The Diesel Exhaust in Miners Study: A Cohort Mortality Study with Emphasis on Lung Cancer

Supplementary Materials

Space considerations prohibited full presentation of results from all analyses in the main article. Full details are provided here for proportional hazard modeling results on the following topics:

1) Ancillary information for the standardized mortality ratio analyses
2) Quartile analysis by worker location group
    a. Unlagged, all tenures
    b. 15-year lag, all tenures
3) Expanded categorical analysis by worker location group
    a. Unlagged, all tenures
    b. 15-year lag, all tenures
    c. Unlagged, excluding workers with <5 years tenure
    d. 15-year lag, excluding workers with <5 years tenure
4) Continuous models by worker location group
    a. 15-year lag
5) Continuous models – ever underground workers
    a. Effect of tenure restriction, exposure range, and lag period
    b. Excluding <5 year tenure by age at starting work at the study facilities
    c. Alternative exposure metrics
    d. Results by state/ore type
6) Continuous models – surface only workers

a. Effect of tenure restriction, exposure range, and lag period

b. Excluding <5 year tenure by age at starting work at the study facilities

7) Continuous models – ever underground and surface only workers

a. Underlying and contributing lung cancer deaths

b. Underlying esophageal cancer deaths

8) Expanded categories and continuous models – ever underground workers

a. Effect of using time since entry to study as underlying time variable.

All models except the last use age as the time variable, with respirable elemental carbon (REC) cumulative exposure and average intensity as time dependent variables, and birth year, sex, and race/ethnicity as fixed effects. In some subgroup analyses the coefficients for race/ethnicity and/or sex were unstable. In these cases, they were omitted from the model. The results were very similar, however, whether these variables were included or omitted.

Note that the numbering of the tables corresponds to the order in which they were mentioned in the main article.

1. Further information pertaining to the standardized mortality ratio analyses

Supplementary Table 1 provides details of the cause of death categories employed in the analysis, together with the International Classification of Diseases, 9th Revision codes. Supplementary Table 2 provides results for causes of death that were not considered a priori but either were found to have statistically elevated or reduced standardized mortality ratios or had 10 or more deaths.

2. Quartile analysis by worker location group

The quartile information presented in Tables 4–6 in the main article is given here in Supplementary Table 9 by worker location group. This approach to presentation permits easy

comparison across location groups, whereas that in the paper permits evaluation by analysis method. Supplementary Table 3 shows information in the same format for unlagged REC exposures.

3. Expanded categorical analysis by worker location group

The expanded categorical analysis information presented in Tables 4–6 in the main article is given here in Supplementary Table 10 by worker location group. Supplementary Table 4 shows information in the same format for unlagged REC exposures, Supplementary Table 5 gives the 15-year lagged results for all tenures (i.e., without excluding workers with <5 years tenure), while Supplementary Table 6 gives the unlagged results for all tenures.

4. Continuous models by worker location group

The continuous modeling results shown in Tables 4–6 in the main article are given here in Supplementary Table 11 by worker location group. For cumulative REC exposure, results are given for untransformed exposure (log-linear model) and log exposure (power model) for the full range of exposures, and for untransformed exposures <1280 µg/m3-y. For average REC intensity, results are given for untransformed or log exposures over the full range of data.

5. Continuous models – ever underground workers

Supplementary Table 7 gives the hazard ratios (HRs) for unlagged and 15-year lagged continuous exposure models with no tenure exclusion and after removal of individuals with <2, <5, and <10 years of tenure at time of event for ever underground workers. For cumulative REC exposure, results are given for untransformed exposure (log-linear model) and log exposure (power model) for the full range of exposures, and for untransformed exposures <1280 µg/m3-y. For average REC intensity, results are given for untransformed or log exposures over the full range of data.

The continuous models in Table 4 of the main article were repeated excluding <5 years of tenure conditional on age at entry to the study facilities (Supplementary Table 12).

Three alternative metrics of historical REC exposure were examined to evaluate the robustness of the assumptions employed in the historical extrapolation of the REC exposures for ever underground workers. Details of their derivation are provided elsewhere (1). In brief, the first two approaches were variations on the modeling and extrapolation procedures in the exposure assessment: 1) employing average observed carbon monoxide (CO) data over time rather than modeled CO information (5-year average); or 2) using an extrapolation factor based on the power model of REC with CO, that is, $REC_X = REC_R\,(CO_X/CO_R)^b$ as presented in the correlation analysis (2) rather than the direct proportionality ratio used in the primary exposure estimates $REC_X = REC_R\,(CO_X/CO_R)$. The third approach used the median instead of the arithmetic mean of the measurements for summarizing the measurement data by job. Identical exposure-response models were used as in Table 4 of the main article, with each alternative estimate replacing the primary metric (Supplementary Table 13).

The continuous models in Table 4 of the main article were repeated for each state/ore type (WY/trona, OH/salt, MO/limestone, and NM/potash) (Supplementary Table 14).

6. Continuous models – surface only workers

Supplementary Table 8 gives the hazard ratios (HRs) for unlagged and 15-year lagged continuous exposure models for with no tenure exclusion and after exclusion of individuals with <2, <5, and <10 years of tenure at time of event for surface only workers. The results are given for untransformed exposure (log-linear model) and log exposure (power model) for the full range of exposures.

The continuous models in Table 5 of the main article were repeated excluding <5 years of

tenure conditional on age at entry to the study facilities (Supplementary Table 12).

7. Continuous models – ever underground and surface only workers

The models in Tables 4 and 5 of the main article were repeated for underlying and contributing lung cancer causes combined (Supplementary Table 15). The models were repeated similarly for esophageal cancer (Supplementary Table 16).

8. Expanded categories and continuous models – ever underground workers

The model results for ever underground workers shown in Supplementary Table 17 were derived using proportional hazard models with time since entry to study as the underlying time variable and adjusting for age and age^2 instead of using age as the time variable as in every other analysis. Also, in comparison to most other analyses, no restriction on tenure is applied. Results are given for the expanded categories and continuous models. The results should be compared with those given for the quartiles and expanded categories in Table 4 of the main article.

Supplementary Table 1. Causes of death examined in the standardized mortality ratio analysis*

Abbreviated title in text	Full LTAS category	ICD9 codes†
A priori causes		
Lung cancer	Malignant neoplasm of trachea, bronchus, and lung	162
Bladder cancer	Malignant neoplasm of bladder and other urinary organs	188, 189.3–189.9
Kidney cancer	Malignant neoplasm of kidney	189.0–189.2
Intestinal cancer	Malignant neoplasm of intestine excluding rectum	152, 153
Rectal cancer	Malignant neoplasm of rectum	154
Pancreatic cancer	Malignancy of the pancreas	157
Prostate cancer	Malignant neoplasm of prostate	185
Leukemia	Leukemia and aleukemia	204–208
Pneumonia	Pneumonia	480–486
Chronic obstructive pulmonary disease	Chronic obstructive pulmonary disease	490–492, 496
Ischemic heart disease	Ischemic heart disease	410–414, 429.2
Cerebrovascular disease	Cerebrovascular disease	430–438
Cirrhosis of the liver	Cirrhosis and other chronic liver diseases	571
Multiple myeloma	Multiple myeloma	203
Hodgkin lymphoma	Hodgkin lymphoma	201
Influenza	Influenza	487
All-cancer	All cancers	140–165, 170–175, 179–208, 273.3
Other causes mentioned in text		
Esophageal cancer	Malignant neoplasm of esophagus	150
Other pneumoconiosis	Other pneumoconiosis	500, 503, 505
Explosion	Explosion	E921, E923
Drowning	Drowning	E910
Electrocution	Electrocution	E925
Machine injuries	Machine injuries	E919
Alcoholism	Alcoholism	291, 303, 305.0
Diabetes mellitus	Diabetes mellitus	250
Asbestosis	Asbestosis	501
Silicosis	Silicosis	502
Other causes with 10 or more deaths		
Melanoma	Melanoma	172
Stomach cancer	Malignancy of stomach	151
Cancer of the biliary passages, liver, and gall bladder	Cancer of the biliary passages, liver, and gall bladder	155, 156
Malignant neoplasm of other and unspecified sites (minor)	Malignant neoplasm of other and unspecified sites (minor)	187, 194–199
Other diseases of the nervous system and sense organs	Other diseases of the nervous system and sense organs	325, 330–337, 341–389
Non-Hodgkin lymphoma	Non-Hodgkin lymphoma	200, 202, 273.3
Conductive disorder	Conductive disorder	426–427
Malignant neoplasm of brain and other parts of the nervous	Malignant neoplasm of brain and other parts of the	191, 192

system	nervous system	
Diseases of the arteries, veins, and lymphatic vessels	Diseases of the arteries, veins, and lymphatic vessels	415–417, 440–459
Hypertension with heart disease	Hypertension with heart disease	402, 404
Other diseases of the heart	Other disease of the heart	420–423, 428, 429.0, 429.1, 429.3–429.9
Other diseases of digestive system	Other diseases of digestive system	040.2, 520–530, 540–543, 555–558, 562–570, 572–579, 997.4
Other respiratory diseases	Other respiratory diseases	470–478, 494, 495, 504, 506–519
Cardiomyopathy	Cardiomyopathy	425

* Disease categories are those intrinsic to the NIOSH Life Table Analysis System (LTAS) Life Table Program. For a full description of the cause-of-death groups used in the NIOSH life-table program see http://www.cdc.gov/niosh/LTAS/rates.html.) Note that the LTAS disease categories do not necessarily match the a priori disease causes exactly.
† ICD9 = International Classification of Diseases, 9th Revision. ICD9 codes are given for brevity because nearly all deaths fell within the period the 9th edition was in use.

Supplementary Table 2. Standardized mortality ratios for non-a priori causes statistically significantly different from 1.0 or with 10 or more deaths for the complete cohort and by worker location*

LTAS cause category†	Worker location		
	Overall **No. deaths,** **SMR (95% CI),** ***P***	**Ever underground‡** **No. deaths,** **SMR (95% CI),** ***P***	**Surface only§** **No. deaths,** **SMR (95% CI),** ***P***
Causes significantly different from 1.0			
Other pneumoconiosis	15 12.20 (6.82 to 20.12) <.001	12 16.21 (8.37 to 28.32) <.001	3 6.13 (1.26 to 17.91) .027
Explosion	8 4.22 (1.82 to 8.31) .002	5 3.96 (1.29 to 9.24) .019	—
Electrocution	10 2.88 (1.38 to 5.30) .006	8 3.51 (1.51 to 6.91) .005	—
Drowning	18 2.80 (1.66 to 4.43) <.001	13 3.06 (1.63 to 5.23) .001	—
Machine injuries	12 1.79 (0.93 to 3.13) .081	11 2.56 (1.27 to 4.58) .010	—
Esophageal cancer	23 1.83 (1.16 to 2.75) .010	16 2.01 (1.15 to 3.26) .016	—
Diabetes mellitus	29 0.66 (0.44 to 0.95) .023	20 0.72 (0.44 to 1.11) .151	—
Alcoholism	9 0.34 (0.15 to 0.64) <.001	6 0.33 (0.12 to 0.71) .002	—
Causes with 10 or more deaths			
Melanoma	15 1.52 (0.85 to 2.51) .152	11 1.73 (0.86 to 3.09) .120	—
Stomach cancer	24 1.28 (0.82 to 1.91) .269	15 1.29 (0.72 to 2.12) .396	—
Cancer of the biliary passages, liver, and gall bladder	16 1.17 (0.67 to 1.89) .606	10 1.16 (0.56 to 2.14) .717	—
Malignant neoplasm of other and	39	29	10

unspecified sites (minor)	0.95 (0.67 to 1.30) .820	1.13 (0.75 to 1.62) .568	0.65 (0.31 to 1.19) .201
Other diseases of the nervous system diseases and sense organs	29 0.93 (0.62 to 1.34) .783	20 1.03 (0.63 to 1.59) .954	—
Non-Hodgkin lymphoma	17 0.93 (0.54 to 1.49) .886	—	10 1.49 (0.72 to 2.75) .280
Conductive disorder	30 0.88 (0.59 to 1.26) .551	20 0.96 (0.59 to 1.49) .985	10 0.75 (0.36 to 1.38) .449
Malignant neoplasm of brain and other parts of the nervous system	13 0.84 (0.45 to 1.44) .649	—	—
Diseases of the arteries, veins, and lymphatic vessels	51 0.84 (0.63 to 1.11) .248	29 0.80 (0.54 to 1.15) .261	22 0.91 (0.57 to 1.38) .752
Hypertension with heart disease	11 0.82 (0.41 to 1.47) .631	—	—
Other diseases of the heart	32 0.82 (0.56 to 1.16) .311	20 0.87 (0.53 to 1.35) .633	12 0.76 (0.39 to 1.32) .401
Other diseases of digestive system	32 0.82 (0.56 to 1.16) .298	23 0.94 (0.60 to 1.41) .879	—
Other respiratory diseases	23 0.81 (0.52 to 1.22) .371	12 0.71 (0.36 to 1.23) .268	11 0.98 (0.49 to 1.75) .905
Cardiomyopathy	12 0.77 (0.40 to 1.35) .455	—	—

* Based on 12 270 individuals, which is the number in the study from 1960–1997, the period for which state rates were available (1960–2004). SMR = standardized mortality ratio; LTAS = Life Table Analysis System; CI = confidence interval; *P* = probability based on two-sided normal approximation to a Poisson distribution when number of deaths >10 or exact method otherwise; — indicates <10 deaths and no significant excess or deficit in deaths from the specified cause.

† See NIOSH-119 cause-of-death categories and corresponding ICD codes for 1960 through 2004 at http://www.cdc.gov/niosh/LTAS/rates.html.

‡ Categorized as ever underground after first going underground (even if surface later).

§ Categorized as surface only until first going underground (if ever).

Supplementary Table 3. Proportional hazards ratios on underlying-cause lung cancer mortality by quartiles of unlagged REC cumulative exposure and average intensity with no tenure exclusion, by worker location and for the complete cohort unadjusted and adjusted for worker location*

Analyses	Results for quartiles			
Ever underground workers†				
Cumulative REC exposure (μg/m^3-y)				
Exposure range	0-<318	318-<802	802-<1565	≥1565
No. LC deaths	30	31	30	31
REC HR (95% CI)	1.00	1.41 (0.84 to 2.38)	2.33 (1.39 to 3.92)	1.52 (0.89 to 2.60)
P	(referent)	.193	.001	.122
Average REC intensity (μg/m^3)				
Exposure range	0-<42	42-<71	71-<145	≥145
No. LC deaths	30	31	30	31
REC HR (95% CI)	1.00	2.60 (1.52 to 4.44)	1.97 (1.12 to 3.45)	2.27 (1.23 to 4.17)
P	(referent)	.001	.018	.008
Surface only workers‡				
Cumulative REC exposure (μg/m^3-y)				
Exposure range	0-<4.9	4.9-<12	12-<23	≥23
No. LC deaths	19	20	19	20
REC HR (95% CI)	1.00	0.92 (0.48 to 1.75)	0.94 (0.49 to 1.79)	0.61 (0.29 to 1.29)
P	(referent)	.793	.841	.191
Average REC intensity (μg/m^3)				
Exposure range	0-<0.86	0.86-<0.94	0.94-<1.91	≥1.91
No. LC deaths	18	19	21	20
REC HR (95% CI)	1.00	2.56 (1.22 to 5.37)	2.11 (0.98 to 4.55)	2.30 (1.01 to 5.21)
P	(referent)	.013	.056	.047
Complete cohort unadjusted for worker location				
Cumulative REC exposure (μg/m^3-y)				
Exposure range	0-<18	18-<198	198-<954	≥954
No. LC deaths	50	50	50	50
REC HR (95% CI)	1.00	0.75 (0.49 to 1.15)	0.86 (0.57 to 1.29)	0.93 (0.61 to 1.41)
P	(referent)	.190	.462	.737
Average REC intensity (μg/m^3)				
Exposure range	0-<1.4	1.4-<29	29-<93	≥93
No. LC deaths	50	50	50	50
REC HR (95% CI)	1.00	0.97 (0.64 to 1.48)	1.19 (0.80 to 1.77)	1.02 (0.66 to 1.57)
P	(referent)	.884	.384	.933
Complete cohort adjusted for worker location§				
Cumulative REC exposure (μg/m^3-y)				
Exposure range	0-<18	18-<198	198-<954	≥954
No. LC deaths	50	50	50	50
REC HR (95% CI)	1.00	0.86 (0.54 to 1.36)	1.19 (0.63 to 2.22)	1.29 (0.68 to 2.45)
P	(referent)	.513	.596	.438
Average REC intensity (μg/m^3)				

Exposure range	0-<1.4	1.4-<29	29-<93	≥93
No. LC deaths	50	50	50	50
REC HR (95% CI)	1.00	1.37 (0.84 to 2.22)	2.34 (1.21 to 4.51)	2.06 (1.03 to 4.12)
P	(referent)	.207	.011	.042

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. Models adjusted for race/ethnicity, birth year, and sex (except ever underground); stratified by state.
† Workers categorized as ever underground after first going underground (even if surface later).
‡ Workers categorized as surface only until first going underground (if ever).
§ Adjusted using a time-dependent variable based on worker location.

Supplementary Table 4. Proportional hazards ratios for underlying-cause lung cancer mortality by unlagged REC cumulative exposure and average intensity using categorical exposure cut-points excluding workers with <5 years tenure, by worker location and for the complete cohort adjusted for worker location*

Analyses	**Results for expanded exposure categories**							
Ever underground workers†								
Cumulative REC exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	80-<160	160-<320	320-<640	640-<1280	≥1280
No. LC deaths	1	2	1	4	8	14	28	35
REC HR (95% CI)	1.00 (referent)	1.57 (0.14 to 17.37)	0.61 (0.04 to 9.91)	1.30 (0.14 to 11.95)	2.05 (0.25 to 16.81)	2.23 (0.29 to 17.27)	4.69 (0.63 to 34.90)	3.23 (0.43 to 24.24)
P		.714	.730	.817	.503	.441	.131	.253
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	4-<8	8-<16	16-<32	32-<64	64-<128	≥128
No. LC deaths	2	2	4	6	5	30	18	26
REC HR (95% CI)	1.00 (referent)	1.38 (0.19 to 9.96)	1.37 (0.25 to 7.64)	2.05 (0.40 to 10.42)	1.72 (0.33 to 8.93)	4.61 (1.09 to 19.50)	3.00 (0.68 to 13.18)	4.38 (1.00-19.23)
P		.751	.721	.386	.518	.038	.146	.050
Surface only workers‡								
Cumulative REC Exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	≥80				
No. LC deaths	32	13	8	4				
REC HR (95% CI)	1.00 (referent)	0.90 (0.43 to 1.86)	1.13 (0.41 to 3.09)	2.66 (0.67 to 10.56)				
P		.769	.819	.165				
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	≥4					
No. LC deaths	44	11	2					
REC HR (95% CI)	1.00 (referent)	1.36 (0.66 to 2.82)	2.34 (0.51 to 10.86)					
P		.411	.277					
Complete cohort adjusted for worker location§								
Cumulative REC Exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	80-<160	160-<320	320-<640	640-<1280	≥1280
No. LC deaths	33	15	9	8	8	14	28	35
REC HR (95% CI)	1.00 (referent)	0.84 (0.44 to 1.60)	0.67 (0.29 to 1.53)	1.38 (0.52 to 3.62)	1.65 (0.54 to 5.04)	1.67 (0.60 to 4.64)	3.43 (1.32 to 8.93)	2.26 (0.86 to 5.95)
P		.593	.342	.516	.381	.325	.012	.097
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	4-<8	8-<16	16-<32	32-<64	64-<128	≥128
No. LC deaths	46	13	6	6	5	30	18	26
REC HR (95% CI)	1.00 (referent)	1.22 (0.64 to 2.33)	1.57 (0.55 to 4.45)	2.10 (0.66 to 6.67)	1.48 (0.43 to 5.08)	3.59 (1.41 - 9.16)	2.17 (0.81 to 5.84)	2.92 (1.10 to 7.78)
P		.542	.396	.207	.530	.007	.125	.032

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; HR probability from two-sided X^2 Wald test. Individuals with <5 years tenure at time of event were excluded. Models adjusted for race/ethnicity, birth year, and sex (except ever underground); stratified by state.

† Workers categorized as ever underground after first going underground (even if surface later).
‡ Workers categorized as surface only until first going underground (if ever).
§ Adjusted using a time-dependent variable based on worker location.

Supplementary Table 5. Proportional hazards ratios for underlying-cause lung cancer mortality by 15-year lagged respirable elemental carbon cumulative exposure and average intensity using categorical exposure cut-points with no tenure restriction, by worker location and for the complete cohort adjusted for worker location*

Analyses	**Results for expanded exposure categories**							
Ever underground workers†								
Cumulative REC exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	80-<160	160-<320	320-<640	640-<1280	≥1280
No. LC deaths	20	4	3	12	16	21	32	14
REC HR (95% CI)	1.00 (referent)	0.87 (0.29 to 2.61)	0.57 (0.16 to 2.01)	1.31 (0.60 to 2.87)	1.37 (0.65 to 2.87)	1.38 (0.68 to 2.80)	2.42 (1.24 to 4.73)	1.15 (0.51 to 2.61)
P		.803	.385	.496	.411	.377	.010	.736
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	4-<8	8-<16	16-<32	32-<64	64-<128	≥128
No. LC deaths	20	2	5	9	10	29	18	29
REC HR (95% CI)	1.00 (referent)	0.59 (0.13 to 2.62)	0.65 (0.23 to 1.85)	1.24 (0.53 to 2.90)	1.20(0.53 to 2.72)	1.82 (0.94 to 3.53)	1.21 (0.58 to 2.53)	1.70 (0.86 to - 3.38)
P		.487	.417	.621	.655	.076	.610	.128
Surface only workers‡								
Cumulative REC exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	≥80				
No. LC deaths	65	7	4	2				
REC HR (95% CI)	1.00 (referent)	0.88 (0.37 to 2.09)	1.59 (0.45 to 5.62)	5.82 (1.15 to 29.39)				
P		.765	.470	.033				
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	≥4					
No. LC deaths	61	15	2					
REC HR (95% CI)	1.00 (referent)	2.09 (1.11 to 3.96)	2.38 (0.53 to 10.81)					
P		.023	.261					
Complete cohort adjusted for worker location§								
Cumulative REC exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	80-<160	160-<320	320-<640	640-<1280	≥1280
No. LC deaths	85	11	7	14	16	21	32	14
REC HR (95% CI)	1.00 (referent)	0.72 (0.37 to 1.40)	0.69 (0.30 to 1.59)	1.59 (0.80 to 3.16)	1.43 (0.73 to 2.81)	1.38 (0.74 to 2.60)	2.44 (1.36 to 4.36)	1.15 (0.55 to 2.37)
P		.328	.383	.190	.295	.311	.003	.712
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	4-<8	8-<16	16-<32	32-<64	64-<128	≥128
No. LC deaths	81	17	7	9	10	29	18	29
REC HR (95% CI)	1.00 (referent)	1.59 (0.92 to 2.76)	1.23 (0.52 to 2.89)	1.88 (0.85 to 4.17)	1.51 (0.70 to 3.27)	2.15 (1.18 to 3.92)	1.31 (0.67 to 2.56)	1.72 (0.93 to 3.19)
P		.096	.642	.121	.299	.012	.426	.086

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; HR probability from two-sided X^2 Wald test. Models adjusted for race/ethnicity, birth year, and sex

(except ever underground); stratified by state.
† Workers categorized as ever underground after first going underground (even if surface later).
‡ Workers categorized as surface only until first going underground (if ever).
§ Adjusted using a time-dependent variable based on worker location.

Supplementary Table 6. Proportional hazards ratios for underlying-cause lung cancer mortality by unlagged respirable elemental carbon cumulative exposure and average intensity using categorical exposure cut-points with no tenure restriction, by worker location and for the complete cohort adjusted for worker location*

Analyses	**Results for expanded exposure categories**							
Ever underground workers†								
Cumulative REC exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	80-<160	160-<320	320-<640	640-<1280	≥1280
No. LC deaths	3	3	2	8	15	24	31	36
REC HR (95% CI)	1.00 (referent)	1.09 (0.22 to 5.45)	0.61 (0.10 to 3.69)	1.19 (0.31 to 4.59)	1.64 (0.46 to 5.80)	1.77 (0.52 to 6.00)	2.62 (0.79 to 8.72)	1.82 (0.54 to 6.08)
P		.912	.591	.803	.446	.362	.116	.332
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	4-<8	8-<16	16-<32	32-<64	64-<128	≥128
No. LC deaths	3	2	4	7	7	33	25	41
REC HR (95% CI)	1.00 (referent)	1.12 (0.18 to 6.81)	1.06 (0.23 to 4.84)	1.86 (0.47 to 7.41)	1.56 (0.40 to 6.08)	3.63 (1.10 to 12.00)	2.64 (0.78 to 8.92)	3.78 (1.13 to 12.66)
P		.904	.945	.377	.525	.034	.119	.031
Surface only workers‡								
Cumulative REC exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	≥80				
No. LC deaths	52	14	8	4				
REC HR (95% CI)	1.00 (referent)	0.77 (0.41 to 1.46)	0.76 (0.30 to 1.92)	1.51 (0.43 to 5.33)				
P		.427	.566	.525				
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	≥4					
No. LC deaths	59	15	4					
REC HR (95% CI)	1.00 (referent)	1.24 (0.66 to 2.34)	2.85 (0.90 to 8.98)					
P		.511	.074					
Complete cohort adjusted for worker location§								
Cumulative REC exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	80-<160	160-<320	320-<640	640-<1280	≥1280
No. LC deaths	55	17	10	12	15	24	31	36
REC HR (95% CI)	1.00 (referent)	0.75 (0.43 to 1.32)	0.58 (0.28 to 1.22)	1.14 (0.51 to 2.56)	1.36 (0.58 to 3.18)	1.46 (0.67 to 3.21)	2.18 (1.02 to 4.66)	1.46 (0.68 to 3.14)
P		.325	.152	.744	.475	.341	.045	.333
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	4-<8	8-<16	16-<32	32-<64	64-<128	≥128
No. LC deaths	62	17	8	7	7	33	25	41
REC HR (95% CI)	1.00 (referent)	1.25 (0.72 to 2.19)	1.89 (0.77 to 4.63)	2.44 (0.85 to 7.04)	1.69 (0.57 to 4.99)	3.69 (1.56 to 8.72)	2.42 (0.99 to 5.90)	3.16 (1.32 to 7.570
P		.431	.166	.098	.344	.003	.052	.010

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. Models adjusted for race/ethnicity, birth year, and sex (except ever underground); stratified by state.

† Workers categorized as ever underground after first going underground (even if surface later).
‡ Workers categorized as surface only until first going underground (if ever).
§ Adjusted using a time-dependent variable based on worker location.

Supplementary Table 7. Proportional hazard ratios on underlying-cause lung cancer mortality by unlagged and 15-year lagged REC cumulative exposure and average intensity as continuous predictors with no tenure exclusion and excluding those with <2, <5, and <10 years tenure, for ever-underground workers*

REC exposure:				Tenure exclusion			
Variable	**Lag (years)**	**Range**	**Units**	**None** **No. LC deaths, HR (95%CI), *P***	**<2 years** **No. LC deaths, HR (95%CI), *P***	**<5 years** **No. LC deaths, HR (95%CI), *P***	**<10 years** **No. LC deaths, HR (95%CI), *P***
Cumulative REC exposure	0	Full	1000 µg/m^3-y	122 1.01 (0.89 to 1.14) .890	111 1.02 (0.90 to 1.16) .714	93 1.05 (0.92 to 1.21) .467	78 1.07 (0.92 to 1.25) .385
			Log µg/m^3-y	122 1.15 (1.00 to 1.31) .046	111 1.19 (1.03 to 1.38) .021	93 1.26 (1.06 to 1.50) .010	78 1.29 (1.06 to 1.57) .012
		<1280 µg/m^3-y	1000 µg/m^3-y	86 2.37 (1.31 to 4.28) .004	75 2.98 (1.58 to 5.62) .001	58 4.07 (1.97 to 8.40) <.001	47 4.90 (2.18 to 11.03) <.001
	15	Full	1000 µg/m^3-y	122 1.03 (0.83 to 1.28) .817	111 1.04 (0.83 to 1.30) .724	93 1.07 (0.85 to 1.35) .585	78 1.10 (0.85 to 1.43) .486
		Full	Log µg/m^3-y	122 1.07 (0.97 to 1.19) .171	111 1.12 (1.00 to 1.25) .052	93 1.19 (1.04 to 1.37) .015	78 1.26 (1.06 to 1.50) .009
		<1280 µg/m^3-y	1000 µg/m^3-y	108 2.79 (1.59 to 4.89) <.001	97 3.19 (1.78 to 5.74) <.001	79 4.06 (2.11 to 7.83) <.001	66 5.19 (2.51 to 0.75) <.001
Average REC intensity	0	Full	100 µg/m^3	122 1.27 (1.02 to 1.58) .036	111 1.23 (0.97 to 1.56) .084	93 1.18 (0.89 to 1.55) .246	78 1.18 (0.85 to 1.64) .335
		Full	Log µg/m^3	122 1.35 (1.12 to 1.62) .002	111 1.32 (1.09 to 1.60) .004	93 1.32 (1.08 to 1.63) .008	78 1.34 (1.07 to 1.68) .012
	15	Full	100 µg/m^3	122 1.14 (0.89 to 1.46) .307	111 1.20 (0.92 to 1.56) .182	93 1.25 (0.93 to 1.68) .138	78 1.32 (0.94 to 1.86) .106
		Full	Log µg/m^3	122 1.11 (0.97 to 1.26) .129	111 1.17 (1.01 to 1.35) .039	93 1.26 (1.06 to 1.50) .010	78 1.33 (1.08 to 1.64) .007

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. Individuals with <2, <5, and <10 years tenure at time of event were excluded. Workers categorized as ever underground after first going underground (even if surface later). Models adjusted for race/ethnicity and birth year; stratified by state. Race/ethnicity was unstable in models with restricted cumulative REC exposure range and tenures <5 and <10 years, and was omitted. Inclusion of the variable had little impact.

Supplementary Table 8. Proportional hazards ratios on underlying-cause lung cancer mortality by unlagged and 15-year lagged REC cumulative exposure and average intensity as continuous predictors with no tenure exclusion and excluding those with <2, <5, and <10 years tenure, for surface only workers*

REC exposure:				Tenure exclusion			
				None	<2 years	<5 years	<10 years
Variable	Lag (years)	Range	Units	No. LC deaths, REC HR (95% CI), *P*	No. LC deaths, REC HR (95% CI), *P*	No. LC deaths, REC HR (95% CI), *P*	No. LC deaths, REC HR (95% CI), *P*
Cumulative REC exposure	0	Full	µg/m^3-y	78 1.00 (0.98 to 1.01) .610	68 1.00 (0.99 to 1.01) .959	57 1.00 (0.99 to 1.02) .663	45 1.01 (0.99 to 1.02) .447
		Full	Log µg/m^3-y	78 0.91 (0.71 to 1.18) .498	68 1.00 (0.72 to 1.38) .979	57 1.01 (0.64 to 1.59) .975	45 1.50 (0.77 to 2.92) .239
	15	Full	µg/m^3-y	78 1.01 (0.99 to 1.03) .254	68 1.01 (1.00 to 1.03) .107	57 1.02 (1.00 to 1.03) .026	45 1.02 (1.01 to 1.04) .007
		Full	Log µg/m^3-y	78 0.93 (0.74 to 1.18) .569	68 0.95 (0.73 to 1.24) .707	57 1.03 (0.75 to 1.42) .842	45 1.20 (0.79 to 1.83) .395
Average REC intensity	0	Full	µg/m^3	78 1.26 (1.02 to 1.55) .030	68 1.24 (0.99 to 1.55) .056	57 1.21 (0.93 to 1.57) .160	45 1.26 (0.95 to 1.66) .112
		Full	Log µg/m^3	78 2.85 (1.27 to 6.42) .011	68 2.72 (1.13 to 6.54) .026	57 2.23 (0.78 to 6.36) .135	45 2.51 (0.76 to 8.25) .130
	15	Full	µg/m^3	78 1.35 (1.08 to 1.68) .008	68 1.31 (1.03 to 1.68) .031	57 1.42 (1.10 to 1.82) .006	45 1.46 (1.13 to 1.88) .004
		Full	Log µg/m^3	78 2.21 (1.11 to 4.41) .025	68 2.02 (0.93 to 4.39) .075	57 2.60 (1.07 to 6.29) .034	45 3.34 (1.22 to 9.18) .019

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. Individuals with <2, <5, and <10 years tenure at time of event were excluded. Workers categorized as surface only until first going underground (if ever). Models adjusted for race/ethnicity, birth year, and sex; stratified by state. Race/ethnicity was unstable in models excluding those with <10 years tenure and was omitted. Inclusion of the variable had little impact.

Supplementary Table 9. Proportional hazards ratios on underlying-cause lung cancer mortality by quartiles of 15-year lagged REC cumulative exposure and average intensity with no tenure exclusion, by worker location and for the complete cohort unadjusted and adjusted for worker location*

Analyses	**Results for quartiles**			
Ever underground workers†				
Cumulative REC exposure (μg/m^3-y)				
Exposure range	0-<108	108-<445	445-<946	≥946
No. LC deaths	30	31	30	31
REC HR (95% CI)	1.00 (referent)	1.50 (0.86 to 2.62)	2.17 (1.21 to 3.88)	2.21 (1.19 to 4.09)
P		.152	.009	.012
Average REC intensity (μg/m^3)				
Exposure range	0-<11	11-<51	51-<111	≥111
No. LC deaths	30	31	30	31
REC HR (95% CI)	1.00 (referent)	1.73 (0.99 to 3.05)	2.11 (1.14 to 3.90)	1.86 (0.98 to 3.52)
P		.056	.018	.057
Surface only workers‡				
Cumulative REC exposure (μg/m^3-y)				
Exposure range	0-<0.70	0.70-<4.6	4.6-<14	≥14
No. LC deaths	19	20	19	20
REC HR (95% CI)	1.00 (referent)	1.28 (0.64 to 2.58)	0.73 (0.35 to 1.53)	1.00 (0.44 to 2.28)
P		.490	.407	.998
Average REC intensity (μg/m^3)				
Exposure range	0-<0.57	0.57-<0.91	0.91-<1.4	≥1.4
No. LC deaths	19	18	21	20
REC HR (95% CI)	1.00 (referent)	1.71 (0.82 to 3.58)	2.22 (1.01 to 4.90)	2.56 (1.09 to 6.03)
P		.154	.049	.031
Complete cohort unadjusted for worker location				
Cumulative REC exposure (μg/m^3-y)				
Exposure range	0-<2.5	2.5-<56	56-<583	≥583
No. LC deaths	50	50	50	50
REC HR (95% CI)	1.00 (referent)	0.58 (0.37 to 0.89)	0.71 (0.45 to 1.10)	0.93 (0.58 to 1.50)
P		.014	.125	.778
Average REC intensity (μg/m^3)				
Exposure range	0-<0.86	0.86-<5.2	5.2-<60	≥60
No. LC deaths	50	50	50	50
REC HR (95% CI)	1.00	1.12 (0.72 to 1.75)	1.32 (0.86 to 2.01)	1.04 (0.66 to 1.64)
P	(referent)	.608	.207	.866
Complete cohort adjusted for worker location§				
Cumulative REC exposure (μg/m^3-y)				
Exposure range	0-<2.5	2.5-<56	56-<583	≥583
No. LC deaths	50	50	50	50
REC HR (95% CI)	1.00	0.55 (0.35 to 0.85)	1.03 (0.60 to 1.77)	1.39 (0.78 to 2.48)
P	(referent)	.007	.925	.261
Average REC intensity (μg/m^3)				

Exposure range	0-<0.86	0.86-<5.2	5.2<60	≥60
No. LC deaths	50	50	50	50
REC HR (95% CI)	1.00 (referent)	1.13 (0.72 to 1.76)	1.98 (1.12 to 3.52)	1.57 (0.86 to 2.86)
P		.600	.019	.144

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. Models adjusted for race/ethnicity, birth year, and sex (except ever underground); stratified by state.

† Workers categorized as ever underground after first going underground (even if surface later).

‡ Workers categorized as surface only until first going underground (if ever).

§ Adjusted using a time-dependent variable based on worker location.

Supplementary Table 10. Proportional hazards ratios for underlying-cause lung cancer mortality by 15-year lagged REC cumulative exposure and average intensity using categorical exposure cut-points excluding workers with <5 years tenure, by worker location and for the complete cohort adjusted for worker location*

Analyses	**Results for expanded exposure categories**							
Ever underground workers†								
Cumulative REC exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	80-<160	160-<320	320-<640	640-<1280	≥1280
No. LC deaths	8	3	2	10	12	14	30	14
REC HR (95% CI)	1.00 (referent)	1.39 (0.36 to 5.39)	0.82 (0.17 to 4.03)	2.69 (0.99 to 7.37)	2.67 (0.98 to 7.27)	2.21 (0.82 to 5.97)	5.01 (1.97 to 12.76)	2.39 (0.82 to 6.94)
P		.634	.807	.054	.055	.119	.001	.109
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	4-<8	8-<16	16-<32	32-<64	64-<128	≥128
No. LC deaths	9	2	5	8	8	27	14	20
REC HR (95% CI)	1.00 (referent)	0.93 (0.19 to 4.49)	1.00 (0.31 to 3.18)	1.79 (0.65 to 4.92)	2.01 (0.74 to 5.50)	3.20 (1.36 to 7.51)	2.11 (0.81 to 5.48)	3.04 (1.20 to 7.71)
P		.930	.998	.261	.173	.008	.125	.019
Surface only workers‡								
Cumulative REC exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	≥80				
No. LC deaths	44	7	4	2				
REC HR (95% CI)	1.00 (referent)	1.16 (0.46 to 2.94)	2.29 (0.60 to 8.75)	8.68 (1.61 to 46.90)				
P		.756	.224	.012				
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	≥4					
No. LC deaths	44	11	2					
REC HR (95% CI)	1.00 (referent)	2.33 (1.11 to 4.90)	4.63 (0.99 to 21.55)					
P		.026	.051					
Complete cohort adjusted for worker location§								
Cumulative REC exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	80-<160	160-<320	320-<640	640-<1280	≥1280
No. LC deaths	52	10	6	12	12	14	30	14
REC HR (95% CI)	1.00 (referent)	0.92 (0.45 to 1.91)	0.93 (0.36 to 2.37)	3.14 (1.39 to 7.14)	2.64 (1.13 to 6.20)	1.99 (0.87 to 4.53)	4.48 (2.13 to 9.40)	2.12 (0.89 to 5.06)
P		.826	.876	.006	.026	.103	<.001	.089
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	4-<8	8-<16	16-<32	32-<64	64-<128	≥128
No. LC deaths	53	13	7	8	8	27	14	20
REC HR (95% CI)	1.00 (referent)	1.72 (0.91 to 3.26)	1.90 (0.75 to 4.80)	2.70 (1.07 to 6.79)	2.48 (0.98 to 6.30)	3.62 (1.72 to 7.60)	2.19 (0.95 to 5.06)	2.94 (1.31 to 6.60)
P		.095	.174	.035	.056	.001	.067	.009

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. Individuals with <5 years tenure at time of event

were excluded. Models adjusted for race/ethnicity, birth year, and sex (except ever underground); stratified by state.
† Workers categorized as ever underground after first going underground (even if surface later).
‡ Workers categorized as surface only until first going underground (if ever).
§ Adjusted using a time-dependent variable based on worker location.

Supplementary Table 11. Proportional hazard ratios for underlying-cause lung cancer mortality by 15-year lagged REC cumulative exposure and average intensity as continuous predictors excluding workers with <5 years tenure, by worker location and for the complete cohort adjusted for worker location*

Analyses	Results for continuous models		
Ever underground workers†			
Cumulative REC exposure			
Exposure range	Full	Full	<1280 μg/m^3-y
Exposure units	1000 μg/m^3-y	Log μg/m^3-y	1000 μg/m^3-y
No. LC deaths	93	93	79
REC HR (95% CI)	1.07 (0.85 to 1.35)	1.19 (1.04 to 1.37)	4.06 (2.11 to 7.83)
P	.585	.015	<.001
Average REC intensity			
Exposure range	Full	Full	
Exposure units	100 μg/m^3	Log μg/m^3	
No. LC deaths	93	93	
REC HR (95% CI)	1.25 (0.93 to 1.68)	1.26 (1.06 to 1.50)	
P	.138	.010	
Surface only workers‡			
Cumulative REC exposure			
Exposure range	Full	Full	
Exposure units	μg/m^3-y	Log μg/m^3-y	
No. LC deaths	57	57	
REC HR (95% CI)	1.02 (1.00 to 1.03)	1.03 (0.75 to 1.42)	
P	.026	.842	
Average REC intensity			
Exposure range	Full	Full	
Exposure units	μg/m^3	Log μg/m^3	
No. LC deaths	57	57	
REC HR (95% CI)	1.42 (1.10 to 1.82)	2.60 (1.07 to 6.29)	
P	.006	.034	
Complete cohort adjusted for worker location§			
Cumulative REC exposure			
Exposure range	<1280 μg/m^3-y		
Exposure units	1000 μg/m^3-y		
No. LC deaths	136		
REC HR (95% CI)	3.62 (1.99 to 6.60)		
P	<.001		
Average REC intensity			
Exposure range	Full		
Exposure units	Log μg/m^3		
No. LC deaths	150		
REC HR (95% CI)	1.20 (1.04 to 1.39)		
P	.015		

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. Individuals with <5 years tenure at time of event were excluded. Models adjusted for race/ethnicity, birth year, and sex (except ever underground); stratified by state.

† Workers categorized as ever underground after first going underground (even if surface later). Race/ethnicity was unstable in model with restricted cumulative REC exposure range and was omitted. Inclusion of the variable had little impact.
‡ Workers categorized as surface only until first going underground (if ever).
§ Adjusted using a time-dependent variable based on worker location.

Supplementary Table 12. Proportional hazard ratios for underlying-cause lung cancer mortality by 15-year lagged REC cumulative exposure and average intensity as continuous predictors with no tenure exclusion and excluding workers with <5 years tenure by age at starting work at the study facilities, and by worker location*

REC exposure:			No tenure exclusion	Excluding <5 years tenure with starting age:				Excluding all <5 years tenure
Variable	Range	Units	No. LC deaths, REC HR (95% CI), *P*	60+ No. LC deaths, REC HR (95% CI), *P*	50+ No. LC deaths, REC HR (95% CI), *P*	40+ No. LC deaths, REC HR (95% CI), *P*	30+ No. LC deaths, REC HR (95%CI), *P*	No. LC deaths, REC HR (95% CI), *P*
Ever underground workers†								
Cumulative REC exposure	<1280 µg/m^3-y	1000 µg/m^3-y	108 2.79 (1.59 to 4.89) <.001	107 2.89 (1.65 to 5.08) <.001	101 3.27 (1.84 to 5.79) <.001	92 3.50 (1.91 to 6.38) <.001	82 3.99 (2.10 to 7.58) <.001	79 4.06 (2.11 to 7.83) <.001
Average REC intensity	Full	Log µg/m^3	122 1.11 (0.97 to 1.26) .129	121 1.12 (0.98 to 1.28) .090	115 1.22 (1.05 to 1.42) .009	106 1.27 (1.08 to 1.50) .005	96 1.26 (1.06 to 1.50) .008	93 1.26 (1.06 to 1.50) .010
Surface only workers‡								
Cumulative REC exposure	Full	µg/m^3-y	78 1.01 (0.99 to 1.03) .254	77 1.01 (0.99 to 1.03) .222	76 1.01 (0.99 to 1.03) .195	66 1.02 (1.00 to 1.03) .063	62 1.02 (1.00 to 1.03) .043	57 1.02 (1.00 to 1.03) .026
Average REC intensity	Full	µg/m^3	78 1.35 (1.08 to 1.68) .008	77 1.35 (1.08 to 1.68) .008	76 1.36 (1.09 to 1.70) .006	66 1.48 (1.20 to 1.82) <.001	62 1.45 (1.16 to 1.80) .001	57 1.42 (1.10 to 1.82) .006

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. Individuals with <5 years tenure and starting age 60+, 50+, 40+, or 30+ years at time of event were excluded. Models adjusted for race/ethnicity, birth year, and sex (except ever underground); stratified by state.

† Workers categorized as ever underground after first going underground (even if surface later). Race/ethnicity was unstable in models with restricted cumulative REC exposure range and starting ages of 30+ and 40+, and was omitted. Inclusion of the variable had little impact.

‡Workers categorized as surface only until first going underground (if ever).

Supplementary Table 13. Proportional hazards ratios on underlying-cause lung cancer mortality. Comparison of alternative 15-year lagged REC cumulative exposure and average intensity with primary estimates with no tenure exclusion and excluding those with <5 years tenure for ever underground workers*

Variable	REC exposure: Range	Units	Tenure exclusion	Metric	No. LC deaths	REC HR (95% CI)	*P*
Cumulative REC exposure	<1280 μg/m^3-y	1000 μg/m^3-y	None	5-year average	105	1.83 (1.00 to 3.35)	.049
				Power	98	1.87 (1.03 to 3.43)	.041
				Median	109	2.35 (1.31 to 4.22)	.004
				Primary	108	2.79 (1.59 to 4.89)	<.001
			<5 years	5-year average	76	2.39 (1.20 to 4.76)	.013
				Power	69	2.64 (1.29 to 5.41)	.008
				Median	80	3.33 (1.71 to 6.47)	<.001
				Primary	79	4.06 (2.11 to 7.83)	<.001
Average REC intensity	Full	Log μg/m^3	None	5-year average	122	1.08 (0.95 to 1.23)	.262
				Power		1.12 (0.98 to 1.28)	.098
				Median		1.11 (0.97 to 1.26)	.143
				Primary		1.11 (0.97 to 1.26)	.129
			<5 years	5-year average	93	1.22 (1.03 to 1.46)	.024
				Power		1.29 (1.08 to 1.55)	.006
				Median		1.26 (1.06 to 1.51)	.010
				Primary		1.26 (1.06 to 1.50)	.010

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. For tenure exclusion analyses, individuals with <5 years tenure at time of event were excluded. Workers categorized as ever underground after first going underground (even if surface later). Models adjusted for race/ethnicity and birth year; stratified by state. Race/ethnicity was unstable in models with restricted cumulative REC exposure range and tenure <5 years excluded, and was omitted. Inclusion of the variable had little impact.

Supplementary Table 14. Proportional hazards ratios on underlying-cause lung cancer mortality by state/ore type. 15-year lagged REC cumulative exposure and average intensity as continuous predictors with no tenure exclusion and excluding those with <5 years tenure, for ever underground workers*

Variable	REC exposure: Range	Units	Tenure exclusion	State/ore type	No. LC deaths, REC HR (95% CI)	*P*
Cumulative REC exposure	<1280 µg/m^3-y	1000 µg/m^3-y	None	MO/limestone	20 5.79 (1.71 to 19.58)	.005
				NM/potash	59 2.19 (1.01 to 4.76)	.047
				OH/salt	6 0.46 (0.03 to 8.21)	.594
				WY/trona	23 4.33 (1.32 to 14.16)	.015
			<5 years	MO/limestone	20 5.78 (1.72 to 19.50)	.005
				NM/potash	43 2.65 (1.05 to 6.65)	.039
				OH/salt	2 11.79 (0.06 to 2500)	.367
				WY/trona	14 8.72 (1.82 to 41.69)	.007
Average REC intensity	Full	Log µg/m^3	None	MO/limestone	22 1.56 (1.03 to 2.35)	.035
				NM/potash	64 1.12 (0.91 to 1.37)	.289
				OH/salt	10 0.90 (0.65 to 1.25)	.521
				WY/trona	26 1.09 (0.86 to 1.39)	.467
			<5 years	MO/limestone	22 1.59 (1.05 to 2.43)	.030
				NM/potash	48 1.14 (0.88 to 1.47)	.317
				OH/salt	6 1.69 (0.55 to 5.22)	.362
				WY/trona	17 1.26 (0.92 to 1.75)	.155

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. For tenure exclusion analyses, individuals with <5 years tenure at time of event were excluded. Workers categorized as ever underground after first going underground (even if surface later). Models adjusted birth year. Race/ethnicity was unstable in some models and was omitted. Inclusion of the variable had little impact, except for OH/salt and WY/trona where the HRs were 13.54 and 9.10 (*P*-values similar) for the restricted exposure and <5 years tenure group.

Supplementary Table 15. Proportional hazards ratios on underlying- and contributing-cause lung cancer mortality by 15-year lagged REC cumulative exposure and average intensity as continuous predictors with no tenure exclusion and excluding those with <5 years tenure, by worker location*

REC exposure:			Tenure exclusion			
			None		<5 years	
Variable	**Range**	**Units**	**No. LC deaths, REC HR (95% CI)**	***P***	**No. LC deaths, REC HR (95% CI)**	***P***
Ever underground workers†						
Cumulative REC exposure	<1280 μg/m^3-y	1000 μg/m^3-y	116 2.48 (1.44 to 4.29)	.001	85 3.44 (1.82 to 6.50)	<.001
Average REC intensity	Full	Log μg/m^3	130 1.10 (0.97 to 1.25)	.140	99 1.24 (1.05 to 1.47)	.012
Surface only workers‡						
Cumulative REC exposure	Full	μg/m^3-y	82 1.01 (0.99 to 1.03)	.266	61 1.02 (1.00 to 1.03)	.035
Average REC intensity	Full	μg/m^3	82 1.36 (1.09 to 1.69)	.006	61 1.43 (1.11 to 1.82)	.005
		Log μg/m^3	82 2.32 (1.17 to 4.58)	.016	61 2.75 (1.16 to 6.53)	.022

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. Individuals with <5 years tenure at time of event were excluded. Models adjusted for race/ethnicity, birth year, and sex (except ever underground); stratified by state.

† Workers categorized as ever underground after first going underground (even if surface later). Race/ethnicity was unstable in models with restricted cumulative REC exposure range and tenure <5 years excluded, and was omitted. Inclusion of the variable had little impact.

‡ Workers categorized as surface only until first going underground (if ever).

Supplementary Table 16. Proportional hazards ratios on underlying-cause esophageal cancer mortality by 15-year lagged REC cumulative exposure and average intensity as continuous predictors with no tenure exclusion and excluding those with <5 years tenure, by worker location*

	REC exposure:		Tenure exclusion			
			None		<5 years	
Variable	**Range**	**Units**	**No. EC deaths, REC HR (95% CI)**	***P***	**No. EC deaths, REC HR (95% CI)**	***P***
Ever underground workers†						
Cumulative REC exposure	<1280 µg/m^3-y	1000 µg/m^3-y	14 1.33 (0.25 to 7.01)	.741	10 2.77 (0.40 to 19.01)	.300
Average REC intensity	Full	Log µg/m^3	16 1.19 (0.81 to 1.73)	.373	12 1.43 (0.85 to 2.40)	.180
Surface only workers‡						
Cumulative REC exposure	Full	µg/m^3-y	7 0.83 (0.65 to 1.05)	.127	5 0.83 (0.64 to 1.06)	.139
Average REC intensity	Full	µg/m^3	7 0.43 (0.09 to 2.16)	.308	5 0.50 (0.06 to 4.01)	.515
		Log µg/m^3	7 0.33 (0.03 to 3.81)	.374	5 0.45 (0.02 to 12.28)	.637

* REC = respirable elemental carbon; EC = esophageal cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. Individuals with <5 years tenure at time of event were excluded. Models adjusted for birth year; stratified by state. Race/ethnicity and sex (for surface only) were unstable in models and were omitted. Inclusion of the variables had little impact.
† Workers categorized as ever underground after first going underground (even if surface later).
‡ Workers categorized as surface only until first going underground (if ever).

Supplementary Table 17. Proportional hazards ratios on underlying-cause lung cancer mortality for 15-year lagged REC cumulative exposure and average intensity with no tenure exclusion, using time since follow-up as the underlying time variable. Expanded categories and continuous modeling results for ever underground workers*

Analyses	**Results for expanded exposure categories**							
Expanded categories (122 LC deaths)								
Cumulative REC exposure (μg/m^3-y)								
Exposure range	0-<20	20-<40	40-<80	80-<160	160-<320	320-<640	640-<1280	≥1280
No. LC deaths	20	4	3	12	16	21	32	14
REC HR (95% CI)	1.00 (referent)	1.63 (0.35 to 7.47)	1.23 (0.24 to 6.27)	2.47 (0.67 to 9.17)	2.78 (0.77 to 9.98)	2.88 (0.82 to 10.16)	5.16 (1.49 to 17.81)	2.56 (0.68 to 9.60)
P		.532	.803	.175	.118	.100	.009	.165
Average REC intensity (μg/m^3)								
Exposure range	0-<2	2-<4	4-<8	8-<16	16-<32	32-<64	64-<128	≥128
No. LC deaths	20	2	5	9	10	29	18	29
REC HR (95% CI)	1.00 (referent)	1.24 (0.20 to 7.59)	1.44 (0.33 to 6.27)	2.73 (0.71 to 10.51)	3.05 (0.82 to 11.44)	4.84 (1.42 to 16.57)	3.21 (0.89 to 11.51)	4.85 (1.34 to 17.50)
P		.819	.625	.143	.097	.012	.074	.016
Continuous models								
Cumulative REC exposure								
Exposure range	Full		Full		<1280 μg/m^3-y			
Exposure units	1000 μg/m^3-y		Log μg/m^3-y		1000 μg/m^3-y			
No. LC deaths	122		122		108			
REC HR (95% CI)	1.11 (0.87 to 1.40)		1.26 (1.07 to 1.49)		3.68 (1.99 to 6.79)			
P	.414		.006		<.001			
Average REC intensity								
Exposure range	Full		Full					
Exposure units	100 μg/m^3		Log μg/m^3					
No. LC deaths	122		122					
REC HR (95% CI)	1.23 (0.92 to 1.65)		1.38 (1.12 to 1.71)					
P	.160		.003					

* REC = respirable elemental carbon; LC = lung cancer; HR = hazard ratio; CI = confidence interval; *P* = HR probability from two-sided X^2 Wald test. Workers categorized as ever underground after first going underground (even if surface later). Models adjusted for age, age^2, race/ethnicity, and birth year; stratified by state.

References

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