

THE MORTALITY OF MINERS AND EX-MINERS IN THE RHONDDA FACH

BY

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A six-year follow-up of 6,474 miners and ex-miners, originally radiographed in 1950-51, has been completed. They represent 97% of all those who were then resident in the Rhondda Fach. In addition, 2,750 non-miners living in the same area were also studied. Death certificates were obtained for all those who had died, including those who had left the area. Standardized mortality ratios (S.M.R.s) have been calculated for the various age and x-ray category groups.

The results suggest that (1) progressive massive fibrosis (P.M.F.) is a more serious disease than a previous study suggested; (2) the S.M.R. of miners and ex-miners without P.M.F. is also significantly raised; (3) there is no sign of any relation between the x-ray category of simple pneumoconiosis and the S.M.R.; and (4) the S.M.R. of ex-miners is significantly higher than that of miners.

In a previous paper (Carpenter, Cochrane, Clarke, Jonathan and Moore, 1956) an attempt was made to see whether the international radiographic classification of the pneumoconioses could be validated predictively by reference to mortality rates of coal-miners. On that occasion the results of a two-and-a-half-year follow-up were reported; the present paper concerns a six-year follow-up of the original population.

Material

The material consists of (1) the male population in the Rhondda Fach defined by nominal census during the winter 1950-51; (2) their ages at that time; (3) the x-ray category of coal-workers' pneumoconiosis (International Labour Organisation, 1953) of those miners and ex-miners who were radiographed at that time; (4) information as to who was alive and who was dead on December 1, 1956, including those who had left the area; and (5) copies of the death certificates of all those who had died. The coding of the death certificates was carried out by the Registrar General's Department.

The word 'miner' in this paper refers to a man who was working as a coal-miner at the time of the survey in 1950-51; 'ex-miner' refers to a man who was not working as a coal-miner at that time, but who had previously worked as a coal-miner for at

least one year; a 'non-miner' refers to a man not working as a coal-miner at the time of the survey and who had in the past worked less than one year as a miner. The material is summarized in Table 1.

The material differs from the previous material not only in the longer follow-up, but also in the fact that those who were not radiographed in 1950-51 have been divided into non-miners, on the one hand, and miners and ex-miners on the other. We also made a small retrospective reduction in the numbers of miners and ex-miners who had previously refused to be radiographed. In the previous paper we pointed out the high S.M.R. of those who were not radiographed and discussed how it might have influenced the results. To minimize this possible error we made a search for films taken by other agencies of those who had previously refused to be radiographed by us. We also relaxed our standards about the date on which the radiographs had been taken, accepting some films which had been taken a considerable time after the survey. This was, we thought, justified by the fact that the majority were radiographs of ex-miners in which progression of simple pneumoconiosis was unlikely to have occurred. In the case of massive fibrosis, the use of these later films may lead to an over-estimate of the category of P.M.F. at the time of the initial survey. However, as the subjects were mostly in the higher age groups, the error should be small because the rate of progression of

TABLE 1
POPULATION OF NON-MINERS, MINERS, AND EX-MINERS IN 1950-51

Age Group	Non-miners				Miners and Ex-miners			
	Total No.	Lapses	Total Radiographed		Total No.	Lapses	Total Radiographed	
			No.	%			No.	%
15 —	606	19	587	96.9	289	—	289	100.0
20 —	493	14	479	97.2	324	1	323	99.7
25 —	737	33	704	95.5	1146	8	1138	99.3
35 —	447	29	418	93.5	1346	14	1332	99.0
45 —	223	24	199	89.2	1337	13	1324	99.0
55 —	148	17	131	88.5	1173	32	1141	97.3
65 —	64	12	52	81.3	765	58	707	92.4
75 —	27	6	21	77.8	275	66	209	76.0
85 +	5	2	3	60.0	20	9	11	55.0
All ages	2750	156	2594	94.3	6675	201	6474	97.0
20 — 64	2048	117	1931	94.3	5326	68	5258	98.7
25 — 74	1619	115	1504	92.9	5767	125	5642	97.8

P.M.F. decreases with increasing age (Cochrane, Carpenter, Clarke, Jonathan and Moore, 1956; Cochrane, Moore and Thomas, 1961a). A few corrections were also made to the ages, after comparing the statement on the death certificate with our previous estimate. Similarly, a few radiographs were reclassified when we found radiographs of better technique, or of a date closer to that of the survey in 1950-51. For example, in the age group 20-64 with radiographs showing category 0 the number of deaths fell from 72 to 63. This was due to four deaths being transferred to higher age groups and eight being transferred to higher x-ray categories. At the same time three deaths were transferred to this age group from those who had previously been 'lapses'.

The net result of these changes is to increase the number of radiographed miners and ex-miners from 6,128 to 6,474, thereby reducing the refusal rate from 5% to 3%. It will also be noted from Table 1 that the percentage radiographed in the 20-64 age group, with which we are chiefly concerned, was 98.7%.

Method of Analysis

The method we have used for the analysis of this material is that of the standardized mortality ratio (S.M.R.), *i.e.* 100 times the ratio of the number observed to the number of expected deaths in any group. The method of calculating the expected number of deaths from the death rates of England and Wales is not the same as that previously described by one of us (R.G.C.) (Carpenter *et al.*, 1956). Had the previous method of estimating the expected number of deaths been used for the longer follow-up period, the S.M.R.s would for the most part have been appreciably nearer 100 than the ones shown. The method used in this paper is such as to give an S.M.R. as comparable as possible with the definition

used in the Registrar General's tables of Occupational Mortality (1958), although our S.M.R.s are based on a follow-up study. The formulae required for calculating the S.M.R. and its standard error are given in the first section of the appendix, and a full discussion of the problem will be published elsewhere.

Results

General.—Table 2 summarizes the S.M.R.s for the two age groups (20 to 64 and 25 to 74) at the time of the first survey. The first point that will be noted in Table 2 is that the S.M.R. of non-miners is close to 100. This is reassuring as it implies that the effects of mining on mortality may be reasonably assessed by comparing the observed and expected numbers of deaths. Other points of interest in Table 2 are: (1) the close similarity between the S.M.R.s for 'all miners and ex-miners' (149.0) and 'all radiographed miners and ex-miners' (145.5) in spite of the high S.M.R. of those not radiographed. This suggests that the lapse rate for the original x-ray survey is no longer a source of error as far as the whole group is concerned. It could, of course, still be a source of error in some of the x-ray category sub-groups; (2) the high S.M.R. for those with P.M.F. (198.9); (3) the raised S.M.R. for those without P.M.F. (132.1); and (4) the similarity between the S.M.R. of those with category 0 (134.0) and those with simple pneumoconiosis (128.8).

Comparison with Previous Data.—Table 3 has been constructed to be comparable with Table 5 of our previous paper (Carpenter *et al.*, 1956). In that table categories 1, 2, and 3 simple pneumoconiosis were grouped with category A, so the same grouping has been used here. Table 3 suggests that when the few x-ray films were re-classified and the ages

TABLE 2
STANDARDIZED MORTALITY RATIOS FOR MALES IN THE RHONDDA FACH 1950/51-1956

Group 1950-51	No. in Group	Observed Deaths	S.M.R.	S.E.
<i>Ages 20 to 64</i>				
All non-miners	2048	62	106.2	± 13.48
All miners and ex-miners	5326	456	149.0	± 6.99
Miners and ex-miners radiographed	5258	438	145.5	± 6.95
Miners and ex-miners not radiographed	68	18	361.8	± 94.38
Pneumoconiosis categories 0, 1, 2, and 3	4456	318	132.1	± 7.41
Pneumoconiosis category 0	2909	207	134.0	± 9.28
Pneumoconiosis categories 1, 2, and 3	1547	111	128.8	± 12.26
Pneumoconiosis categories A, B, and C	802	120	198.9	± 18.18
<i>Ages 25 to 74</i>				
All non-miners	1619	88	114.9	± 12.02
All miners and ex-miners	5767	787	143.4	± 5.11
Miners and ex-miners radiographed	5642	725	136.4	± 5.06
Miners and ex-miners not radiographed	125	62	357.3	± 48.32
Pneumoconiosis categories 0, 1, 2, and 3	4654	517	126.1	± 5.55
Pneumoconiosis category 0	2960	331	126.9	± 6.96
Pneumoconiosis categories 1, 2, and 3	1694	186	124.9	± 9.22
Pneumoconiosis categories A, B, and C	988	208	170.8	± 11.76

TABLE 3
COMPARISON WITH PREVIOUS DATA

Age Group	Period of Follow-up	Data	Method of Calculating Expected Deaths	Miners and Ex-miners														
				Category 0					Categories 1, 2, 3 and A				Categories B and C					
				No.	Observed Deaths	Expected Deaths	S.M.R.	S.E.	No.	Observed Deaths	Expected Deaths	S.M.R.	S.E.	No.	Observed Deaths	Expected Deaths	S.M.R.	S.E.
20-64	1950/51-53	Old	Old	2797	72	60.1	119.8	± 14.12	1772	52	40.7	127.8	± 17.72	460	22	15.8	139.2	± 29.69
	1950/51-53	Revised	Old	2909	63	62.4	100.9	± 12.71	1860	60	43.6	137.7	± 17.78	489	28	16.7	167.6	± 31.67
	1950/51-53	Revised	New	2909	63	62.6	100.6	± 12.60	1860	60	43.1	139.2	± 17.80	489	28	16.4	170.3	± 32.21
	1950/51-56	Revised	New	2909	207	154.5	134.0	± 9.28	1860	135	107.1	126.1	± 10.85	489	96	39.4	243.6	± 24.89
25-74	1950/51-53	Old	Old	2826	115	104.4	110.2	± 10.27	1950	82	73.9	111.0	± 12.25	579	47	33.9	138.6	± 20.22
	1950/51-53	Revised	Old	2960	111	110.6	100.3	± 9.52	2065	97	81.4	119.2	± 12.10	617	53	36.2	146.6	± 20.14
	1950/51-53	Revised	New	2960	111	110.4	100.5	± 9.53	2065	97	80.5	120.4	± 12.18	617	53	35.4	149.9	± 20.71
	1950/51-56	Revised	New	2960	331	260.9	126.8	± 6.96	2065	228	191.3	119.2	± 7.88	617	166	79.4	209.2	± 16.02

Note: The expected deaths are shown corrected to the first decimal place. The S.M.R.s shown are calculated before correcting.

corrected, the grade of pneumoconiosis was increased, especially among the younger men who died. Thus, the population of men with category 0 aged 20 to 64 was increased by 4% due to the reduction of the lapse rates, but the number of deaths in this age group in the 1950/51 to 1953 period was reduced by 12.5%. Among those with categories B and C in this age group, the changes have increased the population by 6.3% and the number of deaths by 27%. This change is of the type to be expected if lapse rates are reduced, *i.e.* the proportion of deaths would be expected to rise because the death rates are in general higher among the defaulters than in the rest of the population.

The results of the two methods of computing S.M.R.s are compared in Table 3 on the revised 1950/51 to 1953 data. For men with pneumoconiosis, whose mortality experience generally exceeds expectation, the new method, as might be predicted from theoretical considerations, gives an S.M.R. which is

larger than that obtained by the old method. When the mortality experience of a group does not show a consistent deviation from expectation, the new method of calculating S.M.R.s will not necessarily be further from 100 than the old, and in fact in the case of men in category 0 the reverse is true.

The S.M.R.s for the period of the six-year follow-up are also shown in Table 3. Neither the revision of the data nor revising the method of calculating S.M.R.s nor extending the duration of the follow-up has greatly affected the S.M.R.s of men in categories 1, 2, 3, and A. However, the prolonged follow-up has enabled us to say that the deviation of their S.M.R. from 100 is unlikely to be fortuitous.

In the category 0 group there seems to be a significant increase in the S.M.R. associated with the increased length of the follow-up. The reason for this is not clear. In the category B and C group there is a similar but much more striking effect which requires a more detailed discussion. A recent paper (Coch-

TABLE 4
COMPARISON OF AVERAGE AREA OF P.M.F. IN EACH AGE GROUP, 1950-51 AND 1958

Age Group	1950-51			1958		
	No. in Group	Average Area of P.M.F. (cm ² .)	S.E.	No. in Group	Average Area of P.M.F. (cm ² .)	S.E.
25 - 34	60	23.29	± 4.19	8	25.31	± 6.34
35 - 44	177	34.77	± 2.67	79	47.55	± 4.04
45 - 54	201	33.41	± 2.51	160	56.59	± 3.40
55 - 64	231	33.24	± 2.13	157	43.55	± 2.93
65 - 74	165	33.36	± 2.34	128	38.38	± 2.74
75 - 84	38	29.73	± 3.21	44	30.81	± 4.18

rane, Moore, and Thomas, 1961b) has shown that the case fatality of P.M.F. is related to the initial area of the P.M.F. shadow, so the S.M.R. of a group will depend on the distribution of the areas of the shadows at the time when the S.M.R. is measured. If we then consider a population of miners with P.M.F., to which no new cases are added, over a period of time, the distribution of the areas will change as time passes, and the new distribution will be the resultant of the progression rate and the case fatality rate. If the progression rate were relatively high and the case fatality relatively low, the mean size would increase, as would the S.M.R. To investigate this possibility we carried out a subsidiary investigation on a population of 872 men with P.M.F., of which the survivors had been re-radiographed eight years later. The areas of the P.M.F. shadows were drawn on tracing paper and measured for all the first films, and for the second films of those who survived. The results are summarized in the Figure and in Table 4, which show the distribution of these areas by age in 1950-51 and those of the survivors in 1958. This clearly demonstrates the expected increase in mean size and explains part of the changes in the S.M.R.s of those with categories B and C seen in Table 3.

The Raised S.M.R. of Miners and Ex-miners without P.M.F.—Table 2 shows that miners with categories 0, 1, 2, and 3 have an S.M.R. significantly higher than expected, while non-miners do not. There are various possible reasons for this.

(a) *The Effect of Colliery Accidents.*—The Registrar General's tables of Occupational Mortality (1958) show that in miners aged 20 to 64, 9.5% of all deaths are due to accidents other than home or motor accidents. Most, but not all, of these fatal accidents will be colliery accidents. The corresponding percentage of industrial accidents for all males is 2.9, and the S.M.R. of miners for this cause of death is 383.

The groups of men we have followed up were initially aged 20 to 64, but by the end of the survey the ages were 26 to 70. They also include men who

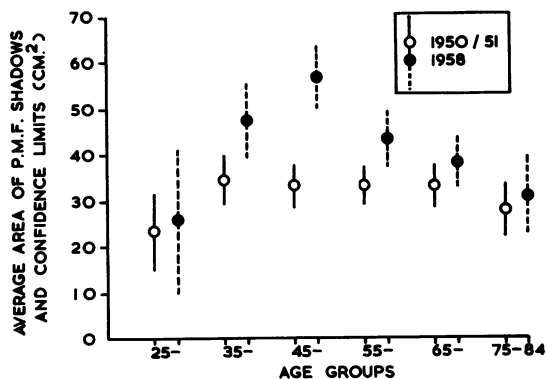


FIGURE.—Comparison of average areas of P.M.F. shadows and their 95% confidence limits in each age group of Rhondda Fach miners and ex-miners in 1950-51 and 1958.

were ex-miners as well as miners. Nevertheless, in category 0, 5% of the deaths were due to colliery accidents, and in categories 1, 2, and 3, 6% of the deaths were due to this cause. On the other hand, among the men working as miners in 1950-51 and initially aged 20 to 64, 18 colliery fatal accidents occurred during the follow-up period, 10% of all deaths in this group. The figures are not quite comparable with the Registrar General's figures but indicate that the colliery fatal accident rate observed in the Rhondda Fach has been slightly, but not significantly, higher than the average for the industry.

Table 5 compares the S.M.R.s of miners in category 0 and in categories 1, 2, and 3 before and after colliery accidents have been excluded. The method used for calculating the S.M.R.s when colliery accidents are excluded is described in the second section of the appendix (p. 45). As is pointed out in the appendix, this method slightly exaggerates the effect of excluding colliery accidents. Nonetheless, the results shown in Table 5 demonstrate that colliery accidents only account for a small proportion of the excess of deaths observed in this group of miners, and that even if this cause of death is excluded there is still a considerable excess of deaths.

TABLE 5
THE EFFECT ON STANDARDIZED MORTALITY RATIOS OF EXCLUDING COLLIERY ACCIDENTS

Age Range 1950-51	Group	Miners and Ex-miners							
		Category 0				Categories 1, 2, and 3			
		No. in Group	Observed Deaths	S.M.R.	S.E.	No. in Group	Observed Deaths	S.M.R.	S.E.
20-64	Including colliery accidents	2,909	207	134.0	± 9.28	1,547	111	128.8	± 12.26
	Excluding colliery accidents	2,909	196	126.8	± 9.00	1,547	104	120.5	± 11.79
25-74	Including colliery accidents	2,960	331	126.9	± 6.96	1,694	186	124.9	± 9.22
	Excluding colliery accidents	2,960	323	123.7	± 6.85	1,694	179	120.1	± 8.99

TABLE 6
STANDARDIZED MORTALITY RATIOS BY X-RAY CATEGORY OF PNEUMOCONIOSIS EXCLUDING COLLIERY ACCIDENTS

Group	No. in Group	Observed Deaths	Colliery Accident Deaths	Other Deaths	S.M.R.	S.E.
<i>Ages 20 to 64</i>						
Non-miners	2,048	62	—	62	106.2	± 13.48
Miners and ex-miners						
Pneumoconiosis category 0	2,909	207	11	196	126.8	± 9.00
Pneumoconiosis category 1	681	61	3	58	140.2	± 18.43
Pneumoconiosis categories 2 and 3	866	50	4	46	102.3	± 15.03
Pneumoconiosis categories 1, 2, and 3	1,547	111	7	104	120.5	± 11.79
Pneumoconiosis categories A, B, and C	802	120	—	120	198.9	± 18.18
<i>Ages 25 to 74</i>						
Non-miners	1,619	88	—	88	114.9	± 12.02
Miners and ex-miners						
Pneumoconiosis category 0	2,960	331	8	323	123.7	± 6.85
Pneumoconiosis category 1	755	94	3	91	120.0	± 12.61
Pneumoconiosis categories 2 and 3	939	92	4	88	120.1	± 12.68
Pneumoconiosis categories 1, 2, and 3	1,694	186	7	179	120.1	± 8.99
Pneumoconiosis categories A, B, and C	988	208	—	208	170.8	± 11.76

The question of the relation between the risk of dying from colliery accidents and that of dying from P.M.F. is one that is sometimes raised, and the material here enables us to attempt an answer by relating the number of colliery accidents to the excess deaths due to P.M.F. For the age group 20 to 64, over this particular period and in this particular community the ratio would be 18 colliery accidents to 59.6 excess deaths in the P.M.F. group or 1:3.3. It should, however, be stressed that the ratio is very sensitive to age, because few colliery accidents occur in men over 65 years of age, and to region, owing to the variation in the prevalence of P.M.F.; and it would be very different if only working miners were concerned.

(b) *The Effect of Category of Simple Pneumoconiosis.*—If simple pneumoconiosis were an important cause of the raised S.M.R., one would in general expect that there would be an increasing S.M.R. with increasing category of simple pneumoconiosis. The break down by x-ray category of simple pneumoconiosis is shown in Table 6. In the 20 to 64 age group the effect of category is irregular, while in the

25 to 74 age group there is clearly no effect at all. There is thus no evidence that simple pneumoconiosis *per se* has any effect on life expectancy.

(c) *With what Causes of Death is this Raised S.M.R. Associated?*—This has been investigated by calculating 'expected' deaths from respiratory and non-respiratory diseases (Table 7). The methods used are described in the third section of the appendix. Table 7 shows that for non-miners aged 20 to 64 there was an excess of respiratory deaths compared with the number expected, but the excess only amounts to three deaths in six years and is not statistically significant. Table 7 also shows that colliery accidents and respiratory deaths together account for much of the excess mortality observed in men with simple pneumoconiosis. The respiratory S.M.R.s for P.M.F. (A, B, and C) are, as expected, very high but the low non-respiratory S.M.R.s in this group serve as a reminder of the possibility that doctors in an area with a known high prevalence of pneumoconiosis may have a bias in favour of giving a respiratory rather than a non-respiratory cause of death in a doubtful case.

TABLE 7
STANDARDIZED MORTALITY RATIOS FOR RESPIRATORY AND NON-RESPIRATORY DISEASES OF NON-MINERS AND MINERS AND EX-MINERS BY CATEGORY OF PNEUMOCONIOSIS

Age Group	Group	Respiratory Deaths					Non-respiratory Deaths (excluding colliery accidents)				
		No.	Observed Deaths	Expected Deaths	S.M.R.	S.E.	No.	Observed Deaths	Expected Deaths	S.M.R.	S.E.
20 - 64	Non-miners	2,048	13	9.9	131.5	±36.48	2,048	49	48.5	101.0	±14.43
	Miners and ex-miners	2,909	51	25.9	197.3	±27.63	2,909	145	128.6	113.3	±9.36
	Category 0	1,547	25	15.0	166.8	±33.36	1,547	79	71.2	111.0	±12.48
	Categories 1, 2, 3	802	74	10.7	699.2	±81.28	802	46	49.7	92.5	±13.65
25 - 74	Non-miners	1,619	15	12.7	117.8	±30.41	1,619	73	63.8	114.4	±13.39
	Miners and ex-miners	2,960	86	41.1	209.2	±22.56	2,960	237	219.6	107.9	±7.01
	Category 0	1,694	44	25.7	171.4	±25.84	1,694	135	123.3	109.5	±9.42
	Categories 1, 2, 3	988	122	19.9	611.5	±55.36	988	86	101.8	84.5	±9.11
	Categories A, B, C										

TABLE 8
STANDARDIZED MORTALITY RATIOS OF MINERS AND EX-MINERS

Age Range	Miners (1950-51)					Miners (1950-51) (excluding colliery accidents)					Ex-miners (1950-51)				
	No.	Observed Deaths	Expected Deaths	S.M.R.	S.E.	No.	Observed Deaths	Expected Deaths	S.M.R.	S.E.	No.	Observed Deaths	Expected Deaths	S.M.R.	S.E.
20-64	2789	174	134.3	129.6	±9.78	2789	156	134.3	116.2	±9.25	2537	282	171.7	164.3	±9.85
25-74	2613	192	162.7	118.0	±8.49	2613	177	162.7	108.8	±8.16	3154	595	386.3	154.0	±6.35

The S.M.R.s of Miners and Ex-miners.—The Registrar General is the accepted authority on the mortality of occupied and retired miners, and the size of his populations makes our numbers seem puny. However, our population has an advantage in that it contains those who left the mining industry and took other jobs. Such men should be automatically excluded from the Registrar General's populations since the death certificate only refers to the last occupation of the deceased. In South Wales particularly, many miners have left the industry because of pneumoconiosis and taken other jobs, so it is possible that our population may be, for this particular area, more representative than the Registrar General's 'occupied and retired miners'.

Table 8 gives the S.M.R.s for our 'miners' and 'ex-miners' as previously defined. Our 'miners' are not exactly the same as the Registrar General's 'occupied and retired miners' but must approximate closely to them. The most recent of the Registrar General's S.M.R.s for coal-miners, as corrected by Heasman and his colleagues (Heasman, Liddell, and Reid, 1958), was 100.0. The same material has been analysed (but not published) by Professor D. D. Reid for the different regions of the National Coal Board. The figure for the South-western Region was 117 (Reid, personal communication, 1961). Our figure for miners is higher and the figure for ex-miners higher still. This certainly sug-

gests, without of course proving, that the S.M.R.s for 'occupied and retired' coal-miners may underestimate the risks associated with the industry in some areas.

Discussion

As regards the miners and ex-miners without P.M.F., all the evidence suggests that their S.M.R. is higher than that for non-miners, but that the excess, although probably respiratory in origin, is not related to the category of simple pneumoconiosis. This agrees surprisingly well with the results of pulmonary disability surveys in the Rhondda Fach. The average ventilatory function of miners and ex-miners aged 55 to 64 without P.M.F. is significantly lower than that of non-miners of the same age living in the same area. There was also no relation between the category of simple pneumoconiosis and the average ventilatory function. In an area in Derbyshire, the average ventilatory function of miners and ex-miners without P.M.F. is very similar to that of the non-miners (Cochrane, Higgins, and Thomas, 1961) so it seems possible that S.M.R.s might be similar too. At any rate it is clearly inadvisable to assume that the S.M.R.s found in the Rhondda Fach are generally applicable.

Our results as regards the lack of relation between the category of simple pneumoconiosis on the one

hand and ventilatory function and mortality on the other are not in agreement with those of the National Coal Board which finds a clear-cut relation between category and ventilatory function (Rogan, Ashford, Chapman, Duffield, Fay, and Rae, 1961). Their results are admittedly closer to what one might have expected, and the discrepancy may well be explained by a greater degree of occupational self-selection amongst miners in the Rhondda Fach.

The S.M.R. of those with P.M.F. raises similar and also additional problems. If the raised S.M.R. of those without P.M.F. is due to non-mining causes, the S.M.R. of those with P.M.F. should be proportionately reduced, *i.e.* from 198.9 to 156, but the present evidence is too uncertain. The alteration of the S.M.R. with time makes an estimate of the 'true' S.M.R. even more difficult. It seems probable that the lethality of P.M.F. is better characterized by case fatality ratios standardized by age and the original area of shadow (Cochrane *et al.*, 1961b).

Such a long-term study could not be completed without the co-operation of a very large number of people. To mention them all would be invidious. We can only express our gratitude to everyone concerned.

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APPENDIX

Method of Calculating the S.M.R.s and their Standard Errors

by

R. G. Carpenter

The first step in calculating the S.M.R. for a group or cohort of men who have been followed up for a number of years is to calculate the expected death rates for each 10-year cohort sub-group for each year of the period covered by the follow-up.

The population that we have followed up in the Rhondda Fach was divided into five- and 10-year cohort groups by sorting on age last birthday on January 1, 1951. The Registrar General tabulates death rates for groups based on age last birthday at the mid-year. Thus in 1951 our cohort groups were on the average six months older than the corresponding age groups for which death rates are tabulated. In 1952 the cohorts were one and a half years older, and in 1953 two and a half years older, than the tabulated age groups, and so on. The expected death rates for age groups corresponding to those of the cohorts were derived as described in the appendix of our previous paper (Carpenter *et al.*, 1956). That is, the death rates for these age groups were derived by linear interpolation on the logarithms of the tabulated death rates. The follow-up only covered the first 11 months of 1956. The analysis for this year is the same as for other years except that the tabulated death rates for England and Wales are replaced by 1,000 times the ratio of deaths in the country during the first 11 months of the year to the mid-period (taken as the mid-year) population.

Both J. Thomas and I, using different methods, have independently investigated the accuracy of deriving the expected death rates of intermediate age groups by this method of interpolation, and we both concluded that it is satisfactory.

In the appendix of the previous paper, I gave a formula for deriving the expected number of deaths in a cohort from the initial population and the expected death rates. But the formula does not take account of the mortality experience of the group concerned. To derive an S.M.R. as comparable as possible to the Registrar General's definition, as used in his tables of Occupational Mortality (1958), it is necessary to take account of the mortality experience of the group. The longer the period of follow-up the more important this becomes. The following formulae make the necessary adjustments.

Let the group of people followed up be divided into *l* five- or 10-year cohorts, and at the start of the survey let there be *p_i* subjects in each cohort (*i* goes from 1 to *l*). The follow-up lasts for *J* years, and it is assumed, as in the present study, that all the subjects are traced. Of the *i*th cohort *d_{ij}* die in the *j*th year of the follow-up. Let

$$D_i = \sum_{j=1}^J d_{ij}$$

Also denote the expected death rate in the *i*th cohort the *j*th year of the follow-up by *r_{ij}*, where *r* is calculated from the national death rates as already described.

Define

$$a_{ij} = r_{ij}/2$$

and for *j* = 1 to *J* - 1

$$a_{ij} = r_{ij}/2 + \sum_{t=j+1}^J r_{it} \dots\dots\dots(1)$$

Also let

$$A_i = p_i \sum_j r_{ij} \dots\dots\dots(2)$$

$$B_i = \sum_j a^2_{ij} d_{ij} \dots\dots\dots(3)$$

$$C_i = \sum_j a_{ij} d_{ij} \dots\dots\dots(4)$$

Then if we denote the fact that the S.M.R. is derived from a cohort study by a subscript *c*, the definition, which is comparable to that of the Registrar General's, is:—

$$\text{S.M.R.}_c = \frac{100 \sum_i D_i}{\sum_i (A_i - C_i)} = 100 S \dots\dots\dots(5)$$

It may also be shown that the variance of this expression is given by:—

$$\text{Var (S.M.R.}_c) = \frac{\sum_i \left\{ D_i + 2 SC_i + B_i S^2 - \frac{1}{p_i} (D_i + SC_i)^2 \right\} 10^4}{\left\{ \sum_i (A_i - C_i) \right\}^2} \dots\dots\dots(6)$$

The derivation of these formulae and the assumptions involved will be published elsewhere.

The S.M.R.s, Colliery Accidents Excluded.—The method used for calculating the S.M.R.s, colliery accidents excluded, was to assume that the men concerned would otherwise have survived. The effect of assuming that these men survived, instead of regarding them as lost from the population from the time they died, has a negligible effect on the calculated expected numbers of deaths and on the standard error of the S.M.R.

The expected death rates have also not been revised to exclude 'other accidents' since they form so small a fraction of the total expected deaths, and also because 'other accidents' are not all industrial accidents. In

consequence, the S.M.R.s, colliery accidents excluded, may be under-estimated by as much as 2½%.

The S.M.R.s for Respiratory and Non-respiratory Deaths.—The S.M.R.s for respiratory and non-respiratory deaths were calculated by J. Thomas as follows. For the standard age groups the proportion of deaths in England and Wales due to respiratory causes, including tuberculosis, may be derived for any year from the appropriate volume of the Registrar General's Statistical Review. The expected proportions of respiratory deaths in the non-standard five- and 10-year age groups, corresponding to those of the cohorts, were obtained from these figures by linear interpolation.

Let *b_{ij}* be the expected proportion of deaths due to respiratory causes in the *j*th year of the survey and in the age group corresponding to that of the *i*th cohort in that year. Then the expected respiratory death rate is:—

$$r'_{ij} = r_{ij} b_{ij}$$

and the expected non-respiratory death rate is:—

$$r_{ij} - r'_{ij}$$

Let *a'_{ij}*, *A'_i*, and *C'_i* correspond to *a_{ij}*, *A_i*, and *C_i*, as defined by equations (1), (2), and (4), when *r'_{ij}* and *a'_{ij}* replace *r_{ij}* and *a_{ij}* in the right-hand side of these equations. Then the expected number of respiratory deaths in the cohort is given by:—

$$\sum_i (A'_i - C'_i)$$

and the S.M.R. for respiratory deaths is given by 100 times the observed respiratory deaths divided by the expected respiratory deaths. The S.M.R. for non-respiratory deaths is:—

$$\frac{100 (\text{total observed non-respiratory deaths})}{(\text{total expected deaths}) - (\text{total expected respiratory deaths})}$$

Determining the S.M.R. of deaths due to a particular cause is analogous to determining the S.M.R. of a cohort which is being depleted by losses other than death. An approximate formula for the standard error of such an S.M.R., comparable to that given by equation (6), has been derived, but it is complicated, and the computations required to evaluate it are substantial. For the present purpose it is sufficient to over-estimate the standard error (s.e.) by using the simple first approximation given by:—

$$\text{s.e.} = \pm \frac{100 \sqrt{(\text{observed respiratory deaths})}}{\text{expected respiratory deaths}}$$

A similar expression was used to estimate the standard error of the S.M.R. for non-respiratory deaths.