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Cancer Mortality Among Coke Oven Workers

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The OSHA standard for coke oven emissions, which went into effect in January 1977, sets a permissible exposure limit to coke oven emissions of 150 μg/m³ benzene-soluble fraction of total particulate matter (BSFTPM). Review of the epidemiologic evidence for the standard indicates an excess relative risk for lung cancer as high as 16-fold in topside coke oven workers with 15 years of exposure or more. There is also evidence for a consistent dose-response relationship in lung cancer mortality when duration and location of employment at the coke ovens are considered.

Dose-response models fitted to these same data indicate that, while excess risks may still occur under the OSHA standard, the predicted levels of increased relative risk would be about 30–50% if a linear dose-response model is assumed and 3–7% if a quadratic model is assumed. Lung cancer mortality data for other steelworkers suggest the predicted excess risk has probably been somewhat overestimated, but lack of information on important confounding factors limits further dose-response analysis.

Introduction

The current standard for occupational exposure to coke oven emissions appeared in the Federal Register in October 1976, and went into effect in 1977 (*1*). This OSHA standard sets a permissible exposure limit to coke oven emissions of 150 μg/m³ benzene-soluble fraction of total particulate matter (BSFTPM) produced by the destructive distillation or carbonization of coal. In addition, the standard specifies minimum work practice and engineering controls, as well as use of respirators and protective clothing. This paper presents an overview of the major epidemiologic research that formed the basis for establishment of the standard. In particular, the evidence for a dose-response relationship between exposure to coal tar pitch volatiles and lung cancer is reviewed. The problems and issues inherent in the evaluation of effects of exposure to various levels of coal tar pitch volatiles is discussed.

By-Product Coke Plant

In order to understand the nature of the exposures, some knowledge of the by-product coke plant is useful. The primary purpose of the by-product coke plant is the transformation of coal into metallurgical coke, with a secondary function being the recovery of chemical by-products resulting from carbonization. The first by-product coke plants were introduced shortly before the turn of the century. Prior to that time beehive ovens were used for the production of the coke required in the steel-making process. Beehive ovens, which allowed the volatiles produced during coal carbonization to escape into the atmosphere, were gradually replaced by by-product coke ovens. Except for brief periods during World War II and the Korean War, virtually all coke has been made in by-product coke ovens in recent years. The by-product coke plant consists of three major areas: a coal-handling area for handling storage and blending of coal; coal oven batteries for production of coke; and by-products plant for recovery of gas and chemical products such as ammonia, naphthalene, benzene, creosote oil and toluene.

A coke battery consists of 10 to 100 ovens made up of heating chambers, coking chambers, and regenerative chambers. Heating and coking chambers alternate, while the regenerative chambers are located underneath. Coal is charged through ports on top of the oven, while doors on both sides of the ovens are removed to push the coke out into railroad quenching cars at the completion of the 16-20 hr combustion time. The effluents created during the coking process are collected and routed through pipes to by-product areas for further refinement. The major

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exposures to workers result from leakage about the lids or pipes at the top of the ovens or from the oven doors due to incomplete sealing.

Background of Coal Tar Cancers

An excellent review of the historical studies of coal tar has been presented previously by Lloyd (*2*). The most important epidemiologic observations are summarized here to provide the background for our investigations of coke plant worker's mortality.

It has been known for over 200 years beginning with Percivall Pott's observation in 1775 of scrotal cancers in London chimney sweeps that some agent produced during combustion of bituminous coal was carcinogenic for the skin of man (*3*).

The next occupational group noted to have a risk of scrotal cancer was men involved in the carbonization of lignite (*4*). This was followed by a report of Manouvriez in 1876 that French briquette workers who were exposed to coke oven tar and pitch suffered from scrotal cancer and facial epithelioma (*5*). Further reports of occupational skin cancers in related occupations followed, leading Great Britain in 1907 to include scrotal epithelioma and epitheliomatous cancer of the skin related to exposure to coal tar compounds under the Workman's Compensation Act.

In 1907 the first report of skin cancers among carbon workers in the United States was published (*6*). Animal studies beginning in the early 1900s eventually resulted in the isolation of 3,4-benzpyrene, a potent skin carcinogen (*7*).

Observations dealing with cancers of other organ sites in association with coal tar or distillate exposures began to appear in the 1930s. Both Japanese (*8*) and British (*9*) producer gas workers were reported to show excesses in lung cancer. The earliest study of coke oven workers published by Reid and Buck (*10*) described a negative finding for lung cancer in retirees, a result which may be partly attributable to study design and partly to our subsequent finding that the highest risk occurs in a small proportion of all coke oven workers. An unpublished report in 1960 by Phair and Stirling deals with competing causes of death among coal tar workers in various industries. They cite a negative finding for white workers (22 observed deaths versus 22 expected), but a 3-fold excess for nonwhite workers (17 observed deaths versus 5.8 expected). This rather puzzling excess was found on further subdivision of the workers to be confined to Allegheny County, Pennsylvania, workers in coke production and handling. The lack of consistency in the results, coupled with certain methodological limitations of the study, led the authors to question the reliability of this observation.

Overview of Long-Term Mortality Studies

In 1962 the Department of Biostatistics, University of Pittsburgh, initiated a study of the relationships between job exposures and cause-specific mortality, 1953-1961, among approximately 59,000 men employed at seven Allegheny County steel plants in 1953. The specific details of the design and results for several occupational groups of concern have been presented (*2, 11–19*). The study data included birthdate, birthplace, race, complete detailed work history at the plant, residence in 1953, and date and cause of death when applicable. Underlying causes for the deaths were coded by a trained nosologist using the Seventh Revision of the International List (*20*).

Our interests centered on men employed at or in the immediate vicinity of the coke ovens. However, classifying workers into various work and exposure groups is complicated, even with the detailed job histories available in the steelworkers study. Terminology from plant to plant and over time is not standardized, and certain job titles are too ambiguous to classify precisely.

The coke ovens and by-products plant can be divided by location at the ovens or type of by-product operation. Generally, jobs have been classified into coke oven or non-oven jobs, with the coke oven group including all jobs requiring some or part of the working day spent at the top or side of the coke ovens. For our analyses based on duration of exposure, priority has been given to the coke oven experience when assigning a worker to oven or non-oven. Similarly, work at the top of the ovens has been given priority over work at the side of the ovens when considering specific subgroups at the coke oven (*21*).

Classification of workers into various categories within the coke plant has been done as described above, with workers in the steel industry who were never in the coke plant being used as the comparison group for calculating expected deaths and mortality ratios. All estimated relative risks have been adjusted for race, age, and calendar period of death. Significance of the relative risks has been assessed by a summary chi-square with one degree of freedom (*22*).

Lloyd (*2*) presented the first analysis of coke plant workers in Allegheny County based on the follow-up period, 1953-1961. His major observations were as follows. There was an excess mortality risk from lung cancer among coke plant workers, which was confined to men employed at the coke ovens. The greatest risk occurred among the topside workers where the estimated relative risk was 10-fold among men with five years or more at the top of the ovens. The risk was apparently limited to nonwhite workers, but an examination by length of exposure at the top of the ovens showed that topside oven workers in the Allegheny County plants at that time were primarily black. This observation suggested that lack of sufficient exposure to produce lung cancer might explain the negative finding for whites. Also, an excess risk of certain digestive cancers occurred in non-oven coke plant workers, but the number of deaths was too small to attempt to delineate the risk further.

Because of the need to define more fully the lung cancer risk among coke oven workers, particularly as related to racial and geographic differences, the study was expanded in the late 1960s to ten additional plants. For these plants the study population was limited to all coke oven workers and a sample of other workers in the plants matched by race and starting date of employment to the coke oven workers. In addition, the mortality observation period for the original Allegheny County steelworkers population was extended through 1966.

Examination of the mortality through 1966 for 4661 coke oven workers in the expanded study revealed that *(15)* the excess lung cancer risks among white and nonwhite workers were similar when length and area of employment at the ovens were taken into account; the excess risk noted for Allegheny County workers occurred in other geographic areas as well; a finding of a significant excess in kidney cancer deaths became apparent with the larger cohort available for study.

Subsequently, we updated the employment histories and mortality for the Allegheny County steelworkers through December 1970. The most recent phase has extended the observation period for mortality through 1975 for both the Allegheny County and non-Allegheny County workers, but unfortunately did not include updating of employment records for either study *(23)*.

Table 1 based on the 1970 update illustrates the relatively consistent findings noted for respiratory cancer among coke oven workers. A strong relationship is observed for increased risks associated with longer duration of exposure and intensity of exposure, i.e., topside versus side oven experience. Among the topside workers with 15 years or more experience, 8 of the 29 workers at risk (28%) died of respiratory cancer leading to an almost 16-fold relative risk. No increased risk of lung cancer has been found among non-oven workers. Other cancer sites noted to be significantly elevated in coke oven workers were kidney and prostate; however, the actual numbers were small and did not provide any clear evidence of a dose-response relationship.

The relative risks of dying from cancers of the digestive organs among non-oven workers are presented in Table 2. This table indicates that the excess mortality risks were confined to cancers of the large intestine and pancreas. While the risk of dying from pancreatic cancer appeared to increase with greater duration of employment, this same pattern was not apparent for cancers of the colon.

Finally, Table 3 summarizes the observed deaths and relative risks of dying from other respiratory diseases. In contrast to the findings for lung cancer, excess risks for oven and non-oven workers are about the same order of magnitude and increase with longer exposure durations. However, the lack of specificity to any particular work area or occupational group complicates the interpretation.

Table 4 based on the mortality through 1975 shows a close consistency in the lung cancer findings among the Allegheny and non-Allegheny County with overall relative risks of about 2.5-

Table 1. *Observed deaths and relative risks of death from cancers of the respiratory system, 1953-1970, for coke oven workers by work area and length of employment through 1953.*

	Employed 5+ yr		Employed 10+ yr		Employed 15+ yr	
Work area	Obs.	Rel. risk	Obs.	Rel. risk	Obs.	Rel. risk
Coke oven	54	3.02**	44	3.42**	33	4.14**
Oven topside full-time	25	9.19**	16	11.79**	8	15.72**
Oven topside part-time	12	2.29**	16	3.07**	18	4.72**
Oven side only	17	1.79*	12	1.99**	7	2.00

*$p < 0.05$.
**$p < 0.01$.

Table 2. Observed deaths and relative risks of death from cancers of the digestive system, 1953-1970, among non-oven workers by length of employment through 1953.

	Employed 5+ yr		Employed 10+ yr		Employed 15+ yr	
Cause of death	Obs.	Rel. risk	Obs.	Rel. risk	Obs.	Rel. risk
All malignant neoplasms of digestive system	28	1.58*	23	1.53	19	1.53
Large intestine	11	2.31*	10	2.52**	8	2.37*
Pancreas	8	3.67**	7	3.75**	6	4.29**
Other	9	0.83	6	0.65	5	0.65

*$p < 0.05$.
**$p < 0.01$.

Table 3. Observed deaths and relative risks of death from nonmalignant respiratory diseases, 1953-1970, for coke plant workers by work area and length of employment through 1953.

	Employed 5+ yr		Employed 10+ yr		Employed 15+ yr	
Work area	Obs.	Rel. risk	Obs.	Rel. risk	Obs.	Rel. risk
Total coke plant	34	1.47*	31	1.82**	25	2.01**
Coke oven	20	1.47	17	1.92*	12	2.20*
Non-oven	14	1.45	14	1.75	13	2.07*
No one coke plant area	0	—[a]	0	—[a]	0	—[a]

*$p < 0.05$.
**$p < 0.01$.
[a]Less than five deaths.

fold. The temporal patterns in excess risk are interesting; they indicate the greatest excess during the earliest follow-up period for Allegheny County coke oven workers (Table 5) and a later peak risk for the non-Allegheny County coke oven workers (Table 6). This observation is not surprising since several of the non-Allegheny County coke plants did not begin operations until the 1940s and would, therefore, be unlikely to show excesses in the earliest follow-up period. Both cohorts have experienced some decrease in relative risk during the most recent period, although it is not possible to conclude whether this is attributable to a reduction in exposure levels. Continued monitoring of these cohorts would be useful to demonstrate the extent to which lowering of exposures is associated with consistent declines in excess risk.

Evaluation of Dose-Response Relationships

Several approaches to investigating dose-response relationships were explored by using mortality data from the steelworkers' study and environmental data described below. The 150 μg/m^3 BSFTPM is discussed relative to the results obtained.

Table 4. Observed and expected mortality, and relative risks from lung cancer among coke oven workers employed 5 yr or more at the coke ovens.

Location	Observed deaths	Expected deaths	Relative risk
Allegheny county plants (1953-1975)	63	28.3	2.63**
Non-Allegheny county plants (1951-1975)	50	31.8	2.49**

**Significant at 1% level.

Table 5. Observed and expected mortality, 1953-1975, and relative risks for cancers of the lung, bronchus and trachea for Allegheny County steelworkers employed at the coke ovens for 5 years or more (n = 987).

Follow-up time, yr	Observed deaths	Expected deaths	Relative risk
5	12	3.87	4.33**
10	33	9.69	4.90**
15	42	16.34	3.20**
20	55	23.58	2.80**
23	63	28.29	2.62**

**Significant at the 1% level, based on summary chi-square with one degree of freedom.

Table 6. Observed and expected mortality, 1951-1975, and relative risks for cancers of the lung, bronchus and trachea for non-Allegheny County steelworkers employed at the coke ovens for 5 yr or more (n = 1004).

Follow-up time, yr	Observed deaths	Expected deaths	Relative risk
7	3	0.98	—[a]
12	11	6.52	2.69**
17	32	17.32	4.01**
22	40	24.36	2.81**
25	50	31.75	2.49**

**Significant at the 1% level, based on summary chi-square with one degree of freedom.
[a]Less than five deaths.

Independent of the steelworkers' study, a survey for exposure to coal tar pitch volatiles (CTPV) was initiated in 1966 by the Pennsylvania Division of Occupational Health at 10 coke oven installations (*24*). The results of the sampling and chemical analysis have been used to estimate average exposure levels for specific jobs at the ovens. Following statistical analysis, the surveyed jobs were categorized into three exposure groups with mean levels of CTPV (mg/m^3) given by 3.15, 1.99 and 0.88, respectively (*25*). (Note that 1 mg/m^3 CTPV can be taken as equivalent to 1000 μg/m^3 BSFTPM when relating our analyses to the OSHA Standard.) The assignment of each of the 106 coke oven jobs into one of these three exposure groups was a difficult problem. Detailed descriptions of the coke-making environment, the work performed, and the evaluation of an industrial hygienist, provided criteria for deciding into which category a job number would be placed. Most of the coke oven titles in the work histories could be assigned with some certainty to one of the exposure groups.

These mean exposure levels were based on samples from one point in time. Also, in only three instances did the coke plants surveyed coincide with plants studied for mortality. Hence, the average exposure levels must be taken as rough approximations at best. It is worthy of mention that another substantial body of exposure data is that developed by the American Iron and Steel Institute (AISI). Since their exposure values are almost always less than those obtained in the Pennsylvania Department of Health survey, dose-response models based on their dose observations would have resulted in greater risks associated with exposures less than those described below.

Following a commonly used procedure, a preliminary index of cumulative exposure was defined as follows:

Cumulative exposure =

$$\sum_{\text{All jobs}} \begin{pmatrix}\text{Mean level} \\ \text{of exposure of jobs}\end{pmatrix} \times (\text{Months at job})$$

A cumulative exposure was calculated for each of the workers in the study group through the end of 1966. Following preliminary evaluation of more detailed intervals the exposure range was then stratified into four exposure intervals: < 200; 200-499; 500-699; and ≥ 700.

A direct method of age adjustment was performed for each of the exposure intervals as well as for the overall oven workers and non-oven controls for each specified cause of death. This analysis indicated that for the nonwhite workers there was a strong association between level of exposure to CTPV and lung cancer mortality (Fig. 1). Thus, CTPV was a reasonable index to use based on its relationship to the lung cancer mortality. The value for the lung cancer rate for each interval may be considered to be the average rate for the entire interval, and the average expo-

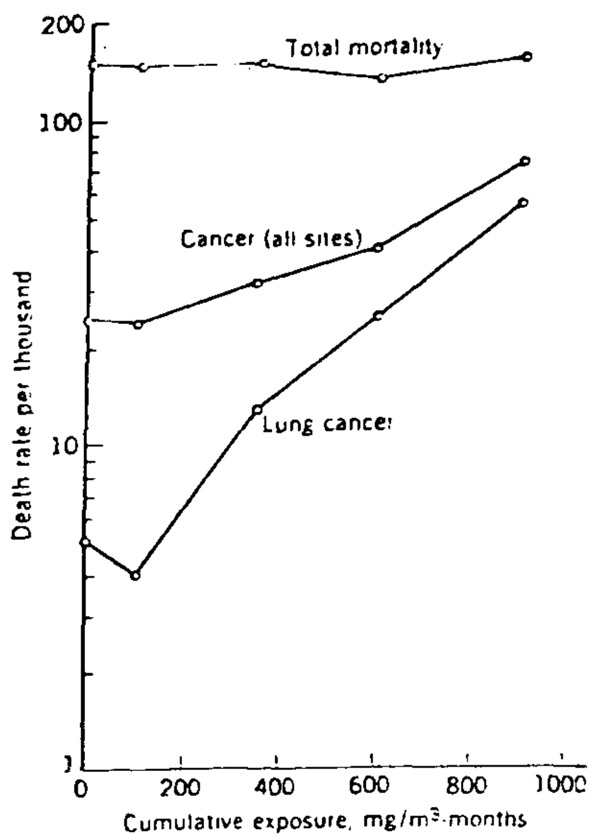

FIGURE 1. Age-adjusted death rate, 1951-1966, for specified causes among nonwhite coke oven workers by cumulative exposure groups.

Table 7. Life-table estimates of lifetime (to age 85) excess risk of lung cancer mortality due to occupational exposure to 150 μg/m³ BSFTPM.

	Linear dose response		Quadratic dose response	
	Est. excess risk	Relative risk[a]	Est. excess risk	Relative risk[a]
0 lag	0.0145	1.31	0.0016	1.03
5 yr lag	0.0159	1.34	0.0020	1.04
10 yr lag	0.0184	1.39	0.0025	1.05
15 yr lag	0.0223	1.47	0.0034	1.07

[a]Total risk of lung cancer mortality as compared with the "normal" lifetime risk of 0.0469, obtained from U.S. mortality statistics for nonwhite males. Relative risk = 1 + excess risk/0.0469. Tabular values interpolated from Land, personal communication as part of Testimony at OSHA Hearings on Coke Oven Standards, May 4, 1976.

sure for each interval can be represented by the midpoint of an exposure interval.

Since the average value of exposure in the lowest exposure level, assuming a 30-year working period at the ovens, would be 220 μg/m³ BSFTPM, this approach indicates no observed excess risk at values close to the standard.

The major difficulty with this approach is the overlapping of follow-up and exposure time. Since time, as well as level of concentration, is necessary to achieve a high-value exposure index, any oven worker dying from lung cancer within a moderate or small period of time from first exposure can no longer accumulate additional exposure. The bias arising from this approach can be avoided to some extent by considering the workers to be at risk in different exposure groups across the observation period, thus recognizing the prospective nature of exposure. A further deficiency in this analysis is that no lag time has been incorporated leading to the possibility of an opposite bias, i.e., overestimation of the amount of exposure causing disease.

Other summary exposure values have been calculated and dose-response relationships evaluated in a collaborative effort with Charles Land of the National Cancer Institute (*26*). With the use of simple linear and quadratic dose-response models, life table methods were employed to estimate lifetime excess risk to age 85 of lung cancer mortality for a hypothetical worker employed from age 20 until death or retirement at age 65 who is exposed occupationally to a constant CTPV concentration. General U.S. population rates give an estimated lifetime risk of 0.0469 for lung cancer mortality from causes other than occupational exposure to coke ovens. Weighted sums of the average monthly CTPV values were calculated assuming 0-, 5-, 10-, and 15-year lag periods and with only partial weight given to exposures occurring during the observation period. With this second approach the estimated risks corresponding to average CTPV levels of 150 μg/m³ of air are not negligible, even for the dose-response models and latency assumptions giving the smallest estimates of risk (Table 7). For example, on assuming 150 μg/m³ average exposure to BSFTPM, the estimated relative risks under the linear model range from 1.31 to 1.47 and under the quadratic from 1.03 to 1.07.

Table 8. All steelworkers standard mortality ratios from lung cancer by race and calendar time.

	Whites		Blacks	
Years	SMR	95% Confidence interval	SMR	95% Confidence interval
1953-57	131	107-159	183	115-277
1958-62	156	134-181	211	149-291
1963-67	145	127-166	198	143-266
1968-75	126	116-138	145	117-178
All years	135	127-144	169	147-195

With respect to the second approach to estimating dose-response, use of the general population for baseline lung cancer mortality may be questioned since Allegheny steelworkers as a whole tend to exhibit lung cancer risks greater than the United States rates (Table 8). This is true even if coke oven workers are not included in the comparison. Thus, part of the estimated excess risk may be attributable to factors other than occupation, such as cigarette smoking or other environmental exposures. Unfortunately, the data necessary to adjust for other confounding factors are not available.

In deciding upon the 150 μg/m³ BSFTPM for an 8-hr period as the permissible limit, OSHA justified this as the lowest level that had been shown to be technologically feasible, acknowledging that such a level is not necessarily absolutely safe.

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