Published in final edited form as:
Cancer Causes Control. 2006 September ; 17(7): 911–919.

Historical estimation of diesel exhaust exposure in a cohort study of U.S. railroad workers and lung cancer

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Abstract

We have previously shown an elevated risk of lung cancer mortality in diesel exhaust exposed railroad workers. To reduce exposure misclassification, we obtained extensive historical information on diesel locomotives used by each railroad. Starting in 1945, we calculated the rate each railroad converted from steam to diesel, creating annual railroad-specific weighting factors for the probability of diesel exposure. We also estimated the average annual exposure intensity based on emission factors. The US Railroad Retirement Board provided railroad assignment and work histories for 52,812 workers hired between 1939–1949, for whom we ascertained mortality 1959–1996. Among workers hired after 1945, as diesel locomotives were introduced, the relative risk of lung cancer for any exposure was 1.77 (95%CI=1.50–2.09), and there was evidence of an exposure response relationship with exposure duration. Exposed workers hired before 1945 had a relative risk of 1.30 (95%CI=1.19–1.43) for any exposure and there was no evidence of a dose response with duration. There was no evidence of increasing risk using estimated measures of intensity although the overall lung cancer risk remained elevated. In conclusion, although precise historical estimates of exposure are not available, weighting factors helped better define the exposure-response relationship of diesel exhaust with lung cancer mortality.

Keywords

diesel exhaust; lung cancer; occupational exposure; emission factors

Introduction

Diesel exhaust is considered to be a likely or probable lung carcinogen by most regulatory and administrative bodies (1–4). The assessment of cancer risk has been limited by lack of studies of exposed workers followed for many years and uncertainties regarding the linkage between exposures with job title used in occupational studies. Therefore, we previously assessed lung cancer mortality over 38 years (from 1959 through 1996) in 54,973 US railroad workers. Lung

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cancer mortality was elevated in workers in diesel exhaust exposed jobs associated with operating locomotives (relative risk=1.40; 95% confidence interval=1.30–1.51) but there was no association with duration of exposure (5).

In our previous analysis, exposure was considered to start in 1959 when 95% of the locomotives used by the railroad industry were powered by diesel. Diesel locomotives were introduced into the US railroad industry in large numbers after World War II and during the 1950's as the industry converted from steam locomotives to diesel power beginning with the largest railroads. Since workers in the cohort were employed in the railroad industry for 10 to 20 years before study entry, many of the workers may have been exposed to diesel exhaust prior to 1959. Although the overall proportion of diesel powered locomotives in service in the US increased from approximately 10% in 1945 and to 50% by 1952 (6), we were previously unable to assess the contribution of exposure before 1959 because we lacked specific information about the acquisition of diesel locomotives by individual railroads. In addition, based on differences in engine design, it is likely that diesel locomotives introduced in the 1940's and 1950's had greater particulate emissions than later locomotives. In this report, we use extensive information about the number and design of locomotives used by each railroad to estimate relative differences in historical and more recent exposures. This information allowed the development of a profile of exposure for jobs in each railroad that could be assigned to each worker, addresses exposures starting with the transition to diesel locomotives, and possibly permits improved estimates of lung cancer risk associated with exposures.

Materials and Methods

Population

The U.S. Railroad cohort has been described in detail elsewhere (5). A cohort of 54,973 white male workers, aged 40–64 and with 10–20 years of prior experience in 1959 was obtained from the U.S. Railroad Retirement Board (RRB). Diesel exposed and unexposed blue-collar workers in, 39 job codes were included. Although detailed historical measurements of exposure were not available, exposure assignments were validated with an industrial hygiene survey conducted in 1981–1982 (7,8). The Brigham and Women's Hospital and VA Boston Healthcare System Institutional Review Boards approved the study protocol.

Outcome and follow-up

Vital status through 1996 was determined from RRB records, the Social Security Death Master and Health Care Financing Administration records. For subjects known to have died, cause of death (ICD-9) was obtained from a search of the National Death Index (NDI) between 1979 (the first year NDI was available) and 1996. Prior to 1979, cause of death was obtained from death certificates.

Lung cancer mortality (ICD-9 Code 162) was defined by the underlying cause of death or by lung cancer appearing elsewhere on the death certificate. This is appropriate because lung cancer is usually rapidly fatal after diagnosis.

Exposure to diesel exhaust

The RRB provided a listing of yearly job code and months of railroad service for each worker from 1959 forward, and total service months worked. Based on the industrial hygiene survey, engineers (engineers and firemen) and conductors (conductors, brakemen, and hostlers) were considered exposed to diesel exhaust. The unexposed group included ticket agents, station agents, signal maintainers and clerks. The shop job codes selected were not specific to diesel locomotive shops, therefore, the shop worker group was considered a separate group with a mix of highly exposed and unexposed workers.

The RRB computerized database also identified each worker's last railroad employer. A detailed examination of a sample of 200 paper work history records indicated that the majority of workers (95%) did not change railroads during their careers. Therefore, we considered that the railroad listed was the employer for an individual's entire career. There were over 500 railroads listed in the railroad worker database, therefore, we limited our assessment to the 93 railroads that individually contributed at least 0.1% of the cohort. This sample included 93% of the eligible cohort (52,812), with 22 larger railroads accounting for 76% of the sample.

For each of the selected railroads we obtained yearly locomotive rosters from builder's records and company specific railroad rosters from 1945 through 1986. After 1986, all workers in the cohort had retired. These rosters were used to determine the fleet composition including the make, model and horse power of each locomotive in service. From this information, the number and type of locomotives that were diesel was calculated annually for each railroad. EPA emission inventory guidance documentation provided emission factors for most locomotives. If an EPA emission factor was not available for a given locomotive type, it was assigned an extrapolated value based on locomotives and diesel engine designs with similar engine characteristics. This metric was based on the assumption that exposure was proportional to the total engine emissions. From these two sources of information two metrics of exposure, an average emission adjustment factor (EAF) and the diesel fraction (DF) were calculated for each year for each railroad. These metrics were assigned to the work history of each cohort member based on the last railroad information from the RRB.

The average EAF is a factor quantifying the relative amount of particulate matter produced by the diesel locomotives for a given railroad for a given year. For each locomotive EAF is calculated using the following formula:

$$\mathrm{EAF}(\mathrm{g}\,/\,\mathrm{hr}) = \mathrm{EF}(\mathrm{g}\,/\,\mathrm{gal}) * \mathrm{HP} * \mathrm{bsfc}\,(\mathrm{gal}\,/\,\mathrm{HP} - \mathrm{hr})$$

Where EF is the US EPA emission factor in units of grams per gallon

HP is the horsepower of the locomotive and

bsfc is brake specific (or power specific) fuel consumption in gallons per horsepower-hour

Therefore, the units of EAF are grams of diesel exhaust particulate per hour. In the diesel emission factor handbook (9) the USEPA suggests the use of a constant bsfc to convert emission factors from grams/gallons of fuel consumed to grams/horsepower hours for large diesel engines since the engines operate over distinct throttle (or load) positions. Therefore, because we are comparing all EAFs to each other, bsfc cancels from the equation, and the units of EAF are relative to the EAFs of all other locomotives. The average yearly EAF for a given railroad is the weighted average of the single unit EAFs over all of the different models in service during the year [∑(N*EAF)/N]. To account for railroad service prior to a railroad merger, a weighted average of the EAFs of precursor railroads was calculated for the years prior to the merger.

The DF represents the probability of diesel exposure for a given railroad each year. The DF was calculated in two ways based on whether or not the first year a railroad was 100% diesel was known from historical sources (referred to as the index year). If the index year was not known at a railroad, starting in 1945 the product of the single unit EAF and number of diesel locomotives for each locomotive model was summed [∑(EAF*N)]. The first year that this sum became constant was used as the index year. For all years previous to the completion of dieselization, the DF was calculated by dividing that year's sum [∑(EAF*N)] by the value of the index year.

Statistical analysis

To assess the relationship of exposure to diesel exhaust with lung cancer mortality, we conducted Cox proportional hazard analyses with calendar year used as the time axis. Mortality follow-up began on January 1, 1959. Each subject contributed person-time to the analysis up until December 31, 1996, or until the date of death, whichever came earlier. We calculated relative risks (RR) and 95% confidence intervals (CI) for workers identified as diesel exposed (engineers and conductors) compared to the unexposed (clerks and signal maintainers). Shopworkers were included in models as a separate group. All models described here and subsequently were performed in SAS (Version 8, SAS Institute Inc., Cary, NC).

We have assumed that "dose" of diesel exhaust exposure, represented by years of cumulative exposure to diesel exhaust particulate, is an important metric in the pathophysiology of lung cancer. Therefore, we considered the effect of cumulative exposure to diesel exhaust using several approaches. We calculated years of work in an exposed job from yearly information on months of work and job title. First year of work was available for workers starting in 1947 or later. For those employed before 1947, we estimated start date based on the total months of service information provided by the RRB, assuming a 12- month year for each year before 1959. Cumulative years of diesel exposure were calculated starting in 1945 by summing the product of yearly months of service and DF for engineers and conductors. We modeled years of exposure as time varying variables for five-year exposure categories. We also constructed models where the exposure was lagged by excluding the last 5, 10 and 15 years.

To account for differences in diesel exhaust exposure between and within individual railroads over time, we calculated a yearly intensity score. Using the overall distribution of the average yearly EAF between 1945 and 1986, we chose cutoffs of <20 μg/hr (group 1), 20-<25 μg/hr (group 2), and ≥25 μg/hr (group 3), to group values below the median, at the median, and above the median level, respectively. For each cohort member, the year-specific intensity score (1, 2, or 3) was multiplied by months of work in each year multiplied by DF to obtain an index of cumulative exposure to diesel exhaust, or "intensity-years". Models were considered with intensity score and DF included as separate terms. Similar models were considered using the average yearly EAF as opposed to intensity score. Time-varying exposure variables were modeled in Cox proportional hazards analyses as continuous variables or in quintiles.

Age was controlled by stratification in 1-year categories. To account for a potential healthy worker survivor effect, we adjusted for total years on work and years off of work in all models. We also stratified all models by year of hire (1939–1944 and 1945–1949) to indirectly assess the influence of exposure to coal burning engines on lung cancer mortality by dividing the cohort into groups that began employment before and after the start of dieselization.

Results

Description of the railroads

The railroads converted from steam to diesel locomotives starting in 1945 through the 1950s. As demonstrated by the distribution of the DF, 5% of the railroads represented in this cohort were fully diesel by 1952, 25% by 1956, 50% by 1957, 75% by 1958 and 100% by 1961 (Figure 1). Two railroads never converted to diesel, and instead converted to electric locomotives.

The average EAF is essentially a measure of intensity of exposure to diesel at each railroad. A plot of average EAF for the railroads in the cohort versus calendar year (Figure 2) indicates that although emissions did increase slightly between 1945 and 1986 there was relatively little variability over time. Although the PM emissions per gallon of fuel or horsepower generally decreased during the transition from locomotives used in the 1940's and 1950's to locomotives introduced later (based on EPA emission factors), the typical locomotive horsepower rating grew, offsetting this difference For example, in the 1950's, a typical locomotive used in road service was 1500 HP, whereas by the 1970's and 1980's, it had increased to 3000 to 4000 HP. Thus, the concentration of particulate in the exhaust gases decreased, but the quantity of gases increased.

Description of the population

The characteristics of the cohort by exposure category at baseline (1959) are presented in Table 1. The three occupational groups are similar in terms of age in 1959 and at death, and years of work. A smaller percentage of the engineers and conductors were hired in 1945 or later, compared to the shopworkers and clerks.

Years of exposure to diesel exhaust and lung cancer mortality

For individuals in the engineer/conductor group (exposed), we weighted each year of work with the year- and railroad-specific DF to account for the probability of exposure to diesel exhaust. Therefore, instead of assuming that diesel exposure began in 1959 (the year marking 95% dieselization of the industry), as in our previous analyses (5), this method accounted for exposure during the transition years.

We assessed the relationship between cumulative years of work and lung cancer risk, controlling for attained age, any shop work, total years worked and time since last worked in models without an exposure lag and with lags of 5, 10 and 15 years. Lung cancer mortality was significantly associated with a diesel exhaust exposed job group regardless of the exposure lag model, but risk did not increase linearly with years of exposure (Table 2). In a 5-year lag model, individuals with any work in a diesel exposed job had a relative risk of 1.41 (95% CI=1.30–1.53), compared to those without work in a diesel exposed job. Analyses of the significance of exposure in the years before death suggest that it is appropriate to exclude exposure in the 5 years before death in the assessment of lung cancer. Therefore, we have chosen to focus on the 5-year lag model in further analyses.

In analyses stratified by year of hire and with a 5 year lag, the relative risk for any work in an exposed job compared to work only in unexposed jobs was greatest among individuals who were hired after 1945, the beginning of dieselization: Hire date 1939–1944 RR=1.30; 95% CI=1.19–1.43; Hire date 1945–1949 RR=1.77; 95%CI=1.50–2.09 (p for interaction=0.003). Further, there was an apparent exposure response with increasing cumulative years of work among individuals who were hired in the later, but not in the earlier group (Table 3). The results from the models without an exposure lag and in models with exposure lags of 10 and 15 years had similar patterns.

Measures of exposure intensity and lung cancer mortality

We also explored the association of lung cancer mortality with "intensity-years", defined as years of work in a diesel exposed job weighted by railroad and year specific categories of intensity of exposure. There was no evidence of increasing risk of lung cancer with quintiles of increasing "intensity-years" (Table 4). In models stratified by year of hire, the magnitude of the relative risks was also greater for workers hired after 1945 than those hired before 1945. Although the upper 3 quintiles of intensity-years had greater relative risks than the lower 2 quintiles, an exposure response relationship was not as evident as with years of exposure (Table 4). Similar results were obtained using the average yearly values of EAF as opposed to the intensity score (data not shown).

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Discussion

In this analysis we used historical railroad rosters and EPA emission factors for diesel locomotives to improve estimates of relative exposures to diesel exhaust at different railroads over time. We calculated weighting factors based on probability of exposure (DF: diesel fraction) and estimates of exposure intensity based on engine emission factors and horsepower (EAF: average emission adjustment factor). This is based on the assumption that worker exposure was roughly proportional to the quantity of locomotive particulate emissions. In survival analyses of weighted cumulative years of exposure to diesel exposed jobs in the railroad industry, we observed an elevated risk of dying of lung cancer compared to work in non-exposed jobs. Overall, there was no evidence of increasing lung cancer risk with increasing measures of exposure. However among workers hired after 1945 (1945–49), as diesel locomotives were introduced, the relative risk for any exposure was 1.77 (95%CI=1.50–2.09), and there was evidence of an exposure-response relationship with exposure duration (0–10 yrs of exposure with a 5 year lag: RR=1.15; 10–15 years: RR=1.49; 15-<20 years: RR=1.89; 20-<25 years: RR=1.83; =25 years: RR=1.78). Exposed workers hired before 1945 (1939–44) had a relative risk of 1.30 (95%CI=1.19–1.43) for any exposure and there was no evidence of a dose response with duration. Although the overall findings were similar to the unweighted analyses presented in our previous publication (5), the weighting factors helped better define the exposure-response relationship of diesel exhaust with lung cancer mortality.

Our observation of lung cancer risk is similar to the risk noted by others in the literature. In more than 35 studies of workers with occupational exposure to diesel exhaust, excess risk of lung cancer is consistently elevated by 20–50% (reviewed in (10,11). Most occupational studies rely on a single report of job title to define exposure. In this study, job title was available for each year of follow-up, and jobs with exposure to diesel emissions were categorized by an industrial hygiene study. Further, railroad specific information on probability and intensity of exposure were incorporated. The increased lung cancer risk in railroad workers occupationally exposed to fine particulate matter is consistent with increased lung cancer risks observed attributable to fine particulate air pollution in prospective population-based cohorts (12,13) and risk of lung cancer attributable to vehicle exhausts in urban settings (14).

Although our exposure metric focused on the measurement of diesel mass emissions, since diesel exhaust is a complex mixture of submicron particles, vapors and gases, the specific agents and mechanisms whereby diesel exhaust could result in lung cancer in humans are uncertain. Additionally, prior to the conversion to diesel locomotives, the railroad industry used steam locomotives powered by coal, and the lung cancer risk associated with exposure to steam engine combustion products has not been characterized. To minimize the influence of steam engine combustion products, we also performed analyses stratifying the cohort by year of hire, before and after 1945, the year when the conversion to diesel began. The observation of an exposure-response relationship only in the group hired later but not in the group hired during the end of the steam era suggests that exposures to previous steam locomotive emissions in this cohort indeed may have also contributed to lung cancer risk and reduced the opportunity to detect an exposure response relationship associated with diesel exposure alone. This was supported by sensitivity analyses to determine the appropriateness of our cutoff date. As the cutoff moved earlier, more into the steam era, there was less evidence of a dose response and the hazard ratios were attenuated.

Although greater lung cancer risks were observed in analyses that incorporated measures of intensity, the exposure response relationship was not as evident. There are a number of opportunities for misclassification, which may partially explain the lack of dose response. These include limitations to the calculation of estimates of exposure intensity and the potential for measurement error when attaching a single exposure factor representing an entire railroad to an individual person. In addition, information regarding railroad company for each subject was limited to a single employer. Although yearly RRB job codes were available, differences in actual job duties and exposures among workers with the same job title may result in exposure misclassification. EPA emission factors are derived using a limited test procedure (9), which we have assumed applies to real-life conditions at all railroads. Further, they are not available for all locomotives, especially those used in the earlier years of the study, but these values were extrapolated from locomotives with similar engine characteristics. Finally, there was no information regarding how the characteristics of emissions (such as particle size distribution, organic content) changed over time.

Since we do not know which trains an individual worked on, we have assumed that during each year of employment individuals are exposed to the average locomotive used by their railroad, which may either under or overestimate their actual exposure. Local level meteorology, operating practices and worker positioning may affect individual exposures. Some early diesel locomotives were operated with the engine stack in front of the cab, exposures (15–17). It was not possible to conduct sampling in the industry to validate the relationship between our exposure model assumptions and personal exposure, and historical exposure measurements were not available. Therefore, it is possible that we may have increased the exposure misclassification, especially in the intensity related analyses.

This analysis includes 93% of the cohort described in previous analyses (5). There is no difference in the overall association of lung cancer mortality with exposure in this subgroup compared to the full cohort. Small RRs may be affected by uncontrolled confounding, such as differences in cigarette smoking habits in subjects with and without diesel exposure. In this retrospective cohort, individual data on smoking history are not available. In previous analyses we have indirectly adjusted for smoking and observed small attenuations of the RRs. However, they have remained statistically significant (5). Therefore, we do not believe that differences in smoking or other confounders account for the observed results. Differences in smoking prevalence by hire date would also not explain the higher RR observed in the group hired later since both the exposed and unexposed workers were hired at the same time and all age ranges are represented in each hire group. Further, all analyses are adjusted by birth cohort indirectly accounting for temporal changes in smoking behavior.

Although precise exposure measurements are unavailable, first generation diesel locomotives in the late 1940’s and the 1950’s were said to be “smokier” than locomotives introduced later, i.e. the emissions were more concentrated, which is consistent with the EPA test data (7,18). It is possible that these locomotives produced particulate matter (PM) at rates up to 1.5 to 2 times that of second generation engines (19). In the early 1960’s and in the 1980’s, a second generation and third generation of locomotives were introduced, respectively. These locomotives had improved emission characteristics compared to the first diesel locomotives, but the volume of emissions was higher partially compensating for the effect of reduced concentration on the total emissions. The smokier first generation locomotives in the larger railroads were generally retired during the 1960’s, and an additional downsizing occurred during the 1980’s when other older models were retired over a short time period as the industry both downsized numbers of units in the fleet and relied more on higher horsepower newer models (20).

Based on this historical information, we had originally hypothesized that there would be greater variation in intensity of exposure between railroads and that the levels across the industry would decrease over time as emission factors decreased with improvements in technology. However, there was little variation in the average railroad EAF (total emissions) as a function of calendar year. The increase in horsepower, also a determinant of emissions, offset the emission improvements and resulted in a relatively constant EAF over time. Therefore, it is not surprising that incorporating railroad and time specific intensity measures to our survival analyses did not change our overall results. Despite the limitations, the calculation of DF and average railroad EAF provide a more precise estimate of exposure than job title alone by incorporating some aspects of the differences between railroads over time and allowing an assessment of pre-1959 exposures.

Conclusions

In this cohort of railroad workers, we observed an elevated risk of dying of lung cancer compared to work in non-exposed jobs, after adjustment for time and railroad-specific differences in probability and intensity of exposure to diesel exhaust. There was a suggestion of an exposure-response relationship with years of work among workers hired after the beginning of the transition from steam to diesel (1945) and these workers had a greater lung cancer mortality risk compared to workers hired earlier. Although precise historical estimates of exposure are not available, these results provide further evidence supporting the carcinogencity of diesel exhaust and support the role of recent regulatory efforts to limit diesel emissions. Further work is needed to determine the effectiveness of changes in diesel engine technology on lung cancer risk.

Acknowledgements

Supported by NIOSH CCR115818 and NCI CA79725. The authors thank Hongshu Guan for programming assistance, and the Railroad Retirement Board, in particular, Eileen Binkus and Anne Alden.

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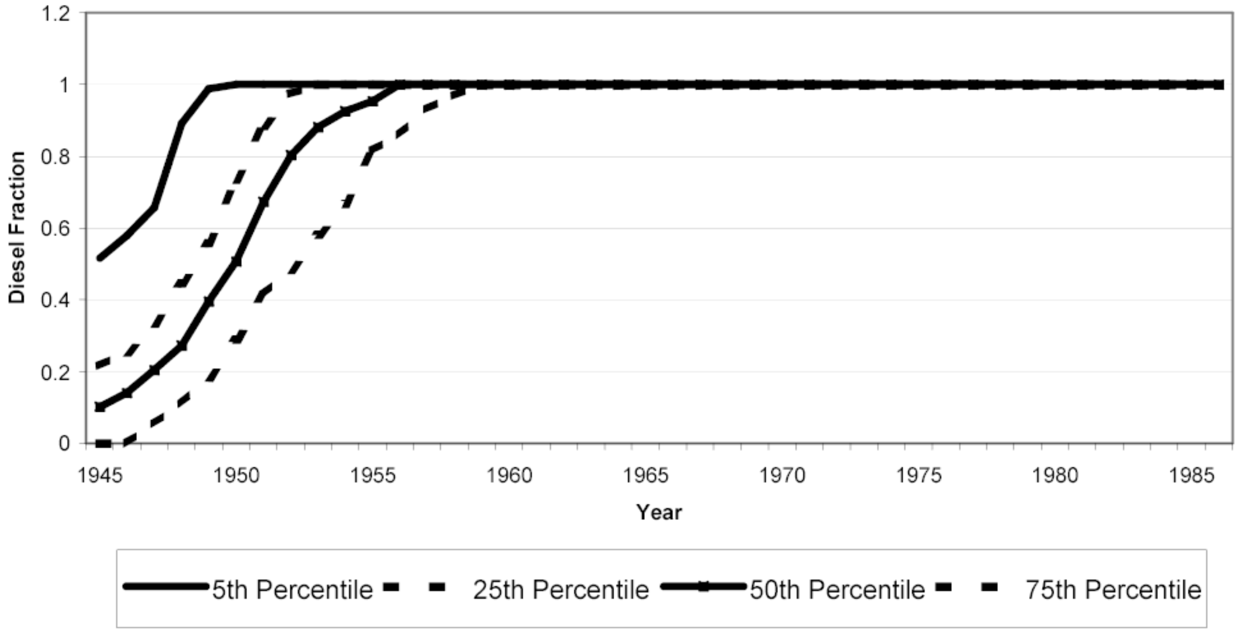

Figure 1.
Distribution of diesel fraction based on calendar year, 1945–1986.

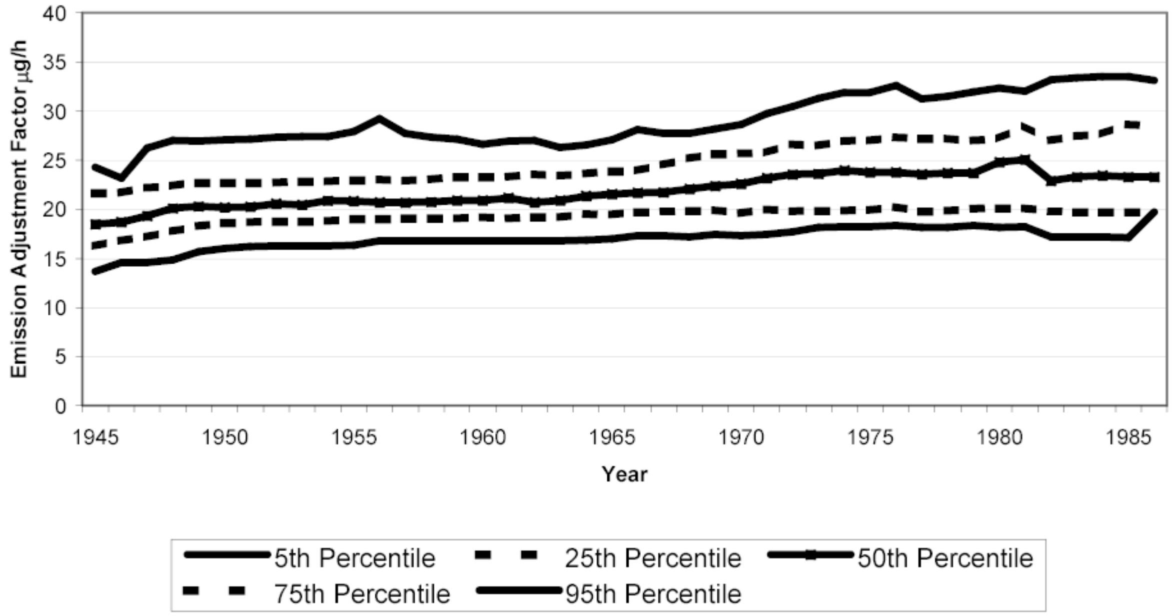

Figure 2.
Distribution of the yearly railroad specific average emission adjustment factor 1945–1986

Table 1

Characteristics of the cohort by job title in 1959

	Engineers and Conductors (exposed)	Shopworkers	Clerks and signal maintainers (unexposed)
N	27,920	11,612	13,280
# lung cancer deaths	2,396	880	918
Mean age in 1959	47.8 (6.2)	49.4 (6.7)	48.8 (6.8)
Mean age of retirement	61.4 (5.6)	61.2 (6.1)	61.3 (6.0)
Mean age at death	69.7 (10.0)	71.5 (10.1)	71.0 (10.1)
Mean years of work	28.5 (6.5)	26.3 (6.7)	27.2 (6.8)
Mean years off work	11.4 (8.2)	13.0 (9.1)	12.7 (8.9)
% hired 1945–1949	13.4	27.7	37.8

Table 2

RR of lung cancer mortality 1959–1996 and diesel fraction weighted cumulative years of work in an engineer or conductor job group (years of diesel exposure) compared to unexposed workers adjusting for age, work in any shop category, years of employment and time since last worked as time dependent covariates.

			Years of Work as Engineer or Conductor				
Lag Model		**Not Exposed**	**0-<10**	**10-<15**	**15-<20**	**20-<25**	**≥25**
None	Cases	916	156	346	582	728	559
	Person years	332,660	72,480	165,639	166,208	161,152	121,594
	RR	ref	**1.23**	**1.36**	**1.52**	**1.41**	**1.27**
	95% CI		1.03–1.47	1.20–1.55	1.36–1.69	1.27–1.56	1.13–1.43
5 years	Cases	916	243	396	557	696	479
	Person years	334,615	192,733	146,830	136,493	122,969	86,094
	RR	ref	**1.22**	**1.34**	**1.48**	**1.47**	**1.29**
	95% CI		1.05–1.43	1.18–1.52	1.33–1.65	1.32–1.63	1.14–1.47

Table 3

RR of lung cancer mortality 1959–1996 and diesel fraction weighted cumulative years of work in an engineer or conductor job group (years of diesel exposure) stratified by year of hire (1939–1944 and 1945–1949). No lag and 5-year lag models are presented, adjusting for age, work in any shop category, years of employment and time since last worked as time dependent covariates.

				Years of Work as Engineer or Conductor				
Hire Date	**Lag Model**		**Not Exposed**	**0-<10**	**10-<15**	**15-<20**	**20-<25**	**≥25**
1939–1944	No Lag	Cases	687	136	296	475	603	417
		Person years	234,808	58,841	136,418	135,907	132,885	93,717
		RR	**ref**	**1.19**	**1.30**	**1.42**	**1.30**	**1.15**
		95% CI		0.98–1.45	1.12–1.50	1.26–1.60	1.16–1.46	1.00–1.32
	5yr Lag	Cases	687	211	330	454	577	355
		Person years	236,322	157,192	120,396	111,181	101,083	66,403
		RR	**ref**	**1.19**	**1.28**	**1.37**	**1.37**	**1.16**
		95% CI		1.00–1.41	1.11–1.47	1.21–1.55	1.21–1.54	1.00–1.34
1945–1949	No Lag	Cases	229	20	50	107	125	142
		Person years	97,852	13,639	29,221	30,301	28,267	27,876
		RR	**ref**	**1.08**	**1.47**	**1.85**	**1.80**	**1.72**
		95% CI		0.68–1.73	1.07–2.02	1.46–2.34	1.43–2.26	1.36–2.17
	5yr Lag	Cases	229	32	66	103	119	124
		Person years	98,292	35,541	26,434	25,313	21,886	19,691
		RR	**ref**	**1.15**	**1.49**	**1.89**	**1.83**	**1.78**
		95% CI		0.77–1.70	1.11–1.99	1.48–2.40	1.45–2.32	1.39–2.28

Table 4

RR of lung cancer mortality 1959–1996 and intensity and years of diesel exposure weighted[a] cumulative years of work in an engineer or conductor job group, stratified by year of hire (1939–1944 and 1945–1949). Models are adjusted for age, work in any shop category, years of employment and time since last worked as time dependent covariates, and include a 5-year exposure lag.

			Quintiles of "intensity-years"				
Hire Date		**Not Exposed**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**
1939–1949 (all)	Cases	916	410	522	472	507	460
	Person years	334,704	248,599	152,914	107,566	94,294	81,655
	RR	**ref**	**1.37**	**1.37**	**1.47**	**1.35**	**1.35**
	95% CI		1.21–1.56	1.23–1.53	1.32–1.65	1.20–1.51	1.19–1.53
1939–1944	Cases	687	326	394	417	427	363
	Person years	236,377	199,407	115,233	97,381	78,075	66,103
	RR	**ref**	**1.26**	**1.33**	**1.33**	**1.28**	**1.24**
	95% CI		1.09–1.46	1.17–1.51	1.17–1.50	1.13–1.45	1.08–1.43
1945–1949	Cases	229	80	98	93	76	97
	Person years	98,327	49,892	29,621	18,810	15,434	15,073
	RR	**ref**	**1.63**	**1.54**	**2.02**	**1.50**	**1.81**
	95% CI		1.24–2.14	1.21–1.96	1.58–2.59	1.14–1.96	1.39–2.35

[a]The intensity score, based on the overall distribution of the EAF, was divided into three groups: <20 μg/hr (group 1), 20-<25 μg/hr (group 2), and ≥25 μg/hr (group 3). For each cohort member, "intensity-years" was calculated by multiplying the year-specific intensity score (1, 2, or 3), and years of diesel exhaust exposure weighted by diesel fraction (DF).