0.90–3.11
Leukemia (204–207)	15	**0.83**	0.50–1.37
Benign neoplasms (210–239)	10	**1.65**	0.89–3.07
Allergic, endocrine & nutritional diseases (240–279)	39	**1.02**	0.74–1.40
Nervous system diseases (320–389)	12	**0.47**	0.27–0.83
Circulatory diseases (390–458)	1,141	**1.01**	0.96–1.07
Ischemic heart diseases (410–414)	820	**1.09**	1.02–1.16
Cerebrovascular diseases (430–438)	121	**0.83**	0.69–0.99
Respiratory diseases (460–519)	99	**0.67**	0.55–0.82
Emphysema (492)	18	**0.64**	0.40–1.02
Digestive diseases (520–577)	111	**0.97**	0.81–1.17
Gastric and duodenal ulcer (531–553)	12	**0.67**	0.38–1.17
Cirrhosis of liver (571)	56	**1.10**	0.84–1.43
Genitourinary diseases (580–629)	23	**0.54**	0.36–0.81
External causes of death (E800–E998)	164	**0.69**	0.59–0.80
All accidents (E800–E949)	116	**0.72**	0.59–0.86
Suicide (E950–E959)	37	**0.66**	0.48–0.92

[a]Causes of death included in the table is the observed deaths ≥ 5

cancer (SMR = 1.25, 95% CI = 0.77–2.00), lung cancer (SMR = 1.13, 95% CI = 0.97–1.32), skin cancer (SMR = 1.18, 95% CI = 0.64–2.20), kidney cancer (SMR = 1.07, 95% CI = 0.61–1.88), non-Hodgkin's lymphoma (SMR = 1.41, 95% CI = 0.91–2.19), multiple myeloma (SMR = 1.68, 95% CI = 0.90–3.11), benign neoplasms (SMR = 1.65, 95% CI = 0.89–3.07), and cirrhosis of liver (SMR = 1.10, 95% CI = 0.84–1.43). There were statistically significant deficits of deaths from nervous system diseases (SMR = 0.47, 95% CI = 0.27–0.83), cerebrovascular diseases (SMR = 0.83, 95% CI = 0.69–0.99), respiratory diseases (SMR = 0.67, 95% CI = 0.55–0.82), genitourinary diseases (SMR = 0.54, 95% CI = 0.36–0.81), all accidents (SMR = 0.72, 95% CI = 0.59–0.86), and suicide (SMR = 0.66, 95% CI = 0.48–0.92). The number of observed cases of most other cancers and non-malignant causes of death were similar to or slightly lower than expected. In general, SMRs were higher among firefighters 65 years of age and older (data not shown).

The risks of mortality from kidney cancer, non-Hodgkin's lymphoma, multiple myeloma and benign neoplasms were highest in firefighters with at least 20 years of service as a firefighter (Table III) and the risks tended to increase with duration of employment, except for non-Hodgkin's lymphoma. The SMRs for colon cancer were 1.78 (95% CI = 1.12–2.82) for firefighters with ≤ 9 years service, 1.11 (95% CI = 0.68–1.81) for firefighters with 10–19 years of service, and 1.67 (95% CI = 1.17–2.40) for firefighters with ≥ 20 years of service. Significantly elevated SMRs were also observed among subjects with less than 10 years of employment for cancers of lung (SMR = 1.52, 95% CI = 1.16–2.01), pancreas (SMR = 2.33, 95% CI = 1.36–4.02), and prostate (SMR = 2.36, 95% CI = 1.42–3.91) (Table III). Lagging exposure by 10 years to allow for a latent period did not substantially change these results (data not shown).

SMRs by company type are presented in Table IV. Among firefighters who worked only in engine companies, significantly elevated SMRs were observed for cancer of the buccal cavity and pharynx (SMR = 2.00, (95% CI = 1.11–2.63), colon cancer (SMR = 1.94, 95% CI = 1.38–2.73), multiple myeloma (SMR = 2.54, 95% CI = 1.15–5.67), benign neoplasms (SMR = 2.95, 95% CI = 1.41–6.19), and ischemic heart diseases (SMR = 1.14, 95% CI = 1.03–1.27). Non-significant excess mortality rates for engine companies were detected for laryngeal cancer (SMR = 1.90, 95% CI = 0.74–4.56), lung cancer (SMR = 1.18, 95% CI = 0.93–1.51), skin cancer (SMR = 1.89, 95% CI = 0.84–4.14), kidney cancer (SMR = 1.37, 95% CI = 0.62–3.05), non-Hodgkin's lymphoma (SMR = 1.64, 95% CI = 0.85–3.15), and cirrhosis of liver (SMR = 1.20, 95% CI = 0.79–1.80). Among firefighters who worked only in ladder companies, there was higher than expected mortality for stomach cancer (SMR = 1.85, 95% CI = 0.69–4.92), bladder cancer (SMR = 1.81, 95% CI = 0.45–7.23), non-Hodgkin's lymphoma (SMR = 2.65, 95% CI = 0.86–8.23), and leukemia (SMR = 2.75, 95% CI = 1.03–7.33), circulatory diseases (SMR = 1.27, 95% CI = 1.05–1.52), and ischemic heart diseases (SMR = 1.33, 95% CI = 1.06–1.65); but, except for leukemia, circulatory diseases, and ischemic heart diseases the SMRs did not reach statistical significance.

Analyses by year of hire did not reveal any strong or consistent patterns (Table V). Among subjects hired before 1935, the notable excesses were for the cancer of buccal

TABLE III. Observed (Obs) Deaths, Standardized Mortality Ratios (SMR), and 95% Confidence Intervals (CI) Among Philadelphia Firefighters by Duration of Employment as a Firefighter (1925–1986) (N = 7,789)

	Duration of employment								
	≤ 9 years			10–19 years			≥ 20 years		
Cause of death (ICD-9)	Obs	SMR	95% CI	Obs	SMR	95%CI	Obs	SMR	95% CI
All causes (001–999)	586	**0.88**	0.81–0.95	862	**1.07**	1.00–1.14	772	**0.91**	0.85–0.98
All cancers (140–209)	143	**1.26**	1.07–1.49	170	**1.10**	0.94–1.27	187	**0.99**	0.86–1.15
Buccal cavity and pharynx (140–149)	4	**1.15**	0.43–3.07	9	**1.83**	0.95–3.51	6	**1.09**	0.50–2.43
Esophagus (150)	0	—	—	3	**0.82**	0.26–2.52	3	**0.65**	0.21–2.02
Stomach (151)	4	**0.55**	0.21–1.48	14	**1.39**	0.83–2.35	6	**0.65**	0.29–1.44
Colon (153)	18	**1.78**	1.12–2.82	16	**1.11**	0.68–1.81	30	**1.68**	1.17–2.40
Rectum (154)	3	**0.86**	0.28–2.66	6	**1.16**	0.52–2.58	5	**0.92**	0.38–2.22
Liver (155–156)	1	**0.40**	0.06–2.83	3	**0.84**	0.27–2.60	4	**1.09**	0.41–2.91
Pancreas (157)	13	**2.33**	1.36–4.02	5	**0.60**	0.25–1.45	5	**0.49**	0.21–1.19
Larynx (161)	1	**0.66**	0.09–4.59	1	**0.43**	0.06–3.05	3	**1.08**	0.35–3.36
Lung (162)	50	**1.52**	1.16–2.01	56	**1.20**	0.92–1.56	56	**0.89**	0.68–1.15
Skin (172–173)	2	**0.75**	0.19–3.01	5	**1.70**	0.71–4.09	3	**1.05**	0.34–3.26
Prostate (185)	15	**2.36**	1.42–3.91	5	**0.47**	0.19–1.12	11	**0.72**	0.40–1.31
Bladder (188)	4	**1.36**	0.51–3.61	7	**1.48**	0.70–3.09	6	**1.01**	0.45–2.25
Kidney (189)	2	**0.72**	0.18–2.87	0	—	—	10	**2.20**	1.18–4.08
Brain (191–192)	2	**0.47**	0.12–1.89	2	**0.44**	0.11–1.75	4	**0.94**	0.35–2.49
Non-Hodgkin's lymphoma (200,202)	6	**1.47**	0.66–3.26	5	**1.03**	0.43–2.47	9	**1.72**	0.90–3.31
Multiple myeloma (203)	1	**0.73**	0.10–5.17	3	**1.50**	0.48–4.66	6	**2.31**	1.04–5.16
Leukemia (204–207)	5	**0.94**	0.39–2.25	7	**1.14**	0.54-2.38	3	**0.45**	0.15–1.40
Benign neoplasms (210–239)	2	**1.01**	0.25–4.04	3	**1.42**	0.46–4.39	5	**2.54**	1.06–6.11
Allergic, endocrine & nutritional diseases (240–279)	14	**1.36**	0.81–2.30	10	**0.76**	0.41–1.40	15	**1.02**	0.61–1.69
Nervous system diseases (320–389)	6	**0.59**	0.27–1.32	2	**0.25**	0.06–1.00	4	**0.54**	0.20–1.44
Circulatory diseases (390–458)	245	**0.92**	0.81–1.04	487	**1.20**	1.10–1.31	409	**0.90**	0.82–0.99
Ischemic heart diseases (410–414)	172	**1.02**	0.88–1.18	362	**1.35**	1.21–1.49	286	**0.90**	0.81–1.02
Cerebrovascular diseases (430–438)	27	**0.81**	0.55–1.08	42	**0.79**	0.58–1.07	52	**0.88**	0.67–1.15
Respiratory diseases (460–519)	30	**0.77**	0.54–1.10	34	**0.68**	0.49–0.96	35	**0.59**	0.42–0.82
Emphysema (492)	7	**1.22**	0.58–2.55	6	**0.63**	0.28–1.41	5	**0.39**	0.16–0.93
Digestive diseases (520–577)	31	**0.84**	0.59–1.20	45	**1.08**	0.81–1.45	35	**0.97**	0.69–1.35
Gastric and duodenal ulcer (531–553)	3	**0.51**	0.17–1.59	8	**1.15**	0.58–2.30	1	**0.19**	0.27–1.37
Cirrhosis of liver (571)	12	**0.80**	0.45–1.41	22	**1.16**	0.76–1.76	22	**1.29**	0.85–1.96
Genitourinary diseases (580–629)	4	**0.27**	0.10–0.71	14	**0.88**	0.52–1.49	5	**0.42**	0.18–1.01
External causes of death (E800–E998)	75	**0.61**	0.49–0.77	59	**0.80**	0.62–1.03	30	**0.72**	0.50–1.03
All accidents (E800–E949)	48	**0.56**	0.43–0.75	48	**0.98**	0.74–1.30	20	**0.73**	0.47–1.13
Suicide (E950–E959)	20	**0.78**	0.50–1.20	7	**0.37**	0.18–0.78	10	**0.89**	0.48–1.66

cavity and pharynx (SMR = 2.11, 95% CI = 1.13–3.91) and ischemic heart diseases (SMR = 1.32, 95% CI = 1.19–1.45). Among firefighters hired between 1935 and 1944, significantly increased mortality was noted for colon cancer (SMR = 2.00, 95% CI = 1.38–2.90), kidney cancer (SMR = 2.11, 95% CI = 1.06–4.24), non-Hodgkin's lymphoma (SMR = 2.19, 95% CI = 1.18–4.07), and benign neoplasms (SMR = 2.63, 95% CI = 1.09–6.32). There were 20 observed deaths from colon cancer among firefighters who were hired after 1945 yielding a significantly elevated SMR of 1.60 (95% CI = 1.03–2.49). No other cause of death was significantly elevated in this group.

The overall mortality experience of the restricted cohort, for whom runs data were available, did not

TABLE IV. Observed (Obs) Deaths, Standardized Mortality Ratios (SMR), and 95% Confidence Intervals (CI) Among Philadelphia Firefighters[a] by Company Type (1925–1986) (N = 7,789)

	Engine company only			Ladder company only			Both engine and ladder companies		
Cause of death (ICD-9)	**Obs**	**SMR**	**95% CI**	**Obs**	**SMR**	**95%CI**	**Obs**	**SMR**	**95% CI**
All causes (001–999)	936	**1.00**	0.94–1.07	213	**1.14**	1.00–1.30	1002	**0.88**	0.83–0.94
All cancers (140–209)	220	**1.22**	1.07–1.40	38	**1.05**	0.76–1.44	220	**0.96**	0.84–1.09
Buccal cavity and pharynx (140–149)	11	**2.00**	1.11–3.63	1	**0.91**	0.13–6.44	5	**0.72**	0.30–1.73
Esophagus (150)	3	**0.70**	0.23–2.19	0	—	—	3	**0.56**	0.18–1.72
Stomach (151)	10	**0.91**	0.49–1.68	4	**1.85**	0.69–4.92	8	**0.64**	0.32–1.30
Colon (153)	33	**1.94**	1.38–2.73	2	**0.59**	0.15–2.35	25	**1.19**	0.81–1.77
Rectum (154)	6	**1.04**	0.47–2.31	0	—	—	7	**1.04**	0.50–2.18
Liver (155–156)	3	**0.75**	0.24–2.34	0	—	—	5	**1.07**	0.45–2.58
Pancreas (157)	8	**0.84**	0.42–1.68	3	**1.57**	0.51–4.88	11	**0.92**	0.51–1.66
Larynx (161)	5	**1.90**	0.74–4.56	0	—	—	0	—	—
Lung (162)	65	**1.18**	0.93–1.51	8	**0.71**	0.36–1.43	83	**1.13**	0.91–1.40
Skin (172–173)	6	**1.89**	0.84–4.20	0	—	—	3	**0.68**	0.22–2.11
Prostate (185)	13	**0.96**	0.56–1.65	4	**1.51**	0.57–4.04	10	**0.66**	0.36–1.23
Bladder (188)	3	**0.53**	0.17–1.65	2	**1.81**	0.45–7.23	11	**1.70**	0.94–3.07
Kidney (189)	6	**1.37**	0.62–3.05	0	—	—	6	**1.05**	0.47–2.34
Brain (191–192)	5	**1.02**	0.43–2.46	0	—	—	3	**0.43**	0.14–1.35
Non-Hodgkin's lymphoma (200,202)	9	**1.64**	0.85–3.15	3	**2.65**	0.86–8.23	8	**1.11**	0.55–2.21
Multiple myeloma (203)	6	**2.54**	1.15–5.68	0	—	—	4	**1.33**	0.50–3.56
Leukemia (204–207)	2	**0.28**	0.07–1.12	4	**2.75**	1.03-7.33	9	**0.98**	0.16–2.62
Benign neoplasms (210–239)	7	**2.95**	1.41–6.19	1	**2.05**	0.29–14.62	2	**0.65**	0.16–2.62
Allergic, endocrine & nutritional diseases (240–279)	15	**0.98**	0.59–1.63	4	**1.30**	0.49–3.47	15	**0.79**	0.48–1.32
Nervous system diseases (320–389)	8	**0.79**	0.40–1.56	1	**0.48**	0.06–3.37	3	**0.23**	0.08–0.74
Circulatory diseases (390–458)	477	**1.04**	0.95–1.14	115	**1.27**	1.05–1.52	527	**0.97**	0.89–1.06
Ischemic heart diseases (410–414)	347	**1.14**	1.03–1.27	80	**1.33**	1.06–1.65	381	**1.03**	0.93–1.14
Cerebrovascular diseases (430–438)	50	**0.81**	0.62–1.07	11	**0.92**	0.51–1.68	57	**0.85**	0.65–1.10
Respiratory diseases (460–519)	40	**0.65**	0.48–0.90	9	**0.74**	0.39–1.43	44	**0.61**	0.46–0.83
Emphysema (492)	11	**0.96**	0.53–1.73	2	**0.88**	0.22–3.54	3	**0.22**	0.07–0.68
Digestive diseases (520–577)	44	**0.98**	0.73–1.31	6	**0.65**	0.30–1.45	57	**1.00**	0.08–1.30
Gastric and duodenal ulcer (531–553)	2	**0.28**	0.06–1.08	0	—	—	10	**1.18**	0.64–2.20
Cirrhosis of liver (571)	23	**1.20**	0.79–1.80	4	**1.00**	0.38–2.66	27	**1.01**	0.69–1.47
Genitourinary diseases (580–629)	9	**0.49**	0.26–0.96	2	**0.56**	0.14–2.26	1	**0.57**	0.32–1.03
External causes of death (E800–E998)	72	**0.81**	0.64–1.02	25	**1.30**	0.88–1.92	64	**0.51**	0.40–0.66
All accidents (E800–E949)	54	**0.89**	0.68–1.16	16	**1.22**	0.75–2.00	43	**0.51**	0.38–0.69
Suicide (E950–E959)	14	**0.66**	0.40–1.13	4	**0.88**	0.33-2.35	9	**0.65**	0.41–1.03

[a] Excludes firefighters who were employed elsewhere (e.g., boat) (Obs = 69).

differ substantially from that of the full cohort (data not shown). Among the restricted cohort, there were no strong patterns of increasing mortality with increasing cumulative number of runs in all positions (Table VI) except for pancreas cancer and leukemia. The results were similar when the analyses included cumulative number of runs as only a firefighter, lieutenant or captain (data not shown).

Table VII compares subjects with high cumulative runs and high number of runs during the first 5 years as a firefighter to subjects with low values. Most of the RRs for cumulative lifetime runs were not elevated. Similar results were obtained based on cumulative runs during the first 5 years as a firefighter, except that the RRs for bladder cancer, kidney cancer, and leukemia were greater than 2.00; however, none of these RRs reached statistical significance.

TABLE V. Observed (Obs) Deaths, Standardized Mortality Ratios (SMR), and 95% Confidence Intervals (CI) Among Philadelphia Firefighters by Hire Year (1925–1986) (N = 7,789)

	Hired before 1935			Hired 1935–1944			Hired after 1944		
Cause of death (ICD-9)	**Obs**	**SMR**	**95% CI**	**Obs**	**SMR**	**95%CI**	**Obs**	**SMR**	**95% CI**
All causes (001–999)	939	**0.99**	0.93–1.06	651	**0.96**	0.86–1.06	630	**0.92**	0.84–1.02
All cancers (140–209)	160	**1.04**	0.89–1.22	185	**1.21**	1.05–1.40	155	**1.03**	0.88–1.21
Buccal cavity and pharynx (140–149)	10	**2.11**	1.13–3.91	4	**0.87**	0.33–2.32	5	**1.10**	0.46–2.64
Esophagus (150)	0	—	—	2	**0.55**	0.14–2.20	4	**1.12**	0.42–2.99
Stomach (151)	17	**1.19**	0.74–1.92	4	**0.60**	0.22–1.59	3	**0.54**	0.18–1.67
Colon (153)	16	**1.00**	0.61–1.63	28	**2.00**	1.38–2.90	20	**1.60**	1.03–2.49
Rectum (154)	7	**1.05**	0.50–2.21	3	**0.73**	0.23–2.26	4	**1.20**	0.45–3.20
Liver (155–156)	4	**0.87**	0.33–2.32	1	**0.36**	0.05–2.53	3	**1.27**	0.41–3.93
Pancreas (157)	4	**0.47**	0.18–1.26	12	**1.48**	0.84–2.61	7	**0.94**	0.45–1.97
Larynx (161)	2	**0.86**	0.22–3.45	2	**0.89**	0.22–3.55	1	**0.48**	0.07–3.42
Lung (162)	47	**1.30**	0.97–1.73	61	**1.15**	0.89–1.47	54	**1.02**	0.78–1.33
Skin (172–173)	3	**1.45**	0.46–4.48	1	**0.43**	0.06–3.03	6	**1.49**	0.67–3.32
Prostate (185)	12	**0.75**	0.43–1.33	14	**1.36**	0.81–2.30	5	**0.83**	0.34–1.98
Bladder (188)	11	**1.71**	0.94–3.08	5	**1.17**	0.49–2.81	1	**0.35**	0.05–2.43
Kidney (189)	2	**0.57**	0.14–2.29	8	**2.11**	1.06–4.24	2	**0.50**	0.12–2.01
Brain (191–192)	1	**0.36**	0.05–2.57	3	**0.70**	0.23–2.17	4	**0.66**	0.25–1.77
Non-Hodgkin's lymphoma (200,202)	3	**0.72**	0.23–2.22	10	**2.19**	1.18–4.07	7	**1.29**	0.62–2.70
Multiple myeloma (203)	4	**2.06**	0.77–5.49	3	**1.43**	0.46–4.42	3	**1.56**	0.50–4.84
Leukemia (204–207)	2	**0.32**	0.08–1.28	6	**1.08**	0.49–2.40	7	**1.10**	0.52–2.31
Benign neoplasms (210–239)	1	**0.48**	0.07–3.45	5	**2.63**	1.09–6.32	4	**1.91**	0.72–5.08
Allergic, endocrine & nutritional diseases (240–279)	21	**1.44**	0.94–2.21	8	**0.69**	0.34–1.39	10	**0.82**	0.44–1.53
Nervous system diseases (320–389)	3	**0.28**	0.09–0.89	7	**0.97**	0.46–2.04	2	**0.25**	0.06–1.00
Circulatory diseases (390–458)	562	**1.12**	1.04–1.22	318	**0.93**	0.83–1.04	261	**0.91**	0.81–1.03
Ischemic heart diseases (410–414)	397	**1.32**	1.19–1.45	229	**0.93**	0.77–1.05	194	**0.93**	0.81–1.07
Cerebrovascular diseases (430–438)	64	**0.78**	0.62–1.00	30	**0.79**	0.55–1.13	27	**1.00**	0.69–1.46
Respiratory diseases (460–519)	53	**0.79**	0.61–1.04	24	**0.51**	0.34–0.76	22	**0.63**	0.42–0.96
Emphysema (492)	14	**1.20**	0.71–2.01	2	**0.20**	0.05–0.80	2	**0.32**	0.08–1.26
Digestive diseases (520–577)	34	**0.78**	0.56–1.09	37	**1.13**	0.82–1.55	40	**1.06**	0.77–1.44
Gastric and duodenal ulcer (531–553)	6	**0.60**	0.27–1.35	5	**1.06**	0.44–2.55	1	**0.30**	0.04–2.10
Cirrhosis of liver (571)	6	**0.50**	0.22–1.12	21	**1.30**	0.85–1.99	29	**1.26**	0.88–1.82
Genitourinary diseases (580–629)	12	**0.46**	0.26–0.81	8	**0.85**	0.43–1.70	3	**0.41**	0.13–1.28
External causes of death (E800–E998)	52	**0.77**	0.59–1.01	29	**0.55**	0.38–0.80	83	**0.70**	0.57–0.87
All accidents (E800–E949)	43	**0.89**	0.67–1.20	22	**0.62**	0.40–0.93	51	**0.66**	0.50–0.87
Suicide (E950–E959)	9	**0.58**	0.30–1.12	6	**0.46**	0.21–1.08	22	**0.80**	0.53–1.23

Table VIII shows the RRs for major causes of death among diesel-exposed firefighters by cumulative number of runs relative to non-exposed firefighters. The RRs for all causes of death and for all cancer combined were either below unity or close to unity in all exposure categories. Compared to the non-exposed group, the RR was elevated for prostate cancer in all three exposed groups, and for the cancers of buccal cavity and pharynx, brain, and rectum in the low- and medium-exposed groups. For leukemia and multiple myeloma the RRs were elevated both in the medium- and high-exposed category. However, none of these excesses were statistically significant. The analyses weighted by station design and number of diesel apparatus per station were similar to the unweighted analyses (data not shown).

DISCUSSION

Philadelphia firefighters experienced slightly lower overall mortality compared to the general population, which

TABLE VI. Observed (Obs) Deaths, Standardized Mortality Ratios (SMR), and 95% Confidence Intervals (CI) Among Philadelphia Firefighters by Cumulative Number of Runs[a] in all Positions (1935–1986) (N = 6,477)

	Low (< 3,323 runs)			Medium (≥ 3,323 & < 5,099 runs)			High (≥ 5,099 runs)		
Cause of death (ICD–9)	**Obs**	**SMR**	**95% CI**	**Obs**	**SMR**	**95%CI**	**Obs**	**SMR**	**95% CI**
All causes (001–999)	644	**0.94**	0.88–1.02	327	**0.93**	0.84–1.04	310	**0.90**	0.81–1.00
All cancers (140–209)	155	**1.14**	0.98–1.34	89	**1.09**	0.88–1.34	96	**1.12**	0.92–1.38
Buccal cavity and pharynx (140–149)	7	**1.72**	0.82–3.61	0	—	—	2	**0.77**	0.19–3.09
Esophagus (150)	2	**0.66**	0.17–2.64	1	**0.50**	0.07–3.54	3	**1.40**	0.45–4.33
Stomach (151)	4	**0.66**	0.25–1.75	1	**0.31**	0.05–2.22	2	**0.66**	0.16–2.63
Colon (153)	23	**1.93**	1.29–2.91	16	**2.22**	1.36–3.62	9	**1.22**	0.64–2.35
Rectum (154)	5	**1.37**	0.51–3.29	1	**0.51**	0.07–3.59	1	**0.54**	0.08–3.85
Liver (155–156)	2	**0.80**	0.20–3.21	1	**0.73**	0.10–5.22	1	**0.76**	0.11–5.38
Pancreas (157)	7	**1.02**	0.48–2.13	5	**1.17**	0.49–2.80	7	**1.61**	0.77–5.74
Larynx cancer (161)	1	**0.53**	0.07–3.76	1	**0.83**	0.11–5.87	1	**0.80**	0.11–5.74
Lung (162)	47	**1.06**	0.79–1.41	30	**1.00**	0.70–1.44	38	**1.18**	0.86–1.63
Skin cancer (172–173)	1	**0.36**	0.05–2.50	5	**3.10**	1.29–7.46	1	**0.52**	0.07–3.75
Prostate (185)	10	**1.33**	0.72–2.48	3	**0.65**	0.21–2.03	6	**1.42**	0.64–3.16
Bladder (188)	4	**1.20**	0.44–3.18	1	**0.50**	0.07–3.56	1	**0.54**	0.08–3.81
Kidney (189)	4	**1.18**	0.44–3.15	4	**1.90**	0.71–5.07	2	**0.89**	0.22–3.55
Brain (191–192)	3	**0.60**	0.19–1.85	2	**0.78**	0.20–3.11	2	**0.73**	0.18–2.93
Non-Hodgkin's lymphoma (200,202)	11	**2.36**	1.31–4.26	4	**1.55**	0.58–4.13	2	**0.73**	0.18–2.94
Multiple myeloma (203)	1	**0.57**	0.88–4.06	3	**2.69**	0.87–8.35	2	**1.73**	0.43–6.90
Leukemia (204–207)	5	**0.84**	0.35–2.02	4	**1.35**	0.51–3.59	4	**1.33**	0.50–3.55
Benign neoplasms (210–239)	3	**1.39**	0.44–4.30	4	**4.25**	1.60–11.37	2	**2.22**	0.55–8.67
Allergic, endocrine & nutritional diseases (240–279)	11	**0.98**	0.54–1.77	5	**0.81**	0.34–1.95	2	**0.32**	0.08–1.28
Nervous system diseases (320–389)	7	**0.87**	0.41–1.82	1	**0.28**	0.04–2.00	1	**0.28**	0.04–2.00
Circulatory diseases (390–458)	301	**1.01**	0.90–1.13	150	**0.89**	0.76–1.04	128	**0.80**	0.67–0.95
Ischemic heart diseases (410–414)	221	**1.05**	0.92–1.19	111	**0.89**	0.74–1.08	91	**0.77**	0.62–0.95
Cerebrovascular diseases (430–438)	29	**0.89**	0.62–1.29	18	**1.05**	0.66–1.67	10	**0.65**	0.35–1.22
Respiratory diseases (460–519)	23	**0.58**	0.39–0.87	9	**0.41**	0.21–0.79	14	**0.69**	0.41–1.16
Emphysema (492)	3	**0.39**	0.13–1.20	1	**0.21**	0.03–1.52	0	—	—
Digestive diseases (520–577)	41	**1.18**	0.87–1.60	19	**1.06**	0.68–1.66	17	**0.93**	0.58–1.50
Cirrhosis of liver (571)	27	**1.53**	1.05–2.25	12	**1.16**	0.66–2.05	11	**0.98**	0.54–1.78
Genitourinary diseases (580–629)	6	**0.60**	0.27–1.34	2	**0.55**	0.14–2.20	3	**0.97**	0.31–3.00
External causes of death (E800–E998)	66	**0.63**	0.49–0.80	23	**0.70**	0.46–1.05	23	**0.70**	0.47–1.06
All accidents (E800–E949)	39	**0.54**	0.39–0.73	16	**0.77**	0.47–1.26	18	**0.92**	0.58–1.46
Suicide (E950–E959)	20	**0.88**	0.57–1.36	5	**0.58**	0.24–1.39	3	**0.39**	0.11–1.05

[a]Cutpoints: Low < median; medium ≥ median and < 75th percentile; high ≥ 75th percentile of cumulative runs among deceased subjects.

is consistent with the healthy worker effect typically seen in studies of occupational populations. A stronger healthy worker effect might have been expected, given the rigorous physical requirements for the job. Interestingly, the small healthy worker effect among Philadelphia firefighters was consistent with the weak effect observed in most other studies of firefighters [Guidotti, 1995]. Deficits of cardiovascular disease mortality are usually the main contributor to the healthy worker effect [McMichael, 1976], but Philadelphia firefighters had an SMR of 1.01 for circulatory disease and an SMR of 1.09 for ischemic heart disease. For jobs with stringent physical fitness entry requirements, the lack of deficit of cardiovascular disease mortality in comparison to general population is surprising and may indicate an absolute, albeit not relative, increased risk in ischemic heart diseases.

Our findings of significant deficits of deaths from nervous system diseases, cerebrovascular diseases, respira-

TABLE VII. Observed (Obs) Deaths, Rate Ratios (RR), and 95% Confidence Intervals (CI) Among Philadelphia Firefighters by Cumulative Runs[a] and Runs During First Five Years as a Firefighter (1935–1986) (N = 6,477)

	Cumulative runs					Runs during first 5 years as a firefighter				
	Low (≤ 3,191 runs)		High (> 3,191 runs)			Low (≤ 729 runs)		High (> 729 runs)		
Cause of death (ICD-9)	**Obs[b]**	**RR**	**Obs**	**RR**	**95%CI**	**Obs**	**RR**	**Obs**	**RR**	**95%CI**
All causes (001–999)	644	**1.00**	637	**0.81**	0.72–0.92	649	**1.00**	632	**1.01**	0.90–1.13
All cancers (140–209)	155	**1.00**	185	**0.93**	0.74–1.16	171	**1.00**	169	**1.05**	0.84–1.30
Buccal cavity and pharynx (140–149)	7	**1.00**	2	**0.19**	0.04–0.96	5	**1.00**	4	**0.77**	0.20–2.98
Stomach (151)	4	**1.00**	3	**1.20**	0.23–6.40	4	**1.00**	3	**1.09**	0.24–4.97
Colon (153)	22	**1.00**	26	**0.80**	0.44–1.47	32	**1.00**	16	**0.50**	0.27–0.92
Rectum (154)	5	**1.00**	2	**0.23**	0.04–1.26	5	**1.00**	2	**0.46**	0.09–2.36
Pancreas (157)	7	**1.00**	12	**1.42**	0.52–3.88	9	**1.00**	10	**1.17**	0.47–2.95
Lung (162)	46	**1.00**	69	**1.10**	0.74–1.63	59	**1.00**	56	**1.03**	0.71–1.49
Prostate (185)	10	**1.00**	9	**0.89**	0.34–2.33	11	**1.00**	8	**0.99**	0.39–2.52
Bladder (188)	4	**1.00**	2	**0.47**	0.08–2.69	2	**1.00**	4	**2.59**	0.46–14.59
Kidney (189)	4	**1.00**	6	**0.88**	0.24–3.27	3	**1.00**	7	**2.51**	0.64–9.84
Brain (191–192)	3	**1.00**	4	**0.98**	0.20–4.85	3	**1.00**	4	**1.18**	0.25–5.70
Non-Hodgkin's lymphoma (200,202)	11	**1.00**	6	**0.49**	0.16–1.46	11	**1.00**	6	**0.52**	0.18–1.53
Leukemia (204–207)	6	**1.00**	7	**1.22**	0.35–4.25	4	**1.00**	9	**2.44**	0.70–8.54
Benign neoplasms (210–239)	3	**1.00**	6	**2.06**	0.46–9.35	5	**1.00**	4	**0.68**	0.16–2.73
Allergic, endocrine & nutritional diseases (240–279)	11	**1.00**	7	**0.52**	0.19–1.48	12	**1.00**	6	**0.48**	0.17–1.37
Nervous system diseases (320–389)	7	**1.00**	2	**0.31**	0.06–1.66	5	**1.00**	4	**1.02**	0.26–4.00
Circulatory diseases (390–458)	299	**1.00**	280	**0.78**	0.65–0.93	292	**1.00**	287	**1.08**	0.91–1.27
Ischemic heart diseases (410–414)	220	**1.00**	203	**0.77**	0.63–0.95	204	**1.00**	219	**1.17**	0.96–1.42
Cerebrovascular diseases (430–438)	27	**1.00**	30	**0.51**	0.26–1.94	26	**1.00**	31	**1.31**	0.77–2.23
Respiratory diseases (460–519)	25	**1.00**	21	**0.61**	0.33–2.14	21	**1.00**	25	**1.27**	0.70–2.30
Emphysema (492)	3	**1.00**	1	**0.26**	0.03–2.69	3	**1.00**	1	**0.40**	0.04–3.91
Digestive diseases (520–577)	37	**1.00**	40	**0.94**	0.57–1.53	43	**1.00**	34	**0.77**	0.48–1.24
Cirrhosis of liver (571)	24	**1.00**	26	**0.81**	0.44–1.49	24	**1.00**	26	**1.00**	0.56–1.79
Genitourinary diseases (580–629)	6	**1.00**	5	**0.95**	0.26–3.44	6	**1.00**	5	**1.04**	0.31–3.43
External causes of death (E800–E998)	69	**1.00**	43	**0.61**	0.39–0.95	47	**1.00**	65	**1.04**	0.66–1.61
All accidents (E800–E949)	43	**1.00**	30	**0.91**	0.50–1.63	29	**1.00**	44	**1.50**	0.86–2.62
Suicide (E950–E959)	20	**1.00**	8	**0.28**	0.11–0.67	14	**1.00**	14	**0.51**	0.22–1.19

[a]Cutpoints: Low < median; and high ≥ median of runs among deceased subjects.
[b]Causes of death included in the table if the number of deaths in the reference category ≥ 3.

tory diseases, genitourinary diseases, all accidents, and suicide were consistent with the results from other cohort studies [Beaumont et al., 1991; Demers et al., 1992; Guidotti, 1993; Tornling et al., 1994].

Colon Cancer

The risk of colon cancer was increased approximately 50% overall and 68% in firefighters employed 20 years or more. The increase was not limited to firefighters in engine companies or firefighters hired after 1935.

Firefighters are exposed to carcinogens, such as asbestos and PAHs, which have been linked to colon cancer [International Agency for Research on Cancer, 1987; Tolbert, 1997]. Increased risk of colon cancer has also been found among workers who were exposed to woods, metals, plastics, fiberglass, and a variety of fumes and solvents [Schottenfeld and Winawer, 1996]. Excess colon cancer has been reported in previous studies of firefighters [Guidotti, 1993; Howe and Burch, 1990; Schwartz and Grady 1986]. Vena and Fiedler [1987] showed a significant excess in colon cancer (SMR = 1.83) among 1,867 fire-

TABLE VIII. Observed (Obs) Deaths, Rate Ratios (RR) and 95% Confidence Intervals (CI) for Major Cause of Death Among Philadelphia Firefighters by Number of Lifetime Runs[a] With Diesel Exposure (1935–1986) (N = 6,447)

	Non-exposed		Low exposed (1–259 runs)			Medium (260–1,423 runs)			High (≥ 1,423 runs)		
Causes of death (ICD-9)	**Obs[b]**	**RR**	**Obs**	**RR**	**95%CI**	**Obs**	**RR**	**95% CI**	**Obs**	**RR**	**95% CI**
All causes (001–999)	890	**1.00**	130	**0.88**	0.73–1.06	131	**0.72**	0.60–0.87	130	**0.66**	0.53–0.83
All cancers (140–209)	227	**1.00**	39	**1.04**	0.74–1.46	43	**0.93**	0.67–1.31	31	**0.68**	0.44–1.05
Buccal cavity and pharynx (140–149)	4	**1.00**	2	**2.76**	0.50–15.34	3	**2.59**	0.49–13.76	—	—	—
Stomach (151)	5	**1.00**	2	**2.46**	0.46–13.11	—	—	—	—	—	—
Colon (153)	37	**1.00**	5	**0.78**	0.31–2.00	2	**0.22**	0.05–9.95	4	**0.41**	0.13–1.32
Rectum (154)	4	**1.00**	2	**2.95**	0.54–16.25	1	**1.11**	0.12–10.47	—	—	—
Liver (155–156)	4	**1.00**	—	—	—	—	—	—	—	—	—
Pancreas (157)	13	**1.00**	3	**1.38**	0.39–4.86	1	**0.36**	0.04–2.86	2	**0.80**	0.14–0.54
Larynx (161)	3	**1.00**	—	—	—	—	—	—	—	—	—
Lung (162)	74	**1.00**	12	**0.97**	0.53–1.79	17	**1.17**	0.68–2.02	12	**1.01**	0.51–2.01
Skin (172–173)	5	**1.00**	—	—	—	1	**0.58**	0.06–5.92	1	**0.16**	0.00–2.43
Prostate (185)	9	**1.00**	5	**2.80**	0.82–8.62	3	**2.24**	0.60–8.33	2	**3.19**	0.63–16.12
Bladder (188)	5	**1.00**	1	**1.38**	0.16–11.96	—	—	—	—	—	—
Kidney (189)	8	**1.00**	1	**0.70**	0.09–5.63	—	—	—	1	**0.48**	0.05–4.74
Brain (191–192)	3	**1.00**	1	**1.85**	0.19–17.95	3	**4.62**	0.81–26.17	—	—	—
Non-Hodgkin's lymphoma (200,202)	13	**1.00**	—	—	—	3	**1.09**	0.26–4.52	1	**0.26**	0.02–2.87
Multiple myeloma (203)	3	**1.00**	—	—	—	2	**5.20**	0.74–36.79	1	**2.74**	0.16–45.72
Leukemia (204–207)	7	**1.00**	1	**0.95**	0.12–7.79	3	**2.50**	0.56–11.10	2	**1.66**	0.22–12.65
Benign neoplasms (210–239)	7	**1.00**	—	—	—	1	**0.52**	0.05–4.98	1	**0.46**	0.03–6.48
Allergic, endocrine & nutritional diseases (240–279)	13	**1.00**	3	**1.39**	0.39–4.94	1	**0.37**	0.05–3.00	1	**0.23**	0.02–2.52
Nervous system diseases (320–389)	7	**1.00**	2	**1.94**	0.39–9.50	—	—	—	—	—	—
Circulatory diseases (390–458)	433	**1.00**	55	**0.76**	0.58–1.02	44	**0.54**	0.39–0.76	47	**0.64**	0.45–0.91
Ischemic heart diseases (410–414)	316	**1.00**	39	**0.74**	0.53–1.04	31	**0.52**	0.36–0.76	37	**0.70**	0.47–1.04
Cerebrovascular diseases (430–438)	47	**1.00**	3	**0.39**	0.12–1.24	3	**0.34**	0.10–1.12	4	**0.47**	0.14–1.55
Respiratory diseases (460–519)	27	**1.00**	6	**1.37**	0.56–3.32	7	**1.45**	0.62–3.41	6	**1.49**	0.53–4.21
Digestive diseases (520–577)	55	**1.00**	5	**0.53**	0.21–1.33	11	**0.93**	0.47–1.85	6	**0.42**	0.16–1.14
Gastric and duodenal ulcer (531–553)	4	**1.00**	1	**1.53**	0.17–13.70	1	**1.93**	0.19–20.31	—	—	—
Cirrhosis of liver (571)	37	**1.00**	2	**0.29**	0.07–1.22	8	**0.79**	0.35–1.78	3	**0.20**	0.05–0.78
Genitourinary diseases (580–629)	9	**1.00**	1	**0.74**	0.09–5.86	1	**0.75**	0.09–6.12	—	—	—
External causes of death (E800–E998)	64	**1.00**	10	**0.87**	0.44–1.73	11	**0.48**	0.23–0.99	27	**0.50**	0.26–0.98
All accidents (E800–E949)	42	**1.00**	5	**0.80**	0.31–2.06	7	**0.71**	0.29–1.80	19	**1.00**	0.42–2.41
Suicide (E950–E959)	18	**1.00**	5	**1.03**	0.36–2.91	1	**0.07**	0.00–0.61	4	**0.10**	0.02–0.39

[a]Cutpoints: Low < median; medium; ≥ median and < 75th percentile; high ≥ 75th percentile of cumulative runs with diesel exposure among deceased subjects.
[b]Causes of death included in the table if the number of deaths in the reference category ≥ 3.

fighters in Buffalo, NY based on 16 deaths. No information on diet as a potential confounding factor was collected in the present study or any other firefighter study conducted to date.

Firefighters are likely to be more physically active on the job than the general population. Despite the reports of a consistent inverse relationship found in other studies between physical activity and risk of colon cancer [Colditz et al., 1997; Shephard and Futcher, 1997], we observed an increased risk of colon cancer among Philadelphia firefighters, suggesting factors exist that negate the protection that might be expected from the increased physical activity.

Lung Cancer

Lung cancer has been associated with vinyl chloride, asbestos, soots, PAHs, diesel exhaust and formaldehyde, which are common airborne contaminants in fire smoke (Industrial Disease Standards Panel Report, 1994). Interestingly, most of the firefighter studies have not shown significant increases of lung cancer [Landrigan et al., 1995]. Howe and Burch [1990] obtained a pooled estimate of 1.08 for lung cancer mortality from nine studies. They concluded that there was no evidence of an increased risk of lung cancer associated with firefighting. A few additional studies published after this pooled analysis did not find an excess risk of lung cancer among firefighters [Aronson et al., 1994, Demers et al., 1994]. The Philadelphia cohort also showed no increased risk.

No smoking data have been available in any of the firefighter studies, including ours. Other survey data indicate that the smoking prevalence among firefighters is similar to that among people in ''blue collar'' jobs [Bates, 1987; Sama et al., 1990; Sterling and Weinkam, 1986]. Although SMRs for some of the cigarette smoking related sites, such as cancers of the buccal cavity, bladder and kidney were elevated, the SMR for lung cancer was not elevated, and the SMR for non-malignant respiratory diseases was significantly decreased, suggesting that cigarette smoking is not elevated among firefighters relative to the comparison population.

Prostate Cancer

The majority of the published studies of firefighters showed a 30–50% increase in risk of prostate cancer [Landrigan et al., 1995]. An incidence study found a significantly increased risk of prostate cancer [SIR = 1.4, 95% CI = 1.1–1.7] among Seattle and Tacoma firefighters [Demers et al., 1994] but there was no gradient with duration of employment. In our cohort, we observed a significantly elevated SMR for prostate cancer among firefighters with less than 10 years of employment (SMR = 2.36, 95% CI = 1.42–3.91), but a deficit of risk among longer term employees. Risk did not increase with increasing duration of employment or number of runs.

Bladder Cancer

There is strong evidence for an association between PAHs, a class of carcinogenic organic substances, and cancer of the bladder [IARC, 1987; Boffetta et al., 1997]. PAHs have been detected at fire scenes [Olshan et al., 1990]. The majority of epidemiological studies on firefighters have found increased risk of bladder cancer. Guidotti [1993] and Vena and Fiedler [1987] reported a threefold increase in bladder cancer deaths compared to the general population mortality rate. In our study, we observed a slight non-significant elevation of mortality of bladder cancer compared to U.S. white men (SMR = 1.25). The risk was highest among those with higher number of runs during their first 5 years of employment as a firefighters based on four observed deaths (SMR = 2.59, 95% CI = 0.64–9.84), and those who were hired before 1935 (SMR = 1.71, 95% CI = 0.94–3.08).

Kidney Cancer

There have been reports of excess risk of renal cancer among persons exposed to asbestos, PAHs, solvents, petroleum products, gasoline, lead, and cadmium [McLaughlin et al., 1996]. Epidemiological studies of firefighters have shown elevated risks of kidney cancer. Burnett et al. [1994] and Guidotti [1993] found statistically significant excess mortality with SMRs of 1.44 and 4.14, respectively. In our cohort, we found a twofold excess mortality among those with ≥ 20 years of service as a firefighters (SMR = 2.20, 95% CI = 1.18–4.08). Guidotti [1993] also showed increased mortality with increasing duration of employment.

Non-Hodgkin's Lymphoma

Benzene and 1,3-butadiene, which form as combustion products from the burning of plastics and synthetics, have been associated with non-Hodgkin's lymphoma [Scherr and Mueller, 1996]. The mortality patterns from published studies of firefighters are intriguing with every study indicating excess risk. In our cohort, we observed significantly increased mortality among those with 20 years or more duration of employment (SMR = 1.72) (Table III). Firefighters who were hired after 1935 had a slightly higher risk than those who were hired before 1935 (Table V). The excess risk was not associated with increasing number of lifetime runs, however. In fact, the SMR was highest in those in the low category.

Multiple Myeloma

Numerous studies have reported relationships between multiple myeloma and exposure to asbestos, benzene, pesticides, paints and solvents, engine exhaust, and metals [Herrinton et al., 1996], although none are well established. Heyer et al. [1990] observed an SMR of 2.25 for multiple myeloma among Seattle firefighters with a 10-fold risk among those with 30 years of service (SMR = 9.89). Similarly, we found risk of multiple myeloma increased with duration of employment as a firefighter (20+years: SMR = 2.31, 95% CI = 1.04–5.16) (Table III). In a meta-analysis, Howe and Burch [1990] concluded that there was a consistent evidence of an association between multiple myeloma and firefighting.

Leukemia

IARC has classified benzene as having sufficient evidence of carcinogency in humans, increasing the risk of leukemia. Benzene is usually present in high concentrations in the fire environment. High levels have been measured at building and car fires [Brant-Rauf et al., 1988]. Several studies showed increased risk of leukemia among firefighters [Industral Disease Standards Panel, 1994]. Our study, however, provided no consistent evidence of increased mortality for leukemia among Philadelphia firefighters. The only statistically significant finding was an SMR of 2.75 (95% CI = 1.03–7.33) among firefighters who worked in ladder companies.

Strength and Limitations of the Study

Most of the previous studies of firefighters included relatively small populations and lacked information on the degree of exposure of the firefighters to toxic substances. This study included nearly 8,000 firefighters with detailed job histories. These data, along with the information on number of company runs, allowed us to carry out analysis with more detailed exposure information compared to previous studies. However, the study still lacked detailed individual exposure monitoring data. We used duration of employment, company runs and station house design as a surrogate for individual exposure. There are many reasons why these surrogates do not classify and rank firefighters perfectly by exposure status. Combustion products and other firefighter exposures have changed over time with changes in building materials, and exposures have most likely varied among firefighters at the same fire. For example, first-in firefighting (the activity of firefighters on the first arriving engine and ladder company) requires extinguishing fires and working inside a structure before heat and toxic gases can be ventilated; therefore, first arriving firefighters may have higher exposures to toxic and carcinogenic products of combustion than firefighters who arrive a few minutes later and handle the tasks. Auto fires are especially dangerous sources of polyvinyl chloride, polyurethane and benzene [Landrigan et al., 1995] and accounted for over 50% of all non-structure fires in Philadelphia from 1945–1986. These fires were almost always extinguished completely by the first-in engine company. Firefighters who work in residential areas may be exposed to different products of combustion than firefighters who respond to fires in industrial or commercial areas. The failure to detect the variations between firefighters at the same fire or the variations across fires might have resulted in misclassification of exposure. Therefore, duration of employment or number of runs, although relatively easily available and readily recorded, may not rank firefighters by exposure correctly and may result in misclassification which may dilute the risk estimates. This is a concern, as our study showed several small non-significant associations.

In addition, if there is a survivor effect in which the healthiest workers continued to be employed for a long term, using duration as a proxy for exposure may mask a true relationship over the range of duration of employment [Robins, 1987]. This may be the reason for observing higher mortality rates in shorter duration of employment category for cancer of the pancreas, prostate and lung.

Small numbers of observed deaths in the subcategories of the duration of employment and cumulative runs analyses resulted in imprecise risk estimates with wide confidence intervals, especially among the restricted cohort with runs data. The study also had limited power to examine the effect of diesel exposure because of the small number of exposed firefighters and short latency period. Many outcomes were examined by several characteristics of the cohort; therefore, multiple testing may have led to some significant findings by chance alone.

CONCLUSION

Our study provides no evidence for an association between the occupation of firefighting and increased risk of overall mortality, all cancers combined, or for lung cancer. However, we observed increased mortality for colon cancer, non-Hodgkin's lymphoma, multiple myeloma, and kidney cancer, consistent with several earlier studies of firefighters. We also observed statistically significant excess risk for ischemic heart diseases. There were deficits of deaths from nervous system diseases, respiratory diseases, and genitourinary diseases. Deaths from all accidents were less than expected indicating a possible effect of training, supervision, or accident prevention programs. Although this study had information not found in many studies of firefighters, such as runs data, diesel information, station house design, the study was still limited by the lack of individual exposure data. Future studies of firefighters should strive to improve exposure assessment and incorporate longer latency for diesel exposure. In the meanwhile, firefighters should continue to take precautions to limit and control their exposure to fire contaminants through proper use of personal protection equipment.

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