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 Manouvrier 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 observa-
tions 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.

| Work area       | Employed 5+ yr | Employed 10+ yr | Employed 15+ yr |
|-----------------|---------------|----------------|-----------------|
|                 | 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   | 8.19**  | 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.

| Cause of death                                      | Employed 5+ yr | Employed 10+ yr | Employed 15+ yr |
|-----------------------------------------------------|----------------|----------------|-----------------|
|                                                     | 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.

| Work area                                            | Employed 5+ yr | Employed 10+ yr | Employed 15+ yr |
|-----------------------------------------------------|----------------|----------------|----------------|
|                                                     | 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.

*Less than five deaths.

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**        |
| 25                 | 63              | 28.29          | 2.62**        |

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

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/m³ BSFTPM is discussed relative to the results obtained.
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            | 3.15         |
| 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.
*Less than five deaths.

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-

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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           |
|                      |                         |
| 0 lag                | 0.0145                  | 0.0016                  |
| 5 yr lag             | 0.0159                  | 0.0020                  |
| 10 yr lag            | 0.0184                  | 0.0025                  |
| 15 yr lag            | 0.0223                  | 0.0034                  |

*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.

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

| Years     | Whites |          |          |
|-----------|--------|----------|----------|
|           | 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             |

REFERENCES

1. U.S. Dept. of Labor. Exposure to coke oven emissions. Fed. Register 206: 46742-46790 (1976).
2. Lloyd, J. W. Long-term mortality study of steelworkers. J. Occup. Med. 13: 53-68 (1971).
3. Pott, P. Cancer scroti. Chirurgical Observations. Hawes, Clark and Collings, London, 1775.
4. Volkman, R. Beitrage zur Chirurgie. Breitkifp and Hartel, Leipzig. 1875.
5. Manouvriez, A. Maladies et hygiene des ouvriers travailant à la fabrication des agglomerés de houille et de brai. Ann. Hyg. Publ. Med. Leg. 45: 459-482 (1876).
6. Leuke, A. W. Epithelioma in carbon workers. Cleveland Med. J. 6: 199-202 (1907).
7. Passey, R. D. Experimental soot cancer. Brit. Med. J. 2: 1112-1113 (1922).
8. Kuroda, S., and Kawahata, K. Über die gewerbliche Entstehung des Lungenkrebses bei Generatorgasarbeitern. Z. Krebsforsch. 45: 36-39 (1936).
9. Kennaway, N. M., and Kennaway, E. L. A study of the incidence of cancer of the lung and larynx. J. Hyg. 36: 236-237 (1936).
10. Reid, D. D., and Buck, C. Cancer in coking plant workers. Brit. J. Ind. Med. 13: 265-269 (1956).
11. Lloyd, J. W., and Ciocco, A. Long-term mortality study of steelworkers. I. Methodology. J. Occup. Med. 11: 299-310 (1969).
12. Robinson, H. Long-term mortality study of steelworkers. II. Mortality by level of income in whites and non-whites. J. Occup. Med. 11: 411-416 (1969).
13. Redmond, C. K., Smith, E. M., Lloyd, J. W., and Rush, H. W. Long-term mortality study of steelworkers. III. Follow-up. J. Occup. Med. 11: 513-521 (1969).
14. Lloyd, J. W., Lundin, F. E. Jr., Redmond, C. K., and Geiser, A. B. Long-term mortality study of steelworkers. IV. Mortality by work area. J. Occup. Med. 12: 151-157 (1970).
15. Redmond, C. K., Ciocco, A., Lloyd, J. W., and Rush, H. W. Long-term mortality study of steelworkers. VI. Mortality from malignant neoplasms among coke oven workers. J. Occup. Med. 14: 621-629 (1972).
16. Lerer, T. J., Redmond, C. K., Breslin, P. P., Salvin, L., and Rush, H. W. Long-term mortality study of steelworkers. VII. Mortality patterns among crane operators. J. Occup. Med. 16: 608-614 (1974).
17. Redmond, C. K., Gustin, J., and Kamon, E. Long-term mortality experience of steelworkers. VIII. Mortality patterns of open hearth steelworkers (a preliminary report). J. Occup. Med. 17: 40-43 (1975).
18. Mazumdar, S., Lerer, T., and Redmond, C. K. Long-term mortality study of steelworkers. IX. Mortality patterns among sheet and tin mill workers. J. Occup. Med. 17: 751-755 (1975).
19. Rockette, H., and Redmond, C. Long-term mortality study of steelworkers. X. Mortality patterns among coal tar pitch workers. J. Occup. Med. 18: 541-545 (1976).
20. WHO. Manual of the International Statistical Classification of Disease, Injuries, and Cause of Death, 7th Revision. World Health Organization, Geneva, Switzerland, 1957.
21. Redmond, C. K., Strobino, B., and Cypess, R. Cancer experience among coke by-product workers. Ann. N.Y. Acad. Sci. 271: 102-115 (1976).
22. Mantel, N. Evaluation of survival data and two new rank order statistics arising in its consideration. Cancer Chemother. Repts. 50: 163-170 (1966).
23. Redmond, C. K., Wieand, H. S., Rockette, H. E., Sass, R., and Weinberg, G. Long-Term Mortality Experience of Steelworkers. DHHS (NIOSH), Pub. No. 81-120, 1981.
24. Fannick, N., Gonsher, L., and Shockley, J., Jr. Exposure to coal tar pitch volatiles at coke ovens. Am. Ind. Hyg. Assoc. J. 33: 461-468 (1972).
25. Mazumdar, S., Redmond, C., Sollecito, W., and Sussman, N. An epidemiological study of exposure to coal tar pitch volatiles among coke oven workers. J. Am. Pollution Control Assoc. 25: 382-389 (1975).
26. Mazumdar, S., and Redmond, C. Evaluating dose response relationships using epidemiological data on occupational subgroups. SIMS, Proceedings of a SIMS Conference, Alta, Utah, (1979).
27. Lloyd, J. W. Study of long-latent disease in industrial populations. J. Wash. Acad. Sci. 64: 135-144 (1972).