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Mortality of gasworkers—final report of a prospective study

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Department of the Regius Professor of Medicine, The Radcliffe Infirmary, Oxford, and eight Area Gas Boards

Doll, R., Vessey, M. P., Beasley, R. W. R., Buckley, A. R., Fear, E. C., Fisher, R. E. W., Gammon, E. J., Gunn, W., Hughes, G. O., Lee, K., and Norman-Smith, Beatrice (1972). *Brit. J. industr. Med.*, **29**, 394-406. **Mortality of gasworkers—final report of a prospective study.** The mortality experience of selected groups of gasworkers employed by four area Gas Boards and observed over a period of eight years was described by us in a report in 1965. The present paper adds a further four years' data to those previously collected for men having regular exposure in coal carbonizing plants and for men having exposure only to by-products of the gas-making process. To these we have added data relating to men employed by four additional area Gas Boards who have been observed over periods of seven to eight years.

The new data provide confirmation that exposure to the products of coal carbonization can give rise to cancer of the lung and leave little doubt that the risk of bladder cancer is also increased. Two additional deaths from scrotal cancer have been observed; there is evidently still a need for vigilance if this disease is to be treated at a stage early enough to prevent death. With respect to all these cancers, work as a topman appears to be particularly hazardous.

The additional data included in the present report fail to settle the question whether the risk of lung cancer is especially associated with the conditions of work in one particular type of retort house; if there are any differences, however, they are likely to be small.

In our original report, a highly significant association between death from bronchitis and exposure to the coal carbonizing process was described. The more recent data for the four original Gas Boards offer only limited support to the view that bronchitis is a specific occupational hazard of gasworkers, and the data for the four additional Gas Boards provide no further support whatsoever. The explanation for these discrepancies is obscure, but they may be due to the major changes that have been occurring in the industry during the last decade.

No evidence was obtained that by-products workers experience any risk of dying as a result of their occupation.

In 1965, we reported the results of a survey of the mortality of selected groups of workers employed by four area Gas Boards, which had extended over a period of eight years (1 September 1953 to 31 August 1961). It was concluded that exposure to the products of coal carbonization can give rise to cancer of the lung and to bronchitis. A comparison between the mortality of men who worked in horizontal retort houses and of those who worked in vertical retort houses suggested that the risk of lung cancer was greater in the former and that the risk of bronchitis was greater in the latter, but these differences were not statistically significant (Doll *et al.*, 1965). There was also a suggestion that men having

regular exposure in carbonizing plants ran an increased risk of dying from bladder cancer, but this finding again did not attain statistical significance.

Accordingly, it was decided to continue to follow the men having regular exposure in coal carbonizing plants for a further four years. In addition, the men having exposure only to by-products of the gas-making process were also followed since insufficient data had accumulated at the end of eight years to indicate whether or not they also suffered any occupational hazard. The results obtained for the total 12-year period of the investigation for these two groups of men form part of the material in the present report. To this we have added new data relating to men employed by four additional area Gas Boards, who have been observed over a period of seven to eight years.

Methods

Four original Gas Boards

The methods used have been described in full in our earlier report (Doll *et al.*, 1965). Briefly, information was sought about men who (1) at the start of the study were employed by, or were in receipt of a pension from, any one of four area Gas Boards (the North-Western, the West-Midlands, the South-Eastern, and the North-Thames—these are referred to as Boards I, II, III, and IV respectively in our earlier report); (2) were between 40 and 65 years of age; and (3) had been employed by the industry for more than five years. For each employee, the information obtained included place of employment, date of birth, and occupation at the beginning of the study.

The new information in the present report is concerned with the 2 449 men who had been categorized at the start of the study as coal carbonizing process workers (occupational class A) and the 579 men who had been categorized as process and maintenance workers in chemical and by-products plant (occupational class C_1)[1]. Follow-up information was sought for each of these men at annual intervals from 1 September 1961 to 31 August 1965, and the mortality rates among them were observed. For each death, information about the cause was obtained from the death certificate which was then classified according to the seventh revision of the international list of causes of death (World Health Organization, 1957). The corresponding populations were determined by working out the numbers of man-years lived in each five-year age group. Death rates were obtained separately for each age group, and the results were summarized by calculating standardized rates for all ages.

Four additional Gas Boards

The methods used to study the workers at the four additional area Gas Boards (the South-Western, the North-Eastern, the Southern, and the East-Midlands) were essentially the same. Observations were made over a period of eight years (1 September or 1 November 1957 to 31 August or 31 October 1965) at three Boards and seven years (1 January 1959 to 31 December 1965) at the fourth. Men in all four occupational classes defined in our original report were included in the investigation, but the numbers of by-products workers (class C_1) were too few to contribute any useful information. The results to be described relate, therefore, only to men having regular exposure in carbonizing plants (class A), men having intermittent exposure (class B), and men having minimal or no exposure (class C_2). Men included in class B were those employed on maintenance work in gas-producing plant and process workers in gas-producing plant other than retort houses, while men included in class C_2 were limited to prepayment meter collectors, credit meter readers, and gas fitters.

[1]The nomenclature of the occupational groups has been retained in its original form to facilitate comparison with our earlier report.

Results

Mortality by occupation

Four original Gas Boards At the time of our last report, 12 of the 2 449 men (0·5%) in occupational class A and 3 of the 579 men (0·5%) in occupational class C_1 remained untraced. All but one of these 15 men (a member of class A), together with all those previously traced, have now been followed successfully for the full 12-year period. Five of the 2 449 men in class A, however, have been excluded from the present analysis as they were found on rechecking not to meet the age criteria for inclusion in the investigation.

During the course of the four additional years of follow-up, nine deaths were discovered which had occurred during the first eight years of the investigation and which, therefore, should have been included in our last report. Only one of these deaths involved a man who was previously untraced. Of the remaining eight, five involved men said to have been alive and in receipt of a Gas Board pension at the end of the first eight years of follow-up. Another important finding was that the death of one man in occupational class A, included in the last report, had been erroneously recorded as being from cancer of the bladder. The correct cause of death was cancer of the *gall*-bladder[2].

[2]It may be noted that the 16 men in occupational class B and the 19 men in occupational class C_2 who were recorded as untraced in our last report have also been followed successfully up to 31 August 1961. Four deaths were found among these men—one in class B (from bronchitis) and three in class C_2 (all from coronary thrombosis). Also, because five deaths before 1 September 1961 were found unexpectedly in classes A and C_1 among men said to have been alive and in receipt of a Gas Board pension at that time, it was decided to recheck the data for men in this category in classes B and C_2 as well. Only two additional deaths were discovered, both in class C_2 (one from coronary thrombosis and one from bronchitis). Inclusion of these six deaths in the appropriate tables in the last report produced no alterations of any consequence.

TABLE 1

STANDARDIZED ANNUAL DEATH RATES PER 1 000 MEN, ALL FOUR ORIGINAL BOARDS GROUPED TOGETHER AND ENGLAND & WALES, BY CAUSE, FOR THE PERIODS 1 SEPT. 1953 TO 31 AUG. 1961, 1 SEPT. 1961 TO 31 AUG. 1965, AND 1 SEPT. 1953 TO 31 AUG. 1965 (NUMBERS OF DEATHS IN PARENTHESES)

Cause of death	*1 Sept. 1953 to 31 Aug. 1961*			*1 Sept. 1961 to 31 Aug. 1965*			*1 Sept. 1953 to 31 Aug. 1965*		
	Class A	*Class C_1*	*E & W*	*Class A*	*Class C_1*	*E & W*	*Class A*	*Class C_1*	*E & W*
Cancer of lung	3·39 (55)	1·16 (5)	2·05	4·08 (44)	1·78 (6)	2·24	3·82 (99)	1·59 (11)	2·13
Cancer of bladder ..	0·28 (4)	0·00 (0)	0·17	0·42 (6)	0·29 (1)	0·17	0·40 (10)	0·13 (1)	0·17
Cancer of skin and scrotum	0·07 (1)	0·00 (0)	0·02	0·19 (2)	0·00 (0)	0·02	0·12 (3)	0·00 (0)	0·02
Other cancer	2·11 (36)	2·41 (9)	2·57	3·02 (34)	2·37 (8)	2·51	2·70 (70)	2·39 (17)	2·55
Bronchitis	3·53 (51)	2·10 (9)	1·61	2·42 (26)	3·12 (9)	1·64	2·98 (77)	2·57 (18)	1·63
Pneumoconiosis ..	0·05 (1)	0·00 (0)	0·07	0·09 (1)	0·00 (0)	0·06	0·08 (2)	0·00 (0)	0·07
Other respiratory disease	1·50 (22)	1·28 (4)	1·31	1·57 (18)	0·75 (2)	1·03	1·55 (40)	0·84 (6)	1·21
Arteriosclerotic and degenerative heart disease	3·77 (58)	3·92 (17)	5·17	5·21 (61)	3·12 (10)	5·86	4·63 (119)	3·54 (27)	5·41
Accidents and other violence	0·74 (14)	0·61 (3)	0·75	0·42 (4)	0·00 (0)	0·73	0·68 (18)	0·49 (3)	0·74
Other causes	4·24 (62)	3·52 (14)	4·94	4·27 (47)	3·07 (10)	4·43	4·25 (109)	3·36 (24)	4·74
All causes	19·68 (304)	15·00 (61)	18·66	21·69 (243)	14·50 (46)	18·69	21·21 (547)	14·91 (107)	18·67

Standard population—total number of man-years at risk for both occupational classes and all four Boards, 1953-65. The one untraced man in class A has been counted as alive at the end of the study.

The first three columns of Table 1 show the revised figures for the numbers of deaths and the annual death rates, standardized for age, for all men in both occupational classes for the first eight years of the investigation. Apart from the reduction in the death rate from bladder cancer in class A, caused by the correction of the error to which reference has already been made, there are no important differences from the results given in our last report which cannot be attributed to the change in the choice of population used for standardization (see footnote to Table 1). The middle three columns of Table 1 show the corresponding data for the final four years of the investigation. In general, they follow a closely similar pattern to that obtained during the earlier period, but a number of features in class A justify special mention. First, the death rate from bladder cancer is two and a half times higher than the national rate. Secondly, the occurrence of two deaths from cancer of the scrotum should be noted. Thirdly, although there is still an excess of deaths from bronchitis in comparison with the national experience, it is less than in the first part of the survey and does not quite attain statistical significance ($P = 0·06$)[1]. This difference, however, is partially compensated by an appreciable excess of deaths from other respiratory diseases.

The last three columns of Table 1 give the consolidated results for the whole 12 years of the investigation. For workers in class A, the mortality rates from both lung cancer and bronchitis are highly significantly in excess of the national rates ($P < 0·001$). The death rates from bladder cancer and from cancer of the skin and scrotum are also significantly higher than the national rates ($P = 0·03$ and 0·02 respectively). For other causes of death, the rates among men in occupational class A are closely similar to those in England and Wales, and in no case differ significantly from them.

The pattern of mortality among the by-products workers (class C_1) is, in general, unremarkable, most of the rates being somewhat below those expected on a national basis. The rate for bronchitis is rather higher than that for England and Wales, but it is based on only 18 deaths and the difference is not quite statistically significant ($P = 0·06$). Thus the complete data for the by-products workers, now based on 107 deaths, do not provide any substantial evidence that such workers experience any specific occupational hazards.

The mortality rates for workers in classes A and C_1 were also examined individually within each of the four Boards. When compared with the rates for the corresponding regional conurbations, the only noteworthy difference between the findings in the first eight years and the last four years of the study

[1]Where comparisons have been made between deaths observed and deaths expected at the national rates, tests of statistical significance are based on the assumption that the observed numbers of deaths follow a Poisson distribution (see Cutler, Schneiderman, and Greenhouse, 1954).

related to bronchitis. The reduction in mortality from this condition in the period 1961-65, to which attention has already been drawn, occurred only in the three Boards (the North-Western, West-Midlands, and North-Thames) in which the level of mortality had been elevated during the first eight years of the study. In the fourth Board (the South-Eastern) in which there had been no elevation in mortality in 1953-61, the situation remained unchanged.

A further analysis was carried out on the data for workers in class A to see if a change in occupational status during the course of the survey was reflected by any change in lung cancer mortality. For this purpose, class A workers still alive on 1 September 1961 were subdivided into four categories on the basis of their occupational status at that time. These categories were: (1) still in class A (1 032 men), (2) transferred to occupations involving only intermittent exposure in carbonizing plants (274 men), (3) retired with Gas Board pension (405 men), and (4) left industry without pension, or transferred to occupations involving minimal or no exposure in carbonizing plants (421 men). A further eight men who did not fall into any of these categories were not considered in this analysis. The excess of lung cancer deaths observed over those expected at the national rates was closely similar in the first three of these categories (category 1—observed 19, expected 10·0; category 2—observed 8, expected 2·9; category 3—observed 13, expected 5·9). In the fourth category, there was no excess of lung cancer deaths (observed 4, expected 4·1). The numbers involved are small and do not justify any firm conclusion; we may note, however, that the men in category 4, who ceased exposure before retiring age (and who, on average, had been employed in the gas industry about seven years less than the men in any of the other three categories), did not show any excess mortality.

Four additional Gas Boards Table 2 shows the numbers of men studied in each Board and in each occupational class. All the 4 687 men, of whom 1 176 were in class A, were successfully traced to the end of the period of follow-up.

Table 3 shows the numbers of deaths and annual death rates, standardized for age, for 11 different causes or groups of causes in each occupational class, together with the corresponding death rates for England and Wales for the same period (1957-65). As in our earlier report concerning the four original Boards, the highest death rate is found among class A workers (17·1 per 1 000) and the

TABLE 2

NUMBER OF MEN STUDIED IN EACH OF THE FOUR ADDITIONAL AREA BOARDS BY OCCUPATIONAL CLASS

Gas Board	*No. of men in occupational class*			*All classes*
	A	*B*	C_2	
South-Western ..	271	266	565	1 102
North-Eastern ..	420	342	544	1 306
Southern	211	471	371	1 053
East-Midlands ..	274	351	601	1 226
All additional Boards ..	1 176	1 430	2 081	4 687

TABLE 3

STANDARDIZED ANNUAL DEATH RATES PER 1 000 MEN ALL FOUR ADDITIONAL BOARDS GROUPED TOGETHER AND ENGLAND AND WALES, 1957–65, BY CAUSE (NUMBERS OF DEATHS IN PARENTHESES)

Cause of death	*Occupational class*				*England & Wales*
	A	*B*	C_2	*All classes*	
Cancer of lung	2·72 (23)	3·50 (40)	1·08 (16)	2·29 (79)	2·03
Cancer of bladder	0·23 (2)	0·16 (2)	0·06 (1)	0·14 (5)	0·15
Cancer of skin and scrotum	0·00 (0)	0·00 (0)	0·00 (0)	0·00 (0)	0·01
Other cancer	2·87 (24)	2·54 (30)	1·77 (26)	2·35 (80)	2·26
Bronchitis	1·28 (11)	0·83 (10)	1·14 (16)	1·06 (37)	1·41
Pneumoconiosis	0·00 (0)	0·00 (0)	0·00 (0)	0·00 (0)	0·06
Other respiratory diseases	0·77 (6)	0·58 (7)	1·41 (6)	0·57 (19)	0·96
Arteriosclerotic and degenerative heart disease	5·65 (47)	5·09 (59)	4·81 (70)	5·04 (176)	5·00
Accidents and other violence	0·69 (6)	0·80 (9)	0·47 (7)	0·63 (22)	0·70
Other causes	2·88 (24)	3·19 (37)	2·61 (37)	2·89 (98)	3·92
All causes	17·09 (143)	16·68 (194)	12·38 (179)	14·97 (516)	16·51

Standard population—total number of man-years at risk for all three occupational classes and all four Boards, 1957-65. Note that this is a different standard population from that used in Table 1 for the four original Boards; the two sets of results are thus not directly comparable.

lowest among the unexposed workers in class C_2 (12·4 per 1 000). Again, the corresponding rate for England and Wales (16·5 per 1 000) is closer to the highest rate than to the lowest.

For lung cancer, the mortality rate among men in class B is 72% above the national rate, a statistically significant excess ($P < 0·01$). In class A, the rate is only 34% higher than that for England and Wales, a non-significant excess. When direct comparisons were made between the three occupational classes, however, using the method of Mantel and Haenszel (1959), it was found that the death rates in both classes A and B were significantly higher than in class C_2 ($P < 0·01$ and $P < 0·001$ respectively), but that the difference in death rates between classes A and B did not reach statistical significance.

The death rates for bladder cancer are all based on very small numbers but are consistent with the existence of an occupational hazard, as indicated by the previous results for class A workers in the four original Boards. In contrast to these results, however, there is no suggestion that bronchitis is any more common as a cause of death among gas-workers in the four additional Boards than it is among the general population. Indeed, the rates for all occupational classes are lower than the corresponding rate for England and Wales.

No deaths were observed in any of the four additional Boards either from cancer of the skin or scrotum or from pneumoconiosis. For other causes of death the rates are likewise unremarkable, being similar to or less than the corresponding national rates.

Table 4 shows the individual results for each of the four additional Boards. As in our previous report, figures are given separately only for cancer of the lung and for bronchitis; other possible occupational causes have been grouped together as have all other causes of death. In this table the mortality rates have been compared with estimates of the

TABLE 4

STANDARDIZED ANNUAL DEATH RATES PER 1 000 MEN AMONG EMPLOYEES OF THE FOUR ADDITIONAL GAS BOARDS COMPARED WITH THE RATES OBSERVED IN THE CORRESPONDING REGION (SOUTH-WESTERN, SOUTHERN, AND EAST-MIDLANDS BOARDS) OR REGIONAL CONURBATION (NORTH-EASTERN BOARD) (NUMBERS OF DEATHS IN PARENTHESES)

Board	*Cause of death*	*Occupational class*				*Region/Regional conurbation*
		A	*B*	C_2	*All classes*	
South-Western	Cancer of lung	2·57 (5)	4·81 (10)	1·66 (7)	2·66 (22)	1·65
	Bronchitis	0·96 (2)	0·94 (2)	0·82 (3)	0·88 (7)	0·91
	Other occupational causes[1]	0·00 (0)	0·45 (1)	0·00 (0)	0·13 (1)	0·22[2]
	Other causes	12·09	9·70	10·46	10·54	12·35
	All causes	15·62 (31)	15·45 (33)	12·94 (52)	14·21 (116)	15·13
North-Eastern	Cancer of lung	3·20 (10)	2·68 (8)	0·24 (1)	1·85 (19)	2·09
	Bronchitis	1·25 (4)	1·41 (4)	1·45 (6)	1·38 (14)	1·80
	Other occupational causes[1]	0·32 (1)	0·00 (0)	0·00 (0)	0·10 (1)	0·22[2]
	Other causes	11·67	15·05	12·72	13·12	14·88
	All causes	16·44 (51)	19·24 (54)	14·41 (59)	16·19 (164)	18·99
Southern	Cancer of lung	3·44 (5)	3·06 (12)	1·56 (4)	2·69 (22)	1·85
	Bronchitis	1·88 (3)	0·46 (2)	1·24 (3)	0·97 (8)	0·99
	Other occupational causes[1]	0·00 (0)	0·23 (1)	0·45 (1)	0·25 (2)	0·22[2]
	Other causes	14·48	12·73	7·81	11·74	11·68
	All causes	19·80 (29)	16·48 (68)	11·06 (29)	15·52 (128)	14·74
East-Midlands	Cancer of lung	1·43 (3)	3·75 (10)	1·02 (4)	1·95 (17)	1·75
	Bronchitis	1·15 (2)	0·74 (2)	1·08 (4)	0·92 (8)	1·34
	Other occupational causes[1]	0·58 (1)	0·00 (0)	0·00 (0)	0·12 (1)	0·22[2]
	Other causes	13·94	10·16	8·41	10·52	12·10
	All causes	17·10 (32)	14·65 (39)	10·51 (39)	13·51 (115)	15·41

[1]Cancers of the bladder, scrotum, and skin, and pneumoconiosis.
[2]In the absence of data for the local distribution of these diseases, the local death rate has been assumed to be the same as for the whole country.

corresponding local rates rather than with the national rates. For one of the Boards (the North-Eastern) the most appropriate comparative data were considered to be those for the Registrar-General's West Yorkshire conurbation. For the other three Boards the regional data were used for comparative purposes in the absence of any appropriate data for conurbations.

In each of the four Boards the mortality rates from lung cancer in both classes A and B were higher than in class C. In two of the Boards lung cancer was a more common cause of death in class A than in class B, but the reverse was true in the other two Boards. In the East-Midlands Board the death rate from lung cancer in class A was below the regional rate.

In occupational class C_2 the death rates from lung cancer were similar to or slightly below the regional rates in three of the Boards. In the North-Eastern Board, however, only one death from this cause was observed, and this marked deficit is largely responsible for the very low overall death rate from lung cancer in class C_2 already shown in Table 3.

The death rates from bronchitis given in Table 4 are unremarkable and provide no indication that this disease is an occupational hazard of gasworkers.

Mortality by type of retort house

As in our previous report, mortality from cancer of the lung and bronchitis has been examined further by dividing class A workers into three categories according to the type of retort house in which they were working on entry to the study. Works in which only horizontal retorts had been used during the 10 years before the beginning of the study were classed as horizontal, works in which only vertical retorts had been used were classed as vertical, and the remainder were classed as mixed.

A somewhat different method of analysis was used from that described in our last report because data for occupational classes B and C_2 were not available for the years 1961-65 for the four original Boards. The following procedure was, therefore, employed. Within each age group and Gas Board the numbers of deaths observed and the numbers of man-years worked by men in each of the three different types of works were obtained. The numbers of deaths expected in the same categories were then calculated on the null hypothesis that the type of works was unrelated to the cause of death. The observed deaths and the expected deaths were then summed over all age groups and all Gas Boards. In this way allowance was made in the calculation for the influence of both age and Board.

The results for the four original Gas Boards are shown in Table 5, subdivided into the two periods of the survey, 1953-61 and 1961-65. The differences between the three types of works are less in the first period than was shown in our earlier report, partly as a result of the inclusion of one additional death from lung cancer and two from bronchitis, and partly as a result of the change in the method of computation. They are, however, still consistent with the hypothesis that vertical retorts are particularly associated with a risk of bronchitis and horizontal retorts with a risk of lung cancer. This hypothesis is also supported by the findings for the period 1961-65, but all the differences are extremely small.

The corresponding results for the four additional Gas Boards are given in Table 6. Since no evidence was obtained that bronchitis is an occupational hazard of retort house workers in these Boards, it is questionable whether the analysis of the deaths from this disease by type of works is justified, but the data have been shown in Table 6 none the less. It will be noted that in the four additional Boards, as in the four original ones, there is some faint suggestion of an association between mortality from

TABLE 5

NUMBERS OF DEATHS FROM LUNG CANCER AND BRONCHITIS AMONG MEN EMPLOYED IN DIFFERENT TYPES OF RETORT HOUSE AND NUMBERS EXPECTED IF THE TYPE OF RETORT HOUSE WAS IMMATERIAL: FOUR ORIGINAL BOARDS

Period	*Cause of death*	*Type of works*					
		Horizontal		*Mixed*		*Vertical*	
		Obs.	*Exp.*	*Obs.*	*Exp.*	*Obs.*	*Exp.*
1953–61	Lung cancer	14	13·07	28	27·11	13	14·82
	Bronchitis	7	7·62	22	25·90	22	17·48
1961–65	Lung cancer	12	9·76	23	23·33	9	10·91
	Bronchitis	4	4·17	11	12·08	11	9·75
1953–65	Lung cancer	26	22·83	51	50·44	22	25·73
	Bronchitis	11	11·79	33	37·98	33	27·23

TABLE 6

NUMBERS OF DEATHS FROM LUNG CANCER AND BRONCHITIS AMONG MEN EMPLOYED IN DIFFERENT TYPES OF RETORT HOUSE AND NUMBERS EXPECTED IF THE TYPE OF RETORT HOUSE WAS IMMATERIAL: FOUR ADDITIONAL BOARDS

Period	*Cause of death*	*Type of works*					
		Horizontal		*Mixed*		*Vertical*	
		Obs.	*Exp.*	*Obs.*	*Exp.*	*Obs.*	*Exp.*
1957–65	Lung cancer	6	4·06	4	5·39	13	13·55
	Bronchitis	0	1·89	2	2·09	9	7·02

bronchitis and vertical retorts and mortality from lung cancer and horizontal retorts.

The statistical significance of these findings was examined by calculating the value of χ^2 for the trend in the ratio between the observed and the expected numbers of deaths from the horizontal retort group through the mixed retort group to the vertical retort group. It was found that none of the values of χ^2, relating either to lung cancer or to bronchitis, indicated a statistically significant trend considering

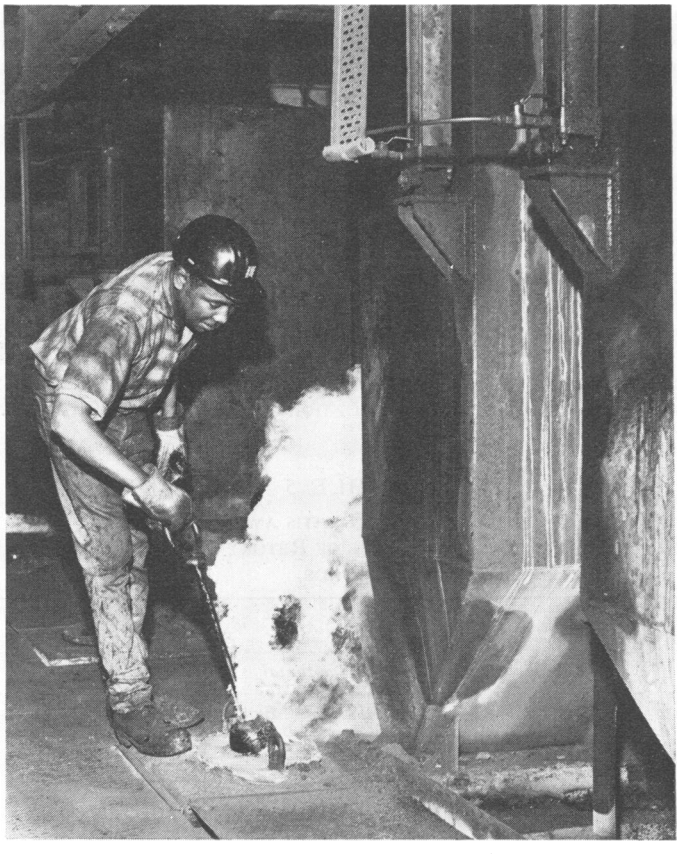

FIG. 1. A topman in a vertical retort house 'rodding' the contents of the retort. Notice the fumes which are of 'foul' gas before the extraction of tar, sulphur, ammonia, benzene, etc.

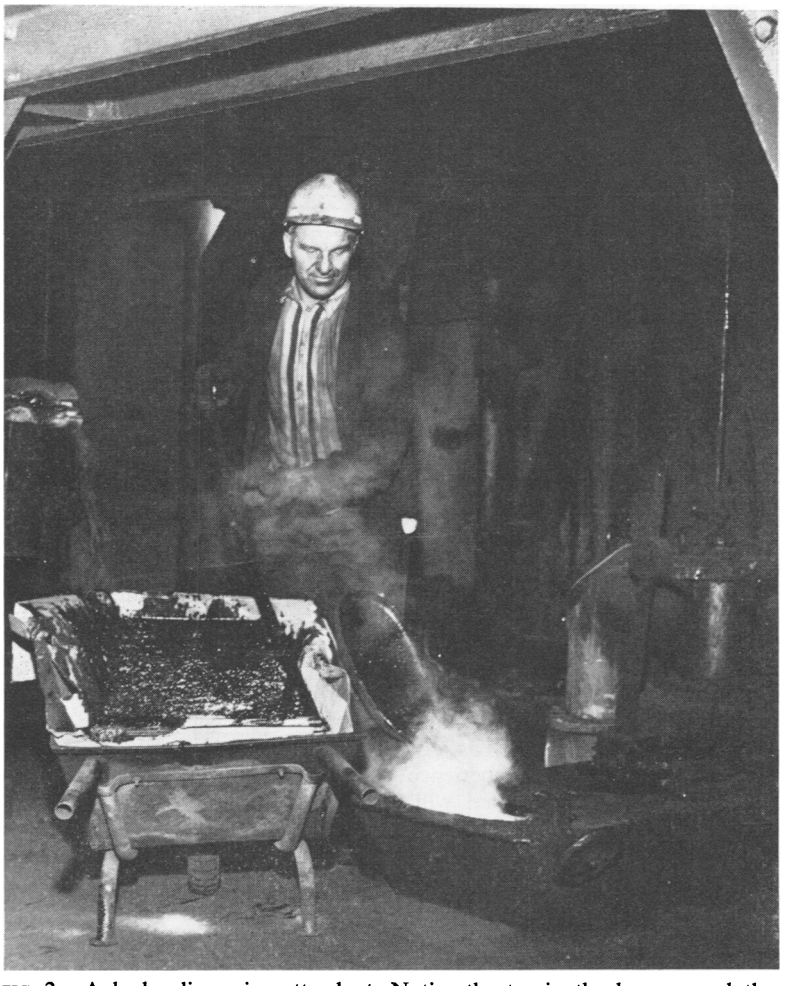

FIG. 2. A hydraulic mains attendant. Notice the tar in the barrow and the fumes of 'foul' gas.

the original Boards and the additional Boards separately, or after combining the data for all eight Boards ($P < 0{\cdot}1$ in every instance).

Mortality by occupation within retort houses

Occupation within retort houses is not easy to classify, partly because different names are given to the same job in different works, but mainly because the men regularly change from one type of work to another. Two occupations, however, that are commonly distinguished are liable to result in much heavier exposure to tar fumes than others, namely, those of topman (Fig. 1) and of hydraulic mains attendant (Fig. 2). An analysis of the occupational histories of the men who died from one or other of the three occupational cancers is shown in Table 7. The length of time was recorded that each man was employed as a topman, a hydraulic mains attendant, and as a retort house worker, and similar data were extracted for other men, selected as controls, who were also employed as retort house workers at the start of the study but died of some cause other than the three occupational cancers or bronchitis. These controls were matched with the men who died of occupational cancer for Board of employment and age at death, within the same five-year age group. The results show that the three men who died of scrotal cancer and the 12 men who died of bladder cancer had worked, on average, for longer periods as retort house workers, and particularly as topmen or hydraulic mains attendants. More of the men who died of lung cancer than the controls had also

TABLE 7

OCCUPATIONAL HISTORIES OF MEN IN CLASS A DYING FROM SCROTAL CANCER, BLADDER CANCER, AND LUNG CANCER, AND MATCHED CONTROLS DYING FROM OTHER CAUSES (for further explanation see text)

	Scrotal cancer		*Bladder cancer*		*Lung cancer*	
	Deaths	*Controls*	*Deaths*	*Controls*	*Deaths*	*Controls*
No. of deaths	3	3	12	12	122	122
No. of deaths in men with any exposure as topmen or hydraulic mains attendants	2	0	1	1	13	8
Total no. of years' exposure of men as topmen or hydraulic mains attendants	70	0	30	4	191	90
Total no. of years' exposure of all men in class A occupations	119	48	331	271	2 851	2 885
Mean no. of years' exposure of all men in class A occupations	39·7	16·0	27·6	22·6	23·4	23·6

worked as topmen or hydraulic mains attendants (13 compared with 8, both out of 122) and they had worked in these occupations for longer periods (15 years on average against 11 years). There was no difference, however, between the average lengths of time that the men who died of lung cancer and their matched controls had worked in the retort houses. This was unexpected. It must be remembered, however, that all the cases of scrotal cancer and more than half the cases of bladder cancer were occupational in origin, whereas about 60% of the cases of lung cancer were due to other causes. The experience of the men whose cancer was occupational will, therefore, have been diluted, and by chance may have been outweighed by the occupational experience of the greater number of men whose lung cancer was due to other causes.

Mortality from leukaemia and multiple myeloma

Leukaemia mortality was examined because some gasworkers might have been exposed to benzene, which is believed to be a leukaemogen (Vigliani and Saita, 1964; Browning, 1962). Table 8 shows the deaths from leukaemia in all eight Boards and in all occupational classes (including classes B and C_2 for the four original Boards for the period 1953-61) compared with the numbers that would have been expected from the national experience. The data have been shown in this way rather than as death rates to facilitate the combination of results relating to different periods of time. The results provide no evidence that gasworkers suffer any special risk. It should be noted, however, that one of the nine deaths from leukaemia was attributed to 'erythraemic myelosis', a type of leukaemia that is characteristic of benzene workers. In Browning's series, 12 out of 57 cases in benzene workers were classified as erythroleukaemia whereas this type of leukaemia does not normally constitute more than 1 or 2% of any clinical series. The gasworker with 'erythraemic myelosis' died aged 56 years after 33 years' employment as a pipe fitter's labourer.

During the course of this analysis it was noted that there were equal numbers of deaths from leukaemia and multiple myeloma. This was unexpected because the mortality from myelomatosis is normally only about one-third of that from leukaemia. The results shown in Table 9, however, provide no evidence that the deaths from myelomatosis were aggregated in any particular occupational class and it is possible that the high mortality for this condition is a chance finding (P = 0·05).

TABLE 8

NUMBERS OF DEATHS FROM LEUKAEMIA IN THE FOUR ORIGINAL BOARDS AND IN THE FOUR ADDITIONAL BOARDS WITH NUMBERS OF DEATHS EXPECTED FROM THE NATIONAL EXPERIENCE

	Occupational class				*All classes*
	A	*B*	C_1	C_2	
Original Boards					
Observed	2	1	0	2	5
Expected	2·40	2·32	0·63	2·99	8·34
Additional Boards					
Observed	2	1	—	1	4
Expected	0·74	0·98	—	1·29	3·01
All Boards					
Observed	4	2	0	3	9
Expected	3·14	3·30	0·63	4·28	11·35

Period of observation in original Boards: classes A and C_1 1953–65; classes B and C_2 1953–61

Period of observation in additional Boards: all classes 1957–65.

TABLE 9

NUMBERS OF DEATHS FROM MYELOMATOSIS IN THE FOUR ORIGINAL BOARDS AND IN THE FOUR ADDITIONAL BOARDS WITH NUMBERS OF DEATHS EXPECTED FROM THE NATIONAL EXPERIENCE

	Occupational class				*All classes*
	A	*B*	C_1	C_2	
Original Boards					
Observed	0	3	0	2	5
Expected	0·90	0·81	0·23	1·03	2·97
Additional Boards					
Observed	2	1	—	1	4
Expected	0·29	0·39	—	0·50	1·18
All Boards					
Observed	2	4	0	3	9
Expected	1·19	1·20	0·23	1·53	4·15

Periods of observation as in Table 7.

Discussion

Cancer of the lung

The extra four years' data for the four original Gas Boards provide adequate confirmation that exposure to the products of coal carbonization can give rise to cancer of the lung. The results for the four additional Boards also support this conclusion, although a puzzling finding is that mortality from lung cancer in two of these Boards (the South-Western and the East-Midlands) was higher among those having only intermittent exposure than among those having regular exposure.

One possible explanation for the latter finding that occurred to us was that men in these two additional Boards might have been classified differently from those in the other Boards and that, as a result, some men with a special risk of lung cancer might have been placed in class B rather than in class A. Accordingly, the occupations of all men in classes A and B both in the original Boards and in the additional Boards were re-examined. No evidence was obtained, however, that the anomalous results could be attributed to misclassification.

A second possibility was that men might have been transferred from class A to class B occupations in the two anomalous Boards in the years immediately preceding the start of the study (at which time major changes were occurring in the gas industry) and that, as a result, the class B workers dying from lung cancer might have included an appreciable proportion of ex-class A workers.

Table 10 shows the results of an analysis to test this hypothesis. Of 20 men in class B dying from lung cancer in the South-Western and East-Midlands Boards, four (20%) had previously worked in class A while only 4 of the 52 men (8%) dying from causes other than lung cancer had done so. This finding suggests that one or two of the deaths from lung cancer among men in class B in these two Boards might be attributed to regular exposure to the products of coal carbonization in class A occupations. It does not, however, explain the anomalous results obtained for these Boards because closely similar findings were obtained when the same analysis was carried out on the data for the remaining six Boards (Table 10).

The reason why mortality from lung cancer is higher among the intermittently exposed workers (class B) in two of the four additional Boards than among the regularly exposed (class A) thus remains obscure. It is clear, however, that considering the

TABLE 10

PREVIOUS EXPOSURE IN OCCUPATIONAL CLASS A OF MEN ALLOCATED TO OCCUPATIONAL CLASS B ON ENTRY TO THE STUDY, WHO SUBSEQUENTLY DIED (PERCENTAGES IN PARENTHESES)

Cause of death	*No. of deaths*	*No. of dead men with any exposure in class A*	*No. of dead men with 5 or more years' exposure in class A*
South-Western and East-Midlands Boards			
Cancer of lung	20	4 (20)	3 (15)
Bronchitis and 'other occupational causes'	5	0	0
Other causes	47	4 (9)	4 (9)
All causes	62	8 (13)	7 (11)
Remaining six Boards			
Cancer of lung	69	13 (19)	11 (16)
Bronchitis and 'other occupational causes'	57	5 (9)	4 (7)
Other causes	414	30 (7)	24 (6)
All causes	540	48 (9)	39 (7)

two classes of exposed workers together in all four additional Boards, a substantially higher death rate from lung cancer was observed than was expected from the national experience and than was found among the unexposed workers in occupational class C_2.

The additional data included in the present report fail to settle the question whether the risk of lung cancer is associated with the conditions of work in one particular type of retort house. So far as they go, the results suggest that the risk is likely to have been greater with horizontal retort houses than with vertical retort houses; but, if there is any difference, it is likely to be small. It is evident, however, that in either case work as a topman is particularly hazardous.

Other evidence indicating that the products of coal carbonization can give rise to cancer of the lung was reviewed in our earlier study (Doll *et al.*, 1965). Since then, more evidence has been reported from Japan and the United States. Kawai, Amamoto, and Harada (1967) followed the employees of the steelworks who had been originally studied by Kuroda and Kawahata (1936). Six men who had been exposed to the gas-making process died of lung cancer under 55 years of age, whereas less than one (0·18) would have been expected from the experience of the other workers. Lloyd (1971) studied 58 828 employees of an American steelworks and found that the mortality from respiratory cancer among the coke plant workers was double that for the steelworkers as a whole. The excess mortality was limited to the men who had been directly employed at the ovens, and among those who had been employed at the tops of the ovens for five years or more the mortality was increased 10-fold (15 deaths from lung cancer against 1·5 expected). Lloyd's paper provides a comprehensive review of the literature, on the basis of which he puts forward the tentative hypothesis that the risk of lung cancer is positively correlated with the temperature of carbonization.

We showed previously that the smoking habits of gasworkers were in no way unusual so that the excess mortality from lung cancer could not be attributed to excessive smoking (Doll *et al.*, 1965). Unfortunately, smoking habits were obtained for only a 10% random sample of the men, and this number is too small to tell whether there is any interaction between smoking habits and the occupational hazard, as was shown for asbestos workers (Selikoff, Hammond, and Churg, 1968) and uranium miners (Lundin *et al.*, 1969).

Cancer of the bladder

The data presented in our first report, taken in conjunction with the previous observations of Henry, Kennaway, and Kennaway (1931) and of Bruusgaard (1959), provided grounds for believing that work in a retort house involved a hazard of developing cancer of the bladder. Our new data confirm this belief. Brief occupational histories of the 12 retort house workers who died of bladder cancer are given in the appendix. The type of employment before entering the gas industry is not known, but there is no suggestion that there can have been prolonged employment in other industries. Six entered the gas industry under 25 years of age and only two over 35 years of age. Death from bladder cancer occurred among men employed in five different Boards and the maximum number in any one Board was three.

At the time of our first report we knew only that 2-naphthylamine had been detected in tar fumes, but we did not know the amount. Now, according to Battye (1966), the amount in a sample of tar condensate obtained from retort house air was about 1·0 part per million against 0·3 part per million in a sample obtained from atmospheric air about 100 metres away from the retort house. From his observations it appears that about 0·2 μg of 2-naphthylamine (and a similar amount of 1-naphthylamine) had been extracted from 100 m^3 of retort house air. Since a man breathes about 10 m^3 of air per shift, it can be calculated, on the assumption that he works five shifts a week for 50 weeks a year, that he will inspire 100 μg in the course of 20 years' employment ($(0{\cdot}2/100) \times 10 \times 5 \times 50 \times 20$). This figure, which is comparable to the amount inhaled by smoking one cigarette a day for the same period (Hoffman, Masuda, and Wynder, 1969), is only a very crude approximation and is almost certainly an underestimate. First, 2-naphthylamine is volatile and the method Battye used is not efficient for the measurement of volatile substances (Commins, personal communication) and, secondly, some further quantities may have been absorbed from the skin as a result of contamination with tar. Moreover, the individuals who developed bladder cancer are likely to have had unusually heavy exposure. It should be noted also that 2- and 1-naphthylamine are not necessarily the only substances present in tar fumes that are capable of causing cancer of the bladder.

Cancer of the scrotum

Cancer of the scrotum has long been recognized as an industrial disease when it occurs among men exposed to coal tar and many of the men in our study must have been exposed to substantial amounts of tar during the course of their employment. Brief occupational histories of the two new deaths are given in the appendix, and details of three other deaths were reported previously (one in a retort house worker and two in ex-workers who for various reasons had been excluded from the principal group under investigation). All five men had first been employed in a retort house before 1925 and had continued to be so employed for at least 30 years.

All were, therefore, employed at a time when precautions to prevent exposure were less effective than they have been since the second world war. It is not surprising that the cases occurred, but there is evidently still a need for vigilance and education if the disease is to be discovered and treated at a stage early enough to prevent death.

Bronchitis

The finding in our original data of a highly significant association between death from bronchitis and exposure to the coal carbonizing process was unexpected, but the excess mortality in retort house workers was so great that it could have been expected to occur by chance less than once in 1 000 times. Despite this, the more recent data for the four original Boards offer only limited support to the view that bronchitis is a specific industrial hazard of gasworkers, and the data for the four additional Boards offer no further support whatsoever. The explanation for these discrepancies is obscure, but it does seem possible that the radical changes that have been occurring in the gas industry during the last 10 to 12 years, which have involved large-scale changes in gas production methods, might be of some significance. It is also possible that the large excess of deaths from bronchitis occurring among retort house workers in the period 1953-61 was at least in part attributable to delayed effects of the extremely unfavourable conditions of work in retort houses during the war years when a 'blackout' was imposed, and that the effects of these conditions had largely worn off in later years.

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Appendix

Deaths from bladder cancer in retort house workers

Case 1 (Board A) Born 1906. Entered gas industry in 1926 as a labourer, transferred to purifying plant (still employed as a labourer) in 1933, became a retort house shift worker in 1944, and continued to work in the retort house until he died in 1959. He was made a chargehand in 1955 and a foreman in 1957.

Case 2 (Board B) Born 1903. Entered gas industry in 1925 and worked in the retort house until he retired because of ill health in 1965; he worked as a labourer in 1925-27 and again in 1963-65 and as a stoker from 1927 to 1963. Died 1965.

Case 3 (Board C) Born 1893. Entered gas industry in 1914 and worked as a retort house carbonizer until he retired in 1958. Died 1965.

Case 4 (Board C) Born 1893. Entered gas industry in 1923 and worked in the retort house until he retired in 1958, at first as a topman (1923-53) and subsequently as a greaser (1953-58). Died 1965.

Case 5 (Board D) Born 1898. Entered gas industry in 1925 and worked as a retort house labourer until he died in 1961.

Case 6 (Board D) Born 1898. Entered gas industry in 1942 and worked as a retort house fireman until 1954, when he entered a sanatorium; returned on light duty as a messroom attendant 1956-58. Died 1958.

Case 7 (Board E) Born 1896. Entered gas industry in 1920 and worked in a retort house until he retired on a pension in 1951, first as a scurfer 1920-26 and subsequently as a foreman. Died 1963.

Case 8 (Board E) Born 1890. Entered gas industry in 1911 and worked in the retort houses until he retired on pension in 1955, first as a stoker 1911-30 and subsequently as a foreman. Died 1959.

Case 9 (Board F) Born 1890. Entered gas industry in 1923; type of employment not known before the beginning of the study (1953) when he was employed in a retort house; worked then until pensioned 1955. Died 1964.

Case 10 (Board G) Born 1893. Entered gas industry in 1936; type of employment not known before the beginning of the study (1953) when he was employed in a retort house; worked then until he left in 1958. Died 1963.

Case 11 (Board G) Born 1897. Entered gas industry in

1921 and worked in the retort houses until 1957, first as a labourer (1921-53) and then as a water-seal attendant (1953-57). Worked in a coaling gang from 1957 until he retired in 1959. Died 1959.

Case 12 (Board G) Born 1895. Entered gas industry in 1919 and worked for various periods as coal elevator attendant and retort house stoker until 1936, and subsequently as a retort house foreman until he retired in 1960. Died 1960.

Deaths from cancer of the scrotum

Case 13 Born 1900. Entered gas industry in 1922 as a retort house topman and remained in the industry in that occupation all his life. Died in May 1962. Cause of death I (a) carcinomatosis, (b) epithelioma of scrotum; II chronic bronchitis and emphysema.

Case 14 Born 1902. Entered gas industry in 1919 as a hopper boy and became a hydraulic mains attendant 10 years later. He remained in this position until 1958 when he became a coke oven labourer. In 1963 he became a carpenter's labourer and lobbyman. Died in February 1965. Cause of death I (a) bronchopneumonia, (b) pyonephrosis, (c) obstruction of ureter by tumour (operation); II carcinoma of the scrotum with secondaries.

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