Original research

Occupational exposures of firefighting and urinary tract cancer risk among men in the Norwegian Fire Departments Cohort

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ABSTRACT

Objectives Increased risks of bladder cancer and mesothelioma were the strongest evidence for the recent reclassification of firefighting as carcinogenic (Group 1) by the International Agency for Research on Cancer. Our study aim was to develop indicators for specific firefighting exposures and examine associations with urinary tract cancer (UTC), including bladder cancer.

Methods We developed indicators for exposure from employment at a fire department or in firefighting jobs, to fire and smoke, and to diesel exhaust for men in the Norwegian Fire Departments Cohort (n=4250). Incident UTC cases were obtained from the Cancer Registry of Norway (1960–2021). Poisson regression was used to estimate incidence rate ratios (IRR) with cumulative exposures grouped into tertiles (reference: lowest exposed tertile) with 0-year, 10-year and 15-year lagging of exposures.

Results During 125 090 person-years of follow-up, there were 76 cases of UTC. IRRs were mostly non-significantly increased in the middle tertile and at or below 1 in the highest tertile for total duration of employment, number of fires attended and fire exposure score with and without lags. In the middle tertile for diesel exhaust exposure, UTC risk was elevated over twofold with 10-year (IRR 2.27, 95% CI 1.22 to 4.20) and 15-year (2.21, 1.18 to 4.16) lags, and near 1 in the highest tertile. Findings for bladder cancer were similar to those for UTC.

Conclusions Dose-response associations between the exposure indicators and UTC were not observed. Future studies using the indicators with more cases are needed.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ In 2022, the International Agency for Research on Cancer classified occupational exposure as a firefighter as carcinogenic to humans (Group 1) and concluded that there was 'sufficient' evidence in humans for mesothelioma and bladder cancer. An earlier study comparing cancer incidence rates among men in the Norwegian Fire Departments Cohort with the general population showed elevated risk of urinary tract cancer (UTC), including bladder cancer, and contributed to this classification. However, little is known about the specific exposures of firefighting that this risk is associated with.

WHAT THIS STUDY ADDS

⇒ In this study, we developed exposure indicators for different aspects of firefighting work using detailed information on work history, fire statistics and working conditions at Norwegian fire departments. The indicators provide a means to examine possible associations between specific exposures of firefighting and disease risk. In the present assessment of UTC risk within the cohort, dose-response associations were not observed.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Precautionary efforts to reduce firefighters' occupational carcinogenic exposures should be maintained, both at the fire scene and the fire station. The exposure indicators developed for the present study will be valuable to future studies with more cases and of other cancer sites, and could contribute to a better understanding of firefighters' cancer risk.

INTRODUCTION

In 2022, the International Agency for Research on Cancer (IARC) updated their evaluation on the carcinogenicity of firefighting and classified exposure as a firefighter as carcinogenic to humans (Group 1).[1] Specifically, the Working Group reported that there was 'sufficient' evidence of causal associations with mesothelioma and bladder cancer. A modest but consistent elevation in bladder cancer risk was observed in their meta-analysis of 10 studies (meta-rate ratio 1.16, 95% CI 1.08 to 1.26).[1 2]

Bladder cancer is the predominant urinary tract malignancy, with the remaining being cancers of the urethra, ureter and renal pelvis. Over 90% of urinary tract cancers (UTCs) are urothelial carcinomas, and the pathogenesis of these cancers is similar.[3–5] Age, sex and tobacco smoking are common important risk factors.[4] In addition, occupational exposures such as to aromatic amines, during aluminium production, in rubber manufacturing, and as a painter have been classified as human bladder carcinogens.[6 7] Exposures suspected of causing bladder cancer include diesel engine exhaust, soot and polycyclic aromatic hydrocarbons (PAHs).[6 7]

Many of these exposures have been identified in firefighters' working environments,[8] but specific measurements of exposures for use in epidemiological studies are widely unavailable. Some studies in the US[9–11] and Australia[12–14] have however used surrogates for exposure in assessments of firefighters' cancer risk, such as number and type of fires attended, or hours spent at fires.

We previously assessed cancer incidence among male firefighters in the Norwegian Fire Departments Cohort compared with the general population in sites with established associations with firefighters' recognised occupational exposures. We observed elevated risk of UTC with longer time since first employment and with earlier periods of first employment.[15] We have now developed indicators for firefighters' occupational exposures using detailed information on work history, working conditions at Norwegian fire departments, and fire-related emergency response statistics, and studied the UTC risk more closely.

METHODS

Study cohort

The Norwegian Fire Departments Cohort was established in 2017–2019, described previously.[15] In short, 15 fire departments in Norway, including many of the largest professional departments comprised of several stations, registered all employees active between 1950 and present with the following information: birth date, national personal identification number, vocational education, department and station(s) at which they worked, and job titles, time periods (month-level) and employment percentage for each position held.

Women in the cohort (n=291) were excluded because of low numbers. Men who died before 1960 (n=30) were excluded based on the follow-up period (1 January 1960–31 December 2021). Because of incomplete registration after 2018, those employed in 2019 (n=11) were excluded. One man diagnosed with UTC prior to start of employment was also excluded. Employees whose only registered employment period was specified as being 0% of full-time work (n=20) or who lacked job title (n=24) were excluded as analyses were based on detailed employment history. Thus, 4250 men were eligible for the study.

Follow-up

The cohort was linked to national registries for the period 1 January 1960–31 December 2021 using Norwegian personal identification numbers.

Date of emigration was obtained from the Norwegian Population Register, date of death from the Cause of Death Registry, and date and diagnosis of cancer from the Cancer Registry of Norway according to the 10th revision of the International Classification of Diseases for the codes C00-C96. UTC cases were defined as malignant neoplasms of the renal pelvis (C65), ureter (C66), bladder (C67), and urethra and other and unspecified urinary organs (C68), and first diagnosis of UTC was included regardless of primary sequence.

Exposure assessment

The development of exposure indicators (table 1) was aided by the project reference group, comprising representatives from firefighters' unions, employers' organisations and interest groups; the Norwegian Directorate for Civil Protection; the Norwegian Labour Inspection Authority; and the Norwegian Cancer Society.

Duration of employment

Among the 4250 men, there were 14 903 work periods.

Missing start month in seven work periods among four individuals was imputed to have begun mid-year. Missing end month in 1773 work periods among 1582 individuals was imputed as the month before a subsequent work period began (n=376), or if it was the final registered work period (n=1397), as the earliest of the month in which they turned 65 years (n=49), the month of emigration (n=2) or death (n=13), or 31 December 2018 (n=1333). Overlapping work periods (n=264) were harmonised by evenly splitting the time or percentage, or by dropping one of the periods, if it appeared in the job title or percentage not to be a main position.

With assistance from the project reference group, 184 job titles in the cohort were divided into 4 categories (online

Table 1 Overview of exposure indicators showing the exposures they are intended to reflect, the period they were available for and the year-specific data they are based on

Indicator	Exposure	Period	Data used
Duration of employment	General exposure of employment at a fire department	1913–2018	All periods of active employment
Duration of fire-exposed employment	General exposure of active firefighting duties	1913–2018	All periods of active employment Firefighting exposure potential for category of job held
Number of fires attended	Fire, smoke, and diesel exhaust exposure at the fire scene	1940–2015	All periods of active employment Firefighting exposure potential for category of job held Annual number of fires (86% structural)
Fire exposure score	Fire and smoke exposure via inhalation, based on number of fires attended and considering respiratory protection	1940–2015	All periods of active employment Firefighting exposure potential for category of job held Type and use of SCBA (negative pressure, manual positive pressure, or automatic positive pressure)
Inhalation score	Fire and smoke exposure via inhalation, based only on respiratory protection	1940–2015	All periods of active employment Firefighting exposure potential for category of job held Type and use of SCBA (negative pressure, manual positive pressure, or automatic positive pressure)
Diesel exhaust exposure score	Diesel exhaust exposure at the fire station	1940–2015	All periods of active employment Number of diesel vehicles Station design (reflecting the possibility for air passage from the vehicle bay) Use of an exhaust removal system

Calculation of the indicators using the data listed are described in the text.
SCBA, self-contained breathing apparatus.

supplemental table 1) with factors representing potential for exposure to live firefighting, as follows: fully fire exposed, factor 1; partly fire exposed, factor 0.5 (where there was an approximately 50% probability of participating in firefighting activities); non-exposed, factor 0; and other exposed, factor 0.5 (where there was no potential for firefighting exposure but there was potential for similar exposures).

Thus, two indicators were constructed: *duration of employment*, with each person's cumulative employment duration summed regardless of job category; and *duration of fire-exposed employment*, with each person's cumulative employment duration summed with each year of active employment multiplied by the category-specific exposure potential factor for the job title held.

Exposure at the fire scene

Indicators measuring exposure at the fire scene were primarily based on fire statistics, which we deemed reflected exposure from both fire and smoke as well as to diesel exhaust from emergency vehicles left running during emergency responses. Statistics on the annual number of fire-related responses attended by fire departments and/or stations in Norway were obtained from the Norwegian Directorate for Civil Protection for the available period 1986–2015. For fire departments in our cohort, 86% of fires were structural. For each department, the average number of fire runs in the earliest 10-year period for which data were available was extrapolated back to 1940 to capture firefighting activities for the high number of employees active from 1940 on.

We divided the annual sum of fire responses attended by each department by the number of teams active at each station each year, corresponding to the annual number of fire runs that a single firefighter could be expected to have attended, to derive the indicator *number of fires attended*.

Alongside registering employees in the cohort, the participating fire departments completed questionnaires on working conditions in 1950–2018, described previously.[16] The questionnaire recorded the types of self-contained breathing apparatuses (SCBA) used during the three phases of structural firefighting: smoke diving (entering smoke-filled areas), knockdown (main extinguishing phase) and overhaul (extinguishing of small remaining fires; online supplemental table 2). The responses for the 1950s were applied to the 1940s, as working conditions during these decades were considered comparable.

Based on the IARC monograph on firefighting[8] and discussions with our project reference group, we aimed to develop simple but representative indicators reflecting exposure potential in smoke diving, knockdown and overhaul, considering both time and intensity. Therefore, where a department responded that they practiced smoke diving, we ascribed 50% of exposure from fires to smoke diving (medium duration, high intensity), and 25% to each of knockdown (medium duration, medium intensity) and overhaul (long duration, low intensity). Where a department did not practice smoke diving, we ascribed 50% of exposure to knockdown (long duration, medium intensity) and 25% to overhaul (long duration, low intensity), with the remaining 25% set to zero for the lack of smoke diving (for a lower total exposure potential).

The influence on exposure according to the type and use of SCBA was determined according to the assigned protection factors during workplace-simulated use[17] and the reported use at Norwegian fire departments as described in the questionnaire and by the project reference group. Thus, for smoke diving, the following factors were applied to modify exposure estimates: 0.01 for positive-pressure SCBA, corresponding to a protection factor of around 100 compared with negative-pressure SCBA; 0.5 for manual positive-pressure SCBA, reported by one department; and 1, for negative-pressure SCBA. During knockdown and overhaul, the factors were: 0.05 if positive pressure was always used; 0.5 if positive-pressure SCBA was sometimes used; and 1 if no SCBA was used.

We applied the protection factors pertaining to SCBA use to the number of fires attended per year to derive the indicator *fire exposure score*, which reflected airway-related fire and smoke exposure considering changes in respiratory protective equipment. However, some instability was observed in the fire statistics. Therefore, we also developed the indicator *inhalation score*, which reflected airway-related fire and smoke exposure based only on the factors reflecting SCBA use.

For the three fire and smoke indicators, each person's exposure accrued was also determined by the category of job title held (ie, annual exposures were multiplied by the category-specific

Table 2 Characteristics of the study sample from the Norwegian Fire Departments Cohort, stratified by total duration of employment attained

		Duration of employment		
	Total	≤25 years	26–32 years	≥33 years
n	4250	2396	933	921
Urinary tract cancer* cases (n (%))	76 (1.8)	24 (1.0)	26 (2.8)	26 (2.8)
Status at end of follow-up (n (%))				
Alive	2896 (68.1)	1954 (81.5)	506 (54.2)	436 (47.3)
Dead	1244 (29.3)	392 (16.4)	396 (42.4)	456 (49.5)
Emigrated	34 (0.8)	26 (1.1)	5 (0.5)	3 (0.3)
Mean birth year (SD)	1953 (24.7)	1965 (21.8)	1940 (19.3)	1935 (19.0)
Mean age at start of follow-up (SD; years)	31.4 (9.9)	30.6 (8.7)	32.3 (9.7)	31.9 (12.2)
Mean age at end of follow-up (SD; years)	60.3 (16.6)	52.0 (15.3)	70.0 (9.9)	74.0 (9.3)
Mean duration of follow-up (SD; years)	29.4 (15.9)	21.4 (13.9)	37.7 (10.5)	42.1 (12.3)
Employment				
Mean year of first employment (SD)	1981 (25.2)	1995 (20.7)	1967 (18.0)	1959 (18.4)
Mean age at first employment (SD; years)	27.9 (6.6)	29.6 (7.7)	27.4 (3.5)	23.6 (2.7)

Follow-up from 1 January 1960 to 31 December 2021.
*International Classification of Diseases 10th revision codes C65–C68.
SD, standard deviation.

factor representing potential for exposure to live firefighting for the job title held).

Diesel exhaust exposure

In the questionnaire, fire departments responded to questions regarding the type (diesel or gasoline) and number of fire service vehicles, use of exhaust removal systems, and station design. Based on the responses and information provided by the project reference group, we developed the indicator *diesel exhaust exposure score*, reflecting diesel exhaust exposure at fire stations. Exposure at the fire scene was considered accounted for in the fire and smoke indicators alongside similar exposures to incomplete combustion products. Thus, we estimated the combined relative intensity of exposure from diesel vehicles in the fire station garage, and office, sleeping and living quarters. For garage exposure, a factor of 0.05 was applied to the number of vehicles if a station reported having an exhaust removal system, and 1 if there was none. For office, sleeping and living quarters, a factor of 1 was applied if there was certain free air passage to the garage; 0.5 for partial passage; and 0 if the station design completely prevented air passage or if there were no sleeping or living quarters.

A second diesel exhaust exposure indicator considering the frequency of all responses (fire runs, non-fire emergencies and false alarms) was also developed, but their inclusion did not change the results of diesel exposure and therefore this indicator was omitted.

Statistical analysis

Poisson regression was performed to estimate incidence rate ratios (IRR; 95% CI) for the association between firefighting exposure and UTC. Follow-up began on the latter of 1 January 1960 or start of first employment, and continued until the first of date of emigration, death, UTC diagnosis, or 31 December 2021.

For each indicator, a person's cumulative exposure per calendar year of follow-up was calculated based on their years and percentages of active employment and was treated as a time-dependent variable in the regression analyses. The exposure variables were categorised into tertiles at the time of diagnosis for an approximately even distribution of cases across categories (reference: lowest tertile). Analyses with unexposed as the reference yielded few cases in the reference group, and limited statistical power. For duration of employment, analyses with more clinically relevant categories (≤14 (reference), 15–24, and ≥25 years) were also conducted. Trend tests across categories were performed by modelling ordinal variables as continuous variables.

As we did not extrapolate indicators beyond 1940, those who began employment before 1940 (n=228, 5.4%) were excluded from analyses based on fire runs and working conditions. Further, workers at one station that did not provide information on diesel vehicles (n=84, 2.0%) were excluded from analyses based on diesel exhaust exposure score.

Models were adjusted for attained age (≤54, 55–69, 70–79, ≥80; model 0); age and period of follow-up (≤1969, ≥1970; model 1); and age and period of first employment (≤1969, 1970–1989, ≥1990; model 2). Multivariable analyses were also conducted with multiple independent exposure indicators in each model (fire exposure and diesel exhaust exposure score, or inhalation and diesel exhaust exposure score).

We also conducted analyses with 10-year and 15-year lagging of exposures to account for the latency period of UTC, and to a limited extent the healthy worker survivor effect (HWSE).[18]

Table 3 Exposure characteristics of the study sample (n=4250) from the Norwegian Fire Departments Cohort using various exposure indicators according to the maximum attained

	Study sample (n (%))
Duration of employment (years)	
Mean (SD)	20.5 (13.1)
≤25	2396 (56.4)
26–32	933 (22.0)
≥33	921 (21.7)
Duration of fire-exposed employment (years)	
Mean (SD)	17.6 (12.0)
≤19	2249 (52.9)
20–29	1133 (26.7)
≥30	868 (20.4)
Number of fires attended	
Median (IQR)	195.4 (44.3–340)
≤156	1726 (42.9)
157–237	696 (17.3)
≥238	1600 (39.8)
Fire exposure score	
Median (IQR)	58.3 (4.3–166)
≤103	2445 (60.8)
104–200	763 (19.0)
≥201	814 (20.2)
Inhalation score	
Median (IQR)	5.3 (0.2–15.5)
≤11	2711 (67.4)
12–23	851 (21.2)
≥24	460 (11.4)
Diesel exhaust exposure score	
Median (IQR)	47.2 (12.3–95.3)
≤34	1690 (42.9)
34–71	767 (19.5)
≥72	1481 (37.6)

Follow-up from 1 January 1960 to 31 December 2021.
IQR, interquartile range; SD, standard deviation.

The following sensitivity analyses were conducted: additional HWSE adjustment using employment status[18,19] per 31 December 2018 (still employed, stopped working/died at age <60 years, or stopped working ≥60 years); restricting analysis to first primary UTCs (the 'first primary cancer approach');[20] restricting cases to bladder cancer (C67) diagnoses; and restricting analysis to a partial inception cohort[21] of those who began working in 1950 or later.

All statistical analyses were conducted using Stata V.17 (Stata Corp).

RESULTS

The 4250 men accrued 125 090 person-years, with a mean age at start of follow-up of 31.4 years (range 15–76, table 2) and mean duration of follow-up of 29.4 years (range 1–62). Mean age at first employment was 27.9 years (range 14–66), median year of first employment was 1981 (IQR 1962–2004) and mean duration of employment 20.5 years (range 0.3–53, table 3).

There were 76 cases of UTC, including 65 first primary cancers, 10 second primaries and 1 third primary. There were 6 cases of malignant neoplasms of the renal pelvis (C65), 4 of the ureter (C66), 64 of the bladder (C67), and 2 of the urethra and other and unspecified urinary organs (C68). Mean age at UTC

Table 4 Incidence rate ratios (IRRs) and 95% CIs for duration of employment and urinary tract cancer (ICD-10 C65–68) risk among men in the Norwegian Fire Departments Cohort

Exposure	Cases	IRR (95% CI) Model 0*	Model 1†	Model 2‡
Duration of employment (years; n=4250)				
No lag				
≤25	24	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
26–32	26	1.12 (0.63 to 2.00)	1.12 (0.63 to 2.00)	1.12 (0.62–2.01)
≥33	26	0.92 (0.51 to 1.66)	0.93 (0.52 to 1.67)	0.89 (0.49–1.62)
p-trend§		0.76	0.77	0.66
Lag 10 years				
≤20	22	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
21–30	27	1.16 (0.63 to 2.12)	1.16 (0.63 to 2.11)	1.16 (0.63–2.14)
≥31	27	1.02 (0.53 to 1.93)	1.02 (0.53 to 1.93)	0.98 (0.51–1.88)
p-trend§		0.99	0.98	0.91
Lag 15 years				
≤20	28	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
21–29	26	1.42 (0.80 to 2.51)	1.41 (0.80 to 2.50)	1.40 (0.79–2.49)
≥30	22	0.90 (0.46 to 1.77)	0.90 (0.46 to 1.77)	0.86 (0.43–1.70)
p-trend§		0.85	0.85	0.74
Duration of fire-exposed employment (years; n=4250)				
No lag				
≤19	24	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
20–29	27	0.84 (0.47 to 1.47)	0.83 (0.47 to 1.47)	0.81 (0.46–1.45)
≥30	25	0.92 (0.51 to 1.66)	0.93 (0.52 to 1.67)	0.88 (0.48–1.61)
p-trend§		0.82	0.83	0.71
Lag 10 years				
≤17	25	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
18–28	25	0.75 (0.42 to 1.34)	0.75 (0.42 to 1.34)	0.74 (0.41–1.33)
≥29	26	1.09 (0.59 to 2.01)	1.10 (0.60 to 2.02)	1.05 (0.56–1.95)
p-trend§		0.77	0.76	0.85
Lag 15 years				
≤15	24	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
16–26	27	1.00 (0.56 to 1.80)	1.00 (0.56 to 1.79)	0.99 (0.55–1.80)
≥27	25	1.02 (0.53 to 1.96)	1.02 (0.53 to 1.96)	0.98 (0.50–1.91)
p-trend§		0.96	0.96	0.95

Follow-up from 1 January 1960 to 31 December 2021.
*Age adjusted (≤54, 55–69, 70–79, ≥80).
†Adjusted for age (as above) and period of follow-up (≤1969, ≥1970).
‡Adjusted for age (as above) and period of first employment (≤1969, 1970–1989, ≥1990).
§Modelled as a continuous variable to test for linear trend.
ICD, International Classification of Diseases; ref, reference.

diagnosis was 70.8 years (SD 10.7), and median year of diagnosis was 1999.5 (IQR 1988–2013).

Results described below refer to model 0 (age adjusted) with exposures lagged 15 years (tables 4 and 5).

With duration of employment, compared with the lowest tertile, a non-significant positive association with UTC was observed in the middle tertile (IRR 1.42, 95% CI 0.80 to 2.51), and a non-significant negative association in the highest (0.90, 0.46 to 1.77). In analyses of duration of fire-exposed employment, IRRs were at or close to 1 for the middle and highest tertile. Analyses with alternative cut-points in duration did not essentially change the results (results not shown).

In analyses of number of fires attended, UTC risk was non-significantly higher in the middle tertile (1.44, 0.76 to 2.70), and non-significantly lower in the highest tertile (0.58, 0.31 to 1.10). Results of analyses with fire exposure score followed a similar pattern, while IRRs were close to 1 for the middle and highest tertile of inhalation score.

Table 5 Incidence rate ratios (IRRs) and 95% CIs for indicators of occupational exposures of firefighting and urinary tract cancer (ICD-10 C65–68) risk among men in the Norwegian Fire Departments Cohort

Exposure	Cases	IRR (95% CI) Model 0*	Model 1†	Model 2‡
Number of fires attended (n=4022)				
No lag				
≤156	21	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
157–237	21	1.25 (0.68 to 2.31)	1.25 (0.68 to 2.31)	1.19 (0.64 to 2.22)
≥238	22	0.52 (0.28 to 0.95)	0.52 (0.28 to 0.95)	0.49 (0.26 to 0.92)
p-trend§		0.02	0.02	0.01
Lag 10 years				
≤134	21	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
135–233	21	1.17 (0.63 to 2.19)	1.17 (0.63 to 2.19)	1.12 (0.59 to 2.13)
≥234	22	0.58 (0.31 to 1.09)	0.58 (0.31 to 1.09)	0.56 (0.29 to 1.06)
p-trend§		0.07	0.06	0.05
Lag 15 years				
≤127	22	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
128–213	20	1.44 (0.76 to 2.70)	1.43 (0.76 to 2.70)	1.39 (0.73 to 2.64)
≥214	22	0.58 (0.31 to 1.10)	0.58 (0.31 to 1.10)	0.55 (0.29 to 1.05)
p-trend§		0.07	0.07	0.05
Fire exposure score (n=4022)				
No lag				
≤103	21	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
104–200	21	1.17 (0.63 to 2.16)	1.17 (0.63 to 2.16)	1.11 (0.59 to 2.10)
≥201	22	0.63 (0.33 to 1.17)	0.63 (0.33 to 1.17)	0.52 (0.27 to 1.01)
p-trend§		0.12	0.12	0.04
Lag 10 years				
≤91	21	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
92–196	21	0.99 (0.53 to 1.85)	0.99 (0.53 to 1.85)	0.94 (0.49 to 1.78)
≥197	22	0.64 (0.33 to 1.21)	0.64 (0.33 to 1.21)	0.54 (0.27 to 1.07)
p-trend§		0.15	0.15	0.07
Lag 15 years				
≤87	22	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
88–178	20	1.31 (0.69 to 2.47)	1.31 (0.69 to 2.47)	1.26 (0.65 to 2.41)
≥179	22	0.70 (0.36 to 1.37)	0.70 (0.36 to 1.37)	0.61 (0.30 to 1.23)
p-trend§		0.25	0.25	0.13
Inhalation score (n=4022)				
No lag				
≤11	22	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
12–23	22	0.87 (0.47 to 1.60)	0.87 (0.47 to 1.60)	0.80 (0.42 to 1.53)
≥24	20	1.02 (0.53 to 1.96)	1.02 (0.53 to 1.96)	0.89 (0.43 to 1.85)
p-trend§		0.95	0.95	0.76
Lag 10 years				
≤10	21	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
11–20	21	0.97 (0.51 to 1.84)	0.97 (0.51 to 1.84)	0.91 (0.47 to 1.78)
≥21	22	1.01 (0.52 to 1.99)	1.01 (0.52 to 1.99)	0.90 (0.43 to 1.88)
p-trend§		0.96	0.96	0.79
Lag 15 years				
≤9	21	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
10–18	21	1.03 (0.54 to 1.97)	1.03 (0.54 to 1.97)	0.97 (0.50 to 1.91)
≥19	22	0.99 (0.50 to 1.98)	0.99 (0.50 to 1.98)	0.89 (0.42 to 1.87)
p-trend§		0.98	0.98	0.75
Diesel exhaust exposure score (n=3938)				
No lag				
≤34	21	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
35–71	21	1.35 (0.74 to 2.49)	1.35 (0.73 to 2.49)	1.36 (0.74 to 2.50)
≥72	21	0.84 (0.45 to 1.54)	0.83 (0.45 to 1.55)	0.85 (0.46 to 1.60)
p-trend§		0.54	0.54	0.62
Lag 10 years				

continued

Table 5 continued

Exposure	Cases	IRR (95% CI) Model 0*	Model 1†	Model 2‡
≤33	21	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
34–59	21	2.27 (1.22 to 4.20)	2.28 (1.22 to 4.24)	2.30 (1.23 to 4.29)
≥60	21	0.93 (0.50 to 1.73)	0.93 (0.50 to 1.75)	0.96 (0.50 to 1.83)
p-trend§		0.75	0.75	0.86
Lag 15 years				
≤25	19	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
26–53	23	2.21 (1.18 to 4.16)	2.22 (1.18 to 4.20)	2.29 (1.20 to 4.36)
≥54	21	1.07 (0.56 to 2.07)	1.08 (0.56 to 2.08)	1.14 (0.57 to 2.25)
p-trend§		0.94	0.95	0.82

Follow-up from 1 January 1960 to 31 December 2021.
*Age adjusted (≤54, 55–69, 70–79, ≥80).
†Adjusted for age (as above) and period of follow-up (≤1969, ≥1970).
‡Adjusted for age (as above) and period of first employment (≤1969, 1970–1989, ≥1990).
§Modelled as a continuous variable to test for linear trend.
ICD, International Classification of Diseases; ref, reference.

In the middle tertile of diesel exhaust exposure, we observed a more than twofold increased UTC risk both with a 10-year (2.27, 1.22 to 4.20) and 15-year lag (2.21, 1.18 to 4.16), while IRRs were close to 1 in the highest tertile.

Multivariable analyses gave similar results, as did sensitivity analyses (results not shown). Results from analyses restricted to bladder cancer (C67) are provided for comparability with studies that use this more specific site definition (online supplemental table 2).

DISCUSSION

We found non-significantly increased UTC risk in the middle versus lowest tertile of duration of employment, number of fires attended, and fire exposure score, and the IRR estimates slightly increased with a 15-year lag compared with none. However, we observed no indication of a dose-response association, and IRRs were close to or below 1 in the highest tertiles. Over twofold significantly increased UTC risk was found in the middle tertile of diesel exhaust exposure with 10-year and 15-year lags, while IRRs were close to 1 in the highest tertile. To our knowledge, no study has closely examined the potential roles of specific exposures on UTC risk among firefighters.

The Working Group for the recent evaluation of firefighting by IARC concluded that a causal association without reasonable doubt exists between occupational exposure as a firefighter and bladder cancer.[1 2] Their meta-analysis demonstrated consistent positive associations for bladder cancer incidence among firefighters compared mostly with the general population, as well as for the broader group of UTCs assessed in some studies.[1 2 15] Exposures such as PAHs and soot were considered plausible causal agents.[1]

Partially consistent with our findings, Glass *et al*[14] observed increased UTC risk with increased employment duration (10–20 and >20 years) among male firefighters in Australia, with few cases (n=2; 3%) observed in the reference category (>3 months to 10 years). When considering number of fire incidents attended by individual firefighters, they observed indications of increased UTC risk not only in the middle (relative cancer incidence ratio 1.80, 95% CI 0.51 to 6.39) but also the highest tertile (1.51, 0.47 to 4.86) compared with the lowest.

In a study of US firefighters, Daniels *et al*[10] did not observe exposure-response associations for bladder cancer incidence when comparing the highest exposed quartile to the lowest using the exposure surrogates exposed days, fire runs and fire hours. In an assessment of cancer mortality in an updated follow-up, with HWSE adjustment using total duration of employment attained, Pinkerton *et al*[11] observed a non-significant positive association between exposed days and bladder cancer mortality (n=37 deaths).

Firefighters are also occupationally exposed to diesel exhaust,[8] which comprises a complex mixture of particles, PAHs and volatile organic compounds, among others.[22] In 2014, diesel exhaust was classified as a carcinogen (group 1) by IARC on the basis of elevated lung cancer risk. A positive and credible association with bladder cancer was noted, though with limited epidemiological evidence.[22]

One previous study from 2001 considered firefighters' cancer mortality and diesel exhaust exposure, and an indication of increased risk of bladder cancer death was observed among low vs non-exposed (relative risk 1.38, 95% CI 0.16 to 11.96), based on six deaths.[9] More recent studies assessing diesel exhaust exposure across various occupations support an association between bladder cancer and high concentrations of exposure.[23 24] Latifovic *et al*[23] found that men exposed at high concentrations for >10 years had an over twofold increased risk compared with unexposed. Koutros *et al*[24] observed a 61% increase in bladder cancer risk with the highest level of diesel exposure, and this increase remained consistent with all lag intervals evaluated (5–40 years). Partially in accordance with these studies, we observed increased UTC risk in the middle tertile of diesel exhaust exposure with 10-year and 15-year lags, suggesting exposure to diesel exhaust may play an important role in firefighters' occupational UTC risk.

The attenuation and drop in risk we observed at high exposures using several indicators are not uncommon in occupational epidemiological studies. Among others, misclassification is a posited cause for this phenomenon,[25] as subjects truly belonging in the highest exposure category can only be misclassified to less exposed categories. This will tend to reduce the estimated IRR in the highest category, while the middle category can be biased in either direction.[26] We attempted to account for all relevant influences on exposures in our indicators, and detailed work histories should have contributed to greater differentiation in the estimation of exposures for individuals. However, the fire statistics required extensive extrapolation. Further, we did not have any present or historical exposure measurements to incorporate into our indicators nor to assess their performance. Therefore, it is possible that misclassification occurred. Potential misclassification would probably be non-differential, as indicators were developed and applied without knowledge of health status of individuals.[27] Assuming non-differential, non-systematic errors, misclassification would attenuate the IRR of the highest exposure category in our age-adjusted models.[26]

We observed no association between inhalation score and UTC risk. Here, it is likely that some misclassification of exposure occurred and that exposure via inhalation remained at higher levels than the proposed protection factors for positive-pressure SCBA suggested. Also, exposure from other routes, such as dermal absorption, may play an important role in UTC risk.

The HWSE is also a posited cause of the attenuation and drop in risk often observed at high exposures.[25] The HWSE is characterised by the phenomenon of unhealthy workers generally leaving work earlier, thus accruing less exposure and potentially contributing to a downward bias in internal comparisons of cumulative exposure and disease outcomes.[18] Some methods proposed to control for this bias include lagging exposure, stratification by employment status, and restricting the study cohort by time-varying factors.[18 21] By lagging exposures, we observed a stronger association between the middle tertile of exposures and UTC risk. Adjusting for employment status can be problematic if prior exposure influences employment status, as adjustment of an intermediate variable on the pathway between exposure and disease induces bias.[18 19 21] Our results did not change essentially when including employment status in our models, nor when restricting the study cohort.

We had no information about tobacco smoking, an important UTC risk factor.[28] In previous reports of this cohort, we observed at-expected lung cancer incidence rates compared with the general population.[19 29] This may reflect smoking habits in line with the general population, or a combined effect of less smoking and occupational exposure to carcinogens. However, as most working populations within a branch or job are relatively homogenous, confounding from uncontrolled lifestyle factors is expected to be small in internal comparisons.[27]

The 15 participating fire departments provided firefighting services for nearly 50% of the Norwegian population as of 2019.[16] Given the population size (3.6 million in 1960 and 5.3 million in 2018),[30] the present study sample is relatively large. However, as we observed only 76 cases of UTC, our analyses had limited statistical power. Nonetheless, our results were stable across models and in sensitivity analyses.

The exposure indicators developed at present aimed to contribute to a better understanding of firefighting exposures and cancer risk. Dose-response associations between the indicators and UTC were not observed. Despite firefighters' occupational exposure to known bladder carcinogens, little support for elevated UTC risk was found in this study. Future studies using the indicators with more cases and of other cancer sites may contribute to a better understanding of firefighters' cancer risk.

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Contributors NM managed the data, carried out statistical analyses and drafted the paper. TKG and KK conceived the study and planned the design and data collection. MBV and JIM provided guidance for the statistical analyses. All authors participated in the interpretation and presentation of results and have read and approved the final manuscript. Guarantor: KK.

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Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by Regional Committee for Medical and Health Research Ethics (reference number: 5646). This study was exempted from the requirement to obtain consent on the grounds that it was practically and financially unfeasible to send letters to those registered in the cohort for participation. Data collection was done retrospectively, and complete overview over workers in the cohort is important to avoid biases and consequent errors in results, and misinterpretation of risk.

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Data availability statement Data may be obtained from a third party and are not publicly available. The data that support the findings of this study are available from the CRN (cohort data and cancer data) and the National Population Register (death and emigration data) but restrictions apply to the availability of these data, which were used under license for the current study and so are not publicly available. Requests for data sharing/case pooling for projects with necessary approvals and legal basis according to the EU General Data Protection Regulation (GDPR) may be directed to principal investigator Dr Kristina Kjærheim; email: kk@kreftregisteret. no.

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Supplementary material

Supplementary table 1.

Job titles (translated to English and original in Norwegian, n=184) used in the Norwegian Fire Departments Cohort, categorized according to potential for exposure to live firefighting.

Job title, English	*Job title, Norwegian (original)*
Fully fire-exposed	
Firefighter trainee	*Aspirant*
Firefighter	*Brannformann*
Firefighter/smoke diving leader	*Brannformann/røykdykkerleder*
Firefighter	*Brannkonstabel*
Firefighter	*Brannkonstabel/brannformann*
Firefighter/smoke diver	*Brannkonstabel/brannformann/røykdykkerformann*
Firefighter/smoke diver	*Brannkonstabel/røykdykkerformann*
Firefighter/smoke diving leader	*Brannkonstabel/røykdykkerleder*
Fire captain/shift captain	*Brannmester/stasjonsleder*
Part time firefighter	*Deltidsbrannmann*
Crew	*Mannskap*
Rescue leader/lieutenant	*Redningsleder/underbrannmester*
Reserve firefighter	*Reservebrannmann*
Reserve firefighter	*Reserveformann*
Smoke/chemical diving leader	*Røyk-/kjem.dykkerleder*
Smoke diver	*Røykdykker*
Smoke diver	*Røykdykkerformann*
Smoke diving leader	*Røykdykkerleder*
Shift captain	*Stasjonsleder*
Technical firefighter	*Teknisk brannformann*
Technical fire chief assistant	*Teknisk underbrannmester*
Lieutenant	*Underbrannmester*
Firefighter, extra	*Vikar som brannkonstabel*
Extra/firefighter	*Vikar/brannkonstabel*
Partly fire-exposed	
Fire- and chimney inspector	*Brann- og feierinspektør*
Fire inspector	*Branninspektør*
Fire inspector/fire engineer	*Branninspektør/ Branningeniør*
Fire inspector/brigade chief	*Branninspektør/brigadeleder*
Fire captain	*Brannmester*
Fire captain, daytime	*Brannmester dagtid*
Fire captain (fire boat)	*Brannmester sjøsprøyte*
Fire captain/fire inspector	*Brannmester/branninspektør*
Fire captain	*Brannmester/overbrannmester*
Fire marshall assistant	*Brannvernlederassistent*
Brigade chief	*Brigadeleder*
Fire preparedness chief	*Leder beredskap*
Deputy fire marshall	*Nestleder beredskap*
Commander-in-chief	*Overbefalsvakt*
Fire captain	*Overbrannmester*

Fire captain, daytime	*Overbrannmester dagtid*
Fire chief (fire boat)	*Overbrannmester sjøsprøyte*
Department chief (department unspecified)	*Seksjonsleder*
Fire boat driver	*Sjøsprøytefører*
Shift captain	*Stasjonsmester*
Technical fire captain	*Teknisk brannmester*
Technical fire captain	*Teknisk overbrannmester*
Lieutenant/shift captain	*Underbrannmester/brannmester*
Lieutenant/shift captain/fire captain	*Underbrannmester/brannmester/overbrannmester*
Lieutenant/shift captain/fire inspector	*Underbrannmetser/brannmester/branninspektør*
Department chief (alarms)	*Utrykningssjef*
Deputy fire chief	*Varabrannsjef*
Extra	*Vikar*
Non-fire-exposed	
Electrician	*1. elektriker*
Manager	*1. fullmektig*
Office clerk	*1. kontorist*
Secretary	*1. sekretær*
Alarm center operator	*110*
Alarm center operator	*Alarmoperatør*
Alarm center operator	*Alarmsentraloperatør*
Ambulance coordinator	*Ambulansekoordinator*
Ambulance manager	*Ambulanseleder*
Shift captain	*Arbeidsleder*
Bookkeeper	*Arkivar*
Bookkeeper/office manager	*Arkivar/Kontorfullmektig/Kontorsjef*
Bookkeeper	*Arkivleder*
Assistant	*Assistent*
Departmental engineer 1	*Avdelingsingeniør 1*
Departmental engineer 2	*Avdelingsingeniør 2*
Department chief	*Avdelingssjef*
Doctor, internal	*Bedriftslege*
Emergency coordinator	*Beredskapskoordinator*
Car painter	*Billakkerer*
Car mechanic	*Bilmekaniker*
Fire engineer	*Branningeniør*
Fire prevention captain	*Brannmester forebyggende avd.*
Fire chief	*Brannsjef*
Fire telegraph officer	*Branntelegrafformann*
Fire safety instructor	*Brannverninstruktør*
Courier	*Bud*
Boat driver	*Båtfører*
Office assistant	*Diverse dagtidsarbeide*
Maintenance and operations staff	*Drift- og vedlikeholdsmedarbeider*
Operations manager	*Driftsleder*
Professional diver	*Dykkerfaglig medarbeider*
Lead diver	*Dykkermester*
Special assignment, retiree	*Engasjement på pensjonistvilkår*

Skilled worker	*Fagarbeider*
Trade union chair	*Fagforeningsformann*
Consultant	*Fagkonsulent*
Department chief (department unspecified)	*Fagsjef*
Manager	*Forvaltning*
Office manager	*Fullmektig*
Office manager/secretary	*Fullmektig/sekretær*
Fireman/stoker	*Fyrbøter*
Physiotherapist	*Fysioterapeut*
Consultant	*Førstekonsulent*
Shift captain	*Gruppeleder*
HSE manager	*HMS-rådgiver*
Consultant	*Informasjonskonsulent*
Information officer	*Informasjonsmedarbeider*
Engineer	*Ingeniør*
Lawyer	*Jurist*
Boiler fitter	*Kjelepasser*
Consultant	*Konsulent*
Secretary, female	*Kontor- og sentralborddame*
Office assistant	*Kontorassistent*
Courier	*Kontorbud*
Office clerk, female	*Kontordame*
Office manager	*Kontorfullmektig*
Office clerk	*Kontorist*
Office clerk/manager	*Kontorist/fullmektig*
Office clerk/manager/secretary/consultant	*Kontorist/Fullmektig/Sekretær/Konsulent*
Office clerk/salary manager/secretary	*Kontorist/lønningsfullmektig/personalsekretær*
Office clerk/manager	*Kontorist/personalfullmektig*
Office clerk/stenographer	*Kontorist/stenograf*
Office clerk	*Kontormedarbeider*
Office manager	*Kontorsjef*
Office and finance manager	*Kontorsjef/økonomisjef*
Inspector	*Kontrollør*
Coordinator	*Koordinator*
Warehouse clerk	*Lagerekspeditør*
Warehouse clerk	*Lagerformann*
Fire marshall	*Leder forebyggende*
Trainee	*Lærling*
Car workshop trainee	*Lærling på bilverkstedet*
Salary manager	*Lønnsleder*
Water storage officer	*Magasinbetjent*
Water storage officer	*Magasinbetjent/magasinformann*
Water storage officer	*Magasinformann*
Mechanic/boiler fitter	*Maskin- og kjelepasser*
Mechanic assistant	*Maskinassistent*
Mechanic	*Maskinist*
Mechanic/mechanic assistant	*Maskinist/maskinistassistent*
Machine fitter	*Maskinpasser*
Temporary machine fitter	*Midlertidig maskinpasser*

District chief	*Områdeleder*
Senior engineer	*Overingeniør*
HR leader	*Personalleder*
Personal secretary	*Personalsekretær*
Trainee	*Praksiskandidat*
Radio technician	*Radiotekniker*
Rescue-dive leader	*Redningsdykkerleder*
Rescue leader	*Redningsleder*
Rescuer	*Redningsmann*
Accountant	*Regnskapsfører*
Cleaning assistant	*Rengjøringsassistent*
Cleaner, female	*Rengjøringskvinne*
Cleaning manager	*Rengjøringsleder*
Cleaner, extra	*Rengjøringsvikar*
Consultant	*Rådgiver*
Secretary	*Sekretær*
Senior consultant	*Seniorkonsulent*
Consultant	*Spesialkonsulent*
Bookkeeping consultant	*Spesialkonsulent arkivleder*
Consultant	*Spesialkonsulent II*
Special assignments	*Spesielle oppdrag*
Stenographer	*Stenograf*
Strong current fitter	*Sterkstrømsmontør*
Low current fitter	*Svakstrømsmontør*
Paramedic	*Sykekjører*
Nurse	*Sykepleier*
Nursing consultant	*Sykepleierkonsulent*
Drawer/artist	*Tegner*
Technician	*Tekniker*
Technician/engineer	*Tekniker/Ingeniør*
Fire telegraph chief	*Telegrafmester*
Supervisor	*Tilsynsleder*
Inspector	*Tilsynsmann*
Shift captain	*Vaktformann*
Shift coordinator	*Vaktkommandør*
Shift leader	*Vaktleder*
Diver	*vanndykker*
Foreman	*Verksmester*
Safety and environment manager	*Verne- og miljøleder*
Chief financial officer	*Økonomisjef*
Other-exposed	
Chimney sweep	*Feier*
Chimney sweep/chimney sweep assistant	*Feier/feiersvenn*
Chimney sweep	*Feierformann*
Chimney inspector	*Feierinspektør*
Chimney sweep chief	*Feierleder*
Chimney sweep trainee	*Feierlærling*
Chimney sweep trainee	*Feierlærling/feiersvenn*

Chimney sweep captain	*Feiermester*
Chimney sweep assistant	*Feiersvenn*

Supplementary 2.

The different types of self-contained breathing apparatus (SCBA) included automatic positive pressure, manual positive pressure, and negative pressure SCBA. Each type describes how the air pressure inside the mask covering the user's face compares to the external environment, with positive pressure SCBA providing a protection factor of around 100 compared to negative pressure SCBA (Howie, 2005).

The phases of structural firefighting are divided as follows: smoke diving, when firefighters wear breathing apparatus and enter smoke-filled rooms and buildings to search, rescue, and extinguish the fire; knockdown, when the fire is extinguished; and overhaul, when any remaining small fires and smoldering material are extinguished (IARC, 2010).

Howie RM. Respiratory protective equipment. Occup Environ Med. 2005;62(6):423-8, 362.

International Agency for Research on Cancer. Painting, firefighting, and shiftwork: IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 98. Lyon, France: International Agency for Research on Cancer; 2010.

Supplementary table 2. Incidence rate ratios (IRR) and 95% confidence intervals (CIs) for indicators of occupational exposures of firefighting and bladder cancer (ICD-10 C67) risk among men in the Norwegian Fire Departments Cohort. Follow-up from January 1, 1960 to December 31, 2021.

		IRR (95% CI)		
Exposure	**Cases**	**Model 0***	**Model 1****	**Model 2*****
Duration of employment (year; n=4250)				
No lag				
≤25	19	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
26–32	23	1.25 (0.66–2.37)	1.25 (0.66–2.37)	1.28 (0.67–2.46)
≥33	22	0.98 (0.51–1.87)	0.98 (0.51–1.87)	0.95 (0.49–1.85)
p-trend†		0.88	0.88	0.80
Lag 10 years				
≤20	19	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
21–30	22	1.07 (0.56–2.06)	1.07 (0.56–2.05)	1.09 (0.56–2.13)
≥31	23	0.92 (0.46–1.83)	0.92 (0.46–1.84)	0.89 (0.44–1.80)
p-trend†		0.80	0.80	0.72
Lag 15 years				
≤20	24	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
21–29	22	1.32 (0.71–2.45)	1.32 (0.71–2.45)	1.32 (0.71–2.47)
≥30	18	0.75 (0.37–1.55)	0.75 (0.37–1.55)	0.71 (0.34–1.49)
p-trend†		0.50	0.50	0.41
Duration of fire-exposed employment (years; n=4250)				
No lag				
≤19	20	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)

20–29	24	0.88 (0.48–1.62)	0.88 (0.48–1.62)	0.87 (0.47–1.63)
≥30	20	0.86 (0.45–1.65)	0.87 (0.45–1.65)	0.83 (0.43–1.61)
p-trend†		0.67	0.67	0.59
Lag 10 years				
≤17	20	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
18–28	21	0.79 (0.41–1.50)	0.79 (0.41–1.50)	0.79 (0.41–1.52)
≥29	23	1.16 (0.59–2.25)	1.16 (0.60–2.25)	1.12 (0.57–2.22)
p-trend†		0.64	0.64	0.69
Lag 15 years				
≤15	20	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
16–26	22	0.97 (0.51–1.84)	0.97 (0.51–1.84)	0.97 (0.51–1.87)
≥27	22	1.00 (0.49–2.01)	1.00 (0.49–2.02)	0.97 (0.47–1.98)
p-trend†		0.99	0.99	0.93
Number of fires attended (n=4022)				
No lag				
≤156	18	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
157–237	16	1.10 (0.55–2.17)	1.10 (0.55–2.17)	1.05 (0.52–2.10)
≥238	19	0.52 (0.27–1.00)	0.52 (0.27–1.00)	0.50 (0.25–0.97)
p-trend†		0.04	0.04	0.03
Lag 10 years				
≤134	18	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
135–233	16	1.03 (0.51–2.06)	1.03 (0.51–2.06)	0.99 (0.49–2.02)
≥234	19	0.58 (0.29–1.14)	0.58 (0.29–1.14)	0.55 (0.28–1.11)
p-trend†		0.09	0.09	0.07
Lag 15 years				
≤127	19	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
128–213	15	1.23 (0.61–2.49)	1.24 (0.61–2.50)	1.21 (0.59–2.47)
≥214	19	0.57 (0.29–1.12)	0.57 (0.29–1.13)	0.54 (0.27–1.09)
p-trend†		0.08	0.08	0.06
Fire exposure score (n=4022)				
No lag				
≤103	18	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
104–200	17	1.10 (0.56–2.15)	1.09 (0.56–2.14)	1.07 (0.53–2.14)
≥201	18	0.59 (0.30–1.16)	0.58 (0.29–1.16)	0.48 (0.23–0.99)
p-trend†		0.11	0.11	0.04
Lag 10 years				
≤91	18	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
92–196	17	0.92 (0.47–1.83)	0.92 (0.47–1.83)	0.89 (0.44–1.80)
≥197	18	0.59 (0.29–1.19)	0.59 (0.29–1.19)	0.50 (0.24–1.04)
p-trend†		0.13	0.13	0.05
Lag 15 years				
≤87	16	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
88–178	19	1.41 (0.70–2.83)	1.41 (0.70–2.84)	1.39 (0.67–2.87)
≥179	18	0.70 (0.34–1.47)	0.71 (0.34–1.48)	0.61 (0.28–1.34)
p-trend†		0.29	0.29	0.16
Inhalation score (n=4022)				

No lag				
≤11	18	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
12–23	19	0.90 (0.46–1.76)	0.90 (0.46–1.75)	0.83 (0.41–1.70)
≥24	16	0.97 (0.47–2.01)	0.97 (0.47–2.00)	0.82 (0.37–1.84)
p-trend†		0.94	0.94	0.65
Lag 10 years				
≤10	17	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
11–20	19	1.07 (0.54–2.13)	1.07 (0.54–2.14)	1.01 (0.48–2.08)
≥21	17	0.93 (0.44–1.97)	0.93 (0.44–1.97)	0.80 (0.35–1.82)
p-trend†		0.84	0.84	0.57
Lag 15 years				
≤9	17	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
10–18	19	1.14 (0.56–2.28)	1.14 (0.57–2.30)	1.07 (0.51–2.23)
≥19	17	0.90 (0.42–1.94)	0.90 (0.42–1.95)	0.79 (0.34–1.80)
p-trend†		0.77	0.78	0.53
Diesel exhaust exposure score (n=3938)				
No lag				
≤34	15	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
35–71	19	1.72 (0.87–3.39)	1.74 (0.87–3.46)	1.75 (0.88–3.46)
≥72	18	1.00 (0.50–2.01)	1.02 (0.50–2.06)	1.07 (0.53–2.18)
p-trend†		0.95	0.96	0.89
Lag 10 years				
≤33	14	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
34–59	20	3.28 (1.63–6.60)	3.36 (1.65–6.82)	3.44 (1.70–6.98)
≥60	18	1.21 (0.58–2.49)	1.23 (0.59–2.56)	1.31 (0.62–2.77)
p-trend†		0.76	0.74	0.58
Lag 15 years				
≤25	14	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
26–53	19	2.51 (1.22–5.15)	2.56 (1.23–5.30)	2.71 (1.30–5.65)
≥54	19	1.32 (0.64–2.76)	1.35 (0.64–2.83)	1.49 (0.69–3.21)
p-trend†		0.57	0.56	0.40

ICD, International Classification of Diseases; ref, reference.

*Age adjusted (≤54, 55–69, 70–79, ≥80).

**Adjusted for age (as above) and period of follow-up (≤1969, ≥1970).

***Adjusted for age (as above) and period of first employment (≤1969, 1970–1989, ≥1990).

†Modelled as a continuous variable to test for linear trend.